APPENDIX A: FISHERIES

A.0 Introduction

This chapter lists the fish species native to the San Lorenzo River, as well as non-native species, and describes the life histories of coho salmon and steelhead, the watershed's native anadromous salmonids. The chapter summarizes the ecological role of these salmonids, followed by a review of the decline of the species throughout their ranges, and within the San Lorenzo River watershed. It then describes major impacts that threaten the survival of coho and steelhead, and closes with a short summary of the National Marine Fisheries Service recovery plan for these species under the federal Endangered Species Act.

It should be noted that climate change will likely exacerbate the problems facing local salmonid fisheries addressed in this chapter. Altered hydrologic patterns may result in increased droughts and more intense rain events. For more information about these potential significant impacts, refer to Chapter 7: Local Climate Change Assessment.

The District has acted as a responsible resource manager, funding long-term steelhead monitoring and habitat evaluation. Figure A.1 and A.2 illustrate some of the District's projects.

Figure A.1. Sampling for steelhead in fastwater habitat of the San Lorenzo River

Collins 2007

Biologists sampling for steelhead in fastwater habitat during monitoring in San Lorenzo River (Henry Cowell Park) during a project funded by the District.

Figure A.2. Measuring and releasing juvenile steelhead in the San Lorenzo River

Collins 2007

Biologists measuring and releasing juvenile steelhead during monitoring in the San Lorenzo River (Henry Cowell Park) during a project funded by the District.

A.0.1 Native fishes

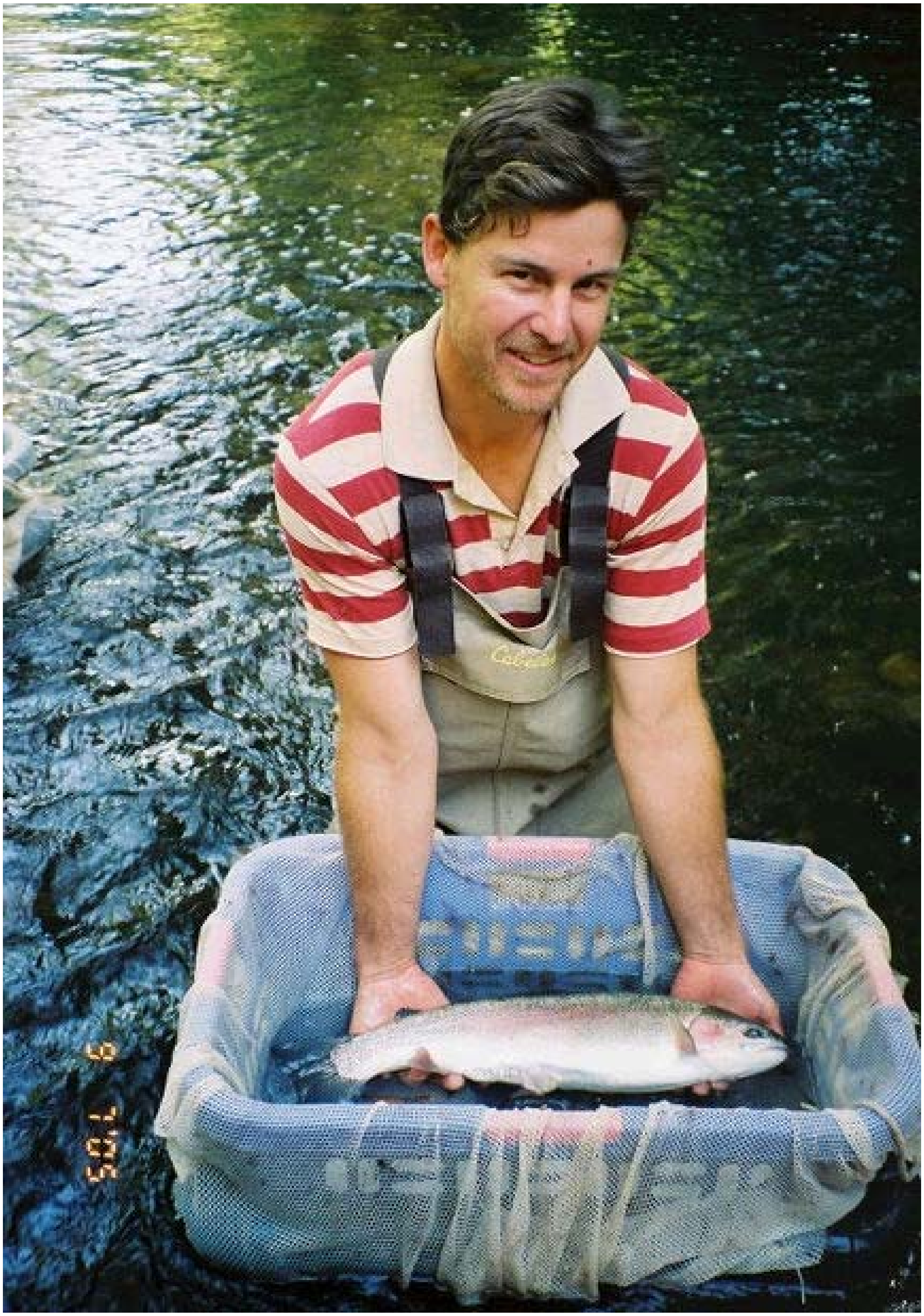
The San Lorenzo River and its estuary are inhabited by at least 25 different species of native fish. These include salmonids and other anadromous fish, which spend part of their lives in the ocean and part in freshwater. The anadromous species of recreational interest are steelhead (*Oncorhynchus mykiss*) and coho salmon (*Oncorhynchus kisutch*). These salmonids live as juveniles in freshwater, spend their major growth and adult stages in the ocean, and return to spawn in their natal freshwater streams where they were originally hatched. Figure A.3 shows a spawning adult coho salmon. Figure A.4 shows a steelhead netted in the San Lorenzo River near Ben Lomond.

Figure A.3 Adult coho salmon spawning.

Anon. 2006

Adult Coho salmon on spawning grounds of Devil’s Gulch Creek, a tributary to Lagunitas Creek.

Figure A.4. Adult steelhead netted in the middle mainstem near Ben Lomond



Alley 2005

The steelhead (*Oncorhynchus mykiss*) spend most of their adult life in the ocean, and return to spawn in freshwater streams where they were originally hatched.

Coho salmon and steelhead are the two species inhabiting the watershed upstream of the lagoon that are listed as threatened or endangered under State or Federal law, and are the only species whose populations have been monitored intensively. However, coho salmon rarely reproduce successfully any longer in the watershed. Young were detected in 2005, 24 years after their last sighting. However, a few stray adults from more northerly drainages have been recently measured and released at the Felton diversion dam in winter.

Other native fish living upstream of the lagoon/estuary include Pacific lamprey (*Lampetra tridentata*), threespine stickleback (*Gasterosteus aculeatus*), speckled dace (*Rhinichthys osculus*) pictured in A.4, coastrange sculpin (*Cottus aleuticus*), prickly sculpin (*Cottus asper*), California roach (*Hesperoleucus symmetricus*), and Sacramento sucker (*Catostomus occidentalis*).

Figure A.5. Pacific lamprey from the San Lorenzo River

Alley 2005

The Pacific lamprey resembles an eel, and also spends its adult life in the ocean, migrating up coastal streams to spawn.

The Pacific lamprey, pictured in Figure A.5, is often mistakenly referred to as an eel. The Pacific lamprey is a 2-3 foot long, silver-gray to steel blue, snake-shaped fish that spends its adult life in the ocean and migrates up coastal streams to spawn. Adult Pacific lamprey can be seen in streams holding onto rocks with their suction mouths or moving rocks to build their nests in spring. The Pacific lamprey is parasitic in the ocean, but not when it spawns in freshwater streams. Juveniles are born eyeless, and remain so for the first part of their lives, as they burrow into the sands of streambeds. The range of the Pacific lamprey is similar to that of steelhead. The Pacific lamprey is locally extinct from areas of southern California.

Anadromous and resident populations of the threespine stickleback, pictured in Figure A.6, have a patchy distribution throughout the watershed (Smith, 1982).

Figure A.6. Threespine stickleback.

Courtesy Alley 2008

Threespine stickleback with males in bright breeding coloration.

Speckled dace, pictured in Figure A.7, and California roach, pictured in Figure A.8, inhabit primarily the mainstem and low gradient tributaries, with the California roach preferring, warmer and slower habitat.

Figure A.7. Speckled dace.

Reis 2006

Speckled Dace captured in the San Lorenzo River at Henry Cowell Park.

Figure A.8. California roach.

Collins 2007

California roach captured in the San Lorenzo River at Henry Cowell Park.

The Sacramento sucker, pictured in Figure A.9, inhabits areas with good pool development. Large adults generally inhabit the mainstem at the bottom of deep pools or congregate under large instream wood clusters. Juveniles and adults are ubiquitous throughout the watershed because they migrate upstream to spawn in spring and have wide environmental tolerances.

Figure A.9. Sacramento sucker.

Alley 1997

Adult Sacramento sucker with mouth extended.

The prickly sculpin, pictured in Figure A.10, primarily inhabits pools. The generally darker prickly sculpins inhabit primarily pools and generally grow larger than coastrange sculpins.

The coastrange sculpin, pictured in Figure A.11, inhabits pools and fastwater habitat (riffles and runs).

Sculpin hide during the day and feed actively at night, as observed by local biologists using starlight goggles (Alley, 2008). Few sculpin of either species are found above the steep San Lorenzo River gorge that flows through Henry Cowell State Park, or above the fish ladder at the Felton diversion dam, except in Newell Creek. Denil fish ladders, such as the one at the Felton water diversion dam, are impassable to sculpin, which migrate downstream as adults to spawn and move back upstream afterwards (Alley, 2008). Young Pacific staghorn sculpin, have been captured in the lagoon and immediately upstream in the flood control channel through Santa Cruz.

Figure A.10. Prickly sculpin

Alley 1997

Large prickly sculpin captured from a pool in Soquel Creek. The generally darker prickly sculpin inhabit primarily pools and generally grow larger than coastrange sculpin.

Figure A.11. Coastrange sculpin

Wheeler 2006

Colorful coastrange sculpin captured from a riffle in the San Lorenzo River at Henry Cowell Park.

A.0.2 Native estaurine fish species

When the sandbar at the river mouth is opened to the ocean by winter storms, the lagoon becomes an estuary, which is inhabited by numerous marine species. Common estuarine species include topsmelt (*Atherinops affinis*), staghorn sculpin (*Leptocottus armatus*), starry flounder (*Platichthys stellatus*) and shiner perch (*Cymatogaster aggregata*). The most notable freshwater species that also utilize the lagoon include steelhead, threespine stickleback, Sacramento sucker and tidewater goby (*Eucyclogobius newberryi*), a federally and state listed endangered species.

The tidewater goby resides only in the lagoon/estuary, where it squirts along the bottom to feed on small invertebrates. Males build nests in burrows in the sand, and the species requires good overwintering shelter and a closed summer sandbar to provide freshwater breeding areas in the lagoon.

A.0.3 Non-native fishes

Though non-native (artificially introduced) fishes pose a serious threat to native species in many regions, they have created little impact in the San Lorenzo River watershed. The non-natives that escape from Loch Lomond have difficulty surviving the large winter stormflows and are seldom found elsewhere in the watershed.

According to Smith (1982):

> The absence of non-native fishes and the variation in species compositions of the native fishes in different streams due to barriers, stream size, and habitat make Santa Cruz County streams ideal for studies on native fish ecology.

Non-native fish occasionally escape into Newell Creek from Loch Lomond where they were originally introduced. Golden shiners (*Notemigonus crysoleucas*) and bluegill (*Lepomis macrochirus*) have been captured in Newell Creek, downstream from the dam. Planted rainbow trout in the reservoir, distinguished by their larger size and different and brighter coloration, have also periodically washed over the dam into Newell Creek and have been captured during fall sampling. Green sunfish (*Lepomis cyanellus*) established a population in Carbonera Creek in the mid 1990s from ponds in Scotts Valley and are presumably still there. A large brown bullhead catfish (*Ictalurus nebulosus*) was observed in the San Lorenzo River near the mouth of Newell Creek in 2003 during a snorkel survey (D. Alley and K. Kittleson, personal observation). Another catfish was observed in the San Lorenzo River in Henry Cowell State Park during an earlier snorkeling survey (W. Heady, personal observation). A third catfish was caught during sampling in lower Carbonera Creek in 1981.

Steelhead and rainbow trout are the same species and interbreed, but steelhead are anadromous and rainbow trout are not; they remain in freshwater. A small percentage of steelhead remain in freshwater as rainbow trout. A small percentage of rainbow trout offspring migrate to the ocean to become steelhead. Ocean-run steelhead grow much faster, are larger as adults than rainbow trout and spawn many more eggs than resident rainbow. These characteristics make the steelhead life history more adapted to local conditions than the rainbow.

A.1. Life cycles and habitat requirements of salmonids

Figure A.12 depicts the life cycles of coho salmon and steelhead.

Figure A.12. Life cycles of coho salmon and steelhead.

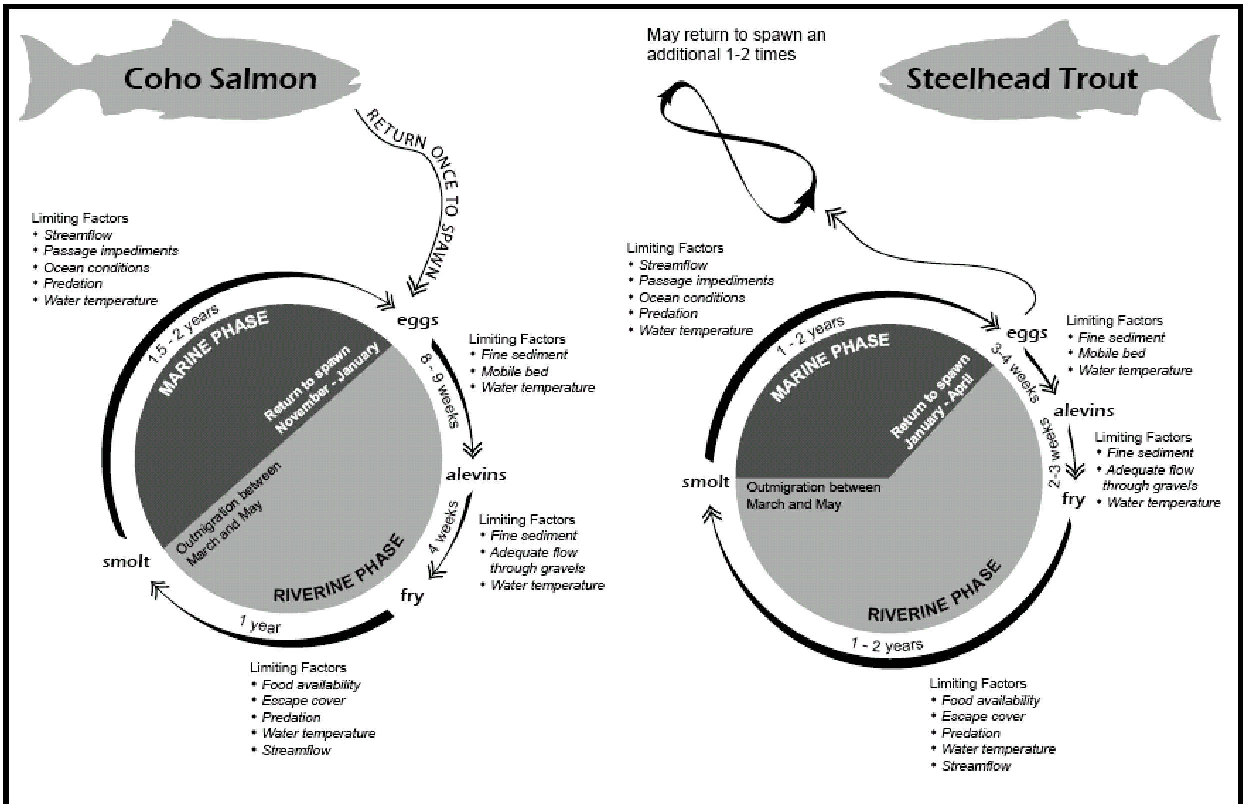


Figure 1.2: Life cycles of the Coho salmon and Steelhead trout showing duration of each stage and critical environmental factors affecting survival and reproduction. Coho salmon live for approximately 3 years before they spawn and die. Steelhead may live for up to 5 years and spawn as many as three times.

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Most adult steelhead migrate upstream from the ocean through an open sandbar after several prolonged storms; the migration seldom begins earlier than December and may extend into May if late spring storms develop. Adult fish may be blocked by natural barriers such as bedrock falls, wide and shallow riffles, and occasionally logjams. Man-made objects, such as culverts, bridge abutments and dams are often significant barriers. Some barriers may completely block upstream migration, but many barriers are passable at higher streamflows. Except in extreme cases, some adult steelhead can pass in most years, since they are capable of timing their upstream movement to match peak stormflow conditions. However, in drought years and years when storms are delayed, incomplete barriers can become serious temporary barriers to spawning steelhead and especially coho salmon, because coho spawn earlier than steelhead.

Coho salmon often have severe problems because their migration period, November through early February, often occurs prior to the stormflows needed to pass shallow riffles, boulder falls and partial logjam barriers. Access at the river mouth can be a problem due to failure of sandbar breaching during drought or delayed stormflow. In recent years, the rainfall pattern of early winter storms has allowed for good coho access to the San Lorenzo system.

Smolts (juvenile steelhead and coho salmon that have physiologically transformed in preparation for ocean life) tend to migrate downstream to the estuary and ocean in March through early June in local streams. In streams where lagoons, which are formed by a closed sandbar in the summer, young-of-the-year (YOY) and yearling fish may spend several months in this highly productive lagoon habitat and grow rapidly. For most local streams, downstream migration is a problem only under extreme drought conditions that cause reaches to dewater and/or the sandbar at the rivermouth to close prematurely before the smolts reach the Bay.

A.1.1 Spawning habitat requirements

Steelhead and coho salmon require spawning sites with gravels containing little sand and silt as well as good flows of clean water moving over and through them. The redds (nests) of all coho salmon and those steelhead that spawn earlier in the winter are more likely to be washed out or buried in fine sediment by succeeding winter storms.

Steelhead spawning success may be limited by scour from winter storms in some Santa Cruz County streams. Unless hatching success has been severely reduced, however, survival of eggs and alevins is usually sufficient to saturate the limited available rearing habitat in most small coastal streams and San Lorenzo tributaries. However, in the mainstem San Lorenzo River downstream of the Boulder Creek confluence, spawning success may be an important limiting factor. The production of YOY fish is related to spawning success, which is a function of the quality of spawning conditions, the pattern of storm events and ease of spawning access to upper reaches of tributaries, where spawning conditions are generally better.

A.1.2 YOY and smolt habitat requirements

In the mainstem San Lorenzo River below Boulder Creek, many steelhead require only one summer of residence before reaching smolt size. Except in streams with high summer flow volumes, steelhead require two summers of residence before reaching smolt size. This is the case for most juveniles inhabiting the upper mainstem above Boulder Creek and all tributaries of the San Lorenzo River. Juvenile steelhead are generally identified as YOY (first year) and yearlings (second year). The slow growth and often two-year residence time of most local juvenile steelhead indicate that the year class can be adversely affected by low streamflows or other problems during either of the two years of residence. Nearly all coho salmon, however, smolt after one year under most conditions, despite their smaller size. Because of their smaller size, juvenile coho salmon have lower survival than steelhead in the ocean.

Growth of YOY steelhead and coho salmon appears to be regulated by available insect food, although escape cover and pool, run and riffle depth are also important in regulating juvenile numbers, especially for larger fish. Aquatic insect production is maximized in unshaded, high gradient riffles dominated by relatively unembedded substrate larger than about 4 inches in diameter. Densities of yearling and smolt-sized steelhead in smaller stream channels, such as the upper San Lorenzo upstream of the Boulder Creek confluence and San Lorenzo tributaries, are usually regulated by water depth and the amount of escape cover during low-flow periods of the year (July-October). Deep habitat with maximum escape cover is best.

Yearling steelhead growth usually shows a large increase during the period of March through June when higher streamflow of sufficient clarity is available. Larger steelhead may smolt as yearlings in spring if they grow large enough. For steelhead that stay a second summer, summer growth is very slight in many tributaries (or even negative in terms of weight) as flow reductions eliminate fast-water feeding areas and reduce insect production. The "growth habitat" provided by higher flows in spring and fall (and in summer for the mainstem river) is very important, since ocean survival to adulthood increases exponentially with smolt size.

During summer in the mainstem San Lorenzo River downstream of the Boulder Creek confluence, steelhead use primarily fast-water habitat where insect drift is the greatest. This habitat is found in deeper riffles, heads of pools and faster runs. YOY and small yearling steelhead that have moved down from tributaries can grow very fast in this habitat if streamflows are high and sustained throughout the summer.

A.1.3 General habitat requirements for salmonids

Pools and step-runs are the primary habitat for steelhead in summer in San Lorenzo tributaries and the upper San Lorenzo River above the Boulder Creek confluence. Primary feeding habitat is at the heads of pools and in deeper pocket water of step-runs. The deeper the pools, the more value they have. Higher streamflow enhances food availability, surface turbulence and habitat depth, all factors in increasing steelhead densities and growth rates. Where found together, young steelhead use pools and faster water in riffles and runs/ step-runs, while coho salmon use primarily pools because of they are poorer swimmers.

Deeper pools, undercut banks, side channels, large unembedded rocks and large wood clusters provide shelter for fish against the high winter flows. In some years, such as 1982 and 1998, extreme floods may make overwintering habitat the critical limiting factor in steelhead production. In years when higher stormflows occur, these refuges are critical, and it is unknown how much refuge is actually needed. The remaining coho streams, such as Gazos Waddell and Scott creeks, have considerably more instream wood for winter refuge than streams where coho have been extirpated (Leicester, 2005).

A.1.4 Natural history of steelhead

Taxonomically, steelhead are grouped with other Pacific salmon. Their range varies historically. Steelhead have been caught along the continental shelf from Japan up through the Bering Sea and south to Baja California (Love, 1996). At sea, steelhead are most abundant between Oregon and the Gulf of Alaska, and may migrate up to 2,900 miles (Love, 1996). Historically, steelhead ranged as far south as the California-Mexico boarder, but their current southern limit is Malibu Creek in Los Angeles County (Alley et al., 2004a). Unfortunately, water extractions, dams, and prolonged drought have all but extirpated steelhead from their southern range. Steelhead spend one to two years in the ocean before returning to spawn. They can reach 45 inches in length and weigh more than 40 pounds (Love, 1996). However, the average fork length of returning adults captured at the Felton diversion dam is consistently between 28 and 29 inches (Terry Umsted, San Lorenzo Valley High School Teacher and Trap Supervisor, personal communication 2006), and weighing approximately 8-10 pounds.

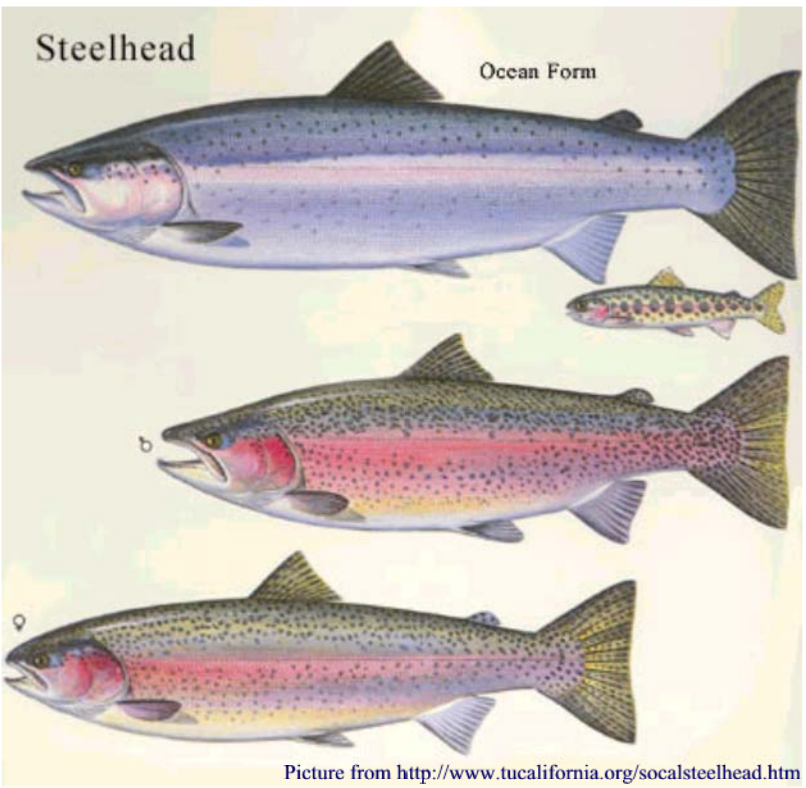
A.1.4.a Life span and survival rates

Steelhead rarely live longer than seven years. Four years is considered a typical lifespan in this region. Despite their fecundity, steelhead survival to spawning is very low. From their extensive research on Scott and Waddell Creeks, Shapovalov and Taft (1954) calculated survival rates from the egg to the adult’s first time returning to spawn. They termed this period primary overall survival. Between the years 1933 and 1938 they calculated primary over-all survival for steelhead in Waddell Creek to be between 0.017% and 0.029%.

A.1.4.b Spawning

Steelhead spawn in streams with coastal access along the Pacific Coast of North America. Steelhead differ from other salmon in their ability to return to sea after spawning and to return again to their natal stream to spawn in later years. Figure A.13 depicts the ocean and freshwater phases of steelhead. This ability has given steelhead the advantage of stronger spawning year classes in the face of annual variability in habitat quality in freshwater and the ocean. In any given year, the returning steelhead adults are from multiple years of previous spawning, unlike other salmon. This gives the steelhead population resilience and adaptability in a fluctuating environment. One or even two successive years of poor smolt production do not necessarily create long-term low numbers of returning adult steelhead in succeeding years.

Figure A.13. Ocean and freshwater phases of steelhead



In some rivers, male steelhead may migrate upstream first, waiting for females and determining a hierarchical ranking. Females create the nest, called a "redd," by turning on their side and slapping their tails on the bottom. This lifts the material into the water column. The lighter sand and silt is carried away by the current. The gravels bounce slightly downstream so that a pit is formed with a mound just downstream of it. A pair (male and female) then spawns in the pit. The female lays eggs while the male emits sperm. Steelhead produce an average of about 6,000 eggs per female, varying from 2,000 to 12,000 (Benkman, 1976; Love, 1996).

The hydraulics within the redd pit actually pull the eggs and sperm into the gravels of the streambed. Satellite males may attempt to swim in and emit their sperm during this time. After the eggs have been laid, the female moves upstream and repeats her digging to bury the fertilized eggs in gravel 8-14 inches thick. A pair or individuals may spawn several times. Females are more likely to survive to spawn multiple times and multiple years. There are usually more females than males at spawning grounds (Love, 1996). After spawning, if the adult has not died of old age, fatigue, disease or predation, it may swim back to the ocean and return to spawn the following year.

Redds are excavated at the tails of pools or glides just upstream of riffles. Steelhead prefer to spawn just upstream of steep, narrowing riffles to maximize the flow of oxygenated water through the interstitial spaces between gravel particles in the streambed. This provides a relatively shallow section with an even bottom of good gravels and enough streamflow to nurture the eggs and larvae. The female spawns in the deepest part of the stream cross-section to avoid dewatering of the nest. Steelhead require spawning beds of deep, loosely aggregated gravels with a minimum of fine sediments. Gravels in the range of 5 to 90 mm are optimal for salmonid spawning beds (Alley et al., 2004a; Alley, 2002). Steelhead may spawn over previously prepared redds of coho or other steelhead.

A.1.4.c Egg incubation and fry emergence

Warmer water decreases incubation time (19 days at an average of 60º F) and cooler water lengthens incubation time (80 days at an average of 40º F) (Shapovalov and Taft, 1954). Shapovalov and Taft (1954) found that the average incubation time for steelhead eggs in Waddell Creek was 25 to 35 days.

The eggs hatch into a larval form called *alevins* or sac fry. Alevin appear like a small larval fish with a yolk sac distending from the belly. The alevins remain within the interspaces of the gravel until the yolk sac is completely absorbed into the belly. The gravels create a refuge with clear water flowing through, providing oxygenated water and removing metabolic wastes.

Juvenile steelhead fry were found to emerge from the gravels 2-3 weeks after hatching and required another 2-3 weeks to complete emergence (Shapovalov, 1937). Thus, fry may emerge from the gravel between 5 ½ and 11 weeks after spawning in Waddell Creek. Shapovalov and Taft (1954) determined that success of emergence was negatively affected by the amount of fine sediment mixed in with the gravels during emergence. Habitat quality and predation determine survival in the stream after emergence.

Loose gravel, absence of silt, shallow burial and warmer temperatures may quicken emergence, while opposite conditions may lengthen emergence time (Benkman, 1976). A quicker emergence time reduces the chance of the entire progeny being lost after disturbance of the redd.

A.1.4.d Juveniles

Once they emerge from the gravels, juvenile steelhead are very active. They spend most of their time swimming to keep from being swept away, to dart after food, and to find cover. Figure A.14 shows juvenile steelhead and coho from Bean Creek.

Warmer water temperature increases productivity (food supply) and digestive rate, but it also increases the metabolism and food requirements of juvenile fish. Thus, fish may grow more rapidly in warmer water where streamflow and food supply are higher; but they also need more food. They require fast moving water to deliver drifting insects to them for food. Juveniles maintain feeding positions in the stream, catching food as it drifts by.

With reduced summer streamflow, less food is carried to the fish. At the same time, rising water temperature increases the metabolic rate of the fish. If not enough food is supplied to balance the metabolic costs, juvenile salmonids may starve. Juveniles must reach a minimal size before they will migrate to the ocean (called smolting), and the larger they are when they smolt, the greater their survival rate to adulthood in the ocean.

Figure A.14. Small young-of-the-year coho salmon and steelhead captured in Bean Creek

Alley 2005

A young-of-the-year (YOY) coho is pictured on the left, and a steelhead is pictured on the right.

A.1.4.e Importance of juvenile size classes

The length of time that juvenile steelhead spend in freshwater depends on how fast they can grow to smolt size. This depends upon food availability and their metabolic demands. There are two different size classes designated for juvenile steelhead, independent of their age. Measured in the fall, those that are less than 75 mm in standard length (SL) are designated as Size Class 1; those that are equal to or greater than 75 mm SL are designated as Size Class 2. This distinction between size classes is made because size will likely determine different behavior patterns for the next year-and-a-half.

Juveniles in Size Class 1 will likely spend another growing season in the stream before entering the ocean (called smolting), while juveniles of Size Class 2 will likely smolt within the next few months of winter and spring. These smolt-sized juveniles have a much higher survival rate than the smaller fish. Dr. Jerry Smith found that most smolts that had grown to Size Class II by the end of their first growing season (fall) smolted as yearlings in the spring. But most juveniles of the smaller size class remained in the stream an additional year.

Locations of high-density populations of small (Size Class I) YOY fish indicate where much of the spawning has occurred. However, it is much more important to know the locations of high-density populations of smolt-sized juveniles (Size Class II) fish, in order to estimate the number of expected adult returns. This is because Size Class II fish have the highest probability of returning as adults.

A.1.4.f Juvenile habitat requirements

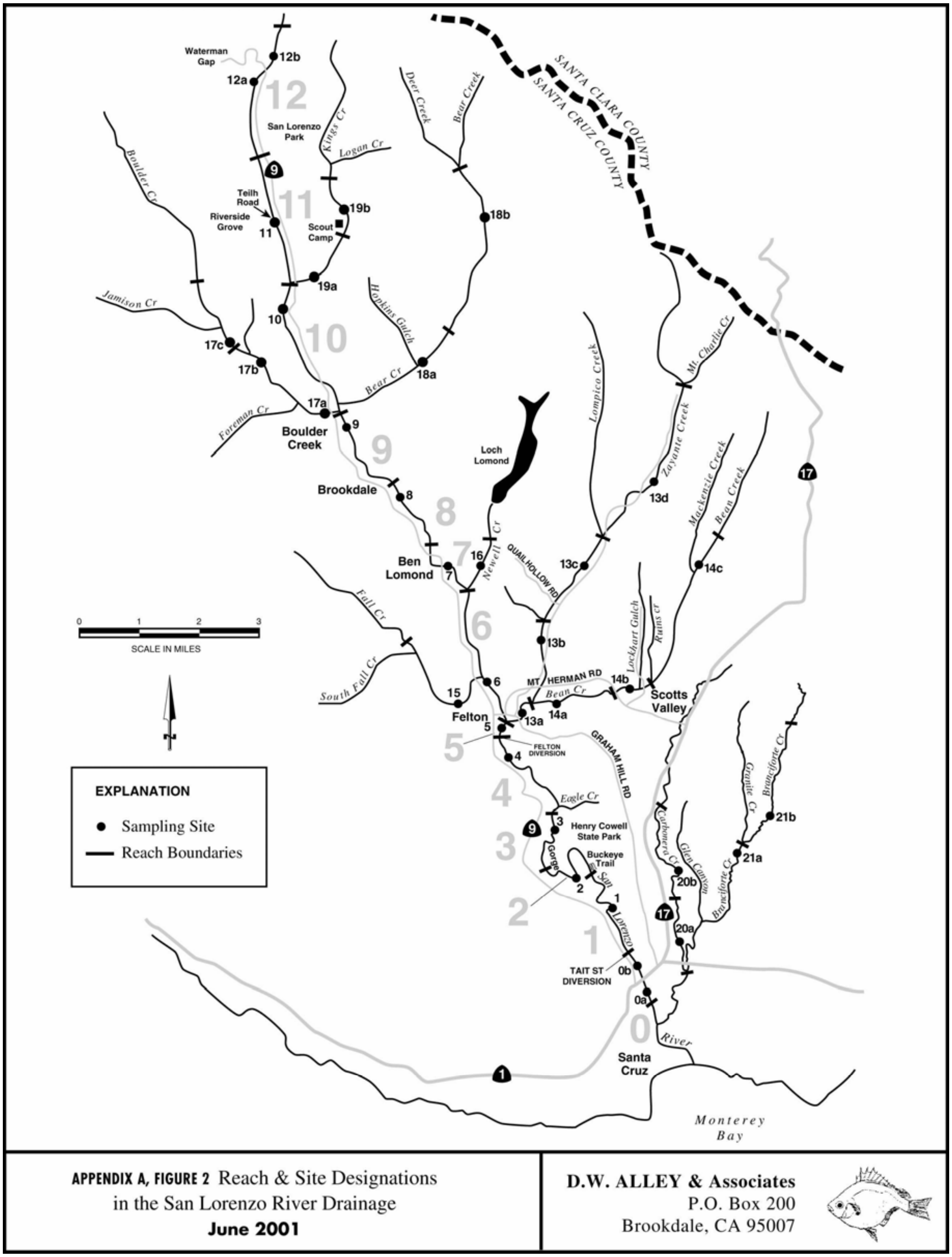
Locations of high-density populations of Size Class II fish are useful indicators of habitat quality. The mainstem of the San Lorenzo River is extremely valuable for its production of smolt-sized juveniles, most of which are fast growing YOY fish.

Every year, many steelhead reach smolt size in just one year in the lower mainstem, downstream of the Zayante Creek confluence, shown on the map as Reaches 0a through 5 in Figure A.15. In these reaches, streamflow, water temperature and food availability are all relatively high. Many juveniles also reach smolt size in one year within the middle mainstem, between the Zayante and Boulder Creek confluences, if conditions are right. Such conditions likely occur in wet years with higher streamflow, shown as Reaches 6 through 9 in Figure A.15.

In most areas of the watershed, young fish require two years of growth to reach smolt size. These areas include the tributaries, the middle mainstem in drier years (because of reduced streamflow) and the upper mainstem in most years upstream of the Boulder Creek confluence in Reaches 10 through 12 in Figure A.15. In these reaches, streamflow and food availability are more limiting to rate of growth. The cooler water temperatures of the shaded areas in the upper mainstem and tributaries contribute to slower growth. Without the streamside trees, however, water temperatures could become too warm for steelhead, recruitment of instream wood would decline and streambank erosion and streambed sedimentation would increase.

The tributaries of the San Lorenzo River provide valuable spawning habitat where most of the YOY steelhead originate. Many of these YOY will then move from tributary spawning areas to the lower and middle mainstem, where they can grow more rapidly. Each year, the tributaries also contribute at least half the smolt sized fish as yearlings and older, slower growing juveniles.

Figure A.15. Reach* and site designations in the San Lorenzo River drainage



*The mainstem river was divided into 3 segments: 1) lower mainstem (Reaches 0-5) from Water St. Bridge to Zayante Cr. confluence, 2) middle mainstem (Reaches 6-9) up to Boulder Creek confluence and 3) upper mainstem (Reaches 10-12) through Waterman Gap.
Source: Alley, 2002.

In the lower and middle mainstem of the San Lorenzo, where summer water temperature is relatively high, juvenile steelhead must use fast-water habitat, such as riffles, runs and the heads of pools, which supply abundant food. In tributaries and upper watershed areas, with limited streamflow and cooler water, juveniles primarily use pools where they feed their heads as fastwater empties into them. They may also use deeper, fastwater habitat called *step-runs*. Most runs and riffles are too shallow for smolt-sized juveniles, but are used by small YOY fish.

Juveniles require escape cover from predators during the spring-summer-fall feeding period and over-wintering shelter from high winter stormflows. During intense stormflows, many juveniles may be flushed out of the system, and spawning redds may be destroyed. Juveniles find escape cover in deep pools, bubble curtains created by water turbulence, cracks and crevices under boulders, undercut banks, bedrock ledges, large instream wood, emergent aquatic vegetation, and overhanging terrestrial vegetation, such as willows. Without sufficient escape cover, juvenile numbers will decline from predation, regardless of food availability or water quality. The larger Size Class 2 fish are more dependent on escape cover and deep water than smaller juveniles. Excessive fine sediment--entering the stream channel from eroding areas—makes pools shallow, and embeds or buries boulders, eliminating escape cover.

The middle mainstem has been substantially impacted by sedimentation and fluctuations in summer baseflow. Correlation analysis showed some habitat partitioning between size classes where larger Size Class 2 fish dominated deeper pools, and smaller Size Class 1 fish (all of them YOY fish) were found more in riffles and runs (Alley et al., 2004a). Alley et al. (2004) found all size classes to be negatively correlated to riffle embeddedness, suggesting that this parameter is important to monitor and improve to recover population numbers. Smith (1982) developed an empirical model that predicted the density of smolt-sized juvenile steelhead at sites in small Santa Cruz County streams (including tributaries of the San Lorenzo) based on the positive correlation between smolt size juvenile densities and water depth and amount of escape cover in aquatic habitat.

A.1.4.g Smolts

When juvenile steelhead reach smolt size in the San Lorenzo drainage, they migrate to the Monterey Bay primarily between March and May (Smith and Alley, unpublished data from 1987-88). Salmonid survival to adulthood in the ocean increases with smolt size (Shapovalov and Taft 1954).

Before migrating to the sea, juveniles change in shape, weight, color and physiology during a process called *smoltification*. They change color, becoming silver with black-tipped fins. They may spend some time in the estuary, feeding, adapting to the salinity changes, and growing. In saltwater, they must drink water and have their gills and kidneys excrete the excess salts afterwards. In freshwater the fish must not absorb water, but must retain salts.
While some steelhead never leave freshwater (e.g., those that remain as resident rainbow trout often in inaccessible headwaters areas), most steelhead in the San Lorenzo River watershed migrate a relatively short distance to the sea.

Little is known about the ocean phase of steelhead. While at sea, steelhead feed upon krill, planktonic organisms, squid and other fish (Love, 1996). Steelhead, like other salmonids, school in large aggregations at sea and are highly migratory. A steelhead tagged in Washington was caught at the tip of the Aleutian Islands, Alaska, a distance of 2,275 miles (Love, 1996). The National Marine Fisheries Service (NMFS) and coastal universities are conducting research to learn more about the behavior and growth rates of steelhead and other salmon at sea. Scientists use tags, radio tracking and ear-bone (otolith) microchemistry in this research.

During their ocean phase, steelhead range further south than other salmonids. Unlike coho and other salmon species, steelhead are not fished commercially. NOAA fisheries research has demonstrated that different species compete for the same food source in the ocean. Steelhead and Chinook salmon sometimes feed on the same species of invertebrates. According to the local Big Creek Hatchery manager, approximately 240,000 juvenile Chinook salmon are brought from San Joaquin River hatcheries to pens in Santa Cruz for imprinting prior to annual release into the Monterey Bay (Strieg, 2006). These planted Chinooks, along with native Chinooks, compete with native steelhead and coho salmon in the bay.

A.1.5 Natural history of coho salmon

Coho salmon, also called silver salmon, range from Asia, across the Bering Strait to Alaska, and south along the Pacific coast of North America. Historically, the southern end the range of coho salmon was streams that flow out to the Monterey Bay, including the San Lorenzo River. Juvenile coho had not been documented during fall sampling of the San Lorenzo drainage since 1981, when several were caught and released in 2005 in Bean Creek, a tributary of the San Lorenzo River (Alley, 2006). These fish were members of the strongest year class (Year 3) of coho for the local area. There are viable populations of coho salmon in Scott and Waddell creeks.

Within the San Lorenzo River watershed, anecdotal evidence indicates that a small coho population once inhabited the middle mainstem and cooler reaches of lower gradient tributaries, such as Zayante, Bean and Kings creeks.

Coho salmon reach 38.5 inches in length, can weigh up to 31 pounds, and may live as long as five years (Love, 1996). Usually, they live three years in streams south of San Francisco Bay. Coho have a much more rigid life cycle than steelhead. They spend only one year in freshwater and two at sea, which creates distinct year classes. At any given time, there are essentially three different cohorts, or year classes of coho in a population specific to a given stream drainage. The size of the returning adult numbers is dependent upon the size and success of the juvenile population three years before. If migration is difficult, spawning is largely unsuccessful or rearing habitat conditions are poor, then an entire year class is affected and becomes weak. This year class remains weak at three-year intervals. If conditions are bad on a three-year interval, the entire year class may be eliminated. The three separate year classes of coho create distinct generations within every local population. If one of these generations is unable to reproduce, that year class can be lost forever unless it is recreated from hatchery plantings. This situation makes coho very susceptible to natural or anthropogenic changes in environmental conditions, and less adaptable than steelhead.

A.1.5.a Spawning

Coho migrate upstream and spawn earlier than steelhead. Most adults migrate upstream between November and February, but some spawn as late as March. Their ability to access spawning grounds depends on streamflow and storm patterns over the winter. As with steelhead, coho await the opening of sandbars at river mouths by winter runoff. At low streamflows, impediments are more likely to delay upstream migration, and adults may wait, just below the temporary barrier, for streamflow to increase. Because coho spawn earlier than steelhead, their redds are more vulnerable to destruction or suffocation from sedimentation resulting from later winter stormflows.

Upon entering fresh water streams, adult coho salmon undergo distinct biochemical and hormonal changes in response to the change in salinity and their intestinal tracts atrophy. Males undergo more extreme morphological changes than females by developing hooked jaws, as shown in Figure A.16. Once migration is initiated, adults stop feeding and begin to deteriorate with and death after spawning inevitable.

Figure A.16. Morphological changes in ocean and freshwater life stages of coho salmon.

Picture from http://www.tucalifornia.org/coho.htm

Males generally migrate upstream first, wait for females, and establish a hierarchical ranking. Females select spawning sites with high water flow through gravel, which provides sufficient oxygen for the eggs. Redds are constructed by the female at the tail of a pool or glide that is followed by a steep riffle. She spawns in the deepest part of the stream cross-section, to avoid dewatering of the nest. This placement provides a relatively shallow section, with an even bottom of gravel and enough streamflow to nurture the eggs and larvae. Coho require spawning beds of deep, loosely aggregated gravels with a minimum of fine sediments. Gravels in the range of 5 to 90 mm are optimal for salmonid spawning beds (Alley et al., 2004a; Alley, 2002). Once she selects a spawning site, the female lies on her side and flaps her tail to excavate a pit in the streambed. After the eggs are laid and fertilized, the female uses the same tail movements upstream of the pit to cover the eggs with gravel. Over several days, she may lay several more pockets of eggs, like this, in a line upstream (US Fish and Wildlife, 2006). The later spawning steelhead may spawn in the same vicinity to either scour out the coho redds or bury them.

Spawning success for steelhead populations is dependent upon the size of the run, extent of streams accessible, and spawning gravel conditions. Smith (1982) reported that although good spawning substrate is sparse throughout the San Lorenzo watershed, it rarely restricts steelhead smolt production. The San Lorenzo River Salmonid Enhancement Plan (Alley et al., 2004a) reported that spawning habitat was abundant enough, and steelhead fecund enough to produce enough juveniles to saturate the limited juvenile habitat in most years; but that spawning conditions were sub-optimal, and limited.

A.1.5.b Incubation and emergence

Incubation time varies inversely with water temperature; cooler waters lengthen incubation time. Shapovalov and Taft (1954) found that the average incubation time for coho salmon eggs in Waddell Creek was 35 to 50 days. Like steelhead eggs, coho eggs hatch into a larval form called *alevins* or sac fry. Emergence of juvenile coho salmon from the gravels begins two to three weeks after hatching, and is completed within two to seven weeks of hatching. Peak emergence occurs at approximately three weeks (Shapovalov and Berrian, 1940).

Emergence of fry may occur 7 to14 weeks after spawning in Waddell Creek, depending on water temperature. Loose gravel, absence of silt, shallow burial, and warmer temperatures hasten coho emergence, as with steelhead. Spawning areas in the lower and middle mainstem are likely warmer than Waddell Creek, leading to faster egg development and fry emergence, particularly in late spring. As with steelhead, survival rates of coho eggs and fry as they emerge from the gravel are reduced as the percent of fine sediment in the gravels increases.

A.1.6 Juvenile coho

While many of the habitat requirements for juvenile coho are similar to those of steelhead, coho prefer lower gradient reaches, cooler water temperatures, deeper pools and more escape cover, such as submerged rootwads, large logs, and unembedded boulders. These habitat characteristics are abundant in old growth forests. The decline in coho populations has been attributed to the widespread cutting of old growth forests (Brown et al., 1994). Juvenile coho primarily inhabit pools; they are unable to swim as well as steelhead in faster moving water. Coho habitat is negatively affected by sedimentation and water diversion. Few areas remaining in the San Lorenzo River watershed provide good quality coho salmon habitat because they require cool, low-gradient (flat) stream reaches. Most flat reaches in the watershed are too warm. Much of the cool, flat habitat has very low summer baseflow, and some is extremely vulnerable to dewatering by well pumping (Alley, personal observation, 2005).

A.1.7 Coho smolts

Juvenile coho smolt primarily from March through early June, approximately one year after they emerge from the gravel. During smoltification, juveniles change in shape, weight, color and physiology, and they increase their ability to excrete salts to prepare for living in saltwater. They may spend time in the lagoon adapting to the salinity changes, feeding, and growing. Smolts become silver in color.

Coho salmon spend 1-2 years at sea before returning to streams to spawn. All female coho spend two years at sea, while many males may return to their natal stream after only one year at sea. In the ocean, the small coho salmon feed primarily on small invertebrates such as krill. As they become larger, they feed on squid and small fish such as herrings, anchovies, rockfish and sand lances (Love, 1996).

The range of coho salmon while at sea is not well documented. During their first year at sea, coho salmon stay near their natal streams; later they may range far to the north, over the continental shelf (Brown et al., 1994; Love, 1996). They can migrate up to 1,000 miles from their natal streams (Love, 1996).

A.2 Ecological role of salmonids

As key predators, juvenile salmonids help keep fresh water aquatic ecology in balance. When they return from the ocean to their natal streams, anadromous salmonids bring nutrients into freshwater ecosystems. Carcasses of anadromous fish are an integral part of nutrient cycling for both aquatic and riparian systems; declines in anadromous species may cause fundamental changes in ecosystems and the loss of species (Spence et al., 1996). Salmonid carcasses, when numerous, contribute significant amounts of nitrogen and phosphorous compounds, the nutrients most often limiting production in headwater streams (Spence et al., 1996). Bilby et al. (1996) showed that 18% of the nitrogen in the foliage of Western hemlock, devil's club and salmonberry, growing within 5 m of a small stream in western Washington is derived from spawning coho salmon.

If there were still 25,000 adult steelhead and 5,000 adult coho returning to the San Lorenzo River watershed, then their contribution of nitrogen and phosphorous might be significant. Under current conditions, adult steelhead carcasses are seldom seen and coho have been functionally eliminated from the system.

Aquatic and terrestrial predators, as well as scavengers, throughout the salmonid range depend on them for food. Birds and other terrestrial organisms cycle salmonid biomass and nutrients through the terrestrial ecosystem. Bacteria and other decomposers break down salmonid carcasses to recycle nutrients that support the productivity of the aquatic ecosystem.

A.3 Decline of salmonids throughout their range

Both coho salmon and steelhead were once common and widespread throughout the coastal streams of the Pacific coast. Coho salmon historically occurred in as many as 582 California streams, from the Oregon boarder to their southern limit around the Monterey Bay (Brown et al., 1994). Salmon have disappeared from nearly half of their historical spawning streams in the Pacific Coastal states (Pacific Coastal Salmonid Conservation and Recovery Initiative, 2000). Brown et al. (1994) reported that coho populations today are probably less than six percent of what they were in the 1940s. Furthermore, there has been at least a 70 percent decline since the 1960s.

A.3.1 Decline of coho

The Central California Coast coho salmon forms a separate evolutionarily significant unit (ESU) of the species, extending from Punta Gorda in Northern California to the San Lorenzo River.

This means that the San Lorenzo River marks the southern end of the ESU range. As a result, the challenges this salmon faces are more extreme than those faced by their northern relatives, in terms of elevated stream temperatures and reduced streamflows (NMFS, 2005).

The Central California Coast Coho Salmon ESU was listed under the federal Endangered Species Act as a threatened species in 1996. Accessible reaches of the San Lorenzo River (excluding stream reaches above Newell Creek Dam) were included within the critical habitat designation for the ESU. In response to a petition filed by the timber industry to de-list coho, NMFS undertook a status review to update information about the species. The petition claimed that coho did not exist historically in central California. NMFS rejected the petition to de-list. Furthermore, the agency determined that the species should be listed as endangered rather than threatened. In 2005, coho were listed as endangered under the federal Endangered Species Act (ESA). Coho salmon south of San Francisco Bay were previously listed as an endangered species by the state of California.

NMFS began the recovery plan for the Central California Coast Coho Salmon ESU in 2005, as required by the federal ESA. Recovery is the process in which listed species and their ecosystems are restored and their future safeguarded to the point that protections under the federal ESA are no longer needed. A variety of actions may be necessary to achieve the goal of recovery, such as the ecological restoration of habitat or implementation of conservation measures with stakeholders (NMFS, 2004). Section A.8, Salmonid Recovery discusses this topic in more detail.

In their report on the status and decline of coho salmon in California, Brown et al. (1994), identified four broadly defined threats that have negatively impacted salmonids:

1. Loss of stream habitat
2. Interactions with hatchery fish, which can produce a loss of genetic integrity, and an increase in competition and disease
3. Overexploitation
4. Climatic factors, such as oceanic conditions and precipitation.

Loss of stream habitat is widely acknowledged as the single most significant factor contributing to the decline of coho throughout California (Brown et al., 1994; Pacific Coast Salmonid Conservation and Recovery Initiative, 2000).

Over at least the past 60 years, the loss of coho salmon habitat has been cumulative (Brown, et al., 1994). Logging, with unpaved roads and skid trails, causes severe habitat degradation for coho salmon (Brown et al., 1994). Habitat loss is extensive in watersheds impacted by early logging with continued sedimentation (Brown et al., 1994). Coho salmon habitat loss from current logging practices still occurs due to accelerated sedimentation (Brown et al., 1994). Burns (1972) indicated that logging severely reduced the number of coho salmon smolts emigrating out of watersheds in California waterways (as cited in Brown, et al., 1994). Graves and Burns (1970) found that smolts emigrated at much smaller sizes from logged watersheds than from untouched watersheds, due to stress from habitat degradation in the logged watersheds (as cited in Brown et al., 1994). Survival rate of smolts to the returning adult stage is positively correlated with larger size at smolting, as stated earlier.

Researchers believe that most natural production of coho salmon in the smaller streams south of San Francisco were lost due to the 1976-1977 drought. The drought exacerbated the cumulative watershed conditions already impacting the species in this area (Brown et al., 1994). The El Niño winters of 1992 and 1983 further diminished local coho populations, due to high rainfall and winter runoff, associated ocean warming and food scarcity in the ESU range, and major damage to streambeds from severe landsliding and sedimentation. These factors severely reduced the survival rate of salmonid juveniles to adulthood. The drought years of 1987-1992 undoubtedly added catastrophic impacts to coho spawning success and juvenile survival.

A.3.2 Decline of steelhead

The US Fish and Wildlife Service adopted a final rule, designating steelhead in the Central California Coast ESU as a federally threatened species, effective October 17, 1997 (US Fish and Wildlife Service, 1998).

At this time, the designation applies only to naturally spawned populations of anadromous forms of *O. mykiss,* residing below long-term naturally occurring or man-made impassable barriers. The San Lorenzo River is included in critical habitat designated for all accessible reaches, except for stream reaches above Newell Creek Dam. Steelhead south of San Francisco Bay are considered a sensitive species by the state of California.

Loss of steelhead and coho habitat has resulted from dams, water diversions, increased stream water temperatures, stream alterations, sedimentation, excessive scour and other impacts associated with agriculture, logging, mining, urbanization, roads and development. These activities are associated with a dramatic reduction in habitat complexity, including the reduction in large instream wood and an increase in sedimentation (Sanderlock, 1991 as cited in Brown et al., 1994). Napolitano (1998) reports high quality fish habitat results from complexity and stable conditions.

Impacts from specific forest practices on salmonid growth and survival and on aquatic habitat are shown in Tables A.1 and A.2. Table A.1 best describes impacts outside the fog belt and Table A.2 describes impacts within the coastal zone, which receives most of the benefits of fog drip.

Table A.1. Forest practices outside the fog belt and their potential impacts to stream environments, habitat quality, and salmonid growth and survival

Forest practice	Potential impact to physical stream environment	Potential impact to quality of salmonid habitat	Potential consequences for salmonid growth and survival
Timber harvest in riparian areas	Increased incident solar radiation	Increased stream temperature; higher light levels; increased autotrophic production	Reduced growth efficiency; increased susceptibility to disease; increased food production; changes in growth rate and age at smolting
	Decreased supply of large woody debris	Reduced cover; loss of pool habitat; reduced protection from peak flows; reduced storage of gravel and organic matter; loss of hydraulic complexity	Increased vulnerability to predation; lower winter survival; reduced carrying capacity; less spawning gravel; reduced food production; loss of species diversity
	Addition of logging slash (needles, bark, branches)	Short-term increase in dissolved oxygen demand; increased amount of fine particulate organic matter; increased cover	Reduced spawning success; short-term increase in food production; increased survival of juveniles
	Erosion of streambanks	Loss of cover along edge of channel; increased stream width; reduced depth	Increased vulnerability to predation; increased carrying capacity for age-0 fish, but reduced carrying capacity for age-1 and older fish
		Increased fine sediment in spawning gravels and food production areas	Reduced spawning success; reduced food supply
Timber harvest on hill slopes; forest roads	Altered streamflow regime	Short-term increase in streamflows during summer until secondary forest growth develops	Short-term increase in juvenile survival
		Increased severity of some peak flow events	Embryo mortality caused by bed-load movement
	Accelerated surface erosion and mass wasting	Increased fine sediment in stream gravels	Reduced spawning success; reduced food abundance; loss of winter hiding space
		Increased supply of coarse sediment	Increased or decreased rearing capacity
		Increased frequency of debris torrents; loss of instream cover in the torrent track; improved cover in some debris jams	Blockage to migrations; reduced survival in the torrent track; improved winter habitat in some torrent deposits
	Increased nutrient runoff	Elevated nutrient levels in streams	Increased food production
	Increased number of road crossings	Physical obstructions in stream channel; input of fine sediment from road surfaces	Restriction of upstream movement; reduced feeding efficiency
Scarification and slash burning (preparation of soil for reforestation)	Increased nutrient runoff; Inputs of fine inorganic and organic matter	Short-term elevation of nutrient levels in streams; increased fine sediment in spawning gravels and food production areas; short-term increase in biological oxygen demand (BOD).	Temporary increase in food production; Reduced spawning success

Source: Spence et al., 1996.

A.4 Decline of salmonids within the San Lorenzo River watershed

The San Lorenzo River watershed provides over 80 miles of stream habitat for anadromous salmonids (Ricker and Butler, 1979). The San Lorenzo River fishery once added significant value both to the county's economy and to the experience of individual anglers.

A.4.1 Decline of steelhead in the watershed

According to the CCRWQCB (2002), "The San Lorenzo River once held the distinction of having the largest steelhead fishery south of San Francisco." The California Department of Fish and Game (CDFG) estimated that 20,000 adult steelhead were present in the San Lorenzo River prior to 1965 (Johansen, 1975). This estimate included any rainbow trout/steelhead larger than 14 inches in length (Strieg, 2005). In the mid-1960's, CDFG estimated that 19,000 adult steelhead inhabited the watershed. NOAA Fisheries estimated the number of adult steelhead in the watershed in 1966 at 500. However, these estimates of historic adult steelhead numbers were anecdotal and lacked supportable scientific evidence. Most estimates were based on creel census data, which reflect the extensive planting program rather than natural production. However, it may be assumed that the steelhead population was greatly reduced from the habitat degradation documented in the 1960's and 1970's, following extensive clear-cut logging and fast-paced suburban development.

Scientifically supportable estimates of juvenile steelhead density first occurred in 1981, when Smith and Alley conducted habitat surveys and sampled juvenile steelhead densities by electrofishing throughout Santa Cruz County (Smith, 1982). Comprehensive estimates of habitat conditions and juvenile population estimates in the San Lorenzo watershed were resumed in 1994 by D.W. Alley & Associates, and have continued through 2005. Although there were likely much larger juvenile populations prior to clear-cut logging and housing development in the 1960s and 1970s, these data suggest a fairly stable juvenile steelhead population from 1981 to 2005, with year-to-year fluctuations. Juvenile numbers have been negatively affected by El Niño events. Poor adult returns resulted from oceanic food shortages, juveniles being flushed out to sea during high stormflows, increased erosion and stream sedimentation from heavy stormflows.

Drier years with reduced streamflow also resulted in smaller juvenile numbers, because of reduced habitat and slower juvenile growth rates. Juvenile numbers have increased in years, such as 2002, when the heaviest stormflows came early in the winter with milder storms. This resulted in less sediment movement and better water clarity after storms. Indices of adult population size for the San Lorenzo River watershed ranged between 1,600 and 2,650 during the period 1998-2001, with juvenile populations ranging between 103,000 and 171,000 (Alley, 2002). These are the best estimates to date from systematically collected data. Adult indices are probably conservatively low, based on the underlying assumptions of the Kelley et al. (1987) model and a 50% reduction factor applied to the number of adults generated by the model from juvenile numbers (Alley, 2002).

The steelhead population has not recovered. NMFS listed steelhead as a threatened species in the Central California Coast Evolutionary Significant Unit (ESU), which includes the San Lorenzo River. The San Lorenzo River watershed has suffered major spawning and rearing habitat degradation. Human-induced habitat loss and degradation resulted from 1) early clear-cut logging that increased erosion, reduced stream shading and diminished summer streamflow with loss of fog drip, 2) contemporary logging since 1960 (clear-cut and later selection cut) that inadequately buffered the riparian corridor from timber harvest and has accelerated erosion from road and skid-trail construction, increased winter storm runoff, reduced summer baseflow with loss of fog drip and reduced large instream wood recruitment, 3) quarrying of sand and gravel that cleared vegetation and increased erosion, and 4) increased human development that brought more vegetation clearing, impermeable surfaces and altered drainage patterns. These land-use patterns increased stormflow peaks, erosion and water demand, resulting in increased surface water diversion and well pumping.

A.4.2 Decline of coho in the watershed

Historic and recent population estimates suggest a worse decline for coho salmon than for steelhead in the San Lorenzo River watershed. The coho salmon population in the early 1950's, prior to hatchery plantings, was described as "small" by Willis Evans, retired CDFG fishery biologist and the last Brookdale Hatchery Manager (Alley and Evans, personal communication 2001). Evans said spawning occurred in the middle mainstem (Reaches 6-9) and eastern tributaries, such as Zayante and Bean creeks, shown in Figure A.15. The coho population was estimated as high as 2,500-10,000 in 1964 (Johnson, 1964), and as low as 750 in 1980 by CDFG staff (CCRWQCB staff report for TMDL, 2001). However, there was no scientific evidence on which to base these estimates. Since systematic juvenile sampling began in 1981, coho juveniles have been detected only in 1981 (Bean and Fall creeks) and in 2005 (Bean Creek). According to NOAA Fisheries, coho salmon were extirpated from the watershed through a combination of habitat loss and five consecutive years of drought conditions, 1987-92 (J. Ambrose, NOAA Fisheries, personal comm.). The severe droughts of 1976-77 undoubtedly made adult fish passage through the San Lorenzo River gorge difficult for coho salmon.

Although coho salmon historically inhabited many coastal streams in San Mateo and Santa Cruz counties, presently they are known to occur south of San Francisco Bay in only San Gregorio, Pescadero, Gazos, Waddell, Scott Creek and San Vicente creeks. Of these creeks, only Scott Creek has three intact year classes. Waddell has two mediocre year classes (Jerry Smith, personal communication). San Vicente Creek probably has two year classes present. San Gregorio, Pescadero and Gazos creeks have only one year class present.

A.4.3 Habitat conditions 1950-1975

Habitat conditions in the watershed were good in the 1950s and then substantially worsened in the 1960s and 1970s, due to clear-cut logging and increased human development. A CDFG survey of Bear Creek in 1956 and of Zayante Creek in 1959 found that habitat conditions were good, but expected to soon worsen following the clear-cut logging that was scheduled to occur in 1960. As expected, a CDFG survey of Zayante Creek in 1966 and 1974 found that extensive habitat damage had resulted from the logging that occurred without riparian protection. Boulder Creek had poor substrate conditions by 1960 and again in 1966, according to CDFG surveys. Kings Creek also had poor conditions by 1966. CDFG stream survey reports for Bear Creek showed poor conditions in 1974.

Other CDFG surveys indicated that substrate conditions in the mainstem San Lorenzo had badly deteriorated to very sandy conditions by 1972. A 1966 CDFG survey estimated the streambed to

be 35% cobble, 20% gravel and 25% sand and silt. The 1972 CDFG survey estimated the streambed to be 3% cobble, 2% gravel and 76% sand and silt.
Suburban residential development increased during this same period, as summer homes were converted to year-round dwellings. Between 1970 and 1976, 280 new homes were built each year. From 1960 to 1976, the watershed population nearly tripled (Ricker and Butler 1979). This increased housing development was accompanied by inadequately constructed or poorly maintained roads (Ricker and Butler 1979).

A.4.5 Recent habitat conditions

Natural processes create aquatic habitats that are critical to salmonids (Spence et al., 1996). Different aquatic habitats are required for different salmonid life stages. For example, graveled-glides are used for adult spawning, fast water habitat is used for juvenile feeding, and pools provide juvenile cover and feeding areas. Large objects in the channel provide slackwater resting sites for overwintering juveniles and migrating adults.

The most common aquatic habitat types within the San Lorenzo River watershed are pools, riffles, runs and step-runs. Lateral scour pools are the most common pool types.

Measurable physical characteristics of aquatic habitats include stream width, streamflow, water depth, escape cover (amount and source of cover), percent embeddedness of larger cobbles and boulders (portion of rocks buried in finer material), streambed composition (percent fine sediment (mostly sand) versus gravel or larger rocks), stream shading (percent canopy closure) and percent of the riparian canopy that is deciduous versus evergreen. Table A.3 lists the percentage of riparian canopy closure by reach within the San Lorenzo River watershed.

Table A.3 Baseline riparian tree canopy closure in the San Lorenzo River watershed. (Refer to map in Figure 4-6)

Reach Designation	Reach Location	Average % Tree Canopy Closure by Reach	Year of Measurement
1	Lower Mainstem- Paradise Park	44	2006
4	Lower Mainstem- Upper Henry Cowell Park	32	2006
6	Middle Mainstem- Above and below Fall Creek Confluence	62	2006
7	Middle Mainstem- Downstream of Ben Lomond Summer Dam	50	2005
8	Middle Mainstem- Downstream of Clear Creek Confluence	51	2006
9	Middle Mainstem- Downstream of Boulder Creek Confluence	57	2005

10	Upper Mainstem- Downstream of Kings Creek Confluence	80	2005
11	Upper Mainstem- Up and Downstream of Teilh Road Bridge	79	2006
12b	Upper Mainstem- Waterman Gap Upstream of Highway 9 Bridge	86	2005
13a	Zayante Downstream of Bean Creek Confluence	84	2006
13b	Zayante Upstream of Lowermost East/ West Zayante Road Bridge	70	2005
13c	Zayante Upstream of Quail Hollow Road Bridge	71	2005
13d	Zayante Mostly Upstream of East Zayante Road Bridge	83	2006
13e	Lower Lompico Creek, Upstream of Bridge Crossing Above Fish Ladder	81	2006
14a	Lower Bean Above Zayante Confluence	84	2005
14b	Middle Bean Downstream of Lockhart Gulch Confluence	72	2005
14c	Bean Above Mackenzie Confluence	79	2006
16	Newell Between Glen Arbor Bridge and the Next One Upstream	75	2006
17a	Lower Boulder Above Highway 9 Bridge	81	2006
17b	Middle Boulder Mostly Above Big Basin Way Bridge Into Bracken Brae	84	2005
17c	Upper Boulder Above Bracken Brae	82	2005
18a	Bear Upstream from Pool Under Oso Viejo Road Bridge to Bear Creek Country Club	78	2006
21b	Branciforte Upstream from Happy Valley School	75	2005

Source: Alley 2007.

Table A.4 quantifies some of the steelhead habitat characteristics within the San Lorenzo River watershed.

Table A.4. Habitat proportions and percent contribution of juvenile production to adult steelhead index of mainstem segments and major tributaries of the San Lorenzo River watershed*

Mainstem segment or tributary	Average % pool**	Average % fastwater habitat**	% of watershed's steelhead habitat length in dry years (miles of habitat***)	% juvenile contribution to adult index
Lower mainstem (above Tait Street)	44	56	13 (7.6 miles)	19
Middle mainstem	70	30	15 (8.9 miles)	6.1
Upper mainstem	62	38	14 (8.4 miles)	13.2
Branciforte	71	29	7.7 (4.6 miles)	8.2
Carbonera	56	44	5.7 (3.4 miles)	4.3
Fall	25	75	2.7 (1.6 miles)	3.3
Zayante (to Mt. Charlie Gulch)	64	46	9.6 (5.7 miles)	13.5
Bean	49	51	9.1 (5.5 miles)	10.0
Newell	63	37	1.8 (1 mile)	1.3
Boulder	57	43	6.1 (3.5 miles)	7.3
Bear	67	33	8.1 (4.7 miles)	10.0
Kings	66	34	6.5 (3.7 miles)	3.8

* Source: Alley 2002.
** Averages of percent habitat proportions for habitat typed reaches in each mainstem segment or tributary.
***Habitat mileage is a conservative estimate, typical of an especially dry year like fall 1981.
Refer to our county-wide Steelhead and Coho Salmon Distribution Map (2004) for best estimates of typical steelhead distribution in tributaries of the San Lorenzo River watershed.

A.5 Aquatic habitat typing

Terms used to identify aquatic habitat types are defined in Table A.5.

Table A.5. Terms used in aquatic habitat typing.

Term	Habitat description
Riffle	Shallow swiftly flowing, turbulent water with some partially exposed substrate, usually cobble dominated. "Low gradient" riffles = channel gradient of <4%. "High gradient" riffles = channel gradient of >4%.
Cascade	Steepest riffle habitat, with alternating small waterfalls and shallow pools. Substrate usually bedrock and boulders.
Bedrock sheet	Thin sheet of water flowing over a smooth bedrock surface. Gradients highly variable. Fairly common in headwater situations, especially north of Zayante Fault, and at geological interfaces within San Lorenzo River watershed.
Pocket water	Section of swift flowing stream containing numerous boulders or other large obstructions, with eddies or scour holes behind obstructions. Generally found in larger mainstems.
Glide	Wide uniform channel bottom. Low to moderate flow velocities, lacking pronounced turbulence. Substrate usually consists of cobble, gravel, and sand. Generally, wide and relatively shallow, with smooth bottom. Generally located at tails of pools in San Lorenzo River watershed.
Run	Swiftly flowing with little surface disturbance, and no major flow obstructions. Often appear as flooded riffles. Typical substrate consists of gravel, cobble, and boulders; bottom may be uneven and rough.
Step-run	A sequence of runs separated by short riffle steps. Substrate usually cobble and boulder dominated. Generally found in headwaters or gorges within San Lorenzo River watershed.
Edgewater	Quiet, shallow area found along margins of stream, typically associated with riffles. Water velocity low or lacking. Substrate varies from cobbles to boulders.
Pool	Large, deep-water section of stream. Pools formed by scour, and classified by scour type.
Mid-channel pool	Large pool formed by mid-channel scour. Scour hole encompasses > 60% of wetted channel. Slow water velocity; substrate highly variable.
Channel confluence pool	Large pool generally formed at confluence of two or more channels.
Corner pool	Lateral scour pool formed at bend in channel. Often a bedrock wall or solid channel barrier outside edge, deflecting stream velocity to scour pool.
Lateral scour pool	Formed by flow scouring around partial channel obstruction. Scour generally confined to < 60% of wetted channel. Scour objects may be logs, rootwads, boulders, bedrock or artificial.
Plunge pool	Located where stream passes over channel obstruction, dropping steeply into streambed belo Resulting scoured out depression often large and deep. Substrate size variable. More common in headwaters, and accompanying old-growth instream wood.
Dammed pool	Water impounded from channel blockage, such as large instream wood, rockslides, or artificial barriers. Substrate tends toward smaller gravel and sands.
Step pool	Series of pools separated by short riffles or cascades; generally found in high gradient, confined mountain streams dominated by boulder substrate.
Secondary channel pool	Mainly associated with gravel bars, sand or silt substrate. In summer, pools dry up, become isolated or have little flow.
Backwater pool	Located along channel margins; caused by eddies around obstructions such as boulders, rootwads, or logs; generally shallow; dominated by fine grain substrate. Low current velocities.

Source: Adapted from the original system developed by Bisson, et al. (1981), modified by Decker, Overton (1985), Sullivan (1988), and Snider (1990).

The most common aquatic habitat types within the San Lorenzo River watershed are pools, riffles, runs and step-runs. Lateral scour pools are the most common pool types.

Measurable physical characteristics of aquatic habitats include stream width, streamflow, water depth, escape cover (amount and source of cover), percent embeddedness of larger cobbles and boulders (portion of rocks buried in finer material), streambed composition (percent fine sediment (mostly sand) versus gravel or larger rocks), stream shading (percent canopy closure) and percent of the riparian canopy that is deciduous versus evergreen.

A.5.1 Local stream reaches

Watersheds are divided into stream reaches, based on their habitat characteristics. Within each reach, each habitat characteristic is tallied, and then averaged for each reach. In this way, for example, the average percent canopy closure is calculated for each reach. Within each reach, the percentage of each habitat type is also calculated. In this way, for example, the percent of pool habitat within the stream length is calculated for each reach.

Based on channel morphology and other habitat characteristics, the mainstem San Lorenzo River has been divided into four sections (Alley, 2002):

Upper mainstem– upstream of Boulder Creek confluence into Waterman Gap and headwaters.
Middle mainstem– between the Boulder Creek and Zayante Creek confluences.
Lower mainstem– San Lorenzo gorge and alluvial reaches below Zayante Creek confluence.
Tributaries-form subwatersheds as they flow into the mainstem.

A.5.1.a Upper mainstem

The upper mainstem has relatively low spring and summer baseflow, is well-shaded with cool water. Here, juvenile steelhead require two years to reach smolt size except during the wettest years. Most juveniles reside in pools. The upper mainstem also has relatively high densities of yearlings, which contributed significantly to the adult steelhead index in 2001 (Table A.6). Between the Boulder Creek and Kings Creek confluences, the mainstem is low gradient, has steep canyon walls with tall redwoods, and is dominated by long, sediment-laden pools separated by short, shallow riffles (Table A.6). Large Sacramento suckers are found under banks and large wood in pools of this stretch. Further upstream, as stream gradient increases, the pools become shorter and habitat variety increases. Limiting factors to salmonids in the upper mainstem include low spring and summer streamflow and sedimentation from erosion, as shown in Figure A.17.

Figure A.17. Streambank erosion on the upper San Lorenzo River

Alley 2005

A collapsing streambank is a source of sedimentation of the streambed in the upper San Lorenzo River.

Table A.6 Habitat proportions & percent contribution of juvenile production to adult steelhead index of mainstem segments & major tributaries of the San Lorenzo River watershed*

Mainstem Segment Or Tributary	Avg % Pool**	Avg % Fastwater Habitat**	% of Watershed's Steelhead Habitat Length in Dry Years (miles of habitat***)	% Juvenile Contribution To Adult Index
Lower mainstem (above Tait Street)	44	56	13% (7.6 miles)	19
Middle mainstem	70	30	15% (8.9 miles)	6.1
Upper mainstem	62	38	14% (8.4 miles)	13.2
Branciforte	71	29	7.7% (4.6 miles)	8.2
Carbonera	56	44	5.7% (3.4 miles)	4.3
Fall	25	75	2.7% (1.6 miles)	3.3
Zayante (to Mt. Charlie Gulch)	64	46	9.6% (5.7 miles)	13.5
Bean	49	51	9.1% (5.5 miles)	10.0
Newell	63	37	1.8% (1 mile)	1.3
Boulder	57	43	6.1% (3.5 miles)	7.3
Bear	67	33	8.1% (4.7 miles)	10.0
Kings	66	34	6.5% (3.7 miles)	3.8

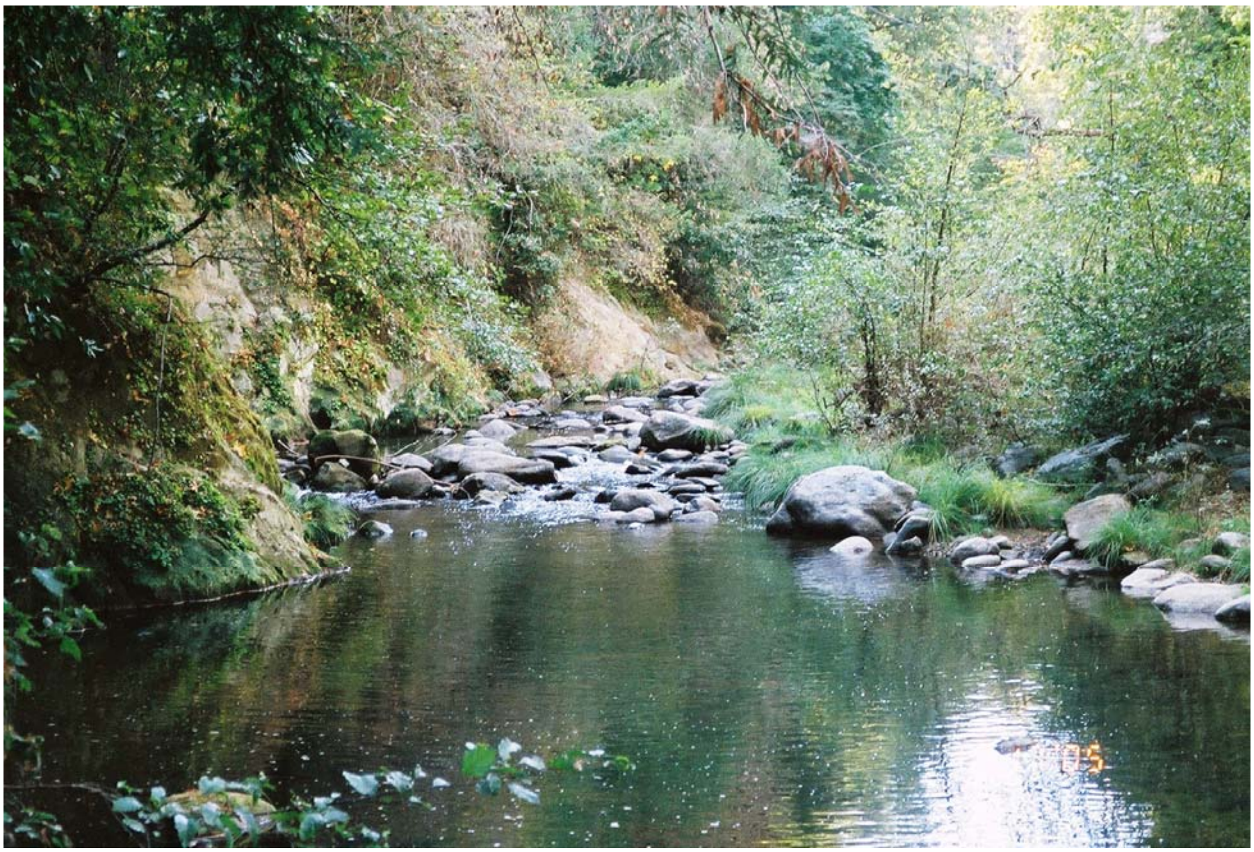
* Source: Alley, 2002.
** Averages of percent habitat proportions for habitat typed reaches in each mainstem segment or tributary.
***Habitat mileage is a conservative estimate, typical of an especially dry year like fall 1981. Refer to county-wide Steelhead and Coho Salmon Distribution Map (2004) for best estimates of typical steelhead distribution in tributaries of the San Lorenzo River watershed.

A.5.1.b The middle mainstem

The middle mainstem begins below Boulder Creek. Bear, Boulder and Clear creeks enter its upper end as tributaries, which contribute large, granitic streambed cobbles and boulders. Tributaries also help to seed the middle mainstem with YOY juvenile steelhead. The middle mainstem has higher streamflow than the upper mainstem and a wider, sunnier canyon. Its increased gradient creates more fastwater feeding habitat (riffles and runs) and better aquatic insect habitat. Riffles, runs and heads of pools are the primary habitats for juveniles. Figure A.18 shows habitat provided by bedrock scoured pools. Water temperatures are warmer, forcing juvenile steelhead to use fastwater habitat to feed. Approximately 70-80% of the length of the middle mainstem is dominated by long, deep pools containing insufficient food for juvenile steelhead, except at the heads of the pools. Spawning habitat is limited. As Table A.6 shows, since 1999, juvenile densities have been low here.

Limiting factors to salmonids in the middle mainstem include periodic onslaughts of sediment from the tributaries (particularly Kings, Bear and Boulder creeks with continued logging and poorly constructed rural roads) and the lack of large instream wood that would counter negative effects of sediment. The other primary limiting factors are low spring and summer streamflows that are worsened by District surface water diversions in the Boulder and Clear Creek sub-watersheds, water storage on Newell Creek (City of Santa Cruz's Loch Lomond) and California-American Water Company's Fall Creek water diversion. Fortunately, the District's surface water diversions are located high in tributary headwaters, are inoperative in drought years, and lose surface flow in mid- to late summer in all but the wettest years.

Figure A.18. Bedrock scoured pool in the middle San Lorenzo River.



Alley 2005

Bedrock scoured pool in the middle San Lorenzo River, with fastwater feeding habitat for salmonids (run then riffle), emptying into a pool .

A.5.1.c The lower mainstem.

With large granite boulders in abundance, the lower mainstem resembles many Sierra Nevada streams. The lower mainstem has much greater spring and summer baseflow than upstream, to create relatively higher food abundance, even in summer. Zayante Creek, draining a sub-watershed that is approximately ¼ of the total watershed area, enters the lower mainstem. Many juvenile steelhead reach smolt size after one growing season every year in lower mainstem. As the river flows through Henry Cowell Park and the canyon gorge, its gradient increases greatly. Through the gorge, there are deeper, fastwater riffles, and more step-runs and runs, which provide good fastwater feeding habitat for juvenile steelhead. The lower mainstem was a major contributor to the adult steelhead index in 2001 (Table A.6). Passage for spawning adult steelhead and coho salmon can be difficult through the gorge in drier winters because of boulder cascades and a wide riffle in the Rincon. Spawning habitat is poor due to high sand content in spawning glides.

After Santa Cruz was built on the alluvial floodplain, wetlands were filled in and built over, and the river's width was narrowed. Downtown Santa Cruz was built on the old river channel. After the 1955 flood, the Army Corps of Engineers built a levied flood control channel for the lower San Lorenzo River, and a concrete channel with vertical walls along lower Branciforte Creek, which joins the river near its mouth. The river is now confined to this narrow, straightened channel. Without wide, intact wetlands and riparian woodlands, the confined stream channel is prone to sedimentation and high stormflow damage. Quiet backwater refuges for fish, once present during stormflows, have been eliminated. The simplified channel facilitates large mammal predation of migrating fish. Recently, the City has attempted to increase habitat complexity within the flood control channel, retaining more riparian vegetation, and forestalling dredging.

A.5.1.d Tributaries

Tributaries entering the upper and middle mainstem from the west (Boulder, Clear and Fall creeks) contribute granite-based substrate, and are relatively steep, as they drain from Ben Lomond Mountain. Tributaries entering from the east (Kings, Bear, Love, Newell and Zayante-Bean creeks) contribute sandstone and shale-based substrate, and are relatively low gradient. The Branciforte-Carbonera creeks contribute granite-based substrate to the San Lorenzo estuary/ lagoon. These tributaries are low gradient in their lower reaches and increase in gradient upstream. Hence, they are more accessible to adult steelhead and coho salmon (if they can negotiate the Branciforte flood control channel). Spawners need not maneuver the San Lorenzo gorge and Felton Dam fish ladder to reach spawning habitat.

Following are short descriptions of each tributary and its aquatic habitat conditions, beginning at the upper mainstem and moving downstream:

Kings Creek has some of the poorest steelhead habitat in the watershed, due to high sedimentation, low spring and summer baseflow, very poor spawning habitat and very limited rearing habitat leading to slow juvenile growth. It contributed only 3.8% to the adult index in 2001 though approximately 6.5% of its length has steelhead habitat. There is anecdotal evidence of coho using the creek in the late 1950s. This tributary contributes considerable sediment to the mainstem. Much sedimentation has occurred concurrently with active logging operations, road erosion, and landsliding. The District completed watershed enhancement projects, including reconfiguring a badly gullying and eroding CDF fire road and removing a concrete wall (remnant of a dam) that was causing streambank erosion. The County reworked the road paralleling the creek. A significant landslide still exists in the Logan Creek drainage, where a road crosses near its base, increasing sediment loads into the creek (Alley et al., 2004a).

Bear Creek is a low gradient, well-shaded tributary that contains many deep, bedrock corner pools and long riffles. However, it has limited cover in pools due to a lack of large wood. Deeper runs offer some yearling habitat when less embedded, but pools are primary habitat. Sedimentation is high in wet winters, such as 2005-2006 (Alley pers. Observation, 2006), it being contributed by significant landsliding in the headwaters and Deer Creek. Rural roads and logging accentuate erosion problems. Bear Creek is a productive steelhead stream, contributing 10% to the adult index in 2001 (Table A.6), though juvenile growth is slow due to low spring and summer baseflow.

Boulder Creek's canyon downstream of the Boulder Creek Country Club, with its steep vertical walls, has some of the most ruggedly beautiful and inaccessible stretches in the entire watershed. The creek's streambed is dominated by large granitic cobbles and boulders in turbulent riffles and runs, and is punctuated with relatively deep pools containing virtually no instream wood. The stream has relatively high winter stream velocities through a very confined, heavily shaded canyon. High winter water velocities wash out large wood, and pools often have little cover except from depth and large, unembedded boulders. Overwintering juveniles are more easily flushed out of Boulder Creek than other tributaries. Course sand deltas are sometimes found at the confluences of its steep tributaries. Spawning habitat is limited, and steep boulder riffles may restrict adult passage in drier years. Resident rainbow trout likely inhabit the upper canyon along with steelhead. Summer water temperature is some of the coolest in the watershed. Low spring and summer baseflow are limiting factors, and juvenile steelhead growth is slow. Steelhead are probably unable to pass through a bedrock chute above the Boulder Creek golf course, across from the Kings Highway junction with Big Basin Way.

Newell Creek has a mile of easily accessible steelhead habitat below a bedrock chute that is likely a passage impediment at flows less than approximately 300 cfs (Alley, 1993; Alley et al. 2004). Winter spawning flows are likely much reduced until Newell Creek Dam spills in winter. The only restriction on releases from the City of Santa Cruz storage reservoir is a minimum flow release of 1 cubic feet per second. This flow is probably above natural levels in summer, but well below natural levels during the important spring months when juvenile steelhead growth is normally highest. Steelhead growth was slow in Newell Creek in 2001 (Alley, 2002). Since winter releases may not mimic natural winter stormflow, spawning habitat may be quite limited when adult steelhead are ready to spawn. YOY densities were moderate and yearling densities were relatively low in 2001 compared to other tributaries (Alley, 2002). The streambed is generally clean, with sediment being retained behind the dam. However, embeddedness of cobbles was high due to lack of flushing flows in 2001 (Alley, 2002). The riparian corridor is well developed and diverse, despite houses being relatively close to the stream in places.

Fall Creek is one of the most shaded and coolest tributaries in the watershed. Even though much of the creek is within Henry Cowell Park, it is subject to large sediment inputs from steep hillslopes prone to landsliding. The landscape is apparently still recovering from past clear-cut logging and limekiln operations. The stream gradient is steep with few pools. The stream is dominated by shallow, fast riffles. Juvenile steelhead growth is very slow despite relatively high summer baseflows. Steelhead are limited by poor pool development, a highly sedimented streambed, and heavy shading. The District water diversion and fish ladder at the lower end of the creek (recently acquired from California-American Water) may cause passage difficulties, should the fish ladder become damaged by high flows.

Zayante Creek and its tributary Bean Creek both pass through a very erosive landscape. They both have long extensions at a low gradient. They are significant contributors to the juvenile steelhead population and adult index (Zayante Creek = 13.5%; Bean Creek = 10%). Lower

Zayante Creek, downstream of the Bean Creek confluence, receives heavy sediment inputs from Bean Creek, but supports relatively high growth rates for juvenile steelhead in wetter years with higher spring/summer baseflow. Still, juvenile densities are typically low. Above the Bean Creek confluence, fish passage improvements on Zayante Creek have been made over a bedrock shelf at the Mount Hermon dam abutment. Between the dam abutment and the Lompico Creek confluence, long pools dominate the stream. A series of bedrock shelves at the tails of pools are followed by short, bedrock riffles emptying into the next pool. Stream shading is moderate. Instream wood and overhanging vegetation provide good cover. Quarries west of Quail Hollow Road deliver chronic supplies of sand to Zayante Creek, upstream of the Trout Farm Inn (Alley, pers. observation). The Trout Farm Inn pond is a source of bullfrogs to the creek. An unusually designed fish ladder was constructed at a modified bedrock shelf under Quail Hollow Road Bridge. A bedrock chute approximately ½ mile upstream of the bridge had a narrow channel cut through it to improve passage. Upstream of Lompico Creek, stream gradient increases and step-runs become ¼ of the habitat (Alley, 2002). This is a high producer of larger yearling steelhead that inhabit primarily pools. A 5-6 foot high bedrock, chute located downstream of Mountain Charlie Gulch, likely causes a low-flow adult passage impediment during dry years and drought (Alley pers. observation). This stretch is subject to periodic high sediment input. Logging was active in the Mountain Charlie drainage by the City of Santa Cruz in the past, accelerating erosion rates from disturbance caused by skid trails and logging roads (Alley pers. observation). The headwaters have experienced recent vineyard development to hasten soil erosion. Despite higher streamflow than other tributaries, low summer streamflow limits fish habitat (Ricker and Butler, 1979) along with streambed sedimentation. The extent of steelhead distribution includes some of Mountain Charlie Gulch and Zayante Creek beyond the Mountain Charlie confluence an unknown distance. However, in 1981, Mountain Charlie Gulch and Zayante Creek above its confluence were dry in fall (Smith 1982; Alley, pers. observation).

Bean Creek near Mount Hermon is extremely sediment-laden and landsliding is common during heavy storms. Pool development and spawning habitat are poor. Heavy foot traffic from Mount Hermon visitors, both in the channel and streamside, has degraded summer habitat. Small rock dams limit fastwater habitat and insect production. A large, active landslide chronically introduces sand to the channel near the quarry opposite Locatelli Lane. A short, periodically very productive steelhead reach exists from the Mt. Hermon Road, cutoff upstream beyond Lockhart Gulch to Ruins Creek. The riparian corridor has been healthy until recently with good pool cover provided by instream wood in a meandering reach. This reach is now seriously threatened by recent land development in the riparian corridor. It has resulted in riparian clearing and destructive streambank stabilization practices intended to protect new houses constructed on low-lying property close to the stream. This stretch has been chronically subjected to instream wood-clearing and periodically substantial sedimentation, as well. Upstream of Ruins Creek, streamflow fell off in short order and, at varying distances from year to year, the stream channel becomes dewatered upstream. In 2004, the dewatered reach extended 9,350 feet upstream past the Mackenzie Creek confluence (Alley, 2005). Estimated streamflow upstream of there was only 0.02 cfs, with steelhead restricted to pool habitat only. This was the low gradient, cool-water reach where coho salmon juveniles were captured and released in 2005 (Alley, 2006). Thus, surface flow in upper Bean Creek is extremely vulnerable to well pumping in the Santa Margarita aquifer to the northwest of Scotts Valley. Steelhead growth is slow and limited by low spring and summer baseflow.

Carbonera Creek is the other tributary that drains out of Scotts Valley to the south, emptying into Branciforte Creek in northern Santa Cruz near Highway 1. Steelhead adult passage in Carbonera Creek is stopped at Moose Lodge Falls behind the Moose Lodge adjacent to Highway 17. The steelhead reach flows through a deep canyon dominated granite-based streambed cobbles and sand, with primarily redwood and tanoak on the steep sideslopes. In the higher gradient reach below the falls, short pools, step-runs and runs dominate the stream. Riffles are scarce. A population of predacious green sunfish was detected in the creek in the mid-1990s, escapees from ponds on Camp Evers Creek in Scotts Valley (Alley, 1997). Summer water temperature is cool, but summer baseflow is limiting and very low. Therefore, juvenile steelhead growth is very slow, but yearling densities were relatively good in 2001 and higher than 12 of 20 sampled tributary sites in 2001 (Alley, 2002). This was because pools were relatively deep and cover was provided primarily by unembedded boulders. The lower reach of Carbonera Creek was lower gradient, badly sand-dominated and subject to substantial sedimentation that limited steelhead habitat. Escape cover and pool scour were completely reliant on instream wood. Yearling densities there were relatively low and steelhead growth was very low, resulting from limiting low streamflow (Alley, 2002). Carbonera Creek contributed 4.3% to the adult index in 2001.

Branciforte Creek has a long, low-gradient reach between the flood-control channel and Granite Creek confluence. Shallow pools dominated more than two-thirds of the stream channel below Granite Creek, with escape cover primarily provided by undercut banks, overhanging vegetation and instream wood. Food was likely in very short supply with bedrock-dominated riffles and low spring and summer baseflow. As gradient increases in Branciforte Creek above Granite Creek, pools shorten (remain mostly shallow except at corner pools) and step-runs increase. Juvenile steelhead inhabit pools where escape cover was provided by unembedded boulders, hanging root masses along the stream edge and undercut banks. Increased step-runs with coarse granitic cobbles offered better aquatic insect habitat.

Several dam abutments with narrow openings between walls are present in the reach above Happy Valley School and may pose passage problems if they collect instream wood, as occurred in 2005 (Alley, 2006). Occasional old-growth redwoods remain creekside in patches, providing streambank stability and undercut banks. A drop structure creates a passage impediment near the Tie Gulch confluence (Alley et al., 2004a). A significant stream diversion existed upstream, adjacent to the junction of Vine Hill and Jarvis Roads in 2003 (Alley, pers. observation). Low spring and summer streamflow, summer water diversion, high sand content of the streambed and man-made passage impediments are limiting factors to juvenile steelhead in Branciforte Creek.

A.6 Limiting factors to steelhead survival in the San Lorenzo River

This section identifies and discusses the factors that limit the chances of steelhead survival in the San Lorenzo River.

The primary limiting factors to fishery productivity in the watershed are those that impact rearing habitat for juveniles (Ricker and Butler, 1979; Smith, 1982). Rearing habitat includes the following characteristics:

- Adequate flows for pool development and to provide fastwater feeding stations for fish

- Escape cover such as undercut banks, rootwads, large instream wood, unembedded cobbles and boulders, surface turbulence, and submerged or overhanging vegetation or debris
- Aquatic and terrestrial insects for food
- Suitable water quality conditions, including water clarity, water temperature, dissolved oxygen concentrations and contaminant levels (Smith, 1982).

Table A.7 lists the factors that affect rearing habitat quality on the San Lorenzo River.

Table A.7. Limiting factors affecting rearing habitat quality variables on the San Lorenzo River

Limiting factors		Habitat quality variable
Primary	Secondary	
Excessive fine sediment	Streamflow	Food availability
Streamflow	Shortage of large woody material	Fast water feeding areas
Excessive fine sediment without large woody material for scour	Streamflow	Escape cover
Excessive fine sediment without large woody material for scour	Streamflow	Adequate water depth
Excessive fine sediment		Water clarity
Absence of closed riparian canopy	Streamflow	Water temperature

Source: Alley et al., 2004a.

Table A.8 ranks limiting factors by relative importance for the mainstem of the San Lorenzo River and its major tributaries.

Table A.8. Assessment of limiting factors for the San Lorenzo River and major tributaries.

Location	Sediment		Adult Passage Impediments	Streamflow	Water Temperature
	Spawning	Rearing			
Lower River Except Gorge[1]	⬤	⬤	•	⬤	⬡
Lower River Gorge	●	⬤	●	•	○
Middle River[1]	•	⬤	•	⬤	○
Upper River	•	⬤	•	○	
Branciforte	◦	⬤	●	○	
Carbonera	•	⬤	◦	●	
Zayante	•	⬤	●	●	
Bean	•	⬤		⬤	
Lompico		⬤	⬤	⬤	
Fall		⬤	•	•	
Newell			○	●	●
Love		⬤		○	
Boulder		⬤	◦	⬤	
Bear		⬤	●	●	
Two-Bar		⬤	●	○	
Kings	•	⬤	•	⬡	

⬡ – Highly Limiting, ○ – Moderately Limiting, ◦ – Minimally Limiting, Blank – Not Limiting. Closed circles denote where enhancement actions could be effective (see Recommendation Section).
1 – Fry abundance in the lower and middle River may depend heavily on spawning in upstream tributaries.

Source: Alley et al., 2004a.

A more detailed discussion of the following limiting factors follows:

- Streambed sedimentation
- Reduced stream flows
- Decreases in instream wood
- Barriers to anadromy

A.6.1 Streambed sedimentation

Sedimentation is one of the principal limiting factors for salmonid populations in the San Lorenzo River. Background sedimentation is a natural part of the river, which is greatly increased from upland human activities.

Sedimentation affects every salmonid life stage within the freshwater environment. Fine sediment reduces water percolation through spawning gravels, impacting survival of salmonid eggs and emerging fry. Fine sediment impacts juvenile rearing habitat by reducing pool depth, and burying boulders and cobbles that juveniles may hide under. Cobbles must be 25% or less embedded before they may provide escape cover for smolt-sized juveniles.

Loss of cracks and crevices between cobbles in riffles decreases aquatic insect habitat and reduces food availability for salmonids. Water turbidity associated with sedimentation also impacts salmonid feeding capability. Salmonids are visual feeders, and need clear water to see their drifting prey. The longer the stream remains turbid after a storm in spring (the most important feeding season for juveniles in small coastal watersheds), the less feeding time available to juvenile salmonids. Thus, turbidity can greatly reduce growth rate.

Sedimentation can affect adult upstream migration by making pools more shallow. In order to migrate upstream past instream barriers, salmonids need adequate pool depth below the barrier in order to jump over it. Adult steelhead generally require these approach pools to be at least as deep (some say twice as deep) as the barrier is high, for a successful jump.

The San Lorenzo River Watershed Management Plan (County of Santa Cruz, 1979) described the effects of excess sediment on fisheries within the watershed:

> Excessive sediment in spawning areas has been found to reduce the number of fish emerging from spawning gravels by up to 85% (Shapovalov and Taft, 1954). Observations of insect production on streams of the San Lorenzo River watershed show biomass to be 75-90% lower on silted reaches of Bean, Zayante, and Carbonera Creeks as compared to the upper San Lorenzo River. Where the rocks became completely surrounded by sand, researchers in Idaho found that the number of young fish that could be supported was reduced by 90% (Bjorn, 1977). Excessive sedimentation is widespread in the streams of the San Lorenzo River watershed. The Department of Fish and Game surveys on the main river show that the percentage of bottom classified as silt measured from 8% in 1966 to 65% in 1972. The amount of gravel present dropped from 20% to 2% (Lang, 1972). Other surveys have pointed out the presence of excessive amounts of silt in all of the tributaries but the relatively undisturbed Fall Creek.

Alley et al. (2004) found that in the middle mainstem, the El Niño high stormflows of winter 1997-98 caused significantly increased embeddedness of cobbles in 1999 (impact delayed a year for sediment to reach the mainstem), compared to 1995 streambed conditions. This increased embeddedness was correlated with decreased juvenile steelhead densities. However, other factors played a part, including substantially higher baseflow during the spring and summer of 1995 compared to 1999. The higher streamflow would also increase juvenile survival and cause more rapid growth rate.

Embeddedness is a very poor predictor of steelhead densities and growth rate in the middle and lower mainstem San Lorenzo River. Streamflow (which affects insect drift rate, habitat depth and often surface turbulence as cover in fastwater habitat) is a good predictor of steelhead densities and especially growth rate in the middle mainstem (Reaches 6-9). In 2007, riffle and run embeddedness was much lower in the middle mainstem (18–34%) compared to 1995 (30–45%) and 1999 (43–48%). Yet smolt-sized steelhead densities were less in 2007 than 1999 at 4 of 5 comparable sites in the lower and middle mainstem San Lorenzo River (Alley, 2008). The critical limiting factor was that streamflow was much lower in 2007.

A.6.2 Decreased stream flow

Decreased stream flow is another principal limiting factor for salmonid populations in the San Lorenzo River.

Adequate winter streamflow is critical for salmonid survival in the following ways:

- Enables fish passage to spawning sites
- Maintains healthy spawning habitat
- Flushes out excess sediment

Adequate winter streamflow is needed to allow adult fish passage to spawning sites, which typically improve in quality nearer the headwaters. Instream flow studies (Alley, 1993; Ricker and Butler 1979) indicate that optimal spawning habitat (in the lower mainstem above the gorge, and in the gorge) occur in the 70-100 cubic feet/second (cfs) range. Therefore, water diversions and well pumping in November, when estimated mean monthly streamflow is 53.8 cfs, and in December when it is 107.9 cfs, may adversely affect these optimal spawning conditions (Alley, 2004).

Adequate winter streamflow is also necessary to flush deleterious sediment out of the system to maintain healthy spawning and rearing conditions.

During drought, fish passage is more difficult, and water diversion during these periods exacerbates the problem, by further reducing surface flow, dewatering the channel, and elevating water temperature. These conditions lead to poor spawning success and reduced rearing habitat. For example, when the Felton Diversion Dam above the steep San Lorenzo River gorge became operational, just prior to the 1976-77 drought, adult steelhead were found stranded in Henry Cowell Park, as reported by Shappel, a CDFG biologist.

In the dry season, adequate summer streamflow (baseflow) is crucial to maintain proper water temperature, ample food supply and adequate rearing habitat for coho and steelhead. Ricker and Butler (1979) used IFG4 and HABTAT models to estimate habitat availability as a function of instream flow within the watershed. They found that, while winter streamflows could exceed instream flow needs of coho and steelhead, summer streamflows were always well below the optimal rate for habitat needs. Ricker and Butler (1979) concluded that any further decrease in streamflow would reduce habitat. For example, they estimated that, for the San Lorenzo River below Boulder Creek, a 50 percent flow reduction (from 3 cfs to 1.5 cfs) resulted in a 60 percent reduction in rearing habitat.

Decreased streamflow due to drought conditions or water extraction may create new passage barriers for fish, or make existing ones more difficult for fish to jump over. For a more complete discussion of this topic, refer to the following section “Barriers to anadromy”.

Reduced streamflow reduces spawning habitat in both winter and spring; it reduces rearing habitat in spring, summer and fall. Reduced streamflow means reduced water depth, slower water velocity, fewer feeding areas, less food availability, less escape cover, and less surface turbulence (which acts as cover and oxygenates the water). Reduced streamflow may, at the same time, increase water temperature in the less shaded reaches. Adequate stream flow is necessary to transport sediment, to scour pools, to recruit spawning gravel and large instream wood, to clean riffles of fine sediment, and to enhance fish cover and insect production.

Ricker and Butler (1979) used IFG4 and HABTAT models to estimate habitat area as a function of streamflow in the San Lorenzo River watershed. They found that natural streamflows exceeded instream flow needs of steelhead and coho salmon only during wet winter months. They reported that during the summer, flows were always well below the optimum level for habitat needs. Ricker and Butler (1979) concluded that any further decreases in flow would lead to a direct reduction in habitat. Generally, they found that the percent of habitat loss was greater than the percent reduction in streamflow. They found that in the San Lorenzo River below Boulder Creek, a 50% flow reduction from 3 cfs to 1.5 cfs resulted in a 60% reduction in habitat from 2,500 ft^2 habitat/1000 ft of stream length to 1,000 ft^2 habitat/1000 ft. During dry years, total spawning habitat in the watershed may be reduced by as much as 70%, and total summer nursery habitat may be reduced by 50%. This may occur on average, once every 10 years (Ricker and Butler, 1979).

In coastal streams, downstream smolt migration may be stopped during drought if the stream goes dry before the migration is finished.

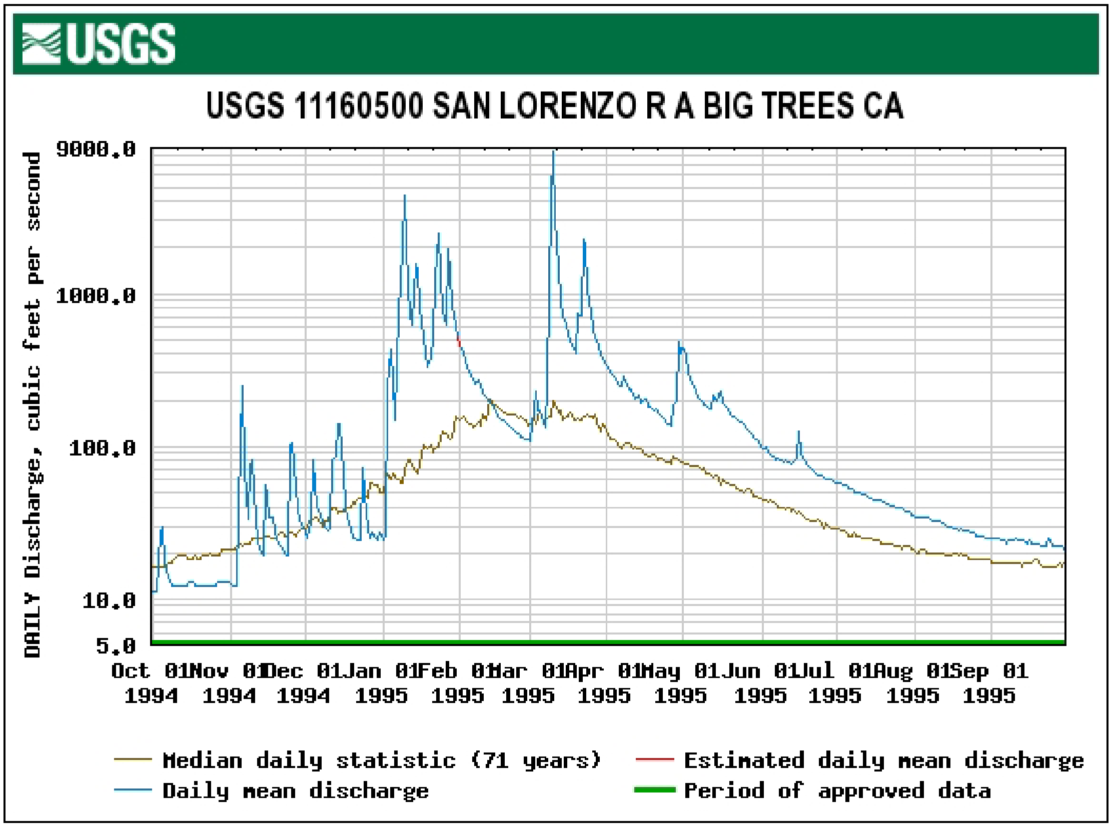
A.6.2.a Municipal water extraction and well-pumping

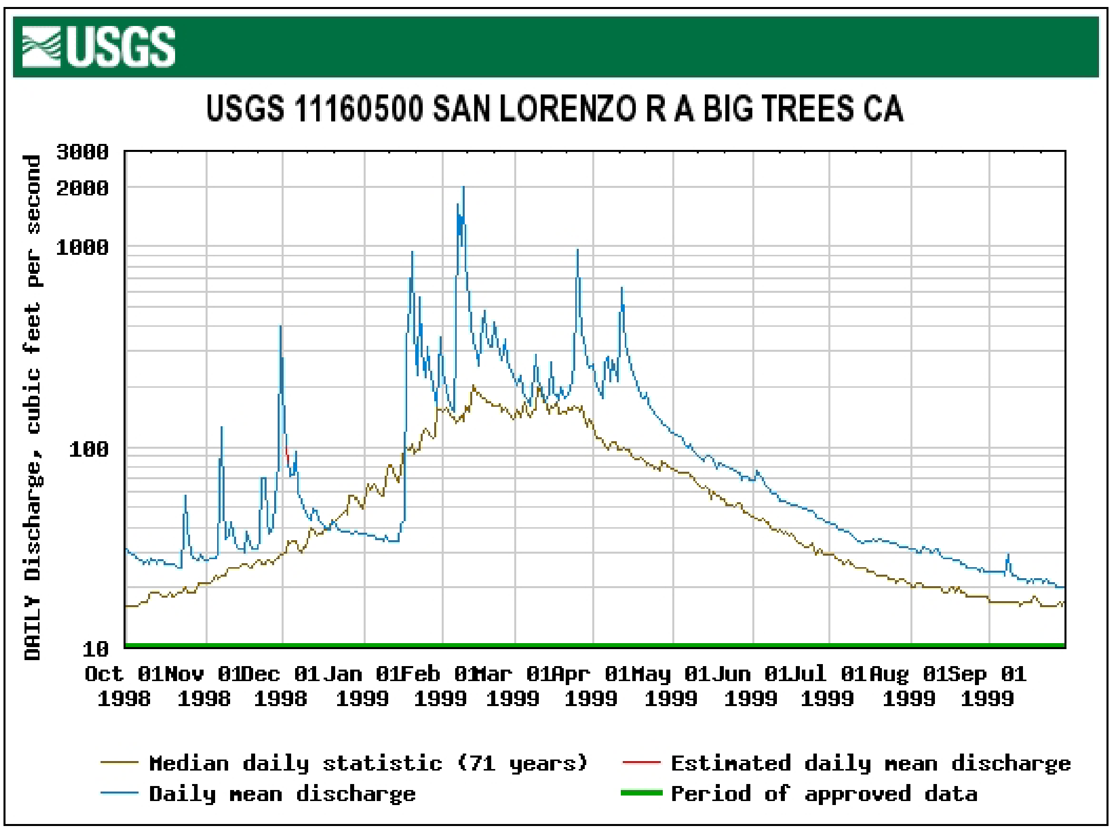
Increased water extraction for municipal supply has caused aquatic habitat loss from reduced streamflow.

Table A.9 summarizes information in the hydrographs beneath it.

Table A.9. A comparison of streamflows on the San Lorenzo River in 1995 and 1996

Date	Streamflow at Big Trees Gage, 1995	Streamflow at Big Trees Gage, 1999
1 April	~320	~210
1 May	400+	~120
1 June	~100	~70
1 July	~55	~32
1 August	~34	~31
1 September	~24	~24


USGS
USGS 11160500 SAN LORENZO R A BIG TREES CA
DAILY Discharge, cubic feet per second
9000.0
1000.0
100.0
10.0
5.0
Oct 1994
01Nov 1994
01Dec 1994
01Jan 1995
01Feb 1995
01Mar 1995
01Apr 1995
01May 1995
01Jun 1995
01Jul 1995
01Aug 1995
01Sep 1995
01
Median daily statistic (71 years)
Daily mean discharge
Estimated daily mean discharge
Period of approved data


USGS
USGS 11160500 SAN LORENZO R A BIG TREES CA
DAILY Discharge, cubic feet per second
3000
2000
1000
100
10
Oct 1998
01Nov 1998
01Dec 1998
01Jan 1999
01Feb 1999
01Mar 1999
01Apr 1999
01May 1999
01Jun 1999
01Jul 1999
01Aug 1999
01Sep 1999
01
Median daily statistic (71 years)
Daily mean discharge
Estimated daily mean discharge
Period of approved data

Streamflow did not become similar until August between years, allowing faster growth rate in 1995. Furthermore, since most salmonids and insects are in fastwater habitat in these reaches, comparisons of embeddedness in pools is irrelevant to juvenile numbers. Additionally, there was only modest increase in embeddedness in 1999 in 3 of the reaches and no increase in Reach 9. No comparisons of percent fines were possible. The decrease in the fish population estimate in 1999 was likely due primarily to less streamflow in 1999 and a change in censusing methods that included better censusing of low-density pools in 1999 and not increased embeddedness.

> Embeddedness is a very poor predictor of steelhead densities and growth rate in the middle and lower mainstem San Lorenzo River. Streamflow (which affects insect drift rate, habitat depth and often surface turbulence as cover in fastwater habitat) is a good predictor of steelhead densities and especially growth rate in the middle mainstem (Reaches 6-9). In 2007, riffle and run embeddedness was much lower in the middle mainstem (18–34%) compared to 1995 (30–45%) and 1999 (43–48%). Yet smolt-sized steelhead densities were less in 2007 than in 1999 at 4 of 5 comparable sites in the lower and middle mainstem San Lorenzo River The critical limiting factor was that streamflow was much lower in 2007 (Alley, 2007).

Analysis of daily flow data at the Big Trees stream gage indicates that the mean and minimum streamflow for October have shown a 17.2% and 32.1% decrease, respectively between 1937 and 1997 (Alley et al., 2004a). This is likely due to water extraction from both surface diversions and well pumping in addition to a possible reduction in late season rainfall (Alley et al., 2004a). In addition, mean and maximum streamflow in December has decreased 36.2% and 46.2%, respectively (Alley et al., 2004a). Well pumping has reduced groundwater storage to a level where the response time between winter rains and release of water to stream channels has increased (Alley et al., 2004a). The capture of early runoff in Loch Lomond before it spills would also partially contribute to the reduction after 1960.

The complete dewatering of the lower San Lorenzo above Highway 1 occurred in the mid-1970s and 1988 resulted from the Santa Cruz City Water Department's water diversion at Tait Street. The drying of the channel occurred only for a short distance, and streamflow resumed downstream. However, the reduced streamflow formed a complete passage barrier. Such an occurrence would be the most critical during downstream smolt migration from March through May. During these months, a complete dewatering of the lower channel or early closure of the river mouth could occur during drought conditions (Alley et al., 2004a). Such an occurrence could kill or prevent smolt-sized fish from entering the ocean, leaving them in poor habitat conditions, and susceptible to predation.

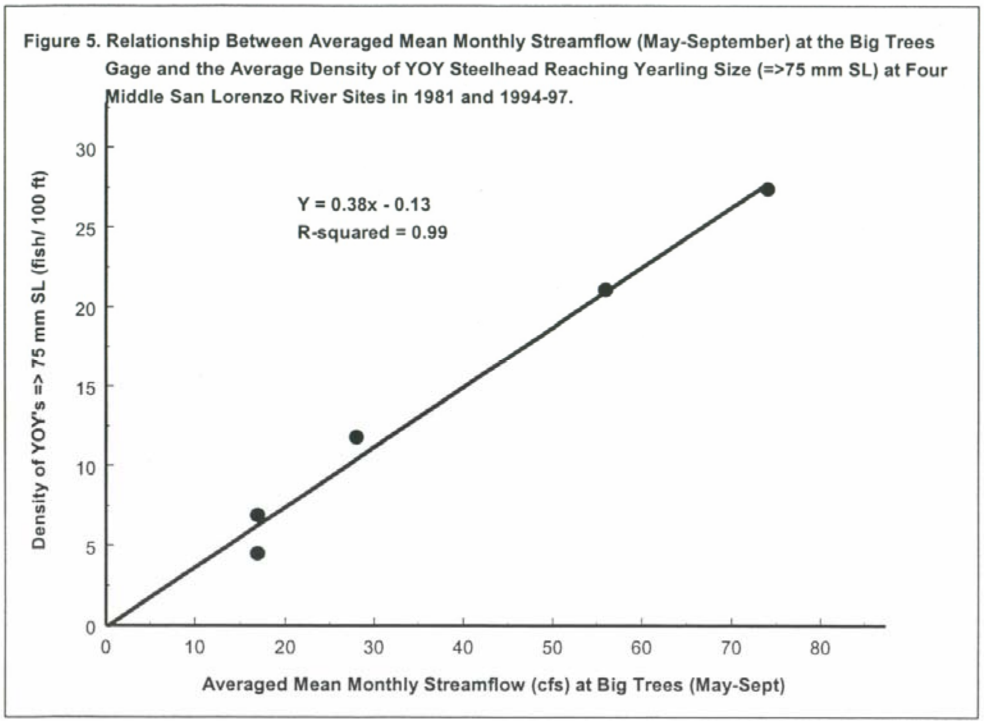
The San Lorenzo River Salmonid Enhancement Plan (Alley et al., 2004a) addressed groundwater extraction as a significant, yet difficult to track, source of flow reduction. Groundwater basins support springs and seeps that are a significant source of summer baseflow for the San Lorenzo River and its tributaries, especially in Bean, Zayante, and Carbonera Creeks. Much of the pumping of significant groundwater resources occurs in the Zayante and Bean Creek watersheds by the Scotts Valley Water District and the San Lorenzo Valley Water District. These groundwater basins are formed in the highly permeable, porous Santa Margarita sandstone formation and underlying Lompico formation. It is estimated that overdraft of the Scotts Valley groundwater basins has reduced summer baseflows to the creeks draining the area underlain by the Santa Margarita. These reductions significantly impact rearing conditions for juvenile steelhead by reducing baseflow during the critical summer months.

A.6.2.b Stream flow & steelhead densities in the San Lorenzo River

Alley et al. (2004) analyzed the relationships between stream flow and local steelhead populations. Figure A.19 illustrates the positive relationship between average mean monthly streamflow (May-September) and the density of YOY steelhead reaching smolt size. Figure A.20 illustrates the positive relationship between the minimum daily streamflow in September and the overall density of smolt-sized juveniles in the middle mainstem. Figure A.21 shows the positive relationship between minimum daily flow in September and the density of YOY steelhead in tributary streams. Figure A.22 shows the linear relationship between annual minimum streamflow and YOY steelhead density in Boulder Creek.

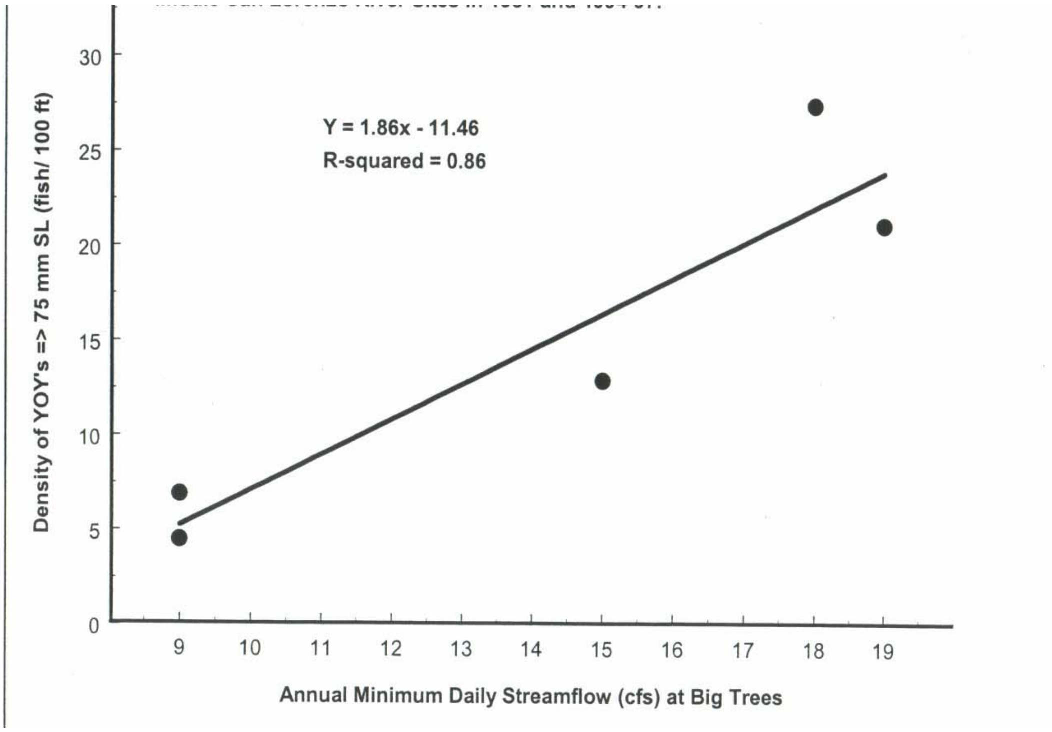
Table A.10 summarizes the combined results of Alley's analyses (Alley et al. 2004a). For all four middle mainstem sites combined, in a dry year (1994), there was a 27% reduction in density of YOY steelhead reaching smolt size and a 17% reduction in total smolt-sized steelhead juvenile density due to water extraction. In a wet year (1995), the reductions were 9% and 6%, respectively, due to water extraction rates. The middle mainstem is downstream of District water diversion points. On Zayante Creek, the percent reduction in YOY densities caused by water extraction was 19% (1994) in a dry year and 9% in a wet year (1998). In lower Boulder Creek below District water diversions, YOY densities were reduced by 28% in a dry year (1994) and 24% in a wet year (1998) due to water extraction. These analyses indicated that water extraction has a measurable (with high correlation coefficients), negative impact on steelhead growth rates in the middle mainstem and YOY densities in San Lorenzo tributaries. (Ricker, 1979).

Figure A.19. Linear relationship between mean monthly streamflow at the Big Trees Gage and fall density of yearling (smolt-sized) juvenile steelhead in the middle mainstem San Lorenzo River.



Source: Alley et al. 2004.

Figure A.20. Linear relationship between annual minimum daily streamflow at Big Trees gage and fall density of yearling (smolt-sized) juvenile steelhead, in the middle mainstem San Lorenzo River.



Source: Alley et al. 2004.

Figure A.21. Linear relationship between annual minimum streamflow and young-of-the-year steelhead density in Boulder Creek.

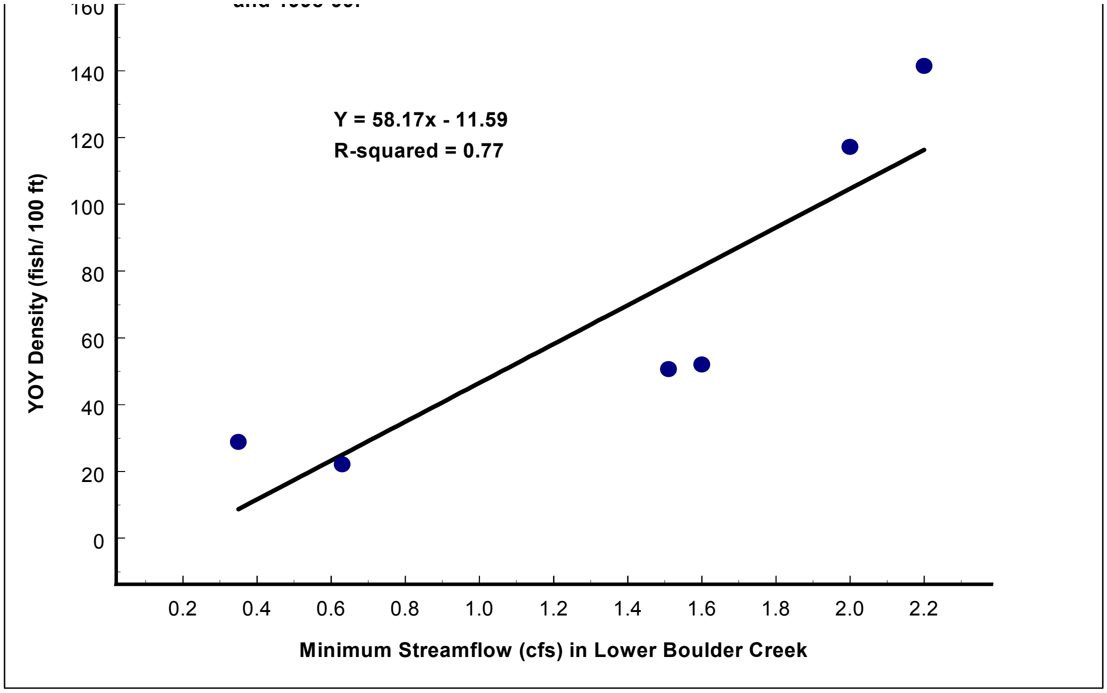
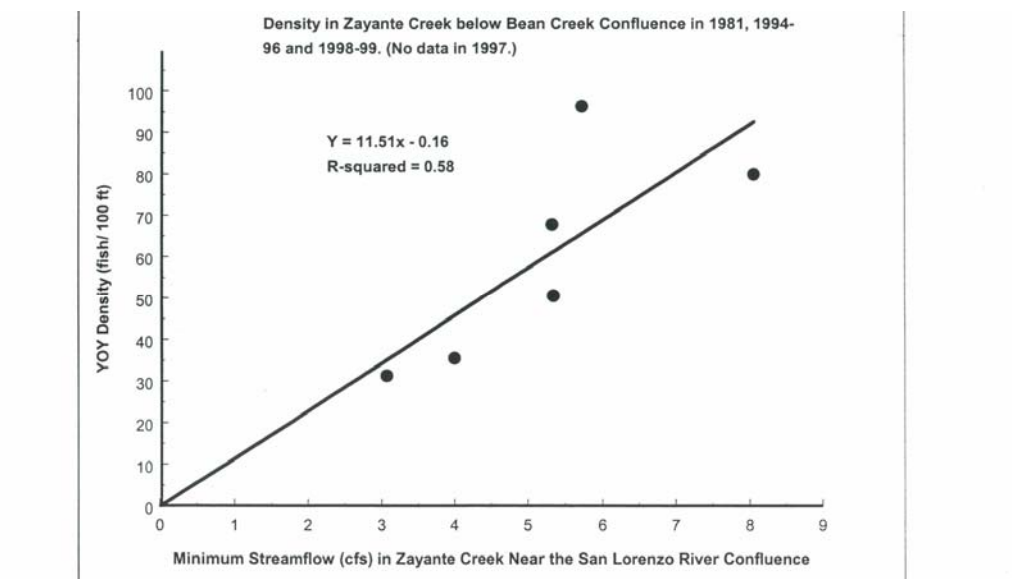
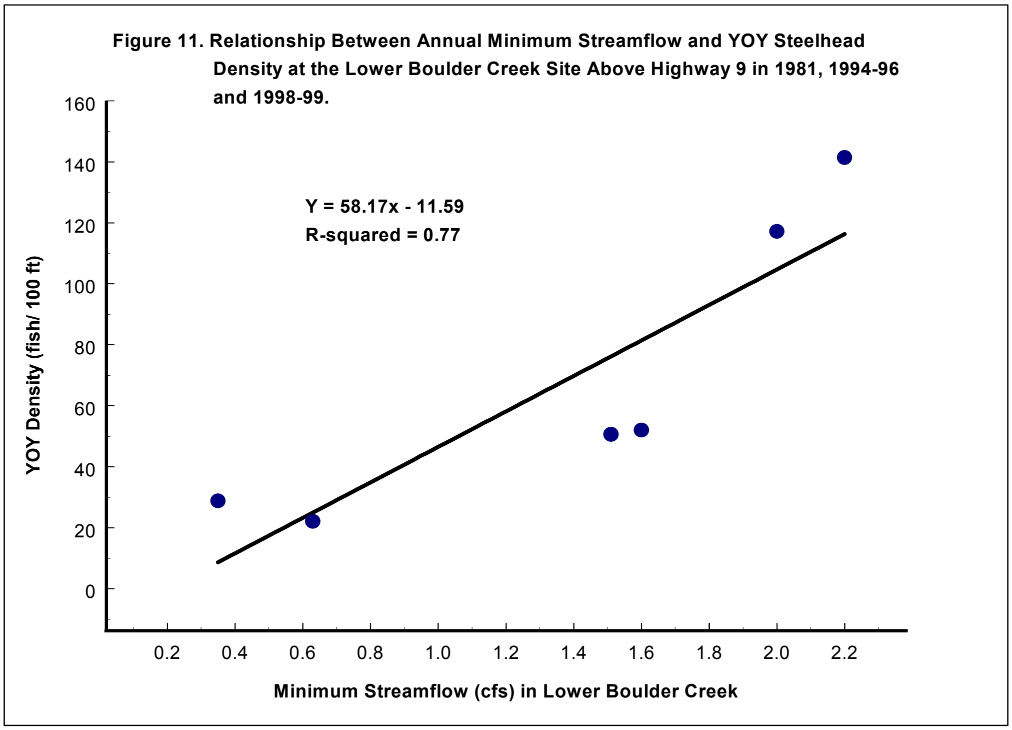


Figure A.22. Linear relationship between annual minimum streamflow and young-of-the-year steelhead density in Zayante Creek.



Source: Alley et al. 2004.

Figure A.23. Linear relationship between annual minimum streamflow and young-of-the-year steelhead density in Boulder Creek.



Source: Alley et. al. 2004.

Table A.10. Estimated instantaneous flow extractions in September and associated estimates of reduced density for yearling-sized young-of-the-year fish (YOYs) at mainstem river sites and reduced total YOY density at tributary sites. (Alley et al., 2004a).

Site		Annual Minimum Flow cfs. Wet/Dry Year Wet Year ('95) Extraction (%) Dry Year ('94) Extraction (%)	Correlation Coefficient (R2) of Linear regression of flow to fish density*	Estimated % Reduction of Age/Size Category due to Water Extraction and Estimated Density with Unimpaired flows (fish/ 100 ft)*			
				YOY's => 75 mm SL		All Juveniles => 75 mm SL	
				1994 dry	1995 wet	1994 dry	1995 wet
Middle River	4-Site Composite	18 / 9 1.51(_9_%) 1.35 (8%	0.86 (YOY=>75mm to annual min. Flow at Big Trees)	27% (9.4)	9% (30.2)	17% (14.4)	6% (44.3)
	Below Fall Creek	14.6 / 5.1 0.9 (6%) 0.8 (16%	0.85 (YOY=>75mm to annual min. Flow at Big Trees)	13% (6.2)	8% (11.8)	12% (6.8)	5% (19.7)
	Ben Lomond	5.8 / 2.5 0.36(6%) 0.2 (8%)	0.89 (YOY=>75mm to annual min. Flow at Big Trees)	22% (12.2)	7% (65.8)	11% (25.4)	5% (90.6)
	Brookdale	4.6 / /1.8 0.36 (8%); 0.2 (11%))	0.87 (YOY=>75mm to annual min. Flow at Big Trees)	36% (4.7)	10% (29.4)	15% (11.7)	8% (40.0)
	Below Boulder Creek	4.2 / 1.1 0.26 (6%) 0.15 (14%)	0.42 (YOY=>75mm to annual min. Flow at Big Trees)	3% (10.0)	3% (11.8)	2% (17.8)	1% (23.0)
Estimated Flow: Wet (1998) Dry (1994) Average Extraction (% reduction)				1994 (dry) YOY's	1998 (wet) YOY's		
Lower Boulder	Above Hwy 9	2.2 / 0.6 0.26 (12-43%)	0.77 (Total YOY to Minimum Measured flow)	28% (30.9)	24% (186.3)		
Bean Creek	Below Lockhart Gulch	6.7 / 2.1 0.5 (7 – 24%)	0.59 (Total YOY to Mean summer flow@ Mt. Hermon)	67% (42.3)	20% (132.7)		
Zayante Creek	Below Bean Creek	8.8 / 3.8 0.65 (9-17%)	0.58 (Total YOY to Minimum Measured flow)	19% (38.8)	9% (87.5)		

* Regressions were developed from density estimates at historical sampling sites within reaches, and estimated reductions in fish densities may not be directly extrapolated to entire reaches. However, the significant correlation coefficients (>= 0.7) indicate that there is a meaningful direct linear relationship between flow and fish density at those sites. Based on available data, the relationship is less direct in other sites downstream of the Zayante Creek confluence with lower correlation coefficients.

A.6.3 Absence of large instream wood

The benefits of instream wood are discussed in Chapter 3. The shortage of instream wood in the San Lorenzo River watershed is the result of logging, development, and logjam removal policies and practices.

Due to clear cutting during from the late 1800s through the 1970s, and continued cutting of large trees along streams, a century has passed with little input of large instream wood. Large, second-growth trees adjacent to streams could be a significant source of large instream wood, but they are also valued as timber. Most of the watershed's streams are lined with roads and houses. Trees are often cleared around homes. The resulting loss of riparian forest greatly reduces the natural rate of input of large instream wood.

Throughout the watershed, much instream wood is removed from streams. The County historically had an active logjam removal program, and continues the program in consultation with the CDFG. The County continues to remove instream wood when it directly increases the risk of flood or property damage in the more developed areas of the watershed, and in response to complaints from streamside residents (Kristen Schroeder Kittleson, personal communication to Alley). However, the County has no permit from NOAA Fisheries for their instream wood activities (Alley, 2006). Liability issues have not been resolved (Alley, 2006).

Despite the intention of protecting public safety, removal of large instream wood accumulations in the upper watershed could increase the erosive force of the river downstream, resulting in increased streambank erosion and loss of property. Large wood in the upper watershed works to sieve out wood and retain it there. Disruption of wood clusters in the upper watershed may increase the transport rate of large wood to the lower watershed to worsen logjams on bridges in the lower watershed. Leicester (2005) hypothesized that release of impounded large wood in the upper watershed may benefit fishery habitat in downstream reaches only if catcher logs were in place downstream.

The ultimate benefit of annual logjam removal was brought seriously into question by research on Soquel Creek after the January 1982 flood. Singer and Swanson (1983) found that most of the wood that jammed up on the Soquel Avenue Bridge was not in the channel when the storm began. The major source of logs during the 1982 flood was forested hillslopes that failed during the flood mainly from debris flows. By September 1983, 59 major logjams had been cleared in 30 miles of stream (Singer and Swanson, 1983). Almost all of these jams were new because watershed streams had been cleared of most logs prior to the January 1982 storm (Dave Hope, pers. comm. [In Singer and Swanson, 1983]). They concluded that increased land use and development in the upper watershed could increase the likelihood and severity of logjams and flooding hazards in Soquel Village if improperly managed. The major types of land use include residential development and timber harvesting. Logging was the major land use activity in the East Branch. Roads play a key role in debris flow initiation. Studies in the Pacific Northwest showed that logging roads increased the rates of debris flow occurrence from 25 to 340 times the natural rate (Swanston and Swanson, 1976).

A.6.4 Barriers to anadromy

Barriers to anadromy, known as *passage barriers*, range from complete obstructions to fish passage during all streamflows, to partial impediments, such as riffles that become too shallow to allow fish passage during low streamflow.

A.6.4.a Types of passage barriers

Passage barriers may be natural or artificial.

Natural passage barriers include waterfalls, bedrock chutes, logjams, large boulder fields, steep riffles, shallow riffles, and bedrock ledges. Natural barriers may be completely removed or altered by storms to allow passage.

Artificial passage barriers include unladdered dams for water storage reservoirs, water diversion dams, summer flashboard dams, weirs, bridge abutments with concrete sills, perched culverts, and instream road crossings. Figure A.24 shows a concrete apron next to a culvert that creates a passage barrier to anadromous fish during low flows.

Figure A.24. Concrete apron at the Highway 9 culvert

Alley 1994

This concrete apron presents a low flow passage problem at Waterman Gap.

Summer dams can result in elevated water temperature in the pools formed behind the dams. These pools may inundate valuable fastwater feeding habitat for juvenile steelhead.

Flashboard dams are usually regulated to prevent impoundment of water until after smolts move downstream, in the late spring. The operation of flashboard dams in the past few years was controversial. However, the belief that juveniles move upstream in the summer appears unsubstantiated and needs further study. Shapovalov and Taft (1954) Davis (1995) both found lack of movement between sites.

NMFS denied permits in the summer of 2003 for Ben Lomond Park and Boulder Creek Recreation District. These dams will not be re-permitted until fish ladders are constructed to allow upstream and downstream movement of fish in summer when the dams are in place. No other flashboard dams will be permitted in the watershed by NMFS until recovery and de-listing of the species is successful.

A.6.4.b Location of passage barriers

The lower a passage barrier is in the watershed, the larger the impact to the salmonid population. Passage barriers low in the watershed cut off more area from spawning migration. Spawning access to tributaries above the San Lorenzo River gorge and upper reaches of the watershed is critical to the survival of the steelhead population. However, several studies (Smith 1982; Alley, 2002; Alley et al., 2004a) report limited spawning availability in the lower and middle mainstem of the San Lorenzo River.

Several passage barriers have been noted in the lower San Lorenzo River gorge, running through Henry Cowell State Park. Table A.11 and Figure A.25 describe the type and location of known passage barriers occurring on the San Lorenzo River and its primary tributaries in 2002 (Alley et al., 2004a). Other barriers, still undocumented, also exist on minor tributaries near their confluence with the mainstem San Lorenzo River.

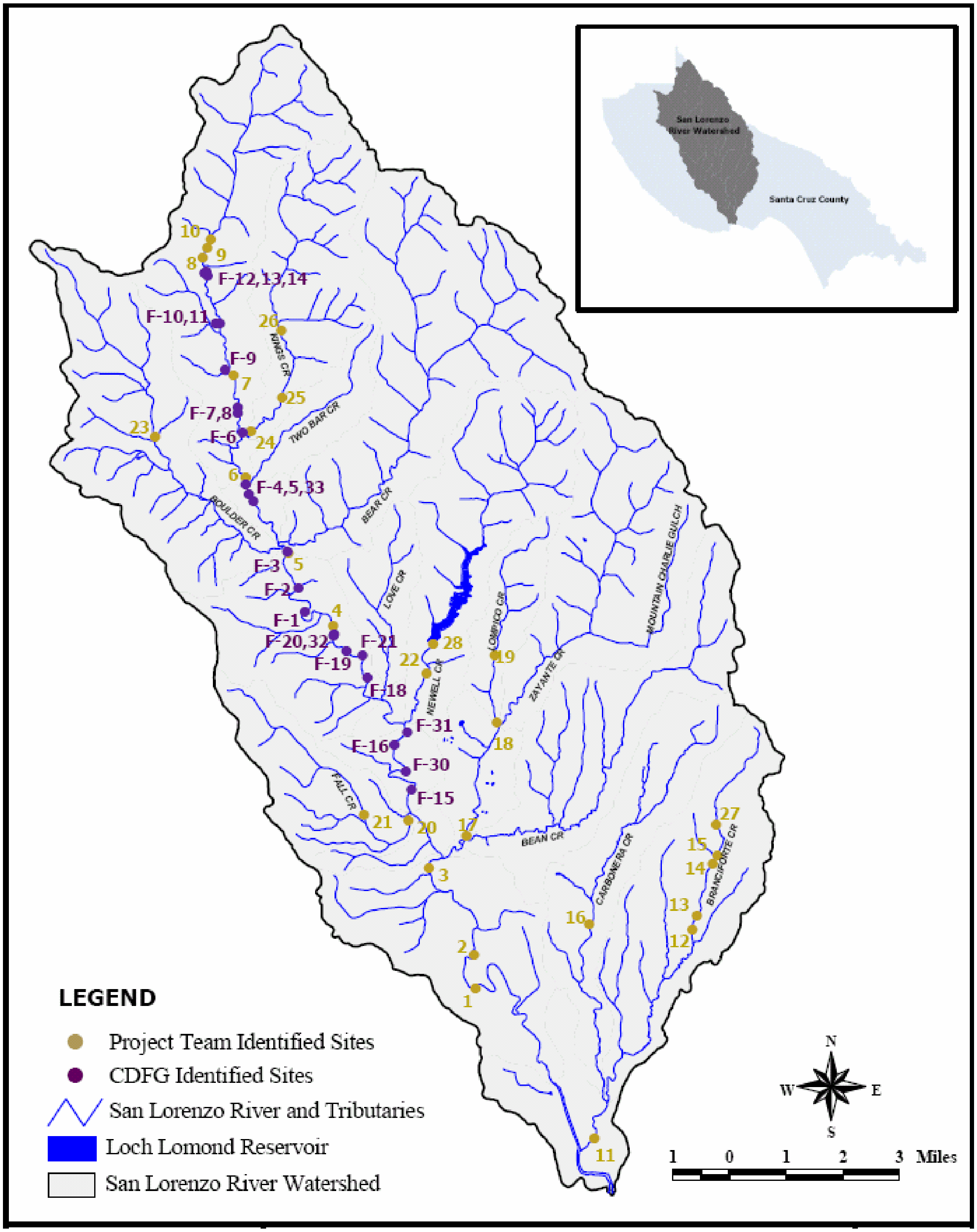
Table A.12 lists human-caused impediments in the mainstem, including potential low-flow impediments . Twenty-one of the impediments identified in this table are current or abandoned flashboard dams. Even though many of the dams were no longer in use, the abutments and concrete sills could impede adult steelhead passage during winters of low water years.

Table A.11. Description and locations of identified fish passage barriers on the San Lorenzo River and its major tributaries

ID	Location	Description	Degree of Passage Impediment
1	San Lorenzo River	Wide critical riffle in upper Rincon	Passable at ~ 70 cfs
2A	San Lorenzo River	Boulder falls above Four Rock	Passable at ~ 100-120 cfs
2B	San Lorenzo River	Boulder cluster just upstream of Four Rock	Passable at ~ 50 cfs
3	San Lorenzo River	Felton Diversion Dam	Difficulty passing at certain intermediate-flow conditions
4	San Lorenzo River	Bedrock outcrop below Brookdale	Low flow barrier
5	San Lorenzo River	Erwin Way flashboard dam apron and base	Low flow barrier
6A	San Lorenzo River	Fern Road flashboard dam apron and base	Low flow barrier
6B	San Lorenzo River	Camp Campbell flashboard dam apron and base	Low flow barrier
7	San Lorenzo River	Bedrock channel above Teilh Road	Passable at ~16.5 cfs
8	San Lorenzo River	Log jam below Waterman Gap	Low flow barrier
9	San Lorenzo River	Riprap boulder jam below Highway 9 repair downstream of Waterman Gap	Low flow barrier
10	San Lorenzo River	Highway 9 bridge apron	Low flow barrier
11	Branciforte Creek	Branciforte flood control channel	Low flow barrier. Passage depends upon maintenance schedule
12	Branciforte Creek	Concrete flashboard dam abutment	
13	Branciforte Creek	15' high Denil ladder over 10' high dam	Needs maintenance to allow passage
14	Branciforte Creek	Flashboard dam abutment with inadequate pool/weir ladder	Needs maintenance to allow passage
15	Branciforte Creek	Rock and concrete wall at Happy Valley Estates	Low flow barrier
16	Carbonera Creek	Moose Lodge Falls	Impassable at all flows
17	Zayante Creek	Flashboard dam abutment	Low flow barrier
18	Lompico Creek	Concrete wall and bedrock chute above fish ladder	Only passable at higher flows
19	Lompico Creek	Concrete floor in creek with approach apron	Low flow barrier
20	Fall Creek	Concrete weir fish ladder	Continuous maintenance required
21	Fall Creek	Boulder falls	Impassable at all flows
22	Newell Creek	Bedrock falls	Passable at ~ 200-300 cfs
	Newell Creek	Loch Lomond Dam	Complete passage barrier
23	Boulder Creek	Bedrock chute	Impassable at all flows
24	Kings Creek	Flashboard dam apron	Low flow barrier
25	Kings Creek	5 bedrock chutes and shelves	Low flow barriers
26	Kings Creek	Bedrock/boulder falls – 2 steps	Impassable at all flows
27	Branciforte Creek	Flashboard dam just downstream of Vine Hill Road	Low flow barrier
	Love Creek	Denil ladder	Needs maintenance to allow passage
	Branciforte Creek	Concrete structure below flashboard dam	Low flow barrier

Source: Alley et al. 2004.

Figure A.25. Location of identified fish passage impediments on the San Lorenzo River and its major tributaries.



Source: Alley et al., 2004a. For descriptions of each gold site refer to Table A.11.
Purple sites are those identified by CDFG and CAB on the mainstem in a survey conducted in summer 2001 (Table A.12). There may be overlap between locations.

Table A.12. Passage impediments* identified by Community Action Board staff in summer 2001 on the San Lorenzo River mainstem

Map ID	CAB ID	Description	Concern	Priority**
1	1	active large concrete flashboard dam	debris and geomorphic and low-moderate flow concerns	Highest
2	2	legacy large concrete flashboard dam	debris and geomorphic and low-moderate flow concerns	High
3	3	active large concrete flashboard dam	debris and geomorphic and low-moderate flow concerns	Highest
4	4	active large concrete flashboard dam	debris and geomorphic and low-moderate flow concerns	High
5	5	active large concrete flashboard dam	debris and geomorphic and low-moderate flow concerns	Highest
6	6	active large concrete flashboard dam	debris and geomorphic and moderate flow concerns	Highest
7	7	grouted bed associated with bank revetment	geomorphic and low flow concern	High
8	8	active large concrete flashboard dam	debris and geomorphic and low-moderate flow concerns	Highest
9	9	grouted bed associated with bank revetment	geomorphic and low flow concern	Highest
10	10	active large concrete flashboard dam	debris and geomorphic and low-moderate flow	highest
11	11	legacy large concrete flashboard dam	debris and geomorphic and low-moderate flow concerns	High
12	12	legacy large concrete flashboard dam	debris and geomorphic and low-moderate flow concerns	High
13	13	legacy large concrete flashboard dam	debris and geomorphic and low-moderate flow concerns	High
14	14	active large concrete flashboard dam	debris and geomorphic and low-moderate flow concerns	High
15	15	small grouted rock dam	low flow concern	Low
16	16	legacy concrete flashboard dam	minor debris and geomorphic and low flow concerns	Low
18	18	legacy concrete flashboard dam	debris and geomorphic and low flow concerns	Moderate
19	19	legacy concrete flashboard dam	debris and geomorphic and low flow concerns	High
20	20	active small grouted rock flashboard dam	minor debris and geomorphic and low flow concerns	Low
21	21N	natural bedrock slide	moderate flow concern	High
30	n/a	legacy concrete flashboard dam	debris and geomorphic and low flow concerns	High
31	n/a	legacy concrete flashboard dam	minor debris and geomorphic and low flow concerns	Low
32	n/a	legacy concrete flashboard dam	debris and geomorphic and low flow concerns	Low
33	5N	legacy small concrete flashboard dam	debris and geomorphic and low flow concerns	Low

Source: Alley et al., 2004a, summarizing walking surveys by CDFG and CAB.
*All manmade, channel spanning structures with potentially adverse effects on fish passage and other important watershed processes on the mainstem from Highway 1 upstream. It does not include the two City of Santa Cruz diversion facilities at Tait St. and Felton. Restoration priority was determined by CAB and CDFG personnel (and not Alley et al.) based on field estimates that considered both the feasibility of fixing the site, and the potential benefit to the fishery. No hydraulic calculations were done.

** The priority ratings for removal of these low flow impediments were not those of the enhancement plan authors (Alley et al., 2004a)

A.6.4.c Effect of streamflows on passage barriers

During the 1976-77 drought, the watershed area available to spawning was reduced by 50%, and the size of the runs was very low (Ricker and Butler, 1979). If streamflow through the San Lorenzo River gorge is low enough, it could prevent upstream salmonid migration. This situation could result from too much water being diverted from the stream at the Felton diversion dam, for human consumption. If coho or steelhead were prevented from migrating upstream through the gorge, most of the watershed would become inaccessible to spawning. Only limited spawning habitat exists below the gorge, except in the Branciforte sub-watershed.

Most of the gorge, consisting of high-gradient riffles and boulder falls, was judged passable in 1992 to adult salmonids at streamflows of 35 cfs or higher, using the criteria of 0.6 feet minimum depth across five contiguous feet of channel width (Alley, 1993). After the El Niño storms of 1997-1998, a critically wide riffle developed in the Rincon area, creating a significant passage impediment that was still present in 2002 (Alley et al., 2002).

In 1991 during a drought, adult steelhead did not reach the Felton diversion dam until the mean daily flow reached 100 cfs (Alley et al., 2004a). Although the boulder cluster above Four Rock in the gorge was presumably limiting passage in 1991, it was observed to have become favorably rearranged in 2002. However, it may remain difficult to pass at streamflows less than 50-70 cfs (Alley, personal observation). Visual observations of the Rincon area in 2001 indicated that adequate passage flows for steelhead may not be reached at flows less than 70 cfs (Alley pers. observation). Water diversion during a drought year, in combination with naturally low baseflows, may prevent adult salmonid access to the upper watershed or at least severely limit it. Mean daily streamflow was less than 50 cfs at the Big Trees Gage for most of the winter from winter 1986-87 through winter of 1990-91 (5 years) except for one to three minor storm events each winter.

Estimated average daily flow extractions in January, March, April and December may significantly reduce streamflow during drought or below average flow years, downstream of the Felton Diversion Dam in the San Lorenzo gorge. This could adversely impact adult salmonid passage during those months during a drought or below average flow years.

In the middle river, the Felton diversion dam may create passage barriers at certain streamflows. Adult salmonids may not find the fish ladder, which is intended to enable upstream migration at low and intermediate streamflows. When water is spilling over the inflated rubber dam, adult salmonids cannot jump over it except at higher stormflows (Alley et al., 2004a).

A.6.5 Poor water quality

Poor water quality is one of the principal limiting factors of salmonid survival in the San Lorenzo River watershed. Water temperature and dissolved oxygen concentration are the water quality parameters most important to salmonid survival. Water contaminants, such as fecal coliform or nitrates that are of concern for human health, are not considered threats to salmonid survival in the San Lorenzo River upstream of the lagoon.

A.6.5.a Water temperature

Water temperature influences virtually all aspects of salmonid life history. Water temperature affects metabolic rate, range of swimming ability, digestive rate, microhabitat selection, as well as competition, predator-prey relationships, and disease-host relationships. Increased water temperature increases metabolic demands and oxygen requirements of juvenile salmonids. Water temperatures generally remain below levels known to be stressful to local steelhead populations within the San Lorenzo River. Exceptions may occur during times of lowest streamflow in unshaded reaches, which are also the times of lowest levels of escape cover and food availability. Fish may starve to death if their metabolic demands from elevated water temperature exceed food supply. Hungry fish are less responsive to predators (Brown et al., 1994).

In the San Lorenzo River, as in other Central Coast streams, water temperature is probably not directly lethal. Higher temperatures, however, increase food demands and restrict steelhead to faster habitats for feeding, especially above 21º C (70º F) (Smith and Li, 1983). Critically high water temperatures reduce the scope of swimming ability for stressed juvenile steelhead and increase the risk of predation. In the warmest reaches of the lower and middle San Lorenzo River, where streamflow and food supply are highest, starvation is not a problem for steelhead. Rather, juvenile steelhead grow faster in these reaches than in cooler tributaries and the upper San Lorenzo, because the abundance of food outweighs the higher metabolic energy costs. The warmer water also speeds digestion and allows for faster assimilation of food to promote faster growth rate.

The lethal water temperature for steelhead is probably above 26-28º C (79-82º F) for several hours during the day. These temperatures are rarely, if ever, reached upstream of the lagoon (Alley et al., 2004a). Even so, warmer temperatures could result in slow growth or starvation in steelhead if food supply becomes very limited. In the upper mainstem and tributaries where streamflow is less, food supply is reduced and cooler water temperature maintains lower metabolic rates for salmonids and reduces food requirements. If shade is removed in these small streams, water temperature may rise too much, causing food requirements of the fish to increase without concomitant increase in food abundance. Cool tributary inflows to the mainstem, such as Clear Creek and Fall Creek help to maintain mainstem water temperatures within a tolerable range for juvenile steelhead inhabiting the mainstem.

Coho generally are found at cooler temperatures than steelhead. Although the lethal temperature limit for coho is similar to steelhead, coho would likely starve at water temperatures above 18-20º C (65-68ºF) in the lower and middle mainstem San Lorenzo River (Alley et al., 2004a). Alley et al. (2004a) also reports that water temperatures cooler than 21^{o} C may not be possible in the lower and middle mainstem San Lorenzo River, especially in areas with a wide stream channel and lack of riparian canopy closure despite a healthy and intact riparian corridor. Even if water temperatures lower than 18^{o} C were possible, few coho would likely survive where pools are often long (more than 200 feet in length), where long pools dominate the stream channel (70-80% of the habitat in the middle mainstem) and where food and fastwater feeding areas are in limited supply (Alley et al., 2004a).

In the Mattole River system (northern California), coho were found only in tributaries where the maximum weekly average water temperatures were 16.7ºC (62ºF) or less and the maximum weekly maximum temperatures were 18.0ºC (64ºF) or less (Welsh et al., 2001). To arrive at these temperature criteria, they determined the average daily water temperature for the weeks under consideration and determined the average maximum daily water temperature for those weeks. Then they correlated the maximum for all of the average weekly temperatures and the maximum for all of the average maximum weekly temperatures to coho presence or absence. Because of the generally sandy substrate in the San Lorenzo system, and the presence of steelhead, the temperature limits found in the Mattole River are probably the appropriate goal for re-establishing coho in the low gradient portions of tributaries in the watershed and possibly the middle mainstem in wet years. In Scott and Waddell creeks in Santa Cruz County, coho have been found at warmer sites than those in the Mattole River, but only where the pools were very productive (small pools, abundant algae, extensive, productive riffles upstream of the pools, etc.) (Smith pers. observation). Branciforte, Carbonera, Zayante, Bean and Bear creeks are potential candidates for coho habitat.

A.6.5.b Dissolved oxygen

Within the San Lorenzo River system above the lagoon, recorded levels of dissolved oxygen are well within the tolerance range of salmonid populations. Steelhead can likely survive dissolved oxygen levels as low as 2mg/l at cool, early morning water temperatures, but would need more dissolved oxygen throughout the day to sustain activity (Alley et al., 2004a). Habitats throughout the San Lorenzo River system meet the San Lorenzo River Salmonid Enhancement Plan goal of 5 mg dissolved oxygen per liter of water (Alley et al., 2004a). Water turbulence in shallow water riffles keeps oxygen levels at, or near, full saturation levels. However, as water warms, the saturation level of oxygen decreases. Cooler water contains more oxygen. Algal blooms in slack water are uncommon in the river, so that possible depressed oxygen levels at night due to eutrofication and high biological oxygen demand (BOD) are not known to occur in the stream environs of the San Lorenzo system. However, it is possible that potentially lethal depressed oxygen levels might occur in the lagoon. Critically low oxygen levels might occur if sufficient saltwater is trapped on the bottom for a long enough time to raise water temperature to critical levels during intense algal blooms. Adequate lagoon inflow during the summer will discourage this condition.

A.6.6 Other potentially limiting factors to salmonids

Hatchery fish planting, pinniped predation and freshwater sport fishing are discussed in this section, as potential limiting factors to salmonids in the San Lorenzo River watershed.

A.6.6.a Hatchery fish planting

Historically, the method that CDFG has used to increase fish populations for commercial and recreational fishing has been the planting of thousands of fish, raised artificially in hatcheries. Hatchery stocking of the San Lorenzo River often came from fish outside the Central California Evolutionary Significant Unit (ESU), from northern and interior California hatcheries. Northern California steelhead and coho salmon have a different genetic makeup that may result in habitat requirements and behavior that is not well suited to the San Lorenzo system.

It was not understood until the early 1980s that central California steelhead and coho have distinctive DNA and behavior adapted to local environmental conditions. Long-term deleterious effects upon native salmonid populations may result from the loss of genetic integrity and adaptation to special environmental challenges that natural selection had achieved. Special physiological adaptation to warmer water temperatures and timing spawning and smolting to match the rainy season may be lost from genetic exchange between native fish and fish from other geographic areas.

Competition for habitat and resources between hatchery and native stocks is of great concern to biologists trying to restore native populations. Hatchery fish were planted at rates perhaps far above the carrying capacity of the aquatic ecosystem, resulting in increased competition in the stream and the ocean and reduced survival of native stocks.

Hatchery stocks may introduce disease to already stressed and depleted natural populations. Any confined rearing situation, such as a hatchery, increases the probability of disease. It is believed that bacterial kidney disease (BKD) found in wild coho salmon was originally spread throughout North America through hatchery planting. After the Big Creek hatchery was experiencing poor egg survival in wild coho salmon stocks, it was discovered that many of the wild brood stock had BKD. As a result, adults are now injected with Erythromycin to eliminate the bacteria before egg-taking, to insure survival of offspring.

The Brookdale Hatchery opened in 1905 to enhance the sport fishery. Steelhead from the Brookdale Hatchery were planted throughout the watershed until 1953 (Cramer et. al, 1995). These planted steelhead came from eggs of Scott Creek and San Lorenzo River steelhead. The Brookdale Hatchery was closed in 1954 because it spread whirling disease to native steelhead populations (W. Evans, personal communication).

Trapping records indicate that hatchery personnel drove the many rural roads in the county, planting fish at most stream crossings. Many were planted above natural barriers where resident rainbow trout populations now exist. In essence, these resident rainbows are genetically isolated. Natural resident populations of rainbow trout resulting from native steelhead may also exist, because headwater areas that were at one time accessed naturally by anadromous steelhead have since become inaccessible.

Steelhead in the San Lorenzo watershed are probably a genetic combination of native stock and hatchery introductions from many sources (Cramer et al., 1995), including:

- Trapped Scott Creek and San Lorenzo adult stocks (plantings from one or the other source 1905-1940; 1980 - present)
- Mt. Shasta rainbow trout (pre-1930)
- Mad River steelhead (1954 -1974)
- Sacramento Valley rainbow trout (1958 - late 1970's)
- Carmel River steelhead (1984 - 85)
- Russian River steelhead (1985).

Planted coho salmon during the 1984-1994 period originated from northern stock from the Noyo River and Prairie Creek in combination with San Lorenzo stock. No coho have been stocked in the San Lorenzo since 1994, as shown in Table A.13.

Table A.13. Number of stocked juvenile steelhead and coho smolts in the San Lorenzo River mainstem, 1959-2000.

Year	Coho	Steelhead
1959	35,800	55,000
1961	300	1,200
1963	40,169	1,396
1964	40,056	0
1965	20,330	0
1967	0	11,791
1969	25,000	0
1970	25,008	29,364
1971	25,008	30,000
1972	20,007	40,250
1973	25,005	185,795
1974	25,008	0
1975	25,009	50,000
1976	25,002	36,840
1977	0	116
1978	0	10,070
1979	25,011	26,070
1980	0	10,500
1981	0	50,040

Year	Coho	Steelhead
1982	0	20,250
1983	19,770	21,000
1984	17,160	37,146
1985	0	24,606
1986	15,991	29,200
1987	0	48,510
1988	20,445	23,256
1990	34,500	52,487
1991	19,880	98,337
1992	1,872	107,515
1993	11,808	93,974
1994	4,047	47,247
1995	0	49,238
1996	0	28,800
1997	0	31,986
1998	0	2,210
1999	0	30,599
2000	0	21,328

Source: CDFG, as cited by Alley et al., 2004a.

In recent years the Monterey Bay Salmon and Trout Project has established a native anadromous fish rearing facility on Big Creek, tributary to Scott Creek, which uses only steelhead and coho brood stock from our local ESU. The Monterey Bay Salmon and Trout Project now plants only steelhead smolts from San Lorenzo stock into the San Lorenzo River. However, if brood stock is not captured throughout the spawning migration period, then artificial selection for either early or late spawners may occur, depending on when the adults are captured for egg-taking. There is a tendency to take brood stock early in the spawning season and under-represent late spawners. Late spawning is adaptive in winters that have large late winter storms that scour out early nests. Early spawners are also more vulnerable to angling. Even if the hatchery plants come from native stocks, the most fit juveniles have not been naturally selected for in the hatchery and may lead to a loss of genetic fitness in the adults that return to spawn. Thus, the artificial selection in the hatchery may weaken genetic fitness. If small fingerlings are planted in streams to grow to smolt size, competition for limited juvenile rearing habitat may depress survival of native fish populations. For these reasons, even hatchery fish from local stocks may reduce reproductive success and their offspring may have reduced survival in the natural environment.

Although fish hatcheries may be a temporary fix for dwindling salmonid populations, they have important value. Drought, combined with water extraction and habitat degradation, have impacted native populations of steelhead to the point of near extirpation. Hatcheries are needed to re-introduce coho to watersheds where they have been lost, such as the San Lorenzo River.

A.6.6.b Pinniped predation (seals and sea-lions)

Pinniped predation of steelhead is a normal function of marine ecology. According to the Santa Cruz County Fish and Game Advisory Committee’s petition to list local steelhead populations as threatened, natural predation is normally not critical to steelhead survival. But with depressed numbers of steelhead, as a result of other impacts, they believed that pinniped predation has become more significant. Some argue that because pinnipeds are a protected species, they have become overabundant. Weise and Harvey (2001) suggest that pinniped predation may be a contributing significant factor to the diminishing steelhead runs in the San Lorenzo River. They estimate that harbor seals have consumed from 3.5 to 19.8% of the steelhead runs, depending on the size of the steelhead run (Weise and Harvey, 2001). More adult spawners may be consumed by pinnipeds in years when run size is already reduced due to other environmental impacts. For example, when sandbars at rivermouths are delayed in opening because of drought and water extraction, salmonids congregate nearshore and become easier prey.

A.6.6.c Freshwater sport fishing

The San Lorenzo River has been popular with steelhead and coho salmon anglers since the early 1900's. The river is easily accessible to the San Francisco Bay area, and is the largest steelhead river south of San Francisco Bay (Benkman, 1976). Sport fishing contributed significantly to the local economy into the 1970s, when it was estimated that an average of 50,000 angler-hours per year were spent on the river. CDFG estimated that that the San Lorenzo was the fourth most fished steelhead river in California (Ricker and Butler, 1979).

Recreational fishing and fish-planting efforts to increase recreational fishing opportunities have negatively impacted the San Lorenzo steelhead population. Cramer et al. (1995) found that most of the estimated harvest rates were sufficiently high to damage steelhead populations during years when ocean and freshwater survival is low.

"Catchable trout" (actually, hatchery steelhead) were planted to supplement the recreational fishery, beginning in 1905. Historical fishing regulations lacked bag limits on salmon and trout, an indication of abundant fish populations. As fish populations dwindled due to increased fishing, bag limits were introduced, and limits steadily increased. Daily bag limits first appeared in the Fish and Game Code in 1941, when summer and winter fishing seasons were first established on California streams. After the 1976-77 drought, summer trout fishing was banned (Ernie Kinzli, Ernie's Casting Pond, pers. comm.).

For the winter fishing season, a daily bag limit of two steelhead was instituted in 1941, with fishing days restricted to Wednesdays, weekends, holidays and the first and last day of the season. This regulation remained in place until 1997 when steelhead became federally protected. The winter fishing season has remained fairly constant, beginning in either mid-November or December 1 to the end of February or 1 week into March. For a while after the federal listing, anglers were allowed to keep 1 hatchery adult per day. Current regulations require catch-and-release only, with barb-less hooks. Fishing is allowed only on the mainstem, downstream of the Lomond Street Bridge in Boulder Creek. State budget cuts have seriously affected the enforcement ability of CDFG, which was already understaffed.

Fishers have played an important role in advocating for restoration of the coho and steelhead populations. Both sport and commercial fishers historically helped to restore salmon and steelhead runs in California. The majority of members of Monterey Bay Salmon and Steelhead Trout Project are recreation-oriented fishers. This group is an important Central Coast organization, which created and now operates the Big Creek Native Anadromous Fish-Rearing Facility (Hatchery). The hatchery provides native central coast steelhead and coho smolts to supplement local runs. It also provides an important salmonid educational program to the public schools in which steelhead are raised in the classroom and released by students into local streams.

A.7 Quantitative assessment of juvenile steelhead and coho salmon populations in the San Lorenzo River

Table A.14 summarizes recent historical salmonid population estimates in the San Lorenzo River. In 1981, Smith (1982) and Alley systematically electro-fished the San Lorenzo River for juvenile coho and steelhead. An index of 1,500 adult steelhead in the mainstem was calculated for winter of 1983-84 from this sampling (Alley, 1995). Alley continued sampling of the mainstem from 1994-1997, sampling the entire watershed from 1998-2001 using a similar methodology to that of Smith (1982). In 2003-2005, they continued to sample the middle and upper mainstem (upstream of the Zayante Creek confluence) and four tributaries (Zayante, Bean, Boulder and lower Bear) in the upper watershed.

H.T. Harvey & Associates sampled the San Lorenzo system in 2002, utilizing non-random methods similar to Alley's, and a random sampling subset within the middle mainstem. H.T. Harvey & Associates did not calculate an index of adult returns for 2002. The critical factor limiting the population is the juvenile stage in freshwater. Poor habitat quality and quantity reduces juvenile numbers in freshwater. Trend analysis of the juvenile steelhead population occurred from1998 through 2001 (Alley, 2002) for the entire watershed. The mainstem was monitored in 1981 and since 1994.

The mainstem was divided into lower (Reaches 1-5), middle (Reaches 5-9) and upper (Reaches 10-12) for biological, hydrologic and geomorphic reasons, as shown in Figure A.25). Tables A.13 and A.14 show annual estimates by size class and age class.

Table A.14. Estimates and indices of returning adult steelhead and adult coho salmon to the San Lorenzo River.

Year or Winter Season	# of Steelhead	# of Coho salmon	Method	Notes	Source
1964	20,000	2,500-10,000	Creel census estimate		Johnson, 1964
1970-71	1,816	383	Creel census		Ricker and Butler 1979
1976-77	1,614 trapped	174 trapped	Count from incomplete Felton fish trapping	Dry year	Ricker and Butler 1979
1977-78	3,000	182 trapped	Incomplete steelhead seasonal estimate; Coho is a total count from Felton fish trapping		Ricker and Butler 1979
1978-79	625	100	Estimate from incomplete Felton fish trapping season	Possible effects from 1975-77 drought	Kelley and Dettman 1981
1979-80	496		Count from incomplete Felton fish trapping		Kelley and Dettman 1981
1983-84	1,500	present	Index from sampling juvenile populations in 1981	Mainstem only	Smith 1982 and D.W. Alley & Assoc.(2006)
1994-95	311	Not observed	Count from incomplete Felton fish trapping		
1996-97	1,080	Not observed	Index from sampling juvenile populations from 1994	Mainstem only	D.W. Alley & Assoc
1997-98	1,780	Not observed	Index from sampling juvenile populations from 1995	Mainstem only	D.W. Alley & Assoc
1998-99	1,540	Not observed	Index from sampling juvenile populations from 1996	Mainstem only	D.W. Alley & Assoc
1999-2000	1,300	Not observed	Index from sampling juvenile populations from 1997	Mainstem only	D.W. Alley & Assoc
2000-01	2,500	Not observed	Index from sampling juvenile populations from 1998	Watershed	D.W. Alley & Assoc
2001-02	2,650	Not observed	Index from sampling juvenile populations from 1999	Watershed	D.W. Alley & Assoc
2002-03	1,650	Not observed	Index from sampling juvenile populations from 2000	Watershed	D.W. Alley & Assoc
2003-2004	1,600 (1,007 trapped at Felton)	14 trapped	Index from sampling juvenile populations from 2001 Trap Count from incomplete Felton fish trapping season	Watershed	D.W. Alley & Assoc ----------------- SLV High trap results
2004-2005	317 trapped	18 trapped	Trap Count from incomplete Felton fish trapping		SLV High trapping results

A.7.1 Overall mainstem trend in smolt-sized juveniles, 1994-2001

The number of smolt-sized juveniles is most important in determining the expected number of adult returns. Table A.15 shows that the 1994-2001 estimates for larger, smolt-sized juveniles produced in the mainstem increased in 1995 after the drier 1994 year, followed by a steady decrease from 1995-2001. Only the lower mainstem produced more smolt-sized fish in 2001 compared to 2000, this being due to more YOY's growing into Size Class 2. In 2001, there were fewer yearlings, and YOY's grew more slowly with reduced streamflow than past years. The production of larger juveniles in 2001 was at a 5-year low for the middle river and remained low in the lower and upper River as occurred in 2000 (Alley, 2002).

A.7.2 Overall watershed trend in smolt-sized juveniles, 1998-2001

Table A.15 shows that the overall smolt population in the watershed was relatively large in 1998 (45,500), even though there were fewer yearlings. This was because there was a large YOY population with the increased habitat brought on by high streamflow, and many of those grew to smolt size in the mainstem with accelerated growth. The smolt population increased in 1999 and then declined considerably in 2000 and 2001.

Table A.15. Estimated trend in juvenile steelhead (rounded to nearest 500), by size-class, in the San Lorenzo River mainstem* for fall 1981, 1994-2001, and in San Lorenzo River tributaries for fall 1998-2001.

Year	Mainstem or Tributaries	Number of size-class 1 steelhead (< 75 mm SL)	Number of size-class 2 & 3 (smolt-sized) steelhead (=> 75 mm SL)	Total number of juveniles
1981	Mainstem	37,000**	31,500**	69,000**
1994	Mainstem	24,500	23,000	45,000
1995	Mainstem	37,000	38,000	75,000
1996	Mainstem	40,000	32,500	72,500
1997	Mainstem	63,000	25,000	88,000
1998	Mainstem	31,000	26,000	58,000
1998	Tributaries	91,500	19,000	111,000
1998	TOTAL	123,000	45,500	168,500
1999	Mainstem	17,500	24,000	41,500
1999	Tributaries	73,500	28,500	102,000
1999	TOTAL	91,000	53,000	144,000
2000	Mainstem	12,500	11,000	23,500
2000	Tributaries	59,000	19,500	78,500
2000	TOTAL	72,000	30,500	102,500
2001	Mainstem	23,500	11,500	35,000
2001	Tributaries	70,000	16,500	86,500
2001	TOTAL	93,500	28,000	121,500

*from Highway 1 to above Waterman Gap
** Prior to 1996, estimates came from sampling site densities extrapolated to reach densities. In 1997, estimates came from habitat-type densities extrapolated to reach densities after habitat proportioning was determined. A revised 1996 estimate was generated, using 1997 habitat proportions. In 1998-2001, habitat proportions were annually determined. Estimates are approximate and rounded to the nearest 500.
Source: Alley 2002.

A.7.3 Overall mainstem trend in total number of juveniles, 1996-2001

Table A.16 shows that the total numbers of juveniles from the mainstem in 2001 were less than half of 1996. Table A.16 also shows that total juvenile steelhead production for the watershed in 2001 was approximately 72% of the 1998 total (Alley, 2002).

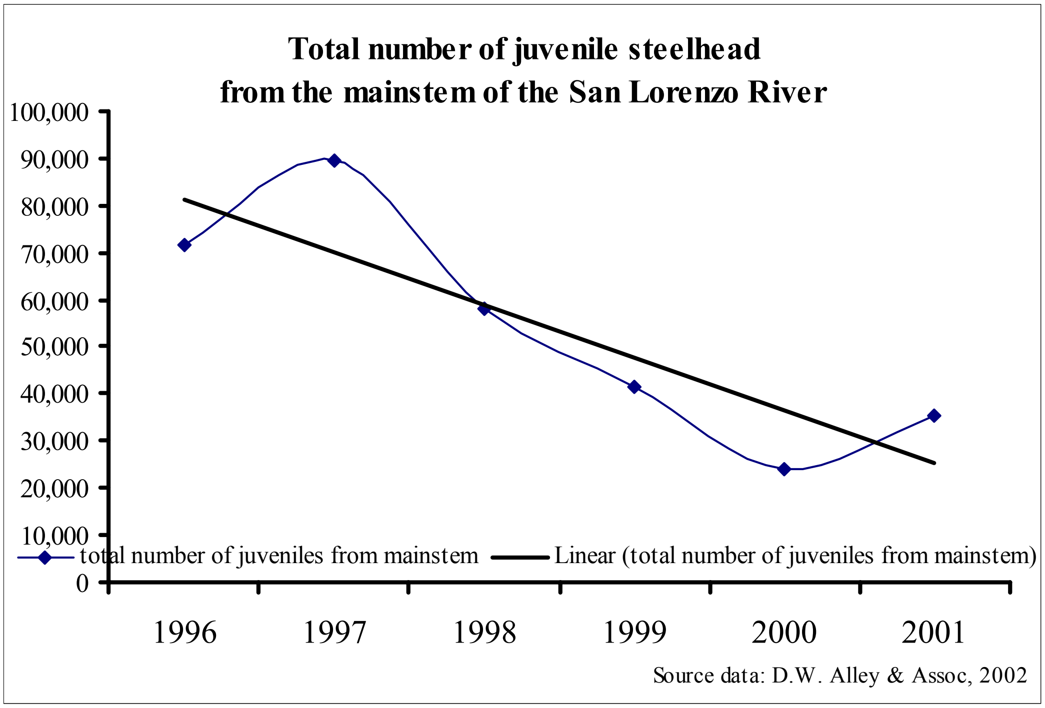
Figure A.26 shows the trend in total juvenile population in the mainstem for 1996-2001. The long-term trend is a dramatic decrease in juvenile production. The population size decreased from 1996 to 2001, with a slight increase from 1996 to 1997 and from 2000 to 2001.

Table A.16. Estimated trend of juvenile steelhead, by age-class, in the San Lorenzo River mainstem* for fall 1996-2000, and in San Lorenzo River tributaries for fall 1998-2000.

Year	Mainstem or Tributaries	Number of YOY** steelhead	Number of yearling steelhead	Total number juveniles
1996	Mainstem	62,000***	9,500***	71,500***
1997	Mainstem	81,500	8,500	89,500
1998	Mainstem	52,500	5,500	58,000
1998	Tributaries	103,500	9,500	113,000
1998	TOTAL	156,000	15,000	171,000
1999	Mainstem	34,500	7,500	41,500
1999	Tributaries	74,500	28,000	102,500
1999	TOTAL	109,000	35,000	144,000
2000	Mainstem	18,000	5,500	24,000
2000	Tributaries	61,000	17,500	78,500
2000	TOTAL	79,500	23,000	102,500
2001	Mainstem	30,500	5,000	35,500
2001	Tributaries	69,500	17,000	86,500
2001	TOTAL	100,000	22,000	122,000

* from Highway 1 to above Waterman Gap
** YOY are young-of-the-year fish
*** All estimates were rounded to the nearest 500. Estimates for all juveniles combined differed when combining age classes versus size classes, because density estimates at sampling sites were determined separately by age and size.
Source: Alley 2002.

Figure A.26. Trend in total number of juvenile steelhead per year for the mainstem San Lorenzo River from 1996-2001.



A.7.4 Overall tributary trend in yearling (smolt-sized) juveniles, 1998-2001

In the tributaries, where growth is slower than in the lower and middle mainstem, only yearlings are smolt-sized in all but the wettest years, such as 1998 and 2005. The tributary smolt (yearling) population in fall 1998 was much less than in 1999 because many of the yearlings were flushed from the watershed during the El Niño storms of winter 1997-98. Then there was a steady decline in smolt production in the tributaries from 1999-2001, with slower growth rate in 2001 due to reduced streamflow, as shown in Tables A.13 and A.14.

A.7.5 Trends in smolt-sized juveniles in the middle and upper mainstem and four upper tributaries, 1998-2005

Trends indicated by data gathered (H.T. Harvey, 2003) (Alley 2004; 2005; 2006) in the upper mainstem and four upper tributaries (Zayante, Bean, Boulder and lower Bear creeks) show how the steelhead population responded after the El Niño. In short, habitat and fish sampling results in 2005 indicated the first solid year of recovery after the negative El Niño effects and a series of drier years. These data are summarized in Table A.17.

In the middle and upper mainstem there was a general decline in smolt production from 1998 through 2002, from approximately 12,000 to 5,000 smolt-sized juveniles. The numbers remained stable during 2002-2004, and then increased to about 7,000 in 2005. This recent increase was likely the result of improved habitat conditions and higher growth rates that were stimulated by higher streamflow. There was also a significant increase in smolt densities from 2004 to 2005 at the middle mainstem sites. With higher streamflows in 2005, YOY growth rate was greater and a higher proportion of them reached smolt size than the previous year.

In the four tributaries, the smolt-sized juvenile numbers increased from approximately 9,000 in 1998 to a high of about 17,000 in 1999, followed by a steady decline in 2000-2002 to about 7,000. In 2004, low smolt production in Zayante Creek resulted from less escape cover, and low smolt production in Bean Creek resulted from more extensive dewatering of reaches of Bean Creek. In 2005, numbers increased to about 13,000, the highest since 1999. This increase resulted from improved habitat, faster growth rate of some YOY steelhead into the smolt-sized group, and perennial flow in the Bean Creek reaches associated with the higher baseflow.

The decline in yearlings and smolt-sized juveniles for all sites sampled together was statistically significant from 2003 to 2004. This decline was likely due to high winter storm events that flushed out over-wintering yearlings, followed by low baseflows in spring and summer that led to slow growth rates of YOY's. When smolt densities at all sampling sites in 2005 were compared to 2004 densities, the increase was statistically significant.

Table A.17. Estimated trend of juvenile steelhead (rounded to nearest 100), by size-class, in the San Lorenzo River middle and upper mainstem* and 4 upper tributaries (Zayante, Bean, Boulder and lower Bear) for fall 1998-2005.

Year	Partial Mainstem or 4 tributaries	Number of size-class 1 steelhead (< 75 mm SL)	Number of size-class 2 & 3 steelhead (=> 75 mm SL)	Total number of juveniles
1997	Mainstem	54,300	10,400	64,700
1998	Mainstem	28,500	12,400	40,900
1999	Mainstem	16,000	8,500	24,500
2000	Mainstem	11,400	6,500	18,000
2001	Mainstem	19,600	5,300	24,900
2002	Mainstem	51,600	4,600	56,200
2003	Mainstem	30,900	5,100	36,000
2004	Mainstem	26,700	4,800	31,600
2005	Mainstem	24,300	6,500	30,800
Average	Mainstem	29,300	7,100	36,400
1998	4 Tributaries	57,600	9,200	66,800
1999	4 Tributaries	39,700	17,200	56,900
2000	4 Tributaries	29,700	11,900	41,600
2001	4 Tributaries	38,000	9,300	47,300
2002	4 Tributaries	62,700	6,400	69,100
2003	4 Tributaries	78,900	12,300	91,200
2004	4 Tributaries	57,900	6,900	64,800
2005	4 Tributaries	57,400	13,200	70,600
Average	4 Tributaries	52,700	10,800	63,500
1998	Combined	86,100	21,600	107,700
1999	Combined	55,700	25,700	81,400
2000	Combined	41,100	128,400	59,600
2001	Combined	57,600	14,600	72,200
2002	Combined	114,300	11,000	125.300
2003	Combined	109,800	17,400	127,200
2004	Combined	84,600	11,700	96,400
2005	Combined	81,700	19,700	101,400
Average	Combined	82,000	17,900	99,900

Source: Alley, 2006.

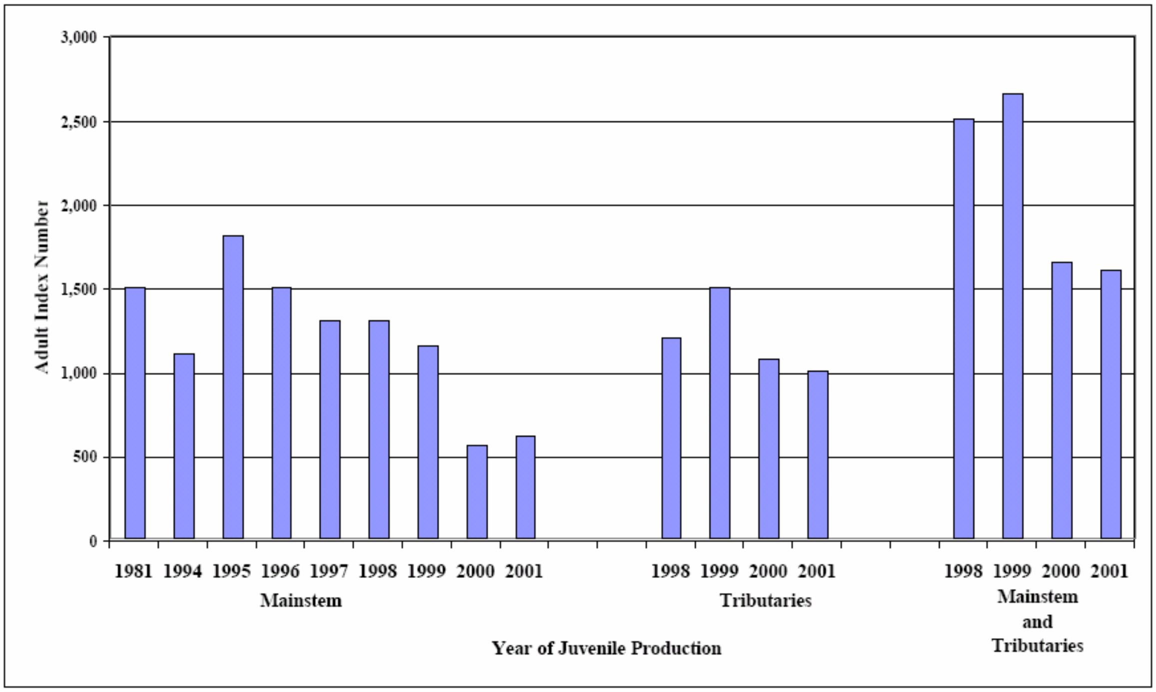
A.7.6 Trends in index of adult returns

Overall, from the 2003-2005 sampling it appears that the adult index has fluctuated since 2001 and was improving in 2005.

An index of adult returns was generated from juvenile production in each year of monitoring by D.W. ALLEY & Associates, based on the production of 3 size classes of juveniles (Alley, 2002). The most evident trend in the adult index was the precipitous decline in the mainstem contribution from 1997-2001 (Figure A.27; Table A.18). As a result, there was a steady decline in the adult index for the entire watershed for 1997-2001, with the relative tributary contribution of smolt-sized juveniles as yearlings increasing. This is indicative of habitat decline in the mainstem, resulting from severe sedimentation of rearing habitat after the El Niño winter of

1997-1998, along with apparent poor spawning success in later years and reduced baseflow through those years. Judging from monitoring of the middle and upper mainstem in 2003-2005, the adult index continued to be low with slight improvement in 2005, as habitat conditions improved (Alley, 2006). The adult index in the four tributaries that were monitored in 2003-2005 indicated a rebound in 2003 from a low in 2001, then a decline in 2004 to below the 2001 estimate, primarily because of stream dewatering in Bean Creek. Then there was a rebound in the adult index in 2005 when Bean Creek was again watered from high baseflows.

Figure A.27. Trends in the index of adult steelhead returns projected for the San Lorenzo River, based on year of juvenile production.



Source: Alley et al., 2004a.

Table A.18. Conservative index of adult steelhead returns to mainstem San Lorenzo River.

Sampling Year	Index of Returning Adults 2 Years Hence
Mainstem	
1981	1,500
1994	1,100
1995	1,800
1996	1,500
1997	1,300
1998	1,300
1999	1,150
2000	550
2001	610
Average	1,200
Middle and Upper Mainstem	
1998	650
1999	450
2000	350
2001	300
2003	350
2004	300
2005	400
Average	400
9 Tributaries	
1998	1,200
1999	1,500
2000	1,100
2001	1,000
Average	1,200
4 Tributaries	
1998	600
1999	900
2000	650
2001	550
2003	850
2004	500
2005	850
Average	700
Mainstem + 9 Tributaries	
1998	2,500
1999	2,650
2000	1,650
2001	1,600
Average	2,100
Partial Mainstem + 4 Tributaries	
1998	1,250
1999	1,350
2000	950
2001	850
2003	1,150
2004	800
2005	1,200
Average	1,100

Source: Alley et al., 2004a; Alley 2006.

A.8 Comparison of fish sampling methods.

For watershed management purposes, it is necessary to know if habitat quality is improving or not, where most YOY and smolt-sized fish are produced, and which stream reaches have the highest potential for supporting these young fish. It is also necessary to know how the juvenile population is responding to habitat changes. By sampling representative habitat of average quality, the juvenile production has been estimated with sufficient accuracy to detect trends in annual production, as well as changes in size classes and age classes in relation to habitat quality (e.g.; increased smolt-sized juveniles when escape cover and water depth increase). A comprehensive salmonid assessment and enhancement plan was developed for the San Lorenzo River, based on data collected from the D.W. ALLEY & Associates' long-term monitoring program (Alley et al., 2004a). The continuing program has included salmonid habitat surveys and measurement of juvenile steelhead abundance. Monitoring of juvenile numbers and habitat conditions, and assessing threats to all life stages, are critical to recovery of the species (NMFS, 2005).

The San Lorenzo River has been censused by D.W. Alley & Associates using a representative reach extrapolation technique (RRET), a well-established, systematic method in fishery biology. Systematic, nonrandom sampling has been commonly used in California to assess trends in fish population size. The RRET method has been used by the CDFG for years in sampling Delta smelt and striped bass to detect population trends and manage populations in the California Delta (J. Smith pers. communication). The NMFS regulatory branch supports continued sampling using this methodology (Haynes, pers. comm. NMFS Santa Rosa 2005). This method relies on professional judgment to select representative sampling sites, rather than random selection. The RRET method is useful for revealing trends in annual fish population numbers, as well as for comparing populations in different portions of the watershed. This method assumes that habitat with average habitat quality will produce approximately average densities of juvenile steelhead. Sampling of representative sites each year enables detection of trends in population size and habitat conditions. Because of the non-random nature of site selection, analysis of variance is not possible with the RRET method. Nor is it possible with this method to establish confidence intervals for juvenile population estimates. If a more statistically robust estimate of juvenile population numbers is needed, a stratified random sampling approach is required. However, the RRET method is sufficient for most watershed management purposes, and is less labor-intensive, and less expensive.

On the other hand, random sampling is currently the basis for most calculations of confidence intervals (to show that patterns seen are not due to random chance), and statistical analyses. However, random sampling does not reveal population trends over time, as does the method RRET method. A random sampling methodology capable of rigorous and robust statistical analysis is the method used by agencies such as USFWS and CDFG. NMFS fisheries laboratory also requested random sampling in 2002. The scope of random sampling necessary to encompass the entire watershed has proven expensive, however.

A random sampling approach used to census juvenile coho is the basin-wide visual estimation technique (BVET) (Hankin and Reeves, 1988; Dolloff, Hankin and Reeves, 1993). BVET uses a stratified random sampling design that allows statistical analysis of variance. It relies primarily on a visual census by snorkeling, with some calibration through electro-fishing. Data collection with BVET reduces the cost of random sampling. However, the BVET method could under-estimate juvenile densities. In heavily shaded stream reaches, where the stream channel is small and fish hide in cover, visual census is not the best approach. In pools in the upper mainstem and tributaries, where calibration between visual estimates and electro-fishing estimates may be attempted, the BVET method is more labor intensive than is necessary for monitoring of trends in juvenile salmonid numbers. Shallower riffles, runs and step-runs are too shallow to visually census, and must be electro-fished. The BVET method recommends a visual census of 25% of the pools, and for calibration, they recommend electro-fishing 10% of those pools. In the San Lorenzo River, this would result in a questionable calibration factor.

A.9 Recovery efforts for coho salmon and steelhead

The National Marine Fisheries Service began a recovery plan for the Central California Coast Coho Salmon ESU (CCC ESU) in 2005, as required by the federal ESA. The agency describes the recovery process:

> Recovery is the process in which listed species and their ecosystems are restored and their future safeguarded to the point that protections under the federal ESA are no longer needed. A variety of actions may be necessary to achieve the goal of recovery, such as the ecological restoration of habitat or implementation of conservation measures with stakeholders (NMFS, 2004).

A priority number of "1" was assigned to the Central Coast coho salmon ESU in accordance with the agency's recovery priority guidelines (55 FR 24296, Section B). "This ranking is based on a high degree of threat, a high recovery potential and an anticipated conflict with development projects or other economic activity" (NMFS, 2005).

The recovery outline lists the following priorities to address the low effective population size and limited spatial distribution of the CCC ESU:

- Conduct and improve research and monitoring on distribution, status and trends.
- Protect and restore watersheds and estuarine habitat complexity and connectivity.
- Improve freshwater habitat quantity and quality.
- Promote and improve operations of current recovery hatcheries and develop hatchery and genetic management plans to minimize negative influences of hatcheries.
- Improve enforcement of fishery rules and regulations.

The recovery outline lists the following priorities to address the low winter and summer survival of juveniles, limited smolt production, reduced spawning success and low productivity of the Central California Coast ESU:

- Focus on freshwater habitat restoration (e.g., erosion control, bank stabilization, riparian protection and restoration and reintroduction of large woody debris).
- Improve riparian protections and habitats.
- Balance water supply and allocation with fisheries' needs through water rights programs, identification and designation of fully appropriated watersheds, development of passive diversion devices and/or off-stream storage, elimination of illegal water diversions, and improved criteria for water drafting, storage and dam operations.
- Improve agricultural, instream gravel mining and forestry practices.
- Improve county/city planning, regulations (e.g., riparian and grading ordinances) and county road maintenance programs.
- Improve state road maintenance and management.
- Remove/upgrade man-made fish passage barriers (e.g., watercourse crossings, dams and others) in high priority watersheds and stream reaches.

- Screen water diversion structures in anadromous fish bearing streams.
- Replace existing outdated septic systems and improve wastewater management.
- Promote concept of multi-use/recycling of water to increase water supply (e.g., use of tertiary treated wastewater for golf courses and other appropriate uses).
- Identify and treat point and non-point source pollution to streams from wastewater, agricultural practices and urban environments.
- Modify channel and flood control maintenance practices, where appropriate, to increase stream and riparian complexity.
- Eliminate artificial breaching of sandbars for improvements in channel and estuarine habitats.
- Improve understanding of life-state survival at the sub-population scale through focused research and monitoring.
- Provide outreach to Federal action agencies regarding section 7(a)(1) and the carrying out of programs that conserve and recover Federally listed salmonids.
- Encourage enforcement, improved performance and needed revision to pertinent state and local rules and regulations such as Forest Practice Rules, urban storm water permits and others.

ACKNOWLEDGMENTS: Appendix A

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