Appendix A

Life history summaries for Central Valley steelhead and Chinook salmon

Species Summaries

Common Name	**Scientific Name (family)**
Chinook salmon	*Oncorhynchus tshawytscha* (Salmonidae)

Legal Status:

Federal	Candidate (Central Valley Fall Chinook Salmon ESU) Not Warranted (Central Valley Late-Fall Chinook Salmon ESU)

Distribution and Population Trends

Chinook salmon are distributed in the Pacific Ocean throughout the northern temperate latitudes in North America and northeast Asia. In North America, they spawn in rivers from Kotzebue Sound, Alaska south to the San Joaquin River in California's Central Valley (Healey 1991). In California, large populations are found in the Sacramento River and its major tributaries. Chinook salmon are also widely distributed in smaller California coastal streams north of San Francisco Bay (Allen and Hassler 1986). Fall Chinook occurring in the San Joaquin river belong to the Central Valley Fall and Late Fall Evolutionary Significant Unit (ESU). The ESU includes all naturally spawned populations of fall-run Chinook salmon in the Sacramento and San Joaquin River Basins and their tributaries, east of Carquinez Strait, California. NMFS (1999) determined that listing was not warranted for this ESU, but subsequently designated the ESU as a candidate for listing. Spring Chinook are extirpated from the San Joaquin basin, and are not included in an ESU.

Four runs of Chinook salmon occur in California fall, late fall, winter, and spring (Leet et al. 1992, Allen et al. 1986, Mills et al. 1997). Fall-run populations (or "fall Chinook") occur throughout the species' range and are currently the most abundant and widespread salmon runs in California (Mills et al. 1997). Winter-run populations are limited to the Sacramento River basin and were listed as endangered under the federal Endangered Species Act in 1994. Two apparently distinct stocks of spring-run Chinook (or "spring Chinook") occur in California: a Sacramento-San Joaquin population and a Klamath-Trinity population (Moyle et al. 1995). Moyle et al. (1995) state that although other spring Chinook populations may have existed in smaller coastal streams between these two basins, such as the Eel River, they have since been extirpated and there is no evidence of recent spawning in these streams.

The San Joaquin River system once supported large runs of both spring and fall Chinook salmon. In the San Joaquin River and its tributaries historic production is estimated to have approached 300,000 fish (Reynolds et al. 1993, as cited in Yoshiyama et al. 1998). The last large run observed in the San Joaquin River was over 56,000 fish in 1945 (Fry 1961, as cited in Moyle et al. 1995). Adult spring Chinook salmon entered the system during periods of high spring snowmelt, held over in deep pools during the summer, then spawned in the upper reaches of the San Joaquin River and its major tributaries—the Stanislaus, Tuolumne, and Merced rivers—in the early fall. Locals living on the San Joaquin River mainstem before dam construction observed spring Chinook holding in the summer in pools near Friant, and moving upstream into the gorge of the San Joaquin River to spawn (currently inundated by Millerton Lake) (CFGC 1921). Dam construction and irrigation diversions, which eliminated access to upstream spawning and holding areas, extirpated the spring run from the basin by the late 1940s (Skinner 1962).

Fall Chinook salmon are currently the most abundant race of salmon in California (Mills et al. 1997). In the San Joaquin Basin, fall Chinook historically spawned in the mainstem San Joaquin River upstream of the Merced River confluence and in the mainstem channels of the major tributaries. Dam construction and water diversion dewatered much of the mainstem San Joaquin River, limiting fall Chinook to the three major tributaries where they spawn and rear downstream of mainstem dams.

Run estimates are available from 1940, but systematic counts of salmon in the San Joaquin Basin began in 1953, long after construction of large dams on the major San Joaquin basin rivers. Comparable estimates of population size prior to 1940 are not available. Since population estimates began, the number of fall Chinook returning to the San Joaquin Basin annually has fluctuated widely. Most recently, escapement in the Tuolumne River dropped from a high of 40,300 in 1985 to a low about 100 resulting from the 1987–1992 dry period (EA 1997). With increased precipitation and improved flow conditions, escapement has increased to 3,300 in 1996 (EA 1997). Since 1991 hatchery production is estimated to compose about 30–60% of the fall Chinook run in the San Joaquin River (PFMC 1998, as cited in Yoshiyama et al. 1998). Figure 1 provides a summary of estimated escapement from 1953–2000 in the Stanislaus, Tuolumne, and Merced rivers.

Due to extensive hatchery introductions, most spring Chinook currently in Sacramento mainstem have hybridized with fall-run fish, and are heavily introgressed with fall Chinook characteristics, particularly with regard to run timing (Yoshiyama et al. 1998). Deer, Mill, and Butte Creek stocks appear to have minimal to no hatchery influence.

Life History

Overview

Chinook salmon vary in length of fresh and salt-water residency, and in upstream and downstream migration timing (Healey 1991). Chinook salmon are the largest of the Pacific salmon species, reaching weights of up to 45 kg (99 lb), although most adults in Oregon weigh 4.5–18 kg (10–40 lbs) (Healey 1991, Kostow 1995). Chinook salmon have genetically distinct runs differentiated by the timing of spawning migration, stage of sexual maturity when entering fresh water, timing of juvenile or smolt outmigration, and other characteristics (Moyle et al. 1989).

Spring Chinook typically spend up to one year rearing in fresh water before migrating to sea, perform extensive offshore migrations, and return to their natal river in the spring or summer, several months prior to spawning (these are also referred to as “stream-type” Chinook). Fall (or “ocean-type”) Chinook migrate to sea during their first year of life-typically within three months after their emergence from spawning gravels, spend most of their ocean life in coastal waters, and return to their natal river in the fall, a few days or weeks before spawning (Moyle et al. 1989, Healey 1991). The following information focuses on the life history and habitat requirements of spring Chinook salmon although information on fall Chinook is also included. Information specific to the San Joaquin River has been included where possible. Table 1 displays the timing of specific life history events for spring Chinook salmon in the San Joaquin River basin based on historical information, and recent information from similar stocks (e.g., Sacramento River basin stocks), and Table 2 displays the general timing of life history events of fall Chinook in the Central Valley.

Adult upstream migration and spawning

Adult Chinook salmon migrate upstream from the ocean to spawn in their natal streams, although a small percentage may stray into other streams, especially during high water years (Moyle et al. 1989). In California rivers, adult spring Chinook typically return to fresh water between March and May while still sexually immature (Marcotte 1984). Upstream migration in the San Joaquin River historically occurred from March through June (CFGC 1921, Hatton and Clark 1942), and holding occurred from April though mid-July (Table 1). There are differences in run timing between basins within the Sacramento/San Joaquin Rivers, which have been attributed to the timing of fall decreases in water temperature. Spring Chinook salmon tend to move up into the cooler reaches of rivers earlier in the season to spawn, and spawn in warmer reaches later (after seasonal changes decrease water temperatures) (Parker and Hanson 1944, as cited in Moyle et al. 1995). Migration timing also appears to be based in part on snow-melt flows (NMFS 1999). Therefore it is likely that current run timing in the San Joaquin River would differ from both historical timing, and the timing in tributaries to the Sacramento River. Fall Chinook salmon in the San Joaquin system typically enter spawning streams from October through December (Table 2). The age of returning Chinook adults in California ranges from 2 to 5 years.

Adult Chinook salmon appear to be less capable of negotiating fish ladders, culverts, and waterfalls during upstream migration than coho salmon or steelhead (Nicholas and Hankin 1989), due in part to slower swimming speeds and inferior jumping ability compared to steelhead (Reiser and Peacock 1985; Bell 1986, as cited in Bjornn and Reiser 1991). Cruising speeds, which are used primarily for long-distance travel, range from 0 to 1 m/s (0 to 3.3 ft/s) (Bjornn and Reiser 1991). Sustained speeds, which can be maintained for several minutes, range from 1 to 3.3 m/s (3.3 to 10.8 ft/s) (Bjornn and Reiser 1991). Darting speeds, which can only be sustained for a few seconds, range from 3.3 to 6.8 m/s (10.8 to 22.3 ft/s) (Bjornn and Reiser 1991). The maximum jumping height for Chinook salmon has been calculated to be approximately 2.4 m (7.9 ft) (Bjornn and Reiser 1991).

Spring Chinook spawning in the San Joaquin River historically occurred from late August to October, with peak spawning occurring in September and October (Clark 1942). Fall Chinook in the San Joaquin system typically spawn from October through December, with spawning activity peaking in early to mid-November. Upon arrival at the spawning grounds, adult females dig shallow depressions or pits in suitably-sized gravels, deposit eggs in the bottom during the act of spawning, and cover them with additional gravel. Over a period of one to several days, the female gradually enlarges the redd by digging additional pits in an upstream direction (Healey 1991). Redds are typically 10–17 m^2 (108–183 ft^2) in size, although they can range from 0.5 to 45 m^2 (5.4–484 ft^2) (Healey 1991). Spring Chinook redds in Deer Creek average 4 m^2 (42 ft^2) (Cramer and Hammack 1952, as cited in Moyle et al. 1995).

Spring Chinook spawners tend to congregate in high densities where stream reaches offer appropriate spawning habitat (Nicholas and Hankin 1989). Before, during, and after spawning, female Chinook salmon defend the redd area from other potential spawners (Burner 1951). Briggs (1953) observed that the defended area could extend up to 6 m (20 ft) in all directions from the redd. Redds may be defended by the female for up to a month (Hobbs 1937). Males do not defend the redd but may exhibit aggressive behavior toward other males while defending spawning females (Shapovalov and Taft 1954). Both male and female adults die within two weeks after spawning (Kostow 1995), with females defending the redd until they become too weak to maintain position over the redd or die.

Spawning gravel availability and redd superimposition

Dams have reduced the supply of spawning gravels in the many rivers in the Sacramento-San Joaquin River basin. Limitations on spawning gravels often result in redd superimposition, whereby later arriving females dig redds on top of existing redds, causing substantial mortality of the previously-deposited eggs (McNeil 1964, Hayes 1987). This has been found to be an important factor affecting Chinook populations in the Tuolumne River, and other rivers where gravel supplies may be limited by dams (EA Engineering 1992).

Clark (1942) conducted detailed surveys of the San Joaquin River for available spawning gravel. 417,000 ft^2 of suitable spawning gravel were found in 26 miles of channel between Lanes Bridge and the Kerchoff Powerhouse (upstream of Friant Dam). The Friant Dam inundated 36% of this area, leaving about 266,800 ft^2 of suitable spawning gravel in the channel below the dam, though it is not clear what criteria were used to determine suitability.

Egg incubation, alevin development, and fry emergence

In the Sacramento River, the egg incubation period for spring Chinook extends from August to March (Fisher 1994, Ward and McReynolds 2001). Egg incubation generally lasts between 40–90 days at water temperatures of 6–12°C (42.8°F to 53.6°F) (Vernier 1969, Bams 1970, Heming 1982, all as cited in

Bjornn and Reiser 1991). At temperatures of 2.7°C (37°F), time to 50% hatching can take up to 159 days (Alderdice and Velsen 1978, as cited by Healey 1991). The alevins remain in the gravel for two to three weeks after hatching and absorb their yolk sac before emerging from the gravels into the water column during November to March in the Sacramento River basin (Fisher 1994, Ward and McReynolds 2001).

Juvenile freshwater rearing

The length of time spent rearing in freshwater varies greatly among spring Chinook juveniles. Chinook may disperse downstream as fry soon after emergence; early in their first summer as fingerlings; in the fall as flows increase; or after overwintering in freshwater as yearlings (Healey 1991). Even in rivers such as the Sacramento River where many juveniles rear until they are yearlings, some juveniles probably migrate downstream throughout the year (Nicholas and Hankin 1989). Although fry typically drift downstream following emergence (Healey 1991), movement upstream or into cooler tributaries following emergence has been observed in some systems (Lindsay et al. 1986, Taylor and Larkin 1986).

Juveniles feed voraciously during summer, and display territoriality in feeding areas and are aggressive towards other juvenile Chinook (Taylor and Larkin 1986, Reimers 1968). Experiments conducted in artificial streams suggest that aggressive behavior among juvenile Chinook results in formation of territories in riffles and size hierarchies in pools having abundant food resources and relatively dense groupings of fish (Reimers 1968). Territorial individuals have been observed to stay closer to the substrate, while other individuals may school in hierarchical groups (Everest and Chapman 1972). At night, juvenile Chinook may move toward stream margins with low velocities and finer substrates or into pool bottoms, returning to their previous riffle/glide territories during the day (Edmundson et al. 1968; Don Chapman Consultants 1989, as cited in Healey 1991). Reimers (1968) speculated that intraspecific interactions or density-dependent mechanisms may cause downstream displacement of fry.

During winter, juvenile Chinook typically reduce feeding activity and hide in cover, conserving energy and avoiding predation and displacement by high flows (Chapman and Bjornn 1969, Meehan and Bjornn 1991). Juvenile Chinook that overwinter in fresh water either migrate downstream in the fall to larger streams that have suitable winter habitat or enter interstitial spaces among cobbles and boulders whereupon growth is suspended for the winter (Chapman and Bjornn 1969, Bjornn 1971, Everest and Chapman 1972, Carl and Healey 1984). Reductions in stream temperatures to 4–6°C (39–43°F) typically cause downstream migration and/or movement into the interstices of the substrate (Morgan and Hinojosa 1996). In some areas, such as the mainstem Fraser River, juveniles have been observed to continue feeding in the winter (Levings and Lauzier 1991, as cited in Morgan and Hinojosa 1996). Morgan and Hinojosa (1996) suggested that juvenile Chinook may maintain territories in winter as well.

Rearing densities

Juvenile Chinook densities vary widely according to habitat conditions, presence of competitors, and life history strategies. Lister and Genoe (1970) reported maximum densities of fall Chinook emergent fry in stream margin habitats as 7.2 fish/m^2 (0.65 fish/ft^2) and in mid-channel habitats as 7.0 fish/m^2 (0.63 fish/ft^2). In the Red River, Idaho, densities of age 0+ Chinook in August averaged approximately 0.6 fish/m^2 (0.05 fish/ft^2) and declined to approximately 0.13 fish/m^2 (0.01 fish/ft^2) in November in low-gradient (1–2%) reaches (Hillman et al. 1987). Bjornn (1978, as cited in Bjornn and Reiser 1991) recorded late-summer age-0+ Chinook densities of up to 1.35 fish/m^2 (0.12 fish/ft^2) in a productive Idaho stream, and fewer than 0.8 fish/m^2 (0.07 fish/ft^2) in less productive third- and fourth-order streams. Densities in low-gradient (0.5%) reaches of Johnson Creek, Idaho were over 1.8/m^2 (0.16 fish/ft^2) (maximum recorded density was 6.5 fish/m^2 [0.59 fish/ft^2]) in early July, whereas densities in a higher gradient (1.3%) reach averaged 0.5 fish/m^2 (0.05 fish/ft^2) (maximum recorded density was 1.4 fish/m^2 [0.13 fish/ft^2]) in late July (Everest and Chapman 1972).

Smolt outmigration and estuarine rearing

In the mainstem San Joaquin River outmigrating trapping at Mossdale in 1939, 1940, and 1941 showed that spring Chinook smolt outmigration historically occurred from January until mid-June, with a peak in February (Hatton and Clark 1942). Data from Hatton and Clark (1942) show that the average total length of age 0+ spring Chinook fry in January was 35 mm, by March fry averaged 40 mm total length, and by the middle of April most fry were between 60 and 70 mm total length. By the end of migration (June) most fish were greater than 80 mm total length. Hatton and Clark (1942) compared fish sizes from the San Joaquin with fry captured in the Sacramento River during the same time period. The January captures from the San Joaquin averaged slightly less in length than fry captured in the Sacramento River, while fry captured later in the migration period were slightly larger.

Most age 0+ outmigrants in Butte Creek move downstream at sizes of 30 to 110 mm (1.18–4.33 inches) (Hill and Weber 1999), while age 1+ outmigrants are generally larger than 120 mm (4.7 inches), and can reach 150 mm (5.91 inches) or more in Butte Creek (Hill and Weber 1999). Trapping records from the Sacramento River basin show that three stages of downstream migration occur among spring Chinook. Some age-0+ juveniles are observed moving downstream from spring to early summer (Hill and Weber 1999, Ward and McReynolds 2001, Fisher 1994). Another group of juveniles are observed migrating downstream as age 1+ from October to January (Hill and Weber 1999, Ward and McReynolds 2001), and a third wave of migrants leave the river as age 1+ yearlings the following spring (Fisher 1994). In many river systems yearling smolts typically outmigrate to the ocean in early spring, either before or during the outmigration of fry and fingerlings (Healey 1991).

In general, fall Chinook fry (length <50 mm) and juveniles (length >50 mm) outmigrate from the spawning areas between January and May. Outmigration of larger juveniles generally occurs from April though June with smolts entering the ocean between April and July (Leet et al 1992).

Juvenile Chinook feed and grow as they move downstream in spring and summer; larger individuals are more likely to move downstream earlier than smaller juveniles (Nicholas and Hankin 1989, Beckman et al. 1998), and it appears that in some systems juveniles that do not reach a critical size threshold will not outmigrate (Bradford et al. 2001). Juveniles that do not disperse downstream in their first spring may display high fidelity to their rearing areas throughout the summer rearing period (Edmundson et al. 1968). Nicholas and Hankin (1989) suggested that the duration of freshwater rearing is tied to water temperatures, with juveniles remaining longer in rivers with cool water temperatures. Bell (1958, as cited in Healey 1991) suggests that the timing of yearling smolt outmigration corresponds to increasing spring discharges and temperatures. Kjelson et al. (1981) observed peak seine catches of Chinook fry in the Sacramento-San Joaquin Delta correlated with increases in flow associated with storm runoff. Flow accounted for approximately 30 percent of the variability in the fry catch. Photoperiod may also be important, although the relative importance of various outmigration cues remains unclear (Bjornn 1971, Healey 1991).

Ocean phase

When fall Chinook salmon produced from the Sacramento-San Joaquin system enter the ocean they appear to head north, and rear off the northern California-southern Oregon coast (Cramer 1987, as cited in Maragni 2001). Fall Chinook typically rear in coastal waters early in their ocean life. Ocean conditions are likely an important cause of density-independent mortality and interannual fluctuations in escapement sizes.

Habitat Requirements

Adult upstream migration and spawning

Adult spring Chinook require large, deep pools with moderate flows for summer holding during their upstream migration. Marcotte (1984) reported that suitability of pools declines at depths less than 2.4 m

(7.9 ft) and that optimal water velocities range from 15 to 37 cm/s (0.5 to 1.2 ft/s). In the John Day River, Oregon, adults usually hold in pools deeper than 1.5 m (4.9 ft) that contain cover from undercut banks, overhanging vegetation, boulders, or woody debris (Lindsay et al. 1986). Adult Chinook salmon require water deeper than 24 cm (0.8 ft) and water velocities less than 2.4 m/s (8 ft/s) for successful upstream migration (Thompson 1972, as cited in Bjornn and Reiser 1991). Water temperatures for adult Chinook holding and spawning are reportedly best when <16°C (60.8ºF), and lethal when >27°C (80.6ºF) (Moyle et al. 1995). Spring Chinook in the Sacramento River typically hold in pools below 21–25ºC (69.8–77ºF). Table 3 provides a summary of spring Chinook holding temperature criteria.

In July of 1942 Clark (1942) observed an estimated 5,000-spring Chinook holding in two large pools directly downstream of the Friant Dam. These fish appeared to be in good condition, and held in large, quiet schools. Flow from the dam was approximately 1,500 cfs, and water temperatures reached a maximum of 22.2ºC (72ºF) in July. Fewer fish were seen in each subsequent visit in August, September, and October, and it was assumed they had moved downstream in search of spawning riffles. A seasonal sand dam was installed in late summer in the San Joaquin, blocking the migration of additional spring Chinook into the upper river. By September fish were observed spawning 10 miles downstream of the Friant Dam. Although some fish may have held in pools downstream of Lanes bridge, Clark (1942) concluded that the abundant spawning he observed in September and October on riffles between Friant Dam and Lanes Bridge were from fish that held in the pools below the dam and dropped back downstream to spawn.

Most Chinook salmon spawn in the mainstem of large rivers and lower reaches of tributaries, although spawning has been observed over a broad range of stream sizes, from small tributaries 2–3 m (6.6–9.8 ft) in width (Vronskiy 1972) to large mainstem rivers (Healey 1991). Chinook prefer low-gradient (<3%) reaches for spawning and rearing, but will occasionally use higher-gradient areas (Kostow 1995). Spawning site (redd) locations are mostly controlled by hydraulic conditions dictated by streambed topography (Burner 1951). Redds are typically located near pool tailouts (i.e., heads of riffles) where high concentrations of intragravel dissolved oxygen are available.

Chinook are capable of spawning within a wide range of water depths and velocities, provided that intragravel flow is adequate (Healey 1991). Depths most often recorded over Chinook redds range from 10 to 200 cm (3.9 to 78 in) and velocities from 15 to 100 cm/s (0.5 to 3.3 ft/s), although criteria may vary between races and stream basins. Fall Chinook salmon, for instance, are able to spawn in deeper water with higher velocities, because of their larger size (Healey 1991); spring Chinook tend to dig smaller redds and use finer gravels than fall Chinook (Burner 1951).

Substrate particle size composition has been shown to have a significant influence on intragravel flow dynamics (Platts et al. 1979). Chinook salmon may therefore have evolved to select redd sites with specific particle size criteria that will ensure adequate delivery of dissolved oxygen to their incubating eggs and developing alevins. In addition, salmon are limited by the size of substrate that they can physically move during the redd building process. Substrates selected likely reflect a balance between water depth and velocity, substrate composition and angularity, and fish size. As depth, velocity, and fish size increase, Chinook are able to displace larger substrate particles. D_{50} values (the median diameter of substrate particles found within a redd) for Chinook have been found to range from 10.8 mm (0.43 in) to 78.0 mm (3.12 in) (Kondolf and Wolman 1993). Chinook in the Central Valley have been observed to use substrate ranging from 31–66 mm (1.22–2.60 in) (Van Woert and Smith, unpublished data 1962, as cited in Kondolf and Wolman 1993; and Kondolf and Wolman 1993).

Egg incubation, alevin development, and fry emergence

Suitable water temperatures, dissolved oxygen delivery, and substrate characteristics are required for proper embryo development and emergence. Review of the literature suggests that 5.8–14.2°C (42.5–

57.5°F) is the optimum temperature range for incubating Chinook salmon (Donaldson 1955, Combs and Burrows 1957, Combs 1965, Eddy 1972, Bell 1973, Healey 1979, Reiser and Bjornn 1979, Garling and Masterson 1985). Sublethal stress and/or mortality of incubating eggs resulting from elevated temperatures would be expected to begin at temperatures of about 14.4°C (58°F) for constant exposures (Combs and Burrows 1957, Combs 1965, Healey 1979).

Delivery of dissolved oxygen to the egg pocket is the major factor affecting survival-to-emergence that is impacted by the deposition of fines in the spawning substrate. Several studies have correlated reduced dissolved oxygen levels with mortality, impaired or abnormal development, delayed hatching and emergence, and reduced fry size at emergence in anadromous salmonids (Wickett 1954, Alderdice et al. 1958, Coble 1961, Silver et al. 1963, McNeil 1964, Cooper 1965, Shumway et al. 1964, Koski 1981). Silver et al. (1963) found that low dissolved oxygen concentrations were related to mortality and reduced size in Chinook salmon and steelhead embryos. Data suggest that growth may be restricted day at oxygen levels below saturation (Silver et al. 1963). Fine sediments in the gravel interstices can also physically impair the fry's ability to emerge through the gravel layer, trapping (or entombing) them within the gravel (Phillips et al. 1975, Hausle and Coble 1976).

Juvenile freshwater rearing
Juvenile Chinook salmon tend to use mainstem reaches and estuaries as rearing habitat more extensively than juvenile coho salmon, steelhead, and sea-run coastal cutthroat trout do. Spring Chinook typically rear in low gradient reaches of mainstem rivers areas and large tributaries (Nicholas and Hankin 1989).

Following emergence, fry occupy low-velocity, shallow areas near stream margins, including backwater eddies and areas associated with bank cover such as large woody debris (Lister and Genoe 1970, Everest and Chapman 1972, McCain 1992). As fry grow, they move into deeper and faster water further from banks (Hillman et al. 1987, Everest and Chapman 1972, Lister and Genoe 1970). Everest and Chapman (1972) observed at least small numbers of Chinook fry in virtually all habitats sampled in early summer. Because Chinook fry tend to be larger than coho fry upon emergence, they may tend to use areas with higher water velocities than coho (Murphy et al. 1989, Healey 1991). Most researchers have not addressed fry habitat requirements separately from juvenile summer habitat requirements, but there seems to be consensus that Chinook fry prefer quiet, shallow water with cover. Everest and Chapman (1972) investigated habitat use of emergent Chinook fry; they found fry using depths less than 60 cm (24 in) and water velocities less than 15 cm/s (0.5 ft/s).

Substantial variability in the depth and velocity preferences of juvenile Chinook has been reported. Juvenile Chinook have been observed in virtually all depths and velocities where researchers have sampled (Hillman et al. 1987, Murphy et al. 1989). Lister and Genoe (1970) found that juvenile Chinook preferred slow water adjacent to faster water (40 cm/s [1.3 ft/s]).

Summer rearing habitat
Juvenile Chinook salmon appear to prefer pools that have cover provided by banks, overhanging vegetation, large substrates, or LWD. Juvenile densities in pools have been found to increase with increasing amounts of cover (Steward and Bjornn, unpublished data, as cited in Bjornn and Reiser 1991). Water temperature may also influence juvenile habitat use. In the South Umpqua River basin, Roper et al. (1994) observed lower densities of juvenile Chinook where water temperatures were higher. In areas where more suitable water temperatures were available, juvenile Chinook salmon abundance appeared to be tied to pool availability.

Temperatures also have a significant effect on juvenile Chinook growth rates. On maximum daily rations, growth rate increases with temperature to a certain point and then declines with further increases. Reduced rations can also result in reduced growth rates; therefore, declines in juvenile salmonid growth rates are a function of both temperature and food availability. Laboratory studies indicate that juvenile Chinook salmon growth rates are highest at rearing temperatures from 18.3° to 21.1°C (65° to 70°F) in the presence of unlimited food (Clarke and Shelbourn 1985, Banks et al. 1971, Brett et al. 1982, Rich 1987), but decrease at higher temperatures, with temperatures >23.3° C (74° F) being potentially lethal (Hanson 1990).

Nicholas and Hankin (1989) suggest that the duration of freshwater rearing is tied to water temperatures, with juveniles remaining longer in rivers with cool water temperatures.

Winter rearing habitat
Juvenile Chinook salmon rearing in tributaries may disperse downstream into mainstem reaches in the fall and take up residence in deep pools with LWD, interstitial habitat provided by boulder and rubble substrates, or along river margins (Swales et al. 1986, Healey 1991, Levings and Lauzier 1991). During high flow events, juveniles have been observed to move to deeper areas in pools and they may also move laterally in search of slow water (Shirvell 1994, Steward and Bjornn 1987). Hillman et al. (1987) found that individuals remaining in tributaries to overwinter chose areas with cover and low water velocities, such as areas along well-vegetated, undercut banks. Lakes may occasionally be used by overwintering Chinook, but they appear to avoid beaver ponds and off-channel slough habitats (Healey 1991). In the winter in the Sacramento/San Joaquin system juveniles rear on seasonally inundated floodplains. Sommer et al. (2001) found higher growth and survival rates of Chinook juveniles that reared on the Yolo Bypass floodplain than in the mainstem Sacramento River, and Moyle (2000) observed similar results on the Cosumnes River floodplain. On the Yolo Bypass bioenergetic modeling suggested that increased prey availability on the floodplain was sufficient to offset increased metabolic demands from higher water temperatures (5°C higher than mainstem). Sommer et al. (2001) believe that the well-drained topography may help reduce stranding risks when flood waters recede.

Hillman et al. (1987) found that the addition of cobble substrate to heavily-sedimented glides in the fall substantially increased winter rearing densities, with Chinook using the interstitial spaces between the cobbles as cover. Fine sediment can act to reduce the value of gravel and cobble substrate as winter cover by filling interstitial spaces between substrate particles. This may cause juvenile Chinook to avoid these embedded areas and move elsewhere in search of suitable winter cover (Stuehrenberg 1975, Hillman et al. 1987).

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Table 1. Life history timing of spring Chinook in the California Central Valley

LIFE STAGE	MONTH Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	NOTES
Adults enter the rivers			▨	▨	▨								Geographic area: California rivers Enter estuaries March through May (Marcotte 1984). Source of data not stated.
Upstream Migration				□▨	■▨	▨□							Geographic area: San Joaquin River In San Joaquin River fish passed the Merced between mid-April and mid-June, and usually peaked there in the first half of May, and peaked at Mendota pool in early June (Hallock and Van Woert 1959). Source of data not stated
Upstream Migration					▨	▨	▨□						Geographic area: San Joaquin River Fish ascend river during May, June, and the first part of July (CFGC 1921). Source of data is personal observation.
Upstream Migration			▨	▨	▨								Geographic area: San Joaquin River March to May in the San Joaquin River (Hatton and Clark 1942). Based on data from the Mendota weir.
Upstream Migration					▨	▨							Geographic area: Sacramento River Ascend rivers in May and June (Rutter 1908). Which rivers, and source of data not stated. Upstream migration has been observed to be bi-modal in the Sacramento River (Fisher, pers. comm., as cited in Marcotte 1984) with a portion of the run migrating to or near spawning areas while the remaining fish hold downstream (where in the river was not stated) and move up in the summer.
Upstream Migration			▨	▨	▨■	▨							Geographic area: Sacramento River basin, Deer and Mill Creeks Migrate up Deer and Mill Creeks from March through June (Vogel 1987a and b, as cited in Moyle et al. 1995). Source of data not stated In 1941 adults were trapped at a weir in Deer Creek from April to July 6 (Parker and Hanson 1944). Migration peaks in late May in Mill Creek. Migration into rivers earlier in southern tributaries and later in northern tributaries (C. Harvey, CFG, pers. comm. 2002). Data based on personal observations in Mill Creek.
Upstream Migration		▨	▨	▨									Geographic area: Sacramento River basin, Butte Creek Entered Butte Creek in February through April (Yoshiyma et al. 1996). Source of data not stated.

LIFE STAGE	MONTH												NOTES
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Upstream Migration					▨	▨							Geographic area: Sacramento River basin, Feather River Enter Feather River in May or June (Yoshiyma et al. 1996). Hatchery influenced population. Source of data not stated.
Upstream Migration			▨	▨	■	■	▨						Geographic area: Sacramento River basin March through July, peaking in May–June (Fisher 1994). Source of data not stated.
Upstream Migration			▨	▨	▨	▨	▨	▨	▨				Jones and Stokes, Foundation Runs Report 2002 Geographic area: not stated Migrate to natal streams March through September (USFWS 1995). Source of data not stated.
Adult Holding					▨	▨	▨						Geographic area: San Joaquin River Congregate in large pools near Friant from May through mid-July (CFGC 1921), and then spawn in gorge upstream. Source of data is personal observation. Fish observed holding on May 23, 1942 in the pool directly below the Friant Dam (Clark 1942). No visits were made prior to this date. Fish were continued to be observed in subsequent visits in August and September in pools downstream of the dam, and directly below the dam. It appeared that fish moved as much as 10 miles downstream from holding pools to spawn.
Adult Holding				▨	▨	▨	▨						Geographic area: Sacramento River basin, Mill Creek Holding as early as late April and early May in Mill Creek. However, no observations conducted before late April, so fish could be holding earlier. Most fish holding by July. (C. Harvey, CFG, pers. comm. 2002). Based on walking and dive surveys. General comment: Many spring Chinook migrate from holding pools to spawning areas further upstream in the watershed, while the rest remain to spawn in the tails of the holding pools (Moyle et al. 1995). No source or location of data stated.
Adult Holding					▨	▨	▨						Jones and Stokes Foundations Runs Report Geographic area: San Joaquin River Congregate in pools after upstream migration during May to early July (Yoshiyama et al. 1998).
Spawning								▨	■	■			Geographic area: San Joaquin River The San Joaquin River below Friant dam was surveyed for one day in late August, late September, early October, and early November of 1942. The first spawning was observed on September 21, and large numbers of fish were spawning on all the riffles observed between Friant Dam and Lanes Bridge on November 4 (Clark 1942). Clark also reports that in detailed surveys prior to dam construction 417,000 ft^2 of spawning gravel were observed between Lanes Bridge and the Kerchoff Powerhouse. He reports that 36% of this area was eliminated by construction of the Friant Dam.

LIFE STAGE	MONTH Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	NOTES
Spawning									░	░			Geographic area: San Joaquin River Spawning took place in September and early October near Friant (Hallock and Van Woert 1959). Source of data not stated.
Spawning								░	░	░			Geographic area: Sacramento River basin Spawning in Deer and Mill Creeks is in late August to mid-October (Moyle et al. 1995). Source of data not stated. Spawning in Deer Creek is usually completed by the end of September (Moyle, pers. obs., as cited in Moyle et al. 1995). Source of data not stated.
Spawning								░	▓	░			Geographic area: Sacramento River basin Spawning in Sacramento River basin from late August to October, with a peak in mid-September (Fisher 1994). Source of data not stated. Spawning in the Sacramento River basin in August (Rutter 1908). Source of data not stated.
Spawning								░	▓	▓			Geographic area: Sacramento River basin, Deer Creek Intensive spawning observed in 1941 from the first week September through the end of October (Parker and Hanson 1944).
Spawning								░	░	░			Jones and Stokes 2002 Foundation Runs Report Geographic area: not stated Spawning August through October, depending on water temperatures (USFWS 1995). Source of data not stated.
Incubation													Embryos hatch after 5-6 month incubation. Alevins remain in gravel an additional 2-3 weeks (Moyle et al. 1995). No source or location of data stated.
Emergence	░	░	░								░	░	Geographic area: Sacramento River basin Emergence November to March in the Sacramento River basin (Fisher 1994). Source of data not stated. Emergence in Butte Creek from November to March (Ward and McReynolds 2001). Based on outmigrant trapping of recently emerged fry.
Rearing	░	░	░	░	░	░	░	░	░	░	░	░	Geographic area: Sacramento River basin Rear 3 to 15 months in the Sacramento River basin (Fisher 1994). Source of data not stated. In Deer and Mill Creeks juveniles typically leave the stream during their first fall, as subyearlings (Moyle et al. 1995). Source of data not stated. Some juveniles outmigrate after hatching, and others move downstream during the following fall as yearlings (C. Harvey, pers. comm., as cited in Moyle et al. 1995). Source of data not stated.

LIFE STAGE	MONTH Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	NOTES
Fry Dispersal	░	▓	░	░	░	░							Geographic area: San Joaquin River Before construction of Friant Dam outmigration occurred during major seasonal runoff. Fish and Game fyke netting in 1939 and 1940 at Mossdale demonstrated a measurable seaward movement of fingerling salmon between January and mid-June, with a peak in February (Hallock and Van Woert 1959).
Fry Dispersal		░	░	▓	░	░							Geographic area: San Joaquin River After construction of Friant Dam outmigration it appeared that the elimination of flood flows altered migration patterns. In 1948 fyke trapping at Mendota there was a fairly steady downstream migration between February and June, but the peak was not reached until April. In 1949 peaks were recorded in early March and again in mid-May (Hallock and Van Woert 1959).
Fry Dispersal	▓	░	░								░	▓	Geographic area: Sacramento River basin Juveniles typically outmigrate during November through Jan. during the first high flows as subyearlings, though some stay as late as March (F. Fisher, pers. comm., as cited in USFWS 1994). Source of data not stated. Juveniles typically outmigrate as fry from Butte Creek between mid-November and mid-February, with a peak in December and January (Hill and Weber 1999, Ward and McReynolds 2001). Based on outmigrant trapping during 1999 and 2000. In Deer and Mill Creeks juveniles typically leave the stream during their first fall, as subyearlings (Moyle et al. 1995). Source of data not stated. In the Sacramento River most downstream movement takes place December to February as parr (Vogel and Marine 1991, as cited in USFWS 1994). Source of data not stated.
Spring Smolts (subyearling)			░	░	░	░							Geographic area: Sacramento River basin Some YOY remain in Butte Creek and outmigrate in late spring or early summer (Hill and Weber 1999, Ward and McReynolds 2001). Based on outmigrant trapping during 1999 and 2000. In the Sacramento River basin ocean entry during March to June (Fisher 1994). Source of data not stated
Fall Smolts (yearling)	░									░	░	░	Geographic area: Sacramento River basin Most yearlings outmigrate from Butte Creek in October to January (Hill and Weber 1999, Ward and McReynolds 2001). Based on outmigrant trapping during 1999 and 2000. In Mill Creek some juveniles outmigrate during the following fall as yearlings (C. Harvey, pers. comm., as cited in Moyle et al. 1995). Source of data not stated.
Fall and Spring Smolts (yearling)	░	░	░	░							░	░	Geographic area: Sacramento River basin Ocean entry from November to April (Fisher 1994). Source of data not stated.

LIFE STAGE	MONTH												NOTES
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Spring Smolts (subyearling)				░	░	░							Jones and Stokes 2002 Foundation Runs Report Geographic area: not stated May rear in freshwater for 3 to 8 months, migrating to the ocean during spring (Raleigh et al. 1986, Moyle 1976).
Fall Smolts (yearlings)										░	░	░	Jones and Stokes 2002 Foundation Runs Report Geographic area: not stated Frequently rear over the summer and migrate to the ocean from October to December, after 12-14 months in freshwater (no source cited).
Juveniles enter the ocean					░								Moyle et al. (1995) "presumes" that all fish have left the Sacramento basin by mid-may. No source of data stated.

░	Span of Life History Activity
▓	Peak of Life History Activity

Table 2. Life history timing of fall Chinook in the California Central Valley.

LIFE STAGE	MONTH																							
	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sept		Oct		Nov		Dec	
Adult Migration																		▒	▒	▒	▒	▒	▒	
Adult Holding																								
Spawning	▒	▒																		▒	▒	▒	▒	▒
Incubation	▒	▒	▒	▒	▒															▒	▒	▒	▒	▒
Emergence (fry)	▒	▒	▒	▒	▒	▒	▒																	
Rearing (juvenile)	░	░	▒	▒	▒	▒	▒	▒	▒	▒	░	░	░	░	░	░	░	░	░	░	░	░	░	░
Outmigration Age 0+							▒	▒	▒	▒														
Outmigration Age 1+	▒	▒	▒																		▒	▒	▒	▒

(source: Reavis 1995)

░	Span of Light Activity
▒	Span of Moderate Activity
▓	Span of Peak Activity

Table 3. Holding temperature criteria for spring Chinook salmon.

Temperature Criteria						Source and Notes
Average		Preferred		Maximum		
°C	°F	°C	°F	°C	°F	
20.3	68.5					Average temperature at mouth of Willamette River, OR, during the 1966 Chinook run (Alabaster 1988)
		3.3–13.3	37.9–55.9			Spring Chinook (Bell 1986). Source not specified.
				17.5–19.0	63.5–66.2	Egg viability and alevin survival may be reduced at temperatures between 17.5–19.0°C (Berman 1990). Yakima River, Washington.
				14.4–19.4	57.9–66.9	Egg mortalities of 50% or more of adults held at 14.4–19.4°C (B. Ready, pers. comm., as cited in Berman 1990).
				22.2	72.0	Adults holding below the Friant Dam on the San Joaquin River appeared in good condition, despite a maximum-recorded July temperature of 72°C (Clark 1942).
				24	76	Adults in the Klamath River apparently unaffected by temperatures as high as 76°F (Dunham 1968, as cited in Boles et al. 1988).
				18.3	65	Sonically tagged San Joaquin River spring Chinook were not observed migrating until temperatures dropped below 65°F (Hallock et al. 1970).
				23.0	73.4	Adult spring Chinook salmon can survive in deep pools with surface temperatures as high as 23.0°C (Hodges and Gharrett 1949, as cited in Beauchamp et al. 1983).
				13.3	56	Eggs will not develop normally if held in constant temperatures exceeding 13.3°C (Leitritz and Lewis 1976). Race or source of data not specified.
				21	70	Migrations blocked at temperatures exceeding 21°C (Major and Mighell 1967, as cited in Armour 1991). Source of data not stated.
11.7–21.1	53–70					Range used by spring Chinook salmon in Deer and Mill Creeks, Sacramento River basin (Moyle et al. 1995). Source of data not given.
		5.6–18.3	42.0–65.0	23.9	75	Maximum for survival (Brett 1959, as cited in Marcotte 1984).
				17–19	63–66	Acute mortality of Chinook salmon broodstock (R. Ducy, Pers. Comm, as cited in Marine 1992).
				18–21	64–70	Considerable pre-spawn mortality of spring Chinook observed in the Rogue River, Or when temperatures were in the range of 18–21°C (M. Everson, pers. comm., as cited in Marine 1992).
				21–25	70–77	Spring Chinook salmon in the Sacramento-San Joaquin system tributaries hold in pools that seldom exceeded 21–25°C (70–77°F) (Moyle 1976, as cited in Moyle et al. 1995).
				21.1	70	Thermal barrier to spring Chinook on the Tucannon River, Wa. (Bumgarner et al. 1997, as cited in McCullough 1999).
		10–14	50–57			Piper et al. (1982). Race not stated, source of data not stated.
20	68					Spring Chinook often hold in pools in Butte Creek, Sacramento River basin, where average daily temperatures exceed 20°C (Williams et al. 2002), though pre-spawn mortality can be high.

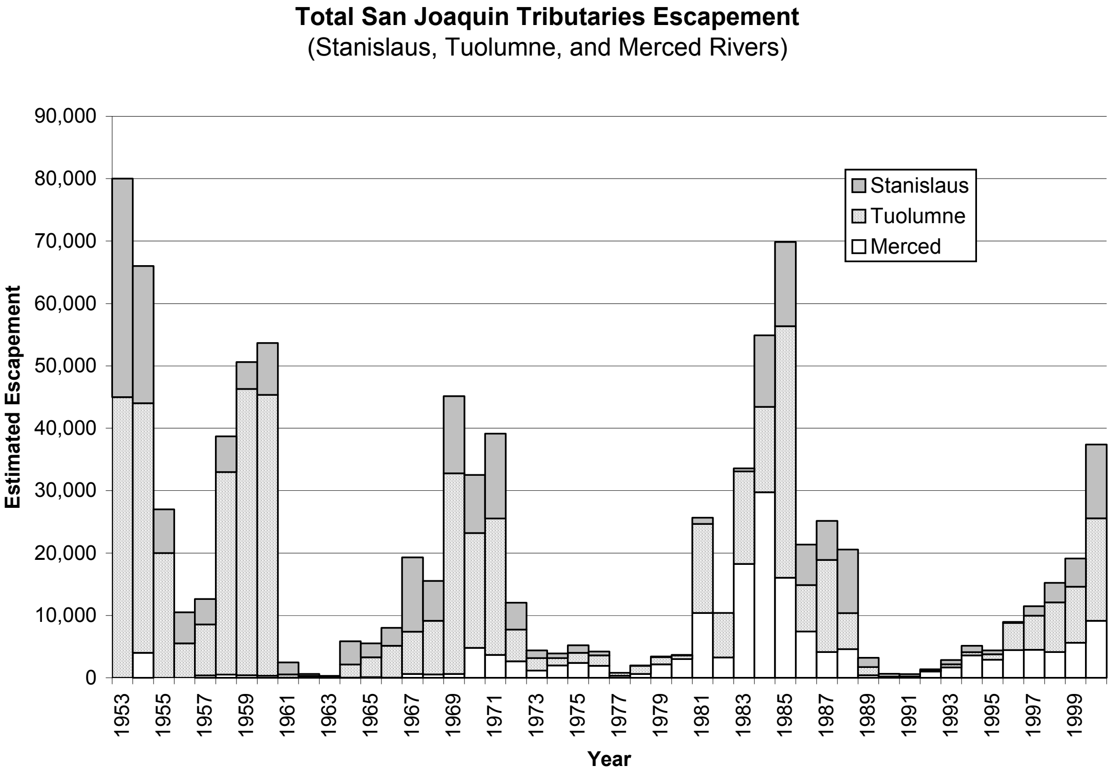

Figure 1. Fall Chinook salmon escapement into San Joaquin basin tributaries 1953 to 2000.

Common Name	Scientific Name (family)
Steelhead	*Oncorhynchus mykiss* (Salmonidae)

Status
The Central Valley steelhead ESU includes naturally spawned steelhead occurring in the Sacramento and San Joaquin rivers and their tributaries and extends into the San Francisco estuary to San Pablo Bay. Steelhead is the term commonly used for the anadromous life history form of rainbow trout *(Oncorhynchus mykiss)*. Only winter-run steelhead stocks are currently present in Central Valley streams (McEwan and Jackson 1996).

The National Marine Fisheries Service (NMFS) considered including resident *O. mykiss* in listed steelhead ESUs in certain cases, including (1) where resident *O. mykiss* have the opportunity to interbreed with anadromous fish below natural or artificial barriers or (2) where resident fish of native lineage once had the ability to interbreed with anadromous fish but no longer do because they are currently above artificial barriers and are considered essential for the recovery of the ESU (NMFS 1998, p. 13350). The U.S. Fish and Wildlife Service (USFWS), which has authority under the Endangered Species Act (ESA) over resident fish, however, concluded that behavioral forms of *O. mykiss* can be regarded as separate Distinct Population Segments (the USFWS version of an ESU) and that lacking evidence that resident rainbow trout need ESA protection, only anadromous forms should be included in the ESU and listed under the ESA (NMFS 1998, p. 13351). The USFWS also did not believe that steelhead recovery would rely on the intermittent exchange of genetic material between resident and anadromous forms (NMFS 1998, p. 13351). In the final rule, the listing includes only the anadromous life history form of *O. mykiss* (NMFS 1998, p. 13369).

From this information, it seems that resident rainbow trout are not protected under the ESA and are not included in the ESU. NMFS, however, considers all *O. mykiss* that have physical access to the ocean (including resident rainbow trout) to potentially be steelhead (Chris Mobley, Dennis Smith, and Steven Edmundson, NMFS, personal communication) and will treat these fish as steelhead because (1) resident fish can produce anadromous offspring, and (2) it is difficult or impossible to distinguish between juveniles of the different life history forms. NMFS considers juvenile *O. mykiss* smaller than 8 inches (203 mm) and adult *O. mykiss* larger than 16 inches (406 mm) to be steelhead (Dennis Smith, NMFS, personal communication). NMFS does not yet have a written policy regarding this position or clarifying their relationship with the USFWS in protecting resident rainbow trout and anadromous steelhead.

Adult resident rainbow trout occurring in Central Valley Rivers are often larger than Central Valley steelhead. Several sources indicate resident trout in the Central Valley commonly exceed 16 inches (406 mm) in length. Cramer et al. (1995) reported that resident rainbow trout in Central Valley rivers grow to sizes of more than 20 inches (508 mm). Hallock et al. (1961) noted that resident trout observed in the Upper Sacramento River upstream of the Feather River were 14–20 inches (356–508 mm) in length. Also, at Coleman National Fish Hatchery, the USFWS found about 15 percent overlap in size distribution between resident and anadromous fish at a length of 22.8 inches (579 mm) (Cramer et al. 1995). NMFS's size criterion for steelhead, therefore, has significant overlap with resident rainbow trout occurring in Central Valley rivers, and many resident adult trout will be considered to be steelhead.

Geographic Distribution

Steelhead are distributed throughout the North Pacific Ocean and historically spawned in streams along the west coast of North America from Alaska to northern Baja California. The species is currently known to spawn only as far south as Malibu Creek in southern California (Barnhart 1991, NMFS 1996a). Two major genetic groups exist in the Pacific Northwest, consisting of a coastal and an inland group separated by the Cascade Range crest (Schreck et al. 1986, Reisenbichler et al. 1992). Historic steelhead distribution in the upper San Joaquin River is not known, but in rivers where they still occur they are normally more widely distributed than Chinook (Voight and Gale 1998, as cited in McEwan 2001, Yoshiyama et al. 1996), and are typically tributary spawners. Therefore it can be assumed steelhead would have been as least as far upstream as Mammoth Pool in the San Joaquin River, and probably in many smaller tributaries.

Population Trends

The National Marine Fisheries Service (NMFS 1996a) has concluded that populations of naturally reproducing steelhead have been experiencing a long-term decline in abundance throughout their range. Populations in the southern portion of the range have experienced the most severe declines, particularly in streams from California's Central Valley and south, where many stocks have been extirpated (NMFS 1996a). During this century, 23 naturally reproducing populations of steelhead are believed to have been extirpated in the western United States. Many more are thought to be in decline in Washington, Oregon, Idaho, and California. Based on analyses of dam and weir counts, stream surveys, and angler catches, NMFS (1997) concluded that, of the 160 west coast steelhead stocks for which adequate data were available, 118 (74 percent) exhibited declining trends in abundance, while the remaining 42 (26 percent) exhibited increasing trends. From this analysis, the NMFS concluded that naturally reproducing populations of steelhead have exhibited long-term declines in abundance across their range. Steelhead stocks in California, however, have declined precipitously. The current population of steelhead in California is roughly 250,000 adults, which is nearly half the adult population that existed 30 years ago (McEwan and Jackson 1996). Current estimates of all steelhead adults in San Francisco Bay tributaries combined are well below 10,000 fish (Leidy 2001). Steelhead in the San Joaquin River were historically very abundant, though data on their population levels is lacking (McEwan 2001). Currently the steelhead population in the San Joaquin River is drastically reduced from historic levels, and considered extinct by some researchers (Reynolds et al. 1990, as cited in McEwan 2001). However, there is evidence that small populations of steelhead persist in some lower San Joaquin River tributaries (e.g., Stanislaus River) (McEwan 2001). In a review of factors affecting steelhead declines in the Central Valley McEwan and Jackson (1996) concluded that all were related to water development and water management. Impassible dams have blocked historic habitat, forcing steelhead to spawn and rear in lower river reaches, where water temperatures are often lethal (Yoshiyama et al. 1996, McEwan 2001).

Life History

Steelhead is the term used for the anadromous life history form of rainbow trout, *Oncorhynchus mykiss*. Steelhead exhibit highly variable life history patterns throughout their range, but are broadly categorized into winter- and summer-run reproductive ecotypes. Only winter steelhead are believed to have occurred in the San Joaquin River. Winter steelhead, the most widespread reproductive ecotype, become sexually mature in the ocean, enter spawning streams in fall or winter, and spawn a few months later in winter or late spring (Meehan and Bjornn 1991, Behnke 1992). The general timing of winter steelhead life history in California is shown in Table 1. In the Sacramento River, steelhead generally emigrate as 1-year olds during spring and early summer months. Emigration appears to be more closely associated with size than age, with 6B8 inches being the size of most downstream migrants. Downstream migration in unregulated streams has been correlated with spring freshets (Reynolds et al. 1993).

Adult upstream migration and spawning

In the Central Valley adult winter steelhead migrate upstream during most months of the year, beginning in July, peaking in September, and continuing through February or March (Hallock et al. 1961, Bailey 1954, both as cited in McEwan and Jackson 1996) (Table 1). Spawning occurs primarily from January through March, but may begin as early as late December and may extend through April (Hallock et al. 1961, as cited in McEwan and Jackson 1996). No information on the run timing or life history of steelhead that occurred in the San Joaquin basin is available apart from the observation of 66 adults seen at Dennett Dam on the Tuolumne River from October 1 through November 30 in 1940 and five in late October of 1942 (CDFG unpublished data). In the Central Valley ESU, adult winter steelhead generally return at ages 2 and 3 and range in size from 2 to 12 pounds (0.9–5.4 kg) (Reynolds et al. 1993).

Adult steelhead migrate upstream on both the rising and falling limbs of high flows, but do not appear to move during flood peaks. Some authors have suggested that increased water temperatures trigger movement, but some steelhead ascend into freshwater without any apparent environmental cues (Barnhart 1991). Peak upstream movement appears to occur in the morning and evening, although steelhead have been observed to move at all hours (Barnhart 1991).

Steelhead are among the strongest swimmers of freshwater fishes. Cruising speeds, which are used for long-distance travel, are up to 1.5 m/s (5 ft/s); sustained speeds, which may last several minutes and are used to surpass rapids or other barriers, range from 1.5 to 4.6 m/s (5 to 15 ft/s), and darting speeds, which are brief bursts used in feeding and escape, range from 4.3 to 8.2 m/s (14 to 27 ft/s) (Bell 1973, as cited in Everest et al. 1985; Roelofs 1987). Steelhead have been observed making vertical leaps of up to 5.2 m (17 feet) over falls (W. Trush pers. comm., as cited in Roelofs 1987).

During spawning, female steelhead create a depression in streambed gravels by vigorously pumping their body and tail horizontally near the streambed. Steelhead redds are approximately 10–30 cm (4–12 in) deep, 38-cm (15-in) in diameter, and oval in shape (Needham and Taft 1934, Shapovalov and Taft 1954). Males do not assist with redd construction, but may fight with other males to defend spawning females (Shapovalov and Taft 1954). Males fertilize the female's eggs as they are deposited in the redd, after which the female moves to the upstream end of the nest and stirs up additional gravel, covering the egg pocket (Orcutt et al. 1968). Females then move two to three feet upstream and dig another pit, enlarging the redd. Females may dig six to seven egg pockets, moving progressively upstream, and spawning may continue for several days to over a week (Needham and Taft 1934). A female approximately 85 cm (33 in) in length may lay 5,000 to 10,000 eggs, with fecundity being related to age and length of the adult female and varying between populations (Meehan and Bjornn 1991). A range of 1,000 to 4,500 eggs per female has been observed within the Sacramento Drainage (Mills and Fisher 1994, as cited in Leidy 2001). In cases where spawning habitat is limited, late-arriving spawners may superimpose their redds atop existing nests (Orcutt et al. 1968).

Although most steelhead die after spawning, adults are capable of returning to the ocean and migrating back upstream to spawn in subsequent years, unlike most other Pacific salmon. Runs may include from

10 to 30% repeat spawners, the majority of which are females (Ward and Slaney 1988, Meehan and Bjornn 1991, Behnke 1992). Repeat spawning is more common in smaller coastal streams than in large drainages requiring a lengthy migration (Meehan and Bjornn 1991). Hatchery steelhead are typically less likely than wild fish to survive to spawn a second time (Leider et al. 1986). In the Sacramento River, California, Hallock (1989) reported that 14 percent of the steelhead were returning to spawn a second time.

Whereas females spawn only once before returning to the sea, males may spend two or more months in spawning areas and may mate with multiple females, incurring higher mortality and reducing their chances of repeat spawning (Shapovalov and Taft 1954). Steelhead may migrate downstream to the ocean immediately following spawning or may spend several weeks holding in pools before outmigrating (Shapovalov and Taft 1954).

Egg incubation, alevin development, and fry emergence
Hatching of eggs follows a 20- to 100-day incubation period, the length of which depends on water temperature (Shapovalov and Taft 1954, Barnhart 1991). In Waddell Creek (San Mareo County), Shapovalov and Taft (1954) found incubation times between 25 and 30 days. Newly-hatched steelhead alevins remain in the gravel for an additional 14–35 days while being nourished by their yolk sac (Barnhart 1991). Fry emerge from the substrate just before total yolk absorption under optimal conditions; later-emerging fry that have already absorbed their yolk supply are likely to be weaker (Barnhart 1991). Upon emergence, fry inhale air at the stream surface to fill their air bladder, absorb the remains of their yolk, and start to feed actively, often in schools (Barnhart 1991, NMFS 1996b). Survival from egg to emergent fry is typically less than 50% (Meehan and Bjornn 1991), but may be quite variable depending upon local conditions.

Juvenile freshwater rearing
Juvenile steelhead (parr) rear in freshwater before outmigrating to the ocean as smolts. The duration of time parr spend in freshwater appears to be related to growth rate, with larger, faster-growing members of a cohort smolting earlier (Peven et al. 1994). Steelhead in warmer areas, where feeding and growth are possible throughout the winter, may require a shorter period in freshwater before smolting, while steelhead in colder, more northern, and inland streams may require three or four years before smolting (Roelofs 1985).

Juveniles typically remain in their natal streams for at least their first summer, dispersing from fry schools and establishing feeding territories (Barnhart 1991). Peak feeding and freshwater growth rates occur in late spring and early summer. In Steamboat Creek, a major steelhead spawning tributary in the North Umpqua River watershed, juveniles typically rest in the interstices of rocky substrate in the morning and evening, and rise into the water column and orient themselves into the flow to feed during the day when water temperatures are higher (Dambacher 1991). In the Smith River of Oregon, Reedy (1995) suggested that rising stream temperatures and reduced food availability occurring in late summer may lead to a decline in steelhead feeding activity and growth rates.

Juveniles either overwinter in their natal streams if adequate cover exists or disperse as pre-smolts to other streams to find more suitable winter habitat (Bjornn 1971, Dambacher 1991). As stream temperatures fall below approximately 7°C (44.6°F) in the late fall to early winter, steelhead enter a period of winter inactivity spent hiding in the substrate or closely associated with instream cover, during which time growth ceases (Everest and Chapman 1972). Age 0+ steelhead appear to remain active later into the fall than 1+ steelhead (Everest et al. 1986). Winter hiding behavior of juveniles reduces their metabolism and food requirements and reduces their exposure to predation and high flows (Bustard and Narver 1975), although substantial mortality appears to occur in winter, nonetheless. Winter mortalities ranging from 60 to 86% for 0+ steelhead and from 18 to 60% for 1+ steelhead were reported in Fish Creek in the Clackamas River basin, Oregon (Everest et al. 1988, as cited in Dambacher 1991).

Juveniles appear to compete for food and rearing habitat with other steelhead. Age 0+ and 1+ steelhead exhibit territorial behavior (Everest and Chapman 1972), although this behavior may dissipate in winter as fish reduce feeding activity and congregate in suitable cover habitat (Meehan and Bjornn 1991). Reedy (1995) found that steelhead in the tails of pools did not exhibit territorialism or form dominance hierarchies.

Parr outmigration appears to be more significant in smaller basins, when compared to larger basins (Dambacher 1991). In some areas juveniles migrate out of tributaries despite the fact that downstream rearing habitat may be limited and survival rates low in these areas, suggesting that migrants are responding to density-related competition for food and space, or to reduction in habitat quality in tributaries as flows decline (Dambacher 1991, Peven et al. 1994, Reedy 1995). In relatively small tributaries with good rearing habitat located downstream, early outmigration may represent an adaptation to improve survival and may not be driven by environment- or competition-related limitations (Dambacher 1991). Steelhead may overwinter in mainstem reaches, particularly if coarse substrates in which to seek cover from high flows are available (Reedy 1995), or they may return to tributaries for the winter (Everest 1973, as cited in Dambacher 1991).

Rearing densities for juvenile steelhead overwintering in high-quality habitats with cobble-boulder substrates are estimated to range from approximately 2.7 fish/m^2 (0.24 fish/ft^2) (W. Trush, pers. comm., 1997) to 5.7 fish/m^2 (0.53 fish/ft^2) (Meyer and Griffith 1997). Reedy (1995) observed higher densities of juvenile steelhead in the Middle Fork Smith River, California, than in the Steamboat Creek basin; he suggests that this may be due to the greater availability of large bed particles used for overwintering cover and velocity refuge in the Middle Fork Smith River than in Steamboat Creek. Everest and Chapman (1972) report age 0+ densities of 1.3 to 1.5 fish/m^2 (0.12 to 0.14 fish/ft^2) in preferred habitat in Idaho.

Smolt outmigration and estuarine rearing

At the end of the freshwater rearing period, steelhead migrate downstream to the ocean as smolts, typically at a length of 15 to 20 cm (5.85 to 7.80 in) (Meehan and Bjornn 1991). A length of 14 cm (5.46 in) is typically cited as the minimum size for smolting (Wagner et al. 1963, Peven et al. 1994). In the Sacramento River, steelhead generally emigrate as 2-year olds during spring and early summer months. Emigration appears to be more closely associated with size than age, with 6–8 inches (152–203 mm) being most common for downstream migrants. Downstream migration in unregulated streams has been correlated with spring freshets (Reynolds et al. 1993).

Evidence suggests that photoperiod is the most important environmental variable stimulating the physiological transformation from parr to smolt (Wagner 1974). During smoltification, the spots and parr marks characteristic of juvenile coloration are replaced by a silver and blue-green iridescent body color (Barnhart 1991) and physiological transformations occur that allow them to survive in salt water.

Less is known regarding the use of estuaries by steelhead than for other anadromous salmonid species; however, the available evidence shows that steelhead in many systems use estuaries as rearing habitat. Smith (1990) concluded that even tiny lagoons unsuitable for summer rearing can contribute to the maintenance of steelhead populations by providing feeding areas during winter or spring smolt outmigration.

Estuarine rearing may be more important to steelhead populations in the southern half of the species' range due to greater variability in ocean conditions and paucity of high quality near-shore habitats in this portion of their range (NMFS 1996a). Estuaries may also be more important to populations spawning in smaller coastal tributaries due to the more limited availability of rearing habitat in the headwaters of smaller stream systems (McEwan and Jackson 1996). Most marine mortality of steelhead occurs soon after they enter the ocean and predation is believed to be the primary cause of this mortality (Pearcy 1992, as cited in McEwan and Jackson 1996). Because predation mortality and fish size are likely to be inversely related (Pearcy 1992, as cited in McEwan and Jackson 1996), the growth that takes place in estuaries may be very important for increasing the odds of marine survival (Pearcy 1992 [as cited in McEwan and Jackson 1996], Simenstad et al. 1982 [as cited in NMFS 1996a], Shapovalov and Taft 1954).

Steelhead have variable life histories and may migrate downstream to estuaries as age 0+ juveniles or may rear in streams up to four years before outmigrating to the estuary and ocean (Shapovalov and Taft 1954). Steelhead migrating downstream as juveniles may rear for one to six months in the estuary before entering the ocean (Barnhart 1991). Shapovalov and Taft (1954) conducted exhaustive life history studies of steelhead and coho salmon in Waddell Creek (Santa Cruz County, California) and found that coho salmon went to sea almost immediately after migrating downstream, but that some of the steelhead remained for a whole season in Waddell Creek lagoon or the lower portions of the stream before moving out to sea. Some steelhead individuals remained in the lagoon rather than moving out to sea and migrated back upstream and underwent a second downstream migration the following year. In Scott Creek lagoon (Santa Cruz County), Marston (1992, as cited in McEwan and Jackson 1996) found that half of the steelhead rearing in the lagoon in June and July of 1992 were less than 90 mm and appeared to be pre-smolts. Coots (1973, as cited in McEwan and Jackson 1996) found that 34% of juvenile steelhead in San Gregorio Creek lagoon captured in summer were juveniles less than 100 mm [3.9 in] in length. From these studies and others, it has been shown estuaries provide valuable rearing habitat to juvenile and yearling steelhead and not merely a corridor for smolts outmigrating to the ocean.

Ocean phase

The majority of steelhead spend one to three years in the ocean, with smaller smolts tending to remain in salt water for a longer period than larger smolts (Chapman 1958, Behnke 1992). Larger smolts have been observed to experience higher ocean survival rates (Ward and Slaney 1988). Steelhead grow rapidly in the ocean compared to in freshwater rearing habitats, with growth rates potentially exceeding 2.5 cm (0.98 in) per month (Shapovalov and Taft 1954, Barnhart 1991). Steelhead staying in the ocean for two years typically weigh 3.15 to 4.50 kg (7 to10 lbs) upon return to fresh water (Roelofs 1985). Unlike other salmonids, steelhead do not appear to form schools in the ocean. Steelhead in the southern part of the species' range appear to migrate close to the continental shelf, while more northern populations of steelhead may migrate throughout the northern Pacific Ocean (Barnhart 1991).

Habitat Requirements

Adult upstream migration and spawning

During their upstream migration, adult steelhead require deep pools for resting and holding (Puckett 1975, Roelofs 1983, as cited in Moyle et al. 1989). Deep pool habitat (>1.5 m) (>4.88 ft) is preferred by summer steelhead during the summer holding period.

Because adult winter steelhead generally do not feed during their upstream migration, delays experienced during migration may affect reproductive success. A minimum depth of about 7 inches (18 cm) is required for adult upstream migration (Thompson 1972, as cited by Barnhart 1986); however, high water velocity and natural or artificial barriers are more likely to affect adult movements than depth (Barnhart 1986, as cited in McEwan and Jackson 1996). Velocities over 8 ft/s (2.4 m/s) may hinder upstream movement (Thompson 1972, as cited in Everest et al. 1985). Steelhead are capable of ascending high barriers under suitable flow conditions and have been observed to make vertical leaps of up to 17 feet (5.1 m) over waterfalls (W. Trush, pers. comm., as cited in Roelofs 1987). Deep pools provide important resting and holding habitat during the upstream migration (Puckett 1975, Roelofs 1983, as cited in Moyle et al. 1989).

Temperature thresholds for the adult migration and spawning life stages are shown in Table 2. These temperatures, however, are from the general literature and may not represent preferred or suitable temperature ranges for Central Valley steelhead stocks. No Central Valley-specific temperature evaluations or criteria were identified by our review. For adult migration, temperatures ranging from 46 to 52^{o}F (8 to 11^{o}C) are considered to be preferred (McEwan and Jackson 1996), while temperatures exceeding 70^{o}F (21^{o}C) are stressful (Lantz 1971, as cited in Beschta et al. 1987). Preferred spawning temperatures range from 39–52^{o}F (4–11^{o}C) (McEwan and Jackson 1996, Bell 1973, 1991), with 68^{o}F (20^{o}C) being considered stressful and 72^{o}F (22^{o}C) considered lethal.

Areas of the stream with water depths from about 18 to 137 cm (7.02 to 53.43 in) and velocities from 0.6 to 1.15 m/s (1.97 to 3.77 ft/s) are typically preferred for spawning by adult steelhead (Moyle et al. 1989, Barnhart 1991). Pool tailouts or heads of riffles with well-oxygenated gravels are often selected as redd locations (Shapovalov and Taft 1954). The average area encompassed by a redd is 4.4–5.9 m2 (47–65.56 ft2) (Orcutt et al. 1968, Hunter 1973, as cited in Bjornn and Reiser 1991). D_{50} values (the median diameter of substrate particles found within a redd) for steelhead have been found to range from 10.4 mm (0.41 in) (Cederholm and Salo 1979, as cited in Kondolf and Wolman 1993) to 46.0 mm (1.81 in) (Orcutt et al. 1968, as cited in Kondolf and Wolman 1993). Steelhead pairs have been observed spawning within 1.2 m (3.94 ft) of each other (Orcutt et al. 1968). Bell (1986) indicates that preferred temperatures for steelhead spawning range from 3.9º to 9.4ºC (39.0º to 48.9ºF). Steelhead may spawn in intermittent streams, but juveniles soon move to perennial streams after hatching (Moyle et al. 1989). In the Rogue River drainage, summer steelhead are more likely to spawn in intermittent streams, while winter steelhead typically spawn in permanent streams (Roelofs 1985).

Egg incubation, alevin development, and fry emergence
Incubating eggs require dissolved oxygen concentrations, with optimal concentrations at or near saturation. Low dissolved oxygen increases the length of the incubation period and cause emergent fry to be smaller and weaker. Dissolved oxygen levels remaining below 2 ppm result in egg mortality (Barnhart 1991). Temperature thresholds for the incubation, rearing, and outmigration life history stages are shown in Table 3. Information available in the literature indicates preferred incubation temperatures ranging from 48 to 52°F (9 to 11°C) (McEwan and Jackson 1996, FERC 1993).

Juvenile freshwater rearing

Age 0+
After emergence from spawning gravels in spring or early summer, steelhead fry move to shallow-water, low-velocity habitats such as stream margins and low-gradient riffles and will forage in open areas lacking instream cover (Hartman 1965, Everest et al. 1986, Fontaine 1988). As fry increase in size in late summer and fall, they increasingly use areas with cover and show a preference for higher-velocity, deeper mid-channel waters near the thalweg (Hartman 1965, Everest and Chapman 1972, Fontaine 1988). In general, age 0+ steelhead occur in a wide range of hydraulic conditions (Bisson et al. 1988), appearing to prefer water less than 50 cm (19.5 in) deep with velocities below 0.3 m/s (0.98 ft/s) (Everest and Chapman 1972). Age 0+ steelhead have been found to be relatively abundant in backwater pools and often live in the downstream ends of pools in late summer (Bisson et al. 1988, Fontaine 1988).

Age 1+ and older juveniles
Older age classes of juvenile steelhead (age 1+ and older) occupy a wide range of hydraulic conditions. They prefer deeper water during the summer and have been observed to use deep pools near the thalweg with ample cover as well as higher-velocity rapid and cascade habitats (Bisson et al. 1982, Bisson et al. 1988). Age 1+ fish typically feed in pools, especially scour and plunge pools, resting and finding escape cover in the interstices of boulders and boulder-log clusters (Fontaine 1988, Bisson et al. 1988). During summer, steelhead parr appear to prefer habitats with rocky substrates, overhead cover, and low light intensities (Hartman 1965, Facchin and Slaney 1977, Ward and Slaney 1979, Fausch 1993). Age 1+ steelhead appear to avoid secondary channel and dammed pools, glides, and low-gradient riffles with mean depths less than 20 cm (7.8 in) (Fontaine 1988, Bisson et al. 1988, Dambacher 1991).

As steelhead grow larger, they tend to prefer microhabitats with deeper water and higher velocity as locations for focal points, attempting to find areas with an optimal balance of food supply versus energy expenditure, such as velocity refuge positions associated with boulders or other large roughness elements close to swift current with high macroinvertebrate drift rates (Everest and Chapman 1972, Bisson et al. 1988, Fausch 1993). Reedy (1995) indicates that 1+ steelhead especially prefer high-velocity pool heads, where food resources are abundant, and pool tails, which provide optimal feeding conditions in summer due to lower energy expenditure requirements than the more turbulent pool heads. Fast, deep water, in addition to optimizing feeding versus energy expenditure, provides greater protection from avian and terrestrial predators (Everest and Chapman 1972).

Age 1+ steelhead appear to prefer rearing habitats with velocities ranging from 10–30 cm/s (0.33–0.98 ft/s) and depths ranging from 50–75 cm (19.5–29.3 in) (Everest and Chapman 1972, Hanson 1977, as cited in Bjornn and Reiser 1991). During the juvenile rearing period, steelhead are often observed using habitats with swifter water velocities and shallower depths than coho salmon (Sullivan 1986, Bisson et al. 1988), a species they are often sympatric with. In comparison with juvenile coho, steelhead have a fusiform body shape that is better adapted to holding and feeding in swifter currents (Bisson et al. 1988). Where the two species coexist, this generally results in spatial segregation of rearing habitat that becomes most apparent during the summer months. While juvenile coho salmon are strongly associated with low-velocity habitats such as pools throughout the rearing period (Shirvell 1990), steelhead will use riffles (age 0+) and higher velocity pool habitats (age 1+) such as scour and plunge pools in the summer (Sullivan 1986, Bisson et al. 1982).

Preferred rearing temperatures range from 48 to 58°F (9 to 20°C), and preferred outmigration temperatures of <57°F (<13°C) (McEwan and Jackson 1996) (Table 3). Myrick (1998) provides the only assessment of temperature tolerances specifically for Central Valley steelhead. These experiments used steelhead that were reared at the Mokelumne River State Fish Hatchery from eggs were collected at the Nimbus Fish Hatchery (American River). These experiments indicate that Central Valley steelhead prefer higher temperature ranges than those reported in the literature for other stocks, with preferred rearing temperatures ranging from 62.6 to 68°F (17 to 20°C) and a maximum temperature tolerated (lethal critical thermal maximum) of 80°F (27°C).

Winter habitat

Steelhead overwinter in pools, especially low-velocity deep pools with large rocky substrate or woody debris for cover, including backwater and dammed pools (Hartman 1965, Swales et al. 1986, Raleigh et al. 1984, Fontaine 1988). Juveniles are known to use the interstices between substrate particles as overwintering cover. Bustard and Narver (1975) typically found age 0+ steelhead using 10–25 cm (3.9–9.7 in) diameter cobble substrates in shallow, low-velocity areas near the stream margin. Everest et al. (1986) observed age 1+ steelhead using logs, rootwads, and interstices between assemblages of large boulders (>100 cm [39.00 in] diameter) surrounded by small boulder to cobble size (50–100 cm [19.7–39.0 in] diameter) materials as winter cover. Age 1+ fish typically stay within the area of the streambed that remains inundated at summer low flows, while age 0+ fish frequently overwinter beyond the summer low flow perimeter along the stream margins (Everest et al. 1986).

In winter, 1+ steelhead prefer water deeper than 45 cm (17.5 in), while age 0+ steelhead often occupy water less than 15 cm (5.8 in) deep and are rarely found at depths over about 60 cm (23.4 in) (Bustard and Narver 1975). Below 7°C (44.6oF), juvenile steelhead prefer water velocities <15 cm/s (0.5 ft/s) (Bustard and Narver 1975). Spatial segregation of stream habitat by juvenile coho salmon and steelhead is less pronounced in winter than in summer, although older juvenile steelhead may prefer deeper pools than coho salmon (Bustard and Narver 1975).

Ocean phase

Little is known about steelhead use of ocean habitat, although changes in ocean conditions are important for explaining trends among Oregon coastal steelhead populations (Kostow 1995). Evidence suggests that increased ocean temperatures associated with El Niño events may increase ocean survival as much as two-fold (Ward and Slaney 1988). The magnitude of upwelling, which determines the amount of nutrients brought to the ocean surface and which is related to wind patterns, influences ocean productivity with significant effects on steelhead growth and survival (Barnhart 1991). Steelhead appear to prefer ocean temperatures of 9º–11.5ºC (48.2º–52.7ºF) and typically swim in the upper 9–12 m (29.52–39.36 ft) of the ocean's surface (Barnhart 1991).

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List of Tables

Table 1. Central Valley winter steelhead life history timing.

LIFE STAGE	MONTH																								Notes
	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sept		Oct		Nov		Dec		
Adult Migration	░	░	░	░	░	░						░	░	░	░	▒	▒	▓	▓	▒	░	░	░	░	Geographic area: Sacramento River, above the mouth of the Feather River Trapping adults between 1953 and 1959 found a peak in late September, with some fish migrating from late June through March (Hallock et al. 1961, as cited in McEwan 2001).
Adult Migration	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	▒	▒	▓	▒	░	░	░	░	Geographic area: Sacramento River, Red Bluff diversion dam Small numbers of adults all year, with a peak in early October (USFWS unpublished data, as cited in McEwan 2001)
Adult Migration			▒																	▓					Geographic area: Mill Creek Adult counts from 1953 to 1963 showed a peak in late October, and a smaller peak in mid-February (Hallock 1989, as cited in McEwan 2001).
Adult Migration	░	░	░	░	░	░	░	░																░	Jones and Stokes 2002 Foundation Runs Report Geographic area: not stated Adult steelhead enter freshwater from late December through late April. No citation.
Spawning	▒	▒	▒	▒	▒	▒																			Mills and Fisher 1994
Spawning	▓	▓	▓	▓	▓	▓	▓	▓															▓	▓	Peak spawning in California streams (McEwan 2001).
Spawning	▒	▒	▒	▒	▒	▒	▒	▒															▒	▒	Jones and Stokes 2002 Foundation Runs Report Geographic area: lower American River Spawning takes place December through April (Gerstung 1971)
Adult (kelts) Return to Sea								▒	▒	▒	▒	▒	▒												Mills and Fisher 1994
Incubation	▒	▒	▒	▒	▒	▒	▒	▒	▒															▒	Reynolds et al. 1993
Emergence																									Eggs hatch in 30 days at 51°F (Leitritz and Lewis 1980, as cited in McEwan 2001).
Emergence							▒	▒	▒	▒															Jones and Stokes 2002 Foundation Runs Report Geographic area: lower American River Fry usually emerge in April and May, depending on water temperature and date of spawning (Gerstung 1971).
Emergence						░	░	░	░	░	░	░	░	░	░	░	░								Jones and Stokes 2002 Foundation Runs Report Geographic area: San Joaquin River

LIFE STAGE	MONTH																								Notes
	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sept		Oct		Nov		Dec		
						░	░	░	░	░	░	░	░	░	░	░	░								Based on the results of emergence analysis for water temperature in SJR, Jones and Stokes estimated that emergence may occur between March 15 and August 30.
Rearing	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	In California scale analysis showed 70% Reared for two years, 29% for one year, and 1% for three years (Hallock et al. 1961, as cited in McEwan 2001).
Outmigration	░	░	░	░	▒	▒	▒	▒	▒	▒	▒	▒	░	░	░	░	░	░	▒	▒	▒	▒	░	░	Geographic area: Sacramento River Migrate downstream in every month of the year, with a peak in the spring, and a smaller peak in the fall (Hallock et al. 1961, as cited in McEwan 2001).
Outmigration	░	░	░	░	▓	▓	░	░	░															░	Geographic area: lower Sacramento Migrated past Knights landing in 1998 from late December through early May, and peaked in mid-March (DFG unpublished data, as cited in McEwan 2001).
Outmigration								▒	▒	▒	▒	▒	▒												Reynolds et al. 1993
Outmigration	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒											Jones and Stokes 2002 Foundation Runs Report Geographic area: Woodbridge Dam Outmigrating yearling and older steelhead detected January through July, and young of year detected April through July (Natural Resource Scientist 1998b, as cited in Jones and Stokes 2000).

░	Span of Light Activity
▒	Span of Moderate Activity
▓	Span of Peak Activity

Table 2. Temperature thresholds for steelhead adult migration and spawning.

Life History Stage	Temperature	Comments	Source
Adult Migration	46–52^{o}F (8–11^{o}C)	preferred	McEwan and Jackson 1996
	>70^{o}F (21^{o}C)	stressful (Columbia River)	Lantz 1971, as cited in Beschta et al. 1987
Spawning	39–49^{o}F (4–9^{o}C)	preferred	Bell 1973, 1991
	39–52^{o}F (4–11^{o}C)	preferred	McEwan and Jackson 1996
	68^{o}F (20^{o}C)	stressful	FERC 1993
	>72 ºF (>22^{o}C)	lethal	FERC 1993
	75^{o}F (24^{o}C)	upper lethal	Bell 1991

Table 3. Temperature thresholds for incubation, rearing, and outmigration of steelhead.

Life History Stage	Temperature ^{o}F (^{o}C)	Comments	Source
Incubation	50^{o}F (10^{o}C)	preferred (hatching)	Bell 1991
	48–52^{o}F (9–11^{o}C)	preferred Aincubation and emergence@	McEwan and Jackson 1996 FERC 1993
	>55^{o}F (>12.8^{o}C)	stressful	FERC 1993
	60^{o}F (15.6^{o}C)	lethal	FERC 1993
Juvenile Rearing	48–52^{o}F (9–11^{o}C)	preferred Afry and juvenile rearing@	McEwan and Jackson 1996
	55–65^{o}F (12.8–18.3^{o}C)	optimal	FERC 1993
	62.6–68^{o}F (17–20^{o}C)	preferred ACentral Valley Steelhead@	Myrick (1998) p. 134
	50–59^{o}F (10–15^{o}C)	preferred	Moyle et al. 1995
	68^{o}F (20^{o}C)	sustained upper limit	Moyle et al. 1995
	77^{o}F (25^{o}C)	lethal	FERC 1993
	80^{o}F (27^{o}C)	lethal critical thermal maximum ACentral Valley Steelhead@ Aabsolute maximum temperature tolerated@	Myrick (1998)
Smolt Outmigration	<57^{o}F (14^{o}C)	preferred	McEwan and Jackson 1996
	>55^{o}F (13^{o}C)	stressful (inhibit gill ATPase activity)	Zaugg and Wagneer 1973, Adams et al., 1975, both as cited in ODEQ 1995

Appendix B

Calaveras River Salmonid Passage Program Report 2001-2003

Calaveras River Salmonid Passage Program – 2001-2003

Summary

Introduction

The Fisheries Foundation of California (FFC) began monitoring Chinook salmon and steelhead passage in the lower Calaveras River below New Hogan Dam (Figure 1) in Fall 2001. The objective of the monitoring is to assess the timing and relative abundance of upstream migrating adult salmon and steelhead and juvenile outmigration. The monitoring program is funded in part with a grant from the Anadromous Fish Restoration Program (AFRP) to improve salmon and steelhead passage, escapement to spawning grounds, and overall salmon and steelhead production in the Calaveras River.

At present salmon and steelhead populations are limited, and viable populations may not exist. The major limiting factors are low streamflow and passage barriers. Low streamflow exacerbates passage from fall through spring when migrations occur. Information from prior years' studies indicates that of the small numbers of salmon and steelhead that ascend the Calaveras River many become stranded and die in either the Old Channel or Mormon Slough before reaching or ascending Bellota Weir to the spawning grounds below New Hogan Dam. In some wet years there may be sufficient fall or winter inflow to allow small numbers of salmon and steelhead to ascend the river to spawning grounds below New Hogan Dam. In such years when successful spawning has occurred some of the juvenile salmon and steelhead that pass downstream from spawning grounds below New Hogan Dam are lost before reaching the mouth. Only in extremely wet years when New Hogan has flood releases are there unimpaired flow conditions for adult upstream migration or juvenile emigration.

This study plan was developed under guidance provided by the CALFED Strategic Plan and Ecosystem Restoration Program Plan (ERP), and the Central Valley Project Improvement Act Anadromous Fish Restoration Program of the US Fish and Wildlife Service (AFRP). Further guidance was obtained from planning efforts of the Calaveras River Technical Advisory Committee (Technical Committee) with participants from the National Marine Fisheries Service (NMFS), AFRP, California Department of Water Resources Fish Passage Program (DWR-FPP), California Department of Fish and Game (DFG), Calaveras County Water District (CCWD), Stockton East Water District (SEWD), S.P. Cramer & Associates, Stillwater Inc., the Fishery Foundation of California (FFC), and various public stakeholder groups.

Figure 1. Calaveras River

Purpose

The purpose of the monitoring program is to assess timing and relative abundance of migrating adult and juvenile salmon and steelhead to help in guiding restoration of the two species in the Calaveras River. A temporary fish ladder has been installed at the Bellota Weir to improve adult fish passage over the weir; however, this ladder only functions under high flows. Downstream there are additional barriers used to back up water for irrigation diversions. Operations of these barriers have been modified to improve adult passage, but they allow little or no passage except at high flows. The study is designed to determine how many salmon and steelhead enter the river and how many of these are able to successfully ascend the river above the Bellota Weir to spawning grounds. Migrants have become stranded in the lower river below the Bellota Weir without gaining access to spawning grounds above the weir. A second element of the study is to determine how many juvenile salmon and steelhead pass downstream past Bellota and how many of these pass successfully through the lower river to tidewater near Stockton.

Objectives

The goal of the passage studies is to contribute information for the limiting factors analysis of the Calaveras River Salmon and Steelhead Life History Study. The study seeks to determine key limiting factors that hinder salmon and steelhead restoration on the river. The study has the following objectives:

1) Determine upstream and downstream migration periods of fall-run Chinook salmon and steelhead/rainbow trout in the Calaveras River, including the peak migration periods of adults and juveniles.
2) Determine at what stream flows the river is passable for adult and juvenile salmon and steelhead along the two alternative migration routes.
3) Determine flow at Bellota Weir when the lower river becomes impassable.
4) Determine how flows at New Hogan Dam, Bellota Weir, and at tidewater relate during different seasons of the year and how such flows may affect migration.
5) Provide insight from studies on flows needed to provide successful passage through both lower river migration routes.
6) Determine if spawning occurs below Bellota Weir and whether such spawning is successful.

Site Description

The Calaveras River empties into the San Joaquin River at the City of Stockton, California. The Lower Calaveras River system consists of two constructed channels, Mormon Slough and the Old Calaveras River Channel, that separate flow below the Bellota Weir. Mormon Slough is a flood control channel that carries most floodwater. The Old River Channels carries local runoff and some irrigation flow. The Bellota Weir complex on the Lower Calaveras River is approximately 25 miles from the mouth on the San Joaquin River and 20 miles below New Hogan Dam (Figure 1). The complex includes the Bellota Weir and the headworks of the Old Calaveras River Channel. The 100-ft wide, 20-ft high weir presently hinders anadromous fish passage at all but flood flows as there are no permanent passage facilities at the diversion dam. Temporary ladders employed historically have proved inadequate. The headworks of the Old River Channel include an earthen weir and two gated culverts that release water downstream for flood control and irrigation. The weirs serve to maintain head for the SEWD diversion located immediately upstream of Bellota Weir. Water is also released from the two weirs to downstream irrigators or groundwater recharge. Above the complex are over 20 miles of potential spawning and rearing habitat for salmon and steelhead below New Hogan Dam. Year-round coldwater releases from the dam provide habitat for salmonids. Some steelhead and salmon spawn in the Mormon Slough below the Belotta Weir, however spawning and rearing habitat below the weir are poor in quality and quantity compared to habitat upstream below New Hogan Dam.

Methods

Monitoring Upstream Passage

Upstream passage into the Calaveras River is monitored at the lower end of the river and at the Bellota Weir by visual observations and trapping or netting of adult salmon and steelhead. Visual observations are made all along the route to determine concentrations of salmon and behavior that indicates difficulty in passing structures. Various structures hinder passage along the two routes from tidewater upstream to the Bellota Weir complex. Simple anecdotal observations are recorded along the two routes during the migration seasons of salmon and steelhead. Gill nets and seines are also used to capture adult salmon and steelhead that may be stranded along the two routes.

A modified Alaskan Weir has been constructed for deployment immediately below the confluence of the Old River and the Diversion Canal to capture adult salmon and steelhead that ascend into lower river from tidewater. Adult salmon and steelhead are counted and released upstream. Plans call for a small number being tagged to determine success of migration as well as routes and timing. Two tag types are used: floy anchor tags and radio tags. Floy tags are used to identify individual salmon only for migration information and mark-recapture population estimates. Radio tags are used to identify specific migration patterns of individual salmon and steelhead including documentation of any difficulties they may have in their migration. A maximum of 20 salmon and 10 steelhead may tagged in any year – any others captured will be counted in the trap and released upstream.

The Alaska Weir is to be placed 100 feet downstream of the confluence of the Diverting Canal and the Old River Channel (Figure 2). The weir design is similar to an A-Frame weir deployed on the Trinity River (Figure 3), but on much smaller scale. Weir placement occurs on the descending limb of the hydrograph when the flows have declined to 50 cfs or below. The weir fishes for 4-8 hours after which it is removed until the next survey period. A minimum of two field technicians monitor the weir at all times while it is in place.

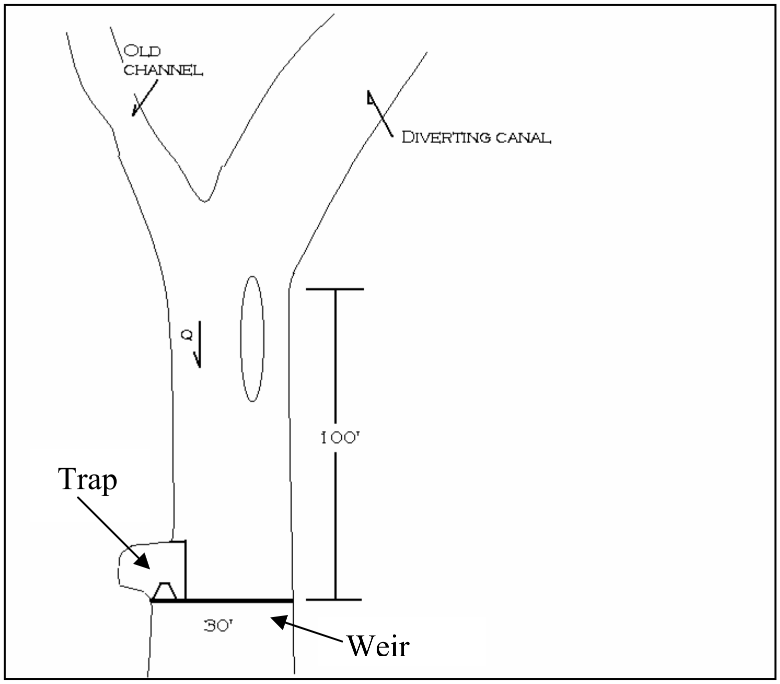


Figure 2. A-frame weir placement in the lower Calaveras River.

Figure 3. Large Alaska Weir deployed on the Trinity River.

Salmonids that encounter the weir are guided through a soft mesh cone (20”-12” reduction) into a low velocity backwater surrounded by plastic coated chain link fencing. The backwater area is checked for fish every 10 minutes with a 20’ beach seine as long as the weir is in place. If it is determined that a fish has entered the backwater area the fish are captured with a 3/8” soft mesh cradle and immediately processed and released upstream.

Processing consists of measuring total length, recording sex, state of maturity, and tagging while the fish are in the cradle. Chinook salmon are tagged beneath the dorsal fin with floy anchor tags and remain partially submerged in the cradle to minimize stress during tagging. A maximum of 10 adult salmon are to be tagged with radio tags using the Interagency Ecological Program protocols for radio tagging salmon in the Delta. Once tagged, they are lifted over the enclosure and released upstream. Tagging fish while in the cradle eliminates the need for recovery time associated with using MS222 or Alka-Seltzer Gold and thus, minimize the time they are retained. We estimate handling times at less than one minute for individual Chinook.

Steelhead captured at the weir are handled similarly to Chinook only they are not all be tagged, and measured and immediately released upstream. A sub-sample of up to 10 fish is to be fitted with radio tags for tracking purposes. Again, the tagging protocol will be that of the IEP for Delta salmon.

Progress of salmon and steelhead moving up the river is monitored at various weirs and low-flow road crossings in Mormon Slough and the Old River Channel. Both visual observations and radio-tag tracking methods are employed. Stranded salmon and steelhead with little or no chance of survival may be captured if reasonably possible and transferred via holding tank with anesthesia to Bellota Weir for release above the weir. The length of transport time is less than 30 minutes. If fish are in good condition, they may be fitted with radio tag as described above, and tracked to spawning grounds above Bellota Weir.

Passage downstream of the Bellota Weir complex at smaller weirs and road crossings is being addressed in engineering studies by DWR and SEWD. An upstream migrant trap is operated at Bellota Weir annually between October and March to determine when, and under what conditions, anadromous fish enter the river, their abundance, size, age and sex distribution, and how many are ad-clipped (strays).

Spawning Distribution and Escapement

An adult carcass count survey is conducted to determine spawning locations, mortality of fish that failed to pass to spawning grounds, and total escapement. Estimates are made of the proportion of the run that passes Bellota Weir to spawn in the reach below New Hogan Dam, an impassable barrier to the salmon. Two independent escapement estimates are made for adult salmon: one with tag returns and a second with the carcass count survey. Estimates are made of the total run and that proportion of the run that passes above the Bellota Weir. Salmon tagged in the lower river below the Bellota Weir provide an independent estimate of the spawning population above the ladder. Because steelhead unlike salmon often survive spawning and thus produce fewer carcasses, estimates of abundance are made using tag return rates from snorkel surveys and ladder or trap collections, as well as visual observations of spawning fish above and below Bellota Weir.

Juvenile Downstream Passage

Downstream passage of juvenile salmon and steelhead is monitored with a combination of snorkel surveys, screw traps, weir/ladder traps, and fyke traps. Particular attention is paid to passage by the diversion structures and the potential for stranding in isolated portions of main channel pools when streamflow subsides. Observations at the Bellota Weir help determine if young salmon or steelhead use the ladder or spillway. Data are collected on numbers observed, size of individual fish, and specific behavior under different flow conditions at the structures. Radio tagging may be used to track the downstream migration of trout smolts captured in the spillway of the Bellota weir and released downstream. Tagged fish will be monitored on their downstream passage with radio receivers. A record of each fish's passage will be made. Fyke net traps are set below the spillway of the Bellota Weir, below the culvert at the head of the Old River Channel (at Bellota), and below the confluence of the channels above tidewater. Other than the radio tagging of ten trout smolts, all other fish counted, fin clipped, and released downstream. The traps will be monitored daily when in place. Fyke net traps are deployed to capture most of the stream flow because standard screw traps are not effective in either channel below Bellota because of low flows and velocity.

Stockton East Water District operates a screw trap in the river above Bellota Weir. S.P. Cramer & Associates (SPCA) began sampling downstream migrants at Shelton Road in Spring 2002 for SEWD. SPCA continues to operate a rotary screw trap at this site 3 to 7 days per week from January through May annually. The primary objectives of this effort are: (1) to monitor the timing and lengths of steelhead and chinook as they out migrate; (2) estimate the number of steelhead and chinook that out migrate each year; (3) evaluate how physical and environmental factors influence migration timing, migration rate, and survival of steelhead and chinook as they out migrate; and (4) evaluate how water management operations influence migration timing, migration rate, and survival of juvenile steelhead and chinook.

Juvenile Production and Survival

Estimates are made of the number of juvenile salmon and steelhead that reach or pass Bellota Weir and escape to the lower river. Estimates are made from the trap counts and mark/recapture experiments. Juvenile salmonids passing downstream of Bellota Weir trapped at the weir outlet are fin clipped and released downstream. Juvenile salmonids trapped in a fyke net near the mouth provide an estimate of number that passed successfully downstream to tidewater. Recaptures of fish tagged at Bellota provide an estimate of the number of fish that passed downstream past Bellota. Out-migrants captured near the mouth are counted and observed for fin clips, and then released downstream. Random beach seining and observations of dead or stranded juveniles will be made between traps at the Bellota Weir and the mouth. Locations (GPS) of dead or stranded salmon or trout are recorded.

Data Analysis and Reporting

Monthly data reports and an annual report are prepared. Data reports are in electronic spreadsheet format. Annual reports are in scientific paper format, documenting the methods, results, and implications of the survey data. Data are included from other available sources. The information obtained in the surveys are shared and reviewed with stakeholder groups, and presented at stakeholder technical meetings.

Population estimates are made using tag returns from traps, carcass surveys, and snorkel surveys in the river. Snorkeling involves underwater observation in the spawning reaches as well as at the approaches to structure in the river below Bellota Weir. Milling of large groups of salmon and steelhead or high concentrations of carcasses below structures is an indicator of difficulty in passing the structures. In extreme cases, long-term delays may be classified as stranding. Stranding may occur if sections become isolated by lack of flow or blocked by structures. Stranding will be documented by radio tagged fish as well as carcasses, or observing fish in locations where there is no way out.

Performance of modified structures (including ladders, culverts, and fishways) is assessed from direct observations by determining the ease at which fish find the ladder and move up through the ladder. The portion of the population that successfully reaches the ladder and passes to upstream spawning ground is determined from the tag returns, population estimates, and direct observation information.

Escapement is estimated using the Peterson Estimate from the number of salmon marked in the lower river marking period and the number of marked fish recovered later during the upstream recovery period. After an initial period of marking, the percent of marked fish in the population is estimated by sampling live and dead fish in the upper river and recording the percent with tags.

$N = m(u + r)/r$; $m/\%R$, where

N = estimate of the number of fish in the population
m = number of marked fish initially placed into the population,
u = number of unmarked fish captured during recovery period,
r = number of marked fish recapture during the recovery period.

%R = percent marked fish recovered during the recovery period.

The key assumption is that the tagged fish are randomly distributed among the population sampled in the upper river. To ensure minimum bias from violation of this assumption, tagging effort is scheduled systematically through the tagging period and the recovery effort covers the entire recovery area. The percentage marked is also determined for live and dead salmon.

Statistical confidence limits are determined from the standard error equation:

$$SE = \sqrt{\frac{M^2 (n+1)(n-R)}{(R+1)^2 (R+2)}} \qquad N \pm 1.96 x SE$$

The Chapman version of the Petersen mark/recapture formula may be used if sample size is low: $N = (m+1)(u + r + 1)/(r + 1)$.

For continuous marking and recovery over a period of time the Schabel Estimate is used:

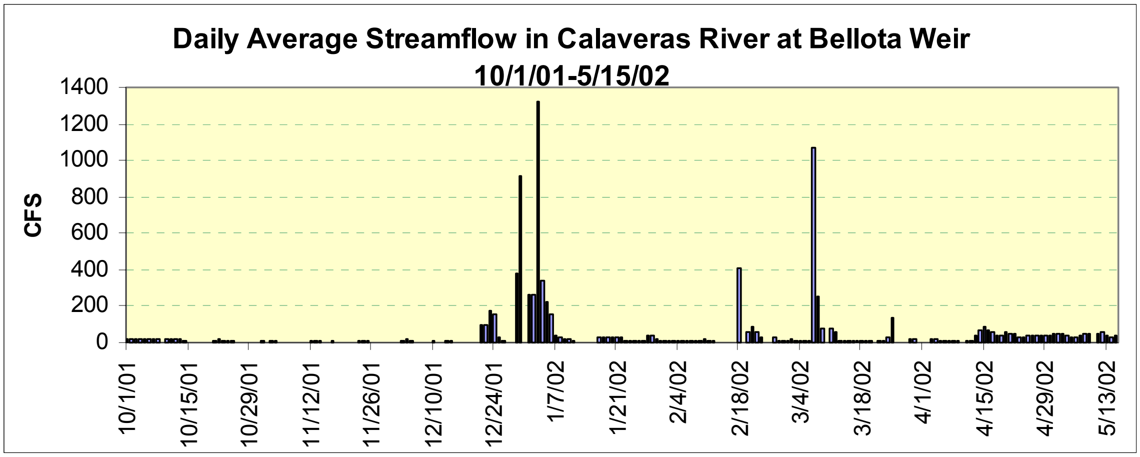
$P = \Sigma m(u + r)/\Sigma r$; where:
m = number of marked fish initially placed into the population,
u = number of unmarked fish captured during recovery period,
r = number of marked fish recapture during the recovery period.

Results to Date

Portions of the study have been completed in the fall through spring of 2001-2002 and 2002-2003. In both years streamflows were extremely low in the lower Calaveras River and the river remained disconnected at tidewater for all but a few days in both years. Even during the short flow events, flows were insufficient at tidewater to attract salmon or steelhead. Only small number of salmon and no steelhead were observed to ascend the river in the fall or winter of these years. Because of the lack of flows, the upstream migrant weir has yet to be employed in the lower river. Foot surveys have been conducted in both years. Fyke nets have been deployed in the spring of 2003 to sample irrigation water released from the Bellota Weir to the Old Channel and Mormon Slough. The following sections summarize the results of these surveys. No radio tags were applied to any adult salmon given the poor shape they were in and the lack of connectivity in the lower river.

Fall 2001 Field Recon and Fish Rescue Activities

We surveyed Mormon Slough below Bellota Weir on several days in mid November 2001 to assess conditions at several barriers where SEWD employees made improvements for fish passage. We were looking for fish that migrated upstream during a recent small flow event that had connected the river to tidewater for several days. Our survey focused on the weirs immediately upstream of tidewater where we expected salmon to be initially hindered in their migration. SEWD had made modifications to the first major weir, Budilesich Weir, with sandbags to improve passage at the weir for adult salmon. The river was not connected at tidewater at the time of the survey but had been several days before. One live adult Chinook salmon was noted in the disconnected pool below the weir. Four live and two dead adult Chinook salmon were observed in isolated pools further downstream of the weir. Scales and otiliths of the dead salmon were collected and presented to DFG. No salmon were observed in pools upstream of Budilesich Weir.



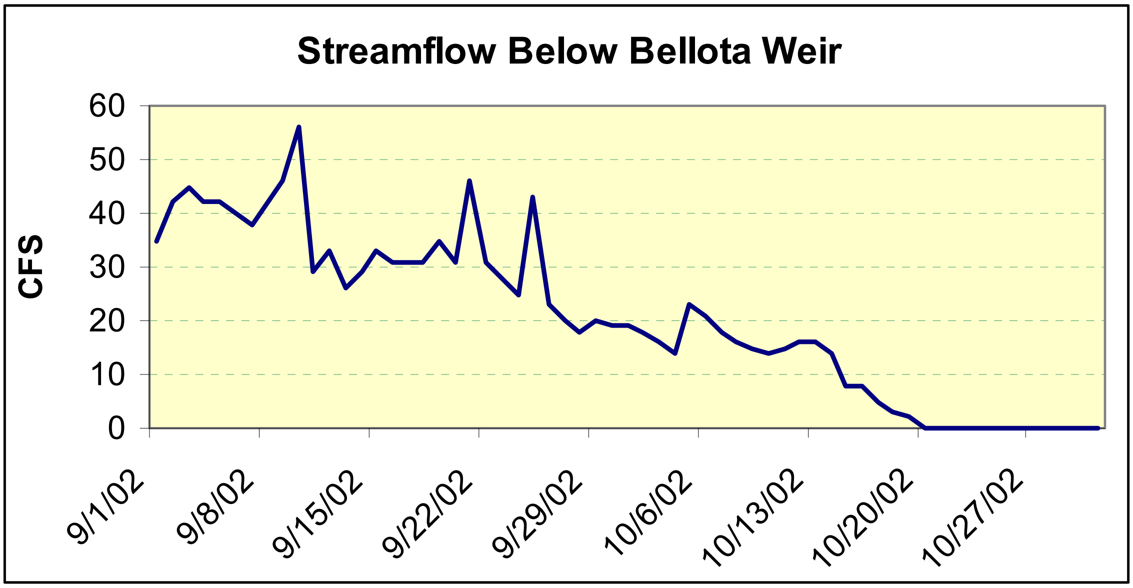
We attempted rescue of salmon stranded in pools below the Budilesich Weir. We seined a total length of 0.15 miles and captured a total of seven live salmon for rescue. Of the 7 fish, 2 were female and 5 were male. The male fish seemed to be in better condition than the females. The fish were fully mature and ready to spawn, as one of the females started to drop her eggs while she was loaded into the truck and we noticed several clusters of eggs on the mud substrate of the channel. This female died in transit to the release point above the Bellota Weir. All of the rescued fish had their adipose fins intact. Further seining downstream of Budilesich Weir yielded two additional live adult salmon that were transported above the Bellota Weir.

Spring 2002 Field Recon Activities

Recon surveys were conducted in the spring of 2002 after the flow event in mid-March connected the river at tidewater for several days. Several live and dead adult steelhead trout were observed in the Mormon Slough below Bellota Weir in late March and early April. Several steelhead redds were also located in riffles below Bellota Weir. Yearling trout, approximately 200-250 mm in length, possibly steelhead smolts, were also captured by angling and gill nets in this same area. No adult trout were captured in the pool below Bellota Weir in two days of netting in April.

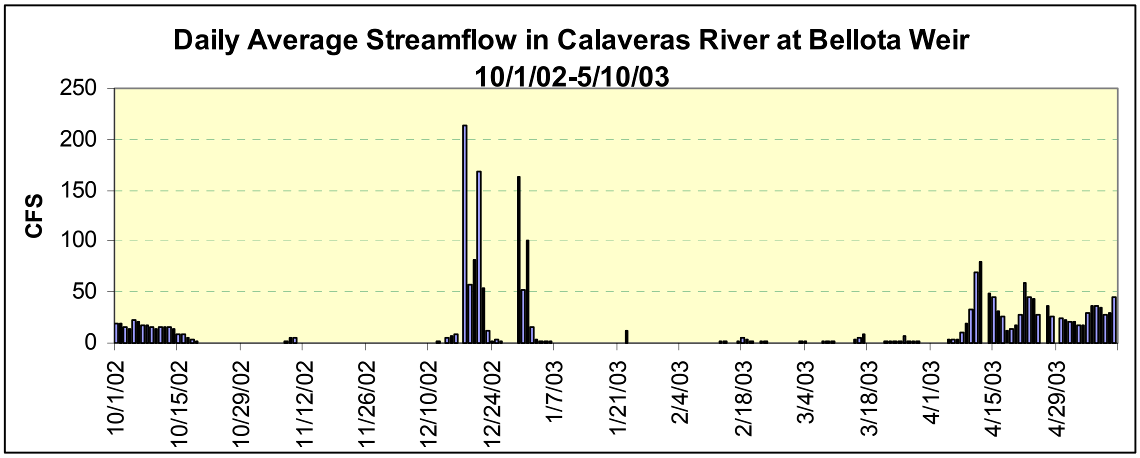
Late Summer and Early Fall Recon Activities

At the end of the irrigation season in late September 2002 flow releases to the lower river below Bellota Weir were dropped from approximately 30-50 cfs to zero drying up the river channels below Bellota. Surveys were conducted on foot during the flow decline and after. Adult and juvenile rainbow trout were noted in the Old River channel. When flows reached zero, juvenile and adult were observed stranded in pools or dead or dying in dried out portions of the streambed. Numerous predator and scavenger birds were also present along the stream channel.



Fall-Winter 2002/2003 Field Recon Activities

Daily recon surveys commenced in November 2002 after a small flow event. Small numbers of live and dead salmon were observed in isolated pools in the lower river (Diverting Canal and Mormon Slough) through November. On December 4 we found one dead Chinook salmon 75 yards upstream of Hwy 99 Bridge. The carcass was an adipose clipped, fresh male, unspawned with a 25-inch fork length.



The lower river remained disconnected through December 18 and daily ground surveys did not observe any further stranded or dead salmon up to that date.

A flow event in the week following the 18th brought few new salmon into the river. Three carcasses were found on December 27th. Two had been marked in November. The third was unmarked and may have been a salmon that migrated into the river in the recent flow event.

On December 28th two salmon carcasses (adult male and female) and two redds were observed 50 yards downstream of the Bellota Weir. The redds were nearly dewatered.

Another flow event occurred during the first week of January 2003. Again, few salmon were observed to migrated from tidewater. One carcass and three live adult salmon were observed in the lower river near tidewater. Three live salmon and three redds were observed in the riffles below the Bellota Weir. One live salmon was observed above the Bellota Weir. Two salmon were observed attempting to passage through the ladders at the Bellota Weir on January 5th, but were not successful. The river again disconnected at tidewater on January 6th and did not reconnect the remainder of the winter and spring through April 2003.

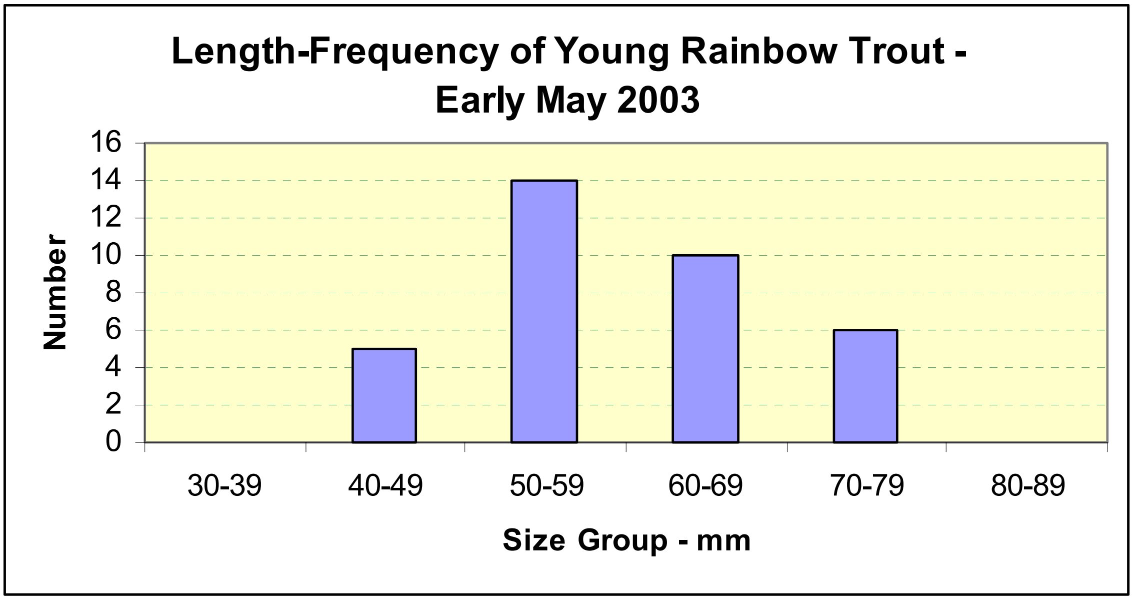
On January 9th one carcass and two live adult salmon were observed below the Bellota Weir. Previously constructed redds were dewatered.

On January 11th one live salmon and two carcasses were observed below the Bellota Weir. The lower river was connected between tidewater and where Potter Creek entered Mormon Slough, as 20-30 cfs flow was discharged from Potter Creek. The source of this flow was a trans-basin diversion from the Stanislaus River that normally would flow to the SEWD water treatment plant connected to Potter Creek.

Most of the carcasses observed after January 6th had been tagged before January 6th. One carcass was observed on three separate occasions. Four distinct carcasses were recaptured after January 6th, thus indicating that surveys were observing most of the carcasses present in the river at the time.

Fyke Net Survey of Juvenile Salmonids – May 2003

Fyke nets positioned in the Old Calaveras Channel and Mormon Slough below Bellota Weir in May 2003 yielded small numbers of juvenile rainbow trout ranging in size from 40 to 80 mm. All but one of these small trout were captured in the Old Calaveras Channel. All of these young trout were parr and not smolting, thus indicating they were not actively out-migrating from the river but rather dispersing within the rearing habitat of the river. No juvenile salmon have been captured.



Discussion

In both the 2001-2002 and 2002-2003 fall through spring anadromous salmonid seasons the lower Calaveras River was disconnected from tidewater for the vast majority of the season and thus few adult and juvenile salmon or steelhead were able to migrate into or out of the lower river. Those adult salmon and steelhead that were able to migrate into the river during short local rainfall events were severely hindered in their passage upstream by existing migration barriers and low water. Carcasses of adult salmon and steelhead were found in lower Mormon Slough below Bellota Weir. Adult salmon and steelhead spawning was also observed in riffles below Bellota Weir. Neither salmon or steelhead eggs or fry could survive subsequent low-flow and high water temperatures in the reach below Bellota Weir. Downstream migrating adult and smolt (yearling) steelhead were observed in the Old River Channel below Bellota Weir, where they were able to over-summer but then died when the irrigation season ended in the fall and flow releases ceased to the Old River Channel. Smolt trout were also collected in the spring passing downstream of Bellota Weir, where they died during the heat of summer.

Peak Migration Periods

Peak migration periods were difficult to discern from the survey data given that the river was connected for only a few days in spring and fall. November and December are likely important migration periods for Chinook salmon. However, because few salmon entered the river during the higher flow events of late December 2002, this period was likely too late to accommodate passage of most of the salmon run. Adult steelhead did migrate into the river either in the February or March flow events of 2002. No young salmon were collected so timing of their outmigration is not known. Juvenile trout were observed moving downstream below Bellota Weir in the spring of 2002 and 2003.

Flow and Passage

Salmon and steelhead were able to enter the river at relatively low flows. Salmon moved into the lower river in November in flows of only a few cfs. However, passage at low flows was a problem. Some salmon were able to reach Bellota Weir during December after flows reached 50-200 cfs. Likewise adult steelhead were able to reach Bellota Weir when spring flows reached 200-1000 cfs. Passage at Bellota Weir appears to be a problem at these flows, although at least one salmon was able to migrate past the weir using the temporary fish ladders in December 2002. Passage at Bellota Weir remains a problem based on the survey results.

Streamflow Conditions for Fish Passage

In both migration seasons studied there was no spill or releases from New Hogan Reservoir to provide fish passage in the lower river. All releases generally were only sufficient to meet diversion demands downstream to Bellota or short distances below Bellota. During the short periods when the river was connected between New Hogan Reservoir and tidewater, most of the flow into tidewater was provided by local runoff, principally from Cosgrove (several miles below New Hogan) and Potter Creeks (several miles below Bellota). Flows in the range of 20-100 cfs appear adequate to provide for passage of adult salmon and steelhead into and through the lower river. At these flows limited data indicate salmon and steelhead are able to negotiate all obstacles with the exception of Bellota Weir. Spawning does occur below Bellota Weir, however egg and fry survival are likely minimal due to poor habitat conditions. Mid October through mid December is the period when salmon would ascend the river. Prior to mid October water temperatures probably would be too high for salmon. After mid December flows may be too late to accommodate the salmon run. February and March would be the period flows are needed to provide steelhead passage.

Future Studies

Present plans call for continued monitoring of juvenile salmonids below the Bellota Weir into summer 2003. Fyke nets will continue to be deployed in the Old River Channel and Mormon Slough. Employment of the Alaska Weir is planned for fall 2003 if flows are sufficient to attract adult salmon to the lower river.

Appendix C

Lower Calaveras River Snorkel Survey 2002

LOWER CALAVERAS RIVER SNORKEL SURVEY 2002
CONTRIBUTION TO THE
LIFE HISTORY LIMITING FACTORS ANALYSIS
PROGRESS REPORT FOR YEAR ONE

INTRODUCTION

This is a report on the snorkel survey conducted during 2002 as part of the first year of the study relating to the Lower Calaveras River Chinook Salmon and Steelhead Life History Limiting Factors Analysis. The purpose of the study is to assess fish community species composition and distribution, and to refine the understanding of temporal and spatial patterns of Chinook salmon and steelhead use of the lower Calaveras River below New Hogan Dam. The goal of this study is to obtain quantitative data on salmonid distribution, abundance, habitat use, growth in length, as well as information on the abundance and distribution of potential predators and competitors. The objectives of these surveys are to: 1) assess distribution and density of juvenile Chinook, steelhead, and other fishes; 2) assess the timing and relative abundance of upstream migrating adults; 3) assess Chinook salmon and steelhead spawning distribution and timing, and 4) assess the timing of juvenile out-migration.

STUDY AREA

The scope of this project encompasses the entire lower Calaveras River from its mouth to New Hogan Dam including the Old Calaveras River channel, the Mormon Slough channel and the Stockton Diverting Canal (Figure 1). Mormon Slough and the Diverting Canal were constructed as a flood bypass system to carry floodwaters around flood-prone areas near Stockton.
The lower Calaveras River study area was divided into four reaches. The uppermost reach, Reach 1, extends from New Hogan Dam downstream to Cosgrove Creek, the upstream end of the Canyon. Reach 2 extends downstream from the mouth of Cosgrove Creek to Jenny Lind crossing and encompasses the Canyon. Reach 3 extends downstream from Jenny Lind to the Bellota Weir. The lower reach spans from the Bellota Weir downstream to the confluence with the San Joaquin River and includes the Old Calaveras River channel and the Mormon Slough/Diverting Canal channel.

- Reach 1– New Hogan Dam downstream to Cosgrove Creek (Hogan Reach)
- Reach 2–Cosgrove to Jenny Lind (Canyon Reach);
- Reach 3–Jenny Lind (Jenny Lind Reach);
- Reach 4– Jenny Lind Reach to Bellota
- Reach 5 – Bellota to Tidewater.

The snorkel survey sampled Reaches 1 through 3 – Reach 4 was not included because of lack of access, poor visibility, and deep water habitat. Reach 5 was not included because of the lack of flow during the survey period.

Figure 1. Location map of lower Calaveras River showing major features and diversion structures.

BACKGROUND

The Calaveras River, a tributary of the San Joaquin River, drains a 590 square mile watershed with a mean unimpaired runoff of 152,100 acre-feet per year. Releases from New Hogan Dam located some 38 miles upstream from the river's mouth at Stockton control flow in the Lower Calaveras River. New Hogan Lake has a storage capacity of 317,000 acre-feet at gross pool and is operated by the US Army Corps of Engineers (Corps) for flood control, water supply and recreation. Designated minimum instream flows below New Hogan in the Calaveras River are 2 cfs. Releases are generally greater and year-round to meet downstream water supply demands. Because much of the demand is for domestic water supply, releases are year-round in contrast to seasonal releases for irrigation. Diversion of the water released from New Hogan occur primarily between the reservoir and Bellota Weir, thus instream flow below Bellota Weir is minimal except during the rainy season when local runoff contributes to the flow.

METHODS

Snorkel surveys were conducted on a biweekly basis from March through October. Methods for direct observation were developed by the contractor on the Stanislaus River and employed during the Calaveras surveys. Multiple sites were selected from riffle/run and pool habitats to represent the typical habitat of each reach. At each site two divers in wet suits and snorkel gear proceeded upstream on each bank counting fish by species and size group on a dive slate. Divers were trained to separate fish by size groups using different sized models of salmonids. Upon completing these transects, one diver proceeded downstream via the center of the channel counting fish not included in the two upstream margin surveys. The stream area of each site was estimated using a tape measure. The sites were standardized through the duration of the survey. The number of each 100-mm size group observed was divided by the survey area to provide numbers per unit area surveyed at each site. The average density by reach and habitat type (riffle/run/glide and pool) was calculated for each survey.

RESULTS

No Chinook salmon were observed in the snorkel surveys. Rainbow trout were the predominant species observed and are the only species presented in this report.

Trout (<100mm)

Young trout were observed in small numbers in the first survey in March and then peaked in the second survey in April (Figure 1). The smallest trout (about 25-30 mm) continued to emerge through the spring. Most of the young trout reached 100 mm by fall, except small numbers continued in the Hogan Reach. Young trout were found predominantly in the upper two reaches below New Hogan Dam.

Young trout densities were about three times greater in riffle and glide habitats compared to pool habitat in spring and summer (Figure 2). In the fall, the small trout that remained in the Hogan Reach were more concentrated in pool habitat.

Figure 1. Average sightings of young trout less than 100 mm in size.

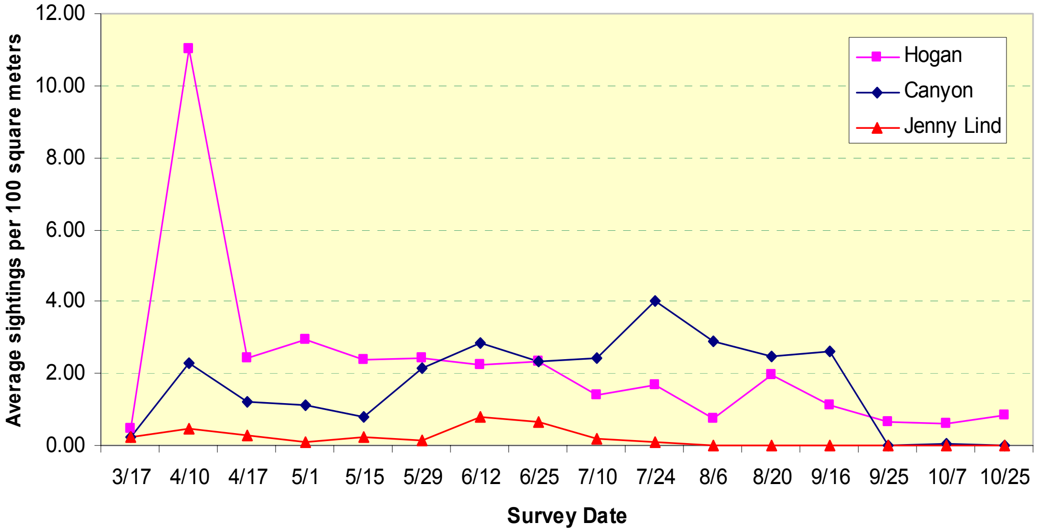
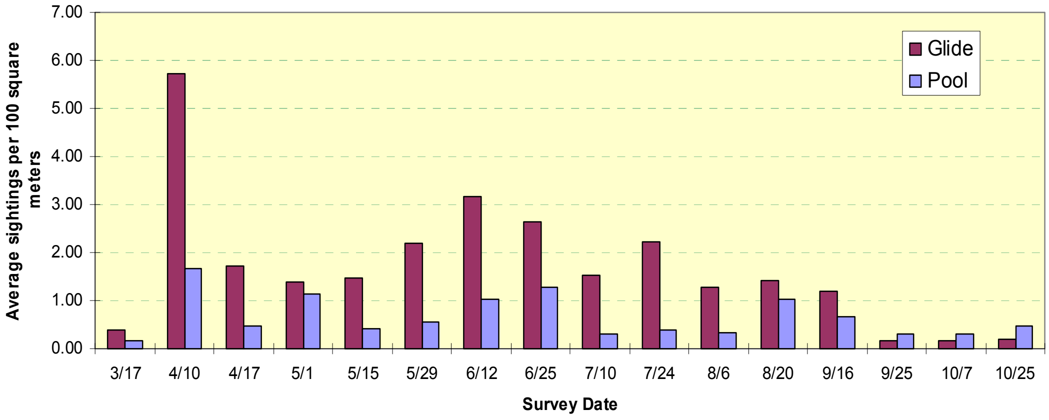


Figure 2. Average sightings of young trout < 100 mm in size by habitat type.



Trout (100-199 mm)

In the initial late winter and early spring surveys few yearling size trout were observed (Figure 3). Through spring density began to rise in the Canyon Reach. Densities gradually increased in all three reaches from summer through fall. Highest densities were in the Canyon Reach except for an apparent shift to higher densities in the Hogan Reach in the fall. These yearling sized trout concentrated in the upper two reaches as did the young trout.

These yearling-sized trout densities were generally similar in riffle/glide and pool habitats (Figure 4). An exception appears in mid-to-late summer when there were higher densities in riffle/glide habitat.

Figure 3. Average sightings of trout 100-199 mm in size by survey reach.

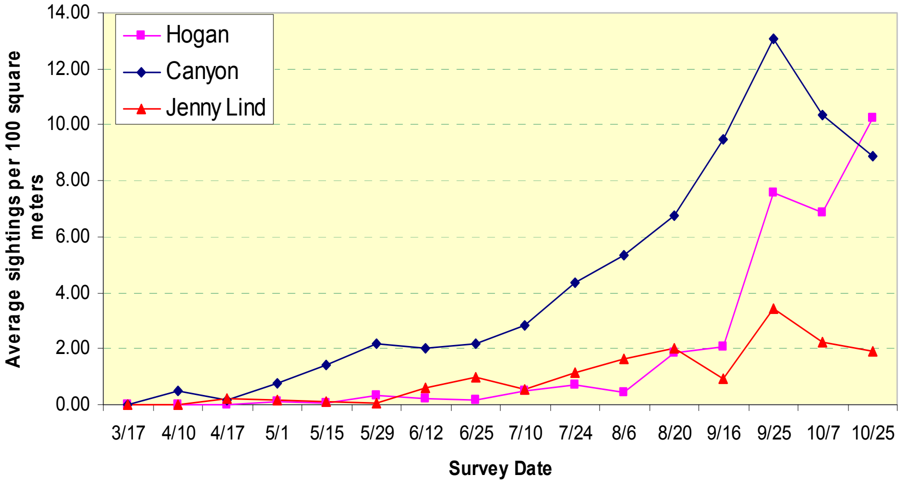
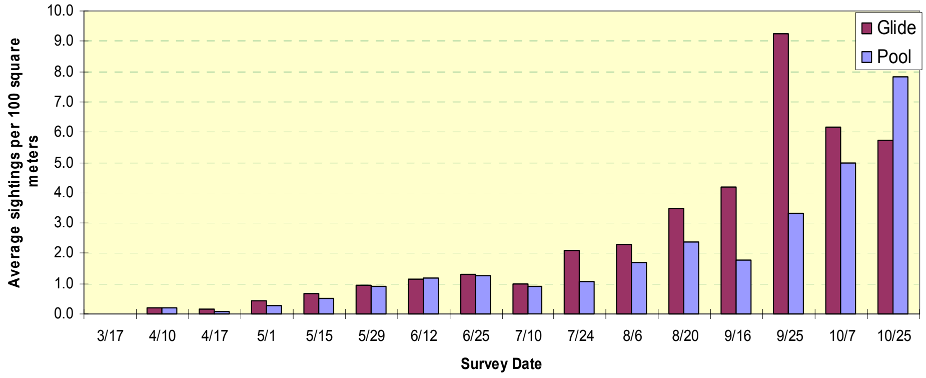


Figure 4. Average sightings of trout 100-199 mm in size by habitat type.



Trout (200-299 mm)

Few of the yearling plus size trout in the 200-299 mm size range were observed in spring (Figure 5). What few observed were in the Canyon Reach. The density increased in all reaches through the summer and fall, with the greatest increase in the Canyon Reach. The density was similar in the riffle/glide and pool sites with the exception of the summer when riffle/glide densities were slightly higher than pools and in the last fall survey where pool density was higher (Figure 6).

Figure 5. Average sightings of trout 200-299 mm in size by survey reach.

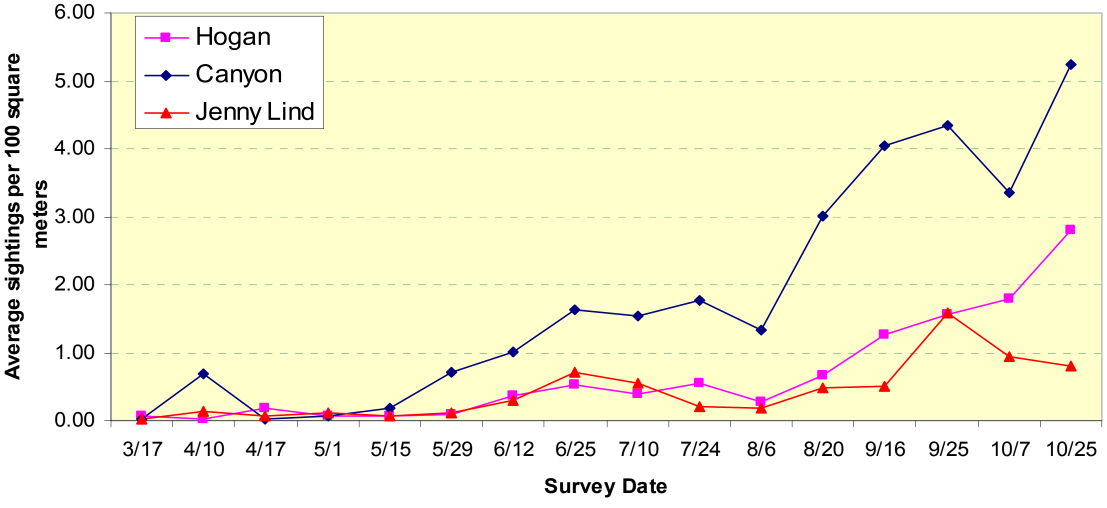
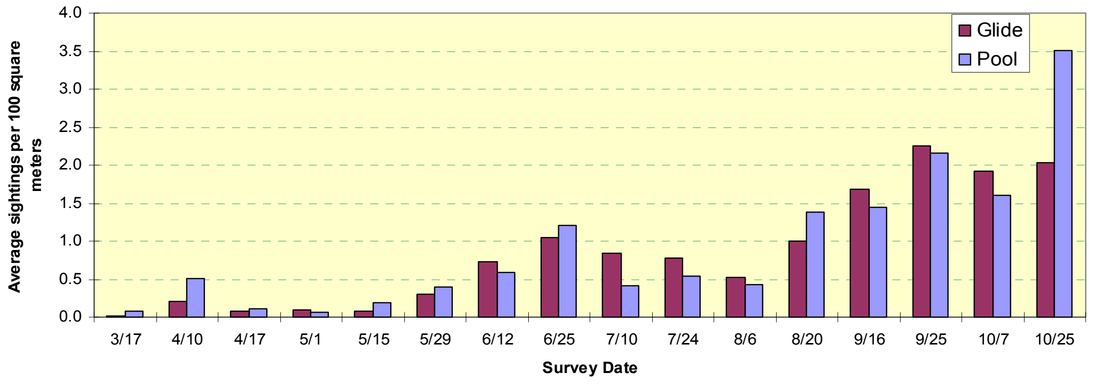


Figure 6. Average sightings of trout 200-299 mm in size by habitat type.



Trout (300+ mm)

Few of the foot-long plus size trout in the 300+ mm size range were observed in spring (Figure 7). What few observed were in the Canyon Reach. The density increased in all reaches through the summer and fall, with the greatest increase in the Canyon Reach. The density was generally higher in the pool sites with the exception of the summer when density was slightly higher in riffle/glides (Figure 8).

Figure 7. Average sightings of trout 300+ mm in size by survey reach.

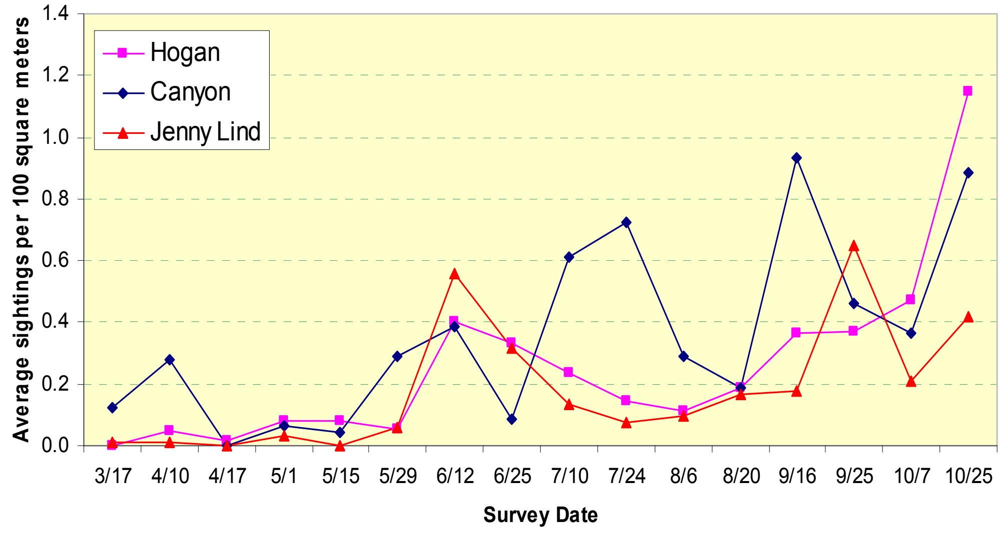
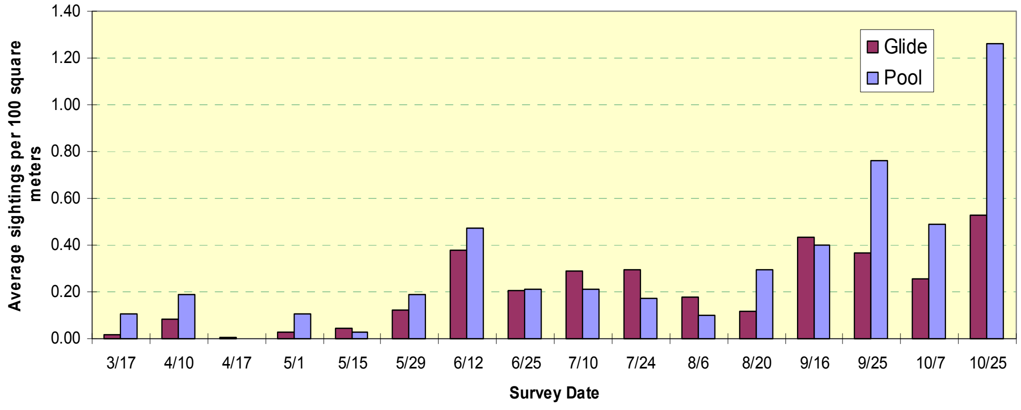


Figure 8. Average sightings of trout 300+ mm in size by habitat type.



Discussion

One of the weaknesses of snorkel surveys is the inability to measure fish size accurately especially when encountering schools or individuals who tend to run for cover when approached. In our survey we were generally able to differentiate young from yearling and older trout except during the summer when young and yearling overlapped in the 100-199 mm size range. Despite these difficulties the survey depicted a number distinct patterns worthy of note.

From the <100 mm results it is apparent that most young were recruited gradually over the spring primarily from the Hogan Reach with lesser production from the Canyon Reach (see Figure 1). This is consistent with earlier surveys that indicate most of the spawning occurs in the Hogan Reach.

In summer there also appears to be a shift in young from the Hogan Reach downstream into the Canyon Reach. This would be indicative of downstream dispersal and young trout seeking better habitat and less competition. This dispersal does not carry down below the Canyon into the Jenny Lind Reach. The Jenny Lind Reach has very low density of young that dwindles to near zero by summer. Summer maximum water temperatures reach only 12C in the Hogan Reach but reach 16-17C in the Jenny Lind Reach (Attachment A). Such higher temperatures may deter downstream movement. The sharp increase in 100-199 mm fish in mid summer (see Figure 3) shows young recruitment into this size range and that it occurs primarily in the Canyon Reach with some in the Hogan and Jenny Lind Reaches. From these patterns it is apparent that young rear predominately in the upper two reaches at least into summer where water temperatures are in the optimal range of 12-15C.

Low densities of yearling and older trout in late winter may be indicative of several factors acting to limit overwintering trout density in the upper river:

(1) They may have emigrated during the winter from the river as steelhead smolts for the estuary.
(2) They may have moved downstream into lower gradient habitats of the reach between Jenny Lind and the Bellota Weir.
(3) They may have sought refuge in the stream substrate and could not be observed by divers.

All three factors likely have some effect. Evidence of factors 1 and 2 is indicated with observations of young trout passing over Bellota Weir into the lower river during the winter and spring. Evidence of factor 3 is indicated from 7-9C winter river temperatures that are known to cause over-wintering salmonids to seek refuge in stream substrate in rivers and streams throughout North America. Observations of 200+ mm trout reappearing by late spring long after the river has warmed indicate that factor 2 is a likely cause. Such movement may be due to the lower river warming to 16C and higher by late May, which may cause the upstream movement to cooler reaches, a pattern that was distinct in summer (see Figures 5 and 7). (Note: the lower reach between Jenny Lind and Bellota Weir was not surveyed because water clarity was generally marginal, water was deep, and access was limited. Limited sampling in the fall indicate density was very low in the lower reach; however, movement to the lower reach may not occur until winter.)

Higher late summer and fall densities are likely indicative of sharply falling releases from New Hogan Reservoir (see Figure A-1). A drop in densities in mid-April is also likely due to higher flow and volume.

Sharply higher summer density of trout in the Canyon Reach (Figure 9) was due to a combination of continuing recruitment of young and the movement of trout of all sizes into the reach from upstream and downstream reaches. The higher gradient, shade, and cover of the Canyon Reach may be another feature that attracts trout. Higher density of trout in summer in riffle/glide habitat (Figure 10) is also indicative of the trout seeking higher velocity, more oxygenated habitats.

Figure 9. Average sightings of total trout in all size groups.

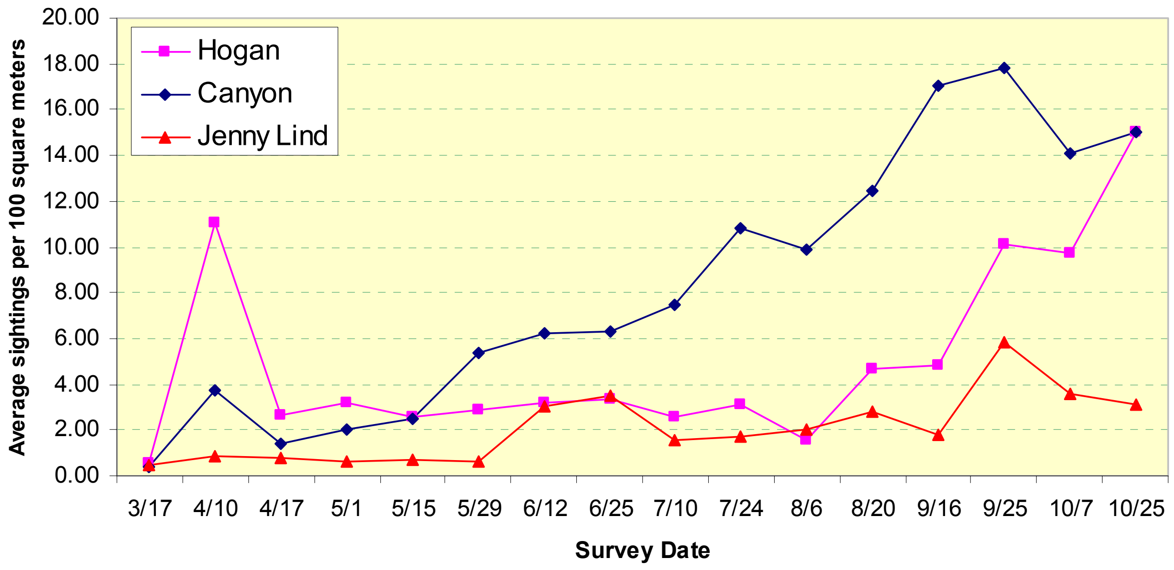
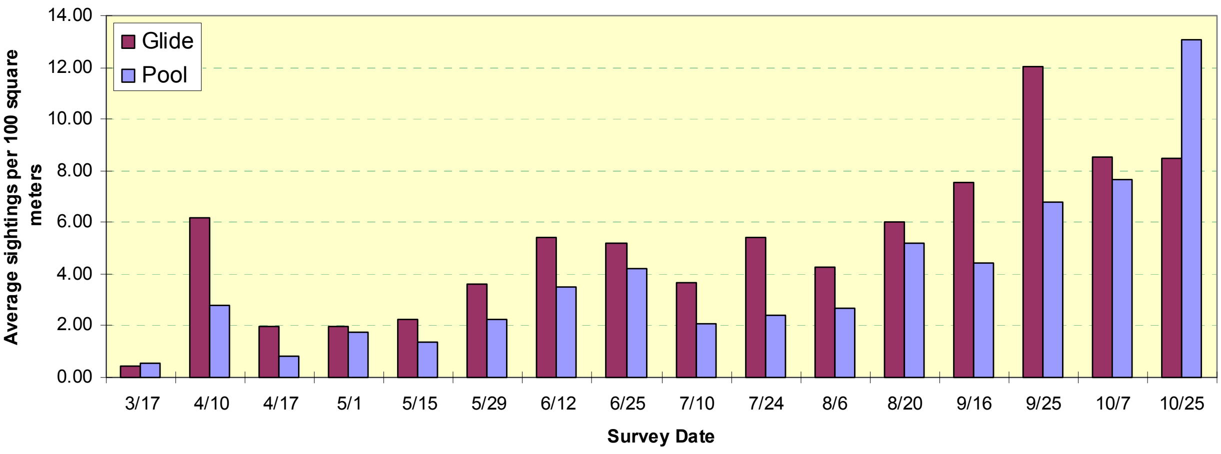
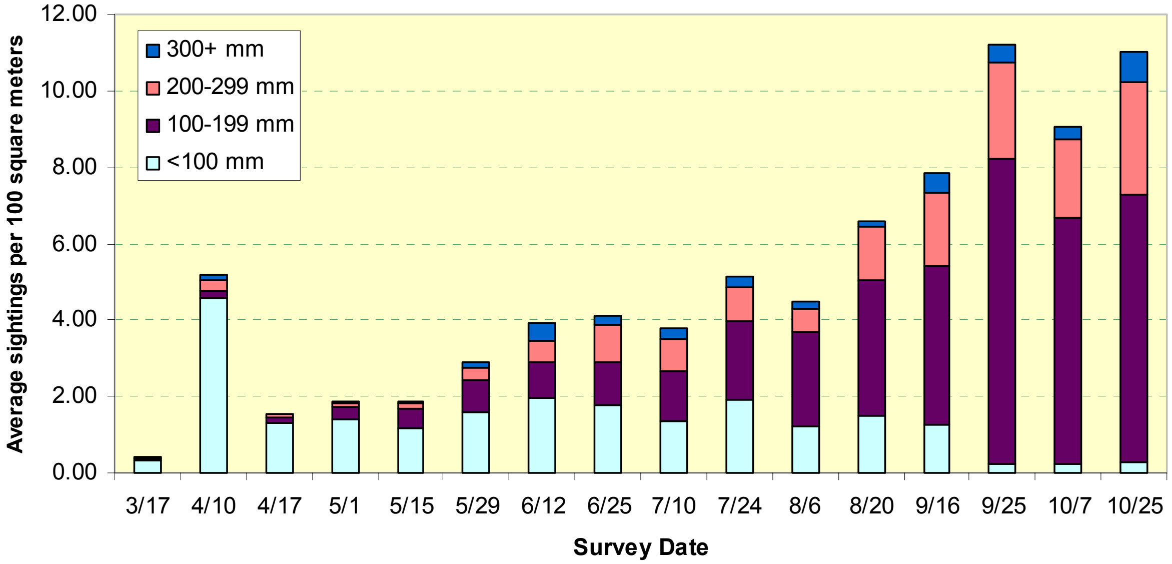


Figure 10. Average sightings of trout of all size groups by habitat type.



From the size distribution of the trout (Figure 11) there appears to be continued recruitment of young from emergence into summer and growth of young into the 100+ size group in summer into fall. As stated earlier the build up of 200+ mm sized trout through the summer is due to growth of 100-199 mm fish into the larger size group and movement of fish from lower unsampled reaches. The sharp increase in densities in the fall is due to sharply falling streamflow and stream volume.

Figure 11. Average density of trout in all size groups across survey area by survey.

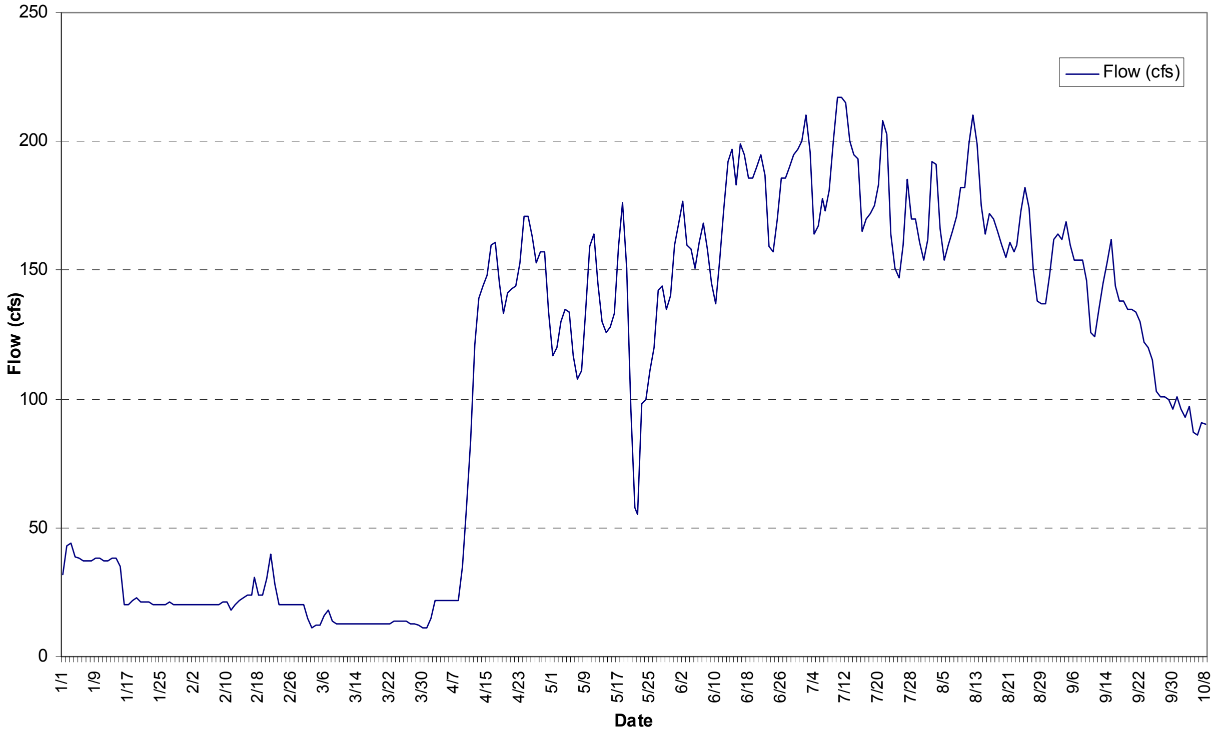


Conclusions

- The majority of trout spawning occurs in the Hogan Reach.
- Most young rear in the upper river that includes the Hogan and Canyon Reaches.
- The highest density of trout occurs in the Canyon Reach.
- Summer habitat conditions especially water temperature are more optimal in the upper two reaches and less optimal at Jenny Lind and below.
- Trout density declines sharply during the winter as trout emigrate from the river, seek refuge in substrate, and move to the lower reach below Jenny Lind.

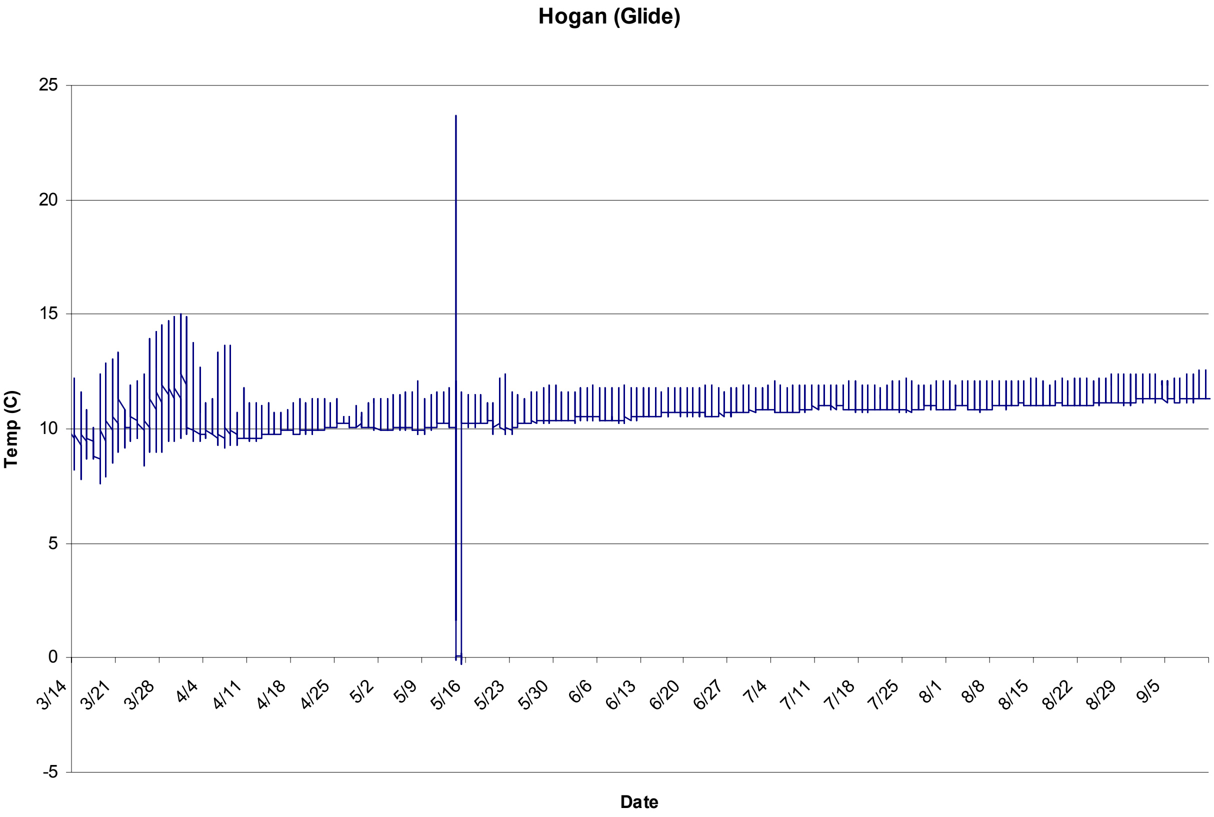
Appendix C Attachments

Daily Mean Outflow at New Hogan Dam



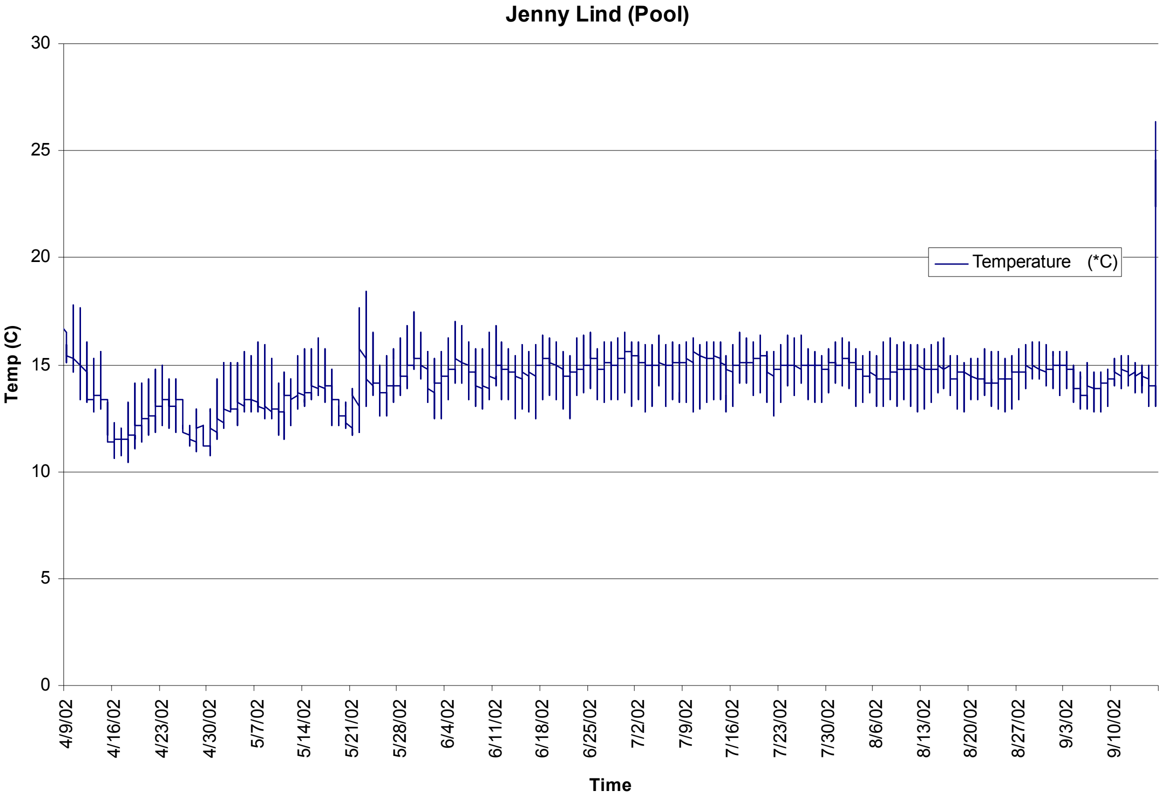
Appendix C Attachments

Water temperature below New Hogan Dam.



Appendix C Attachments

Water temperature at Jenny Lind.



Appendix D

Supplemental Water Temperature Data Report 2002

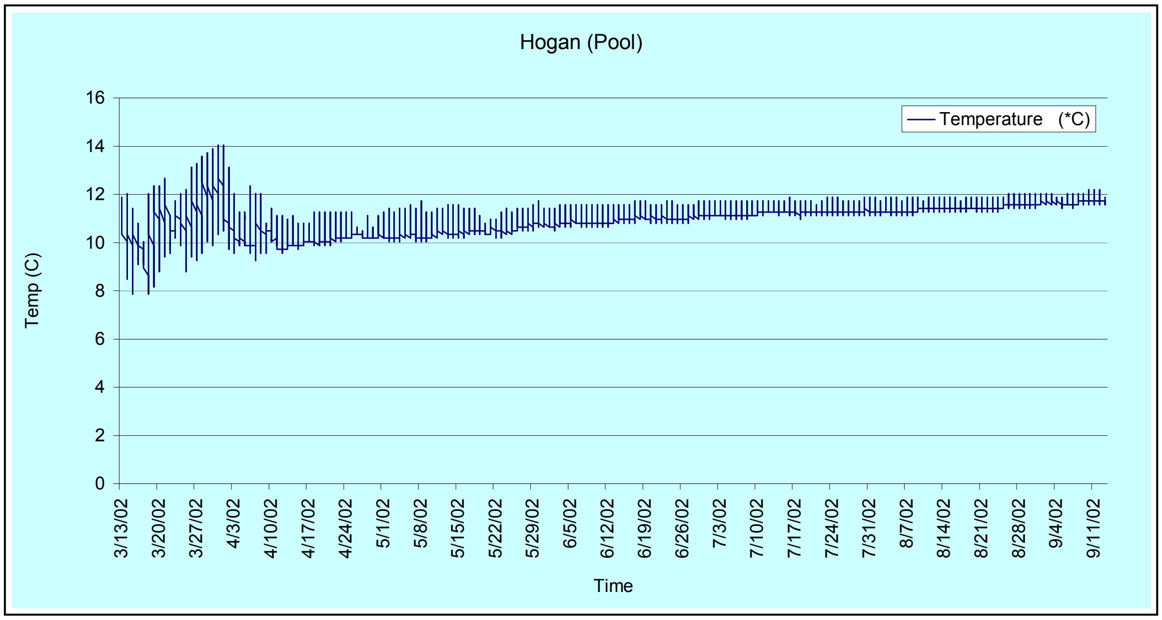
Supplemental Water Temperature Data Report – Calaveras River 2002

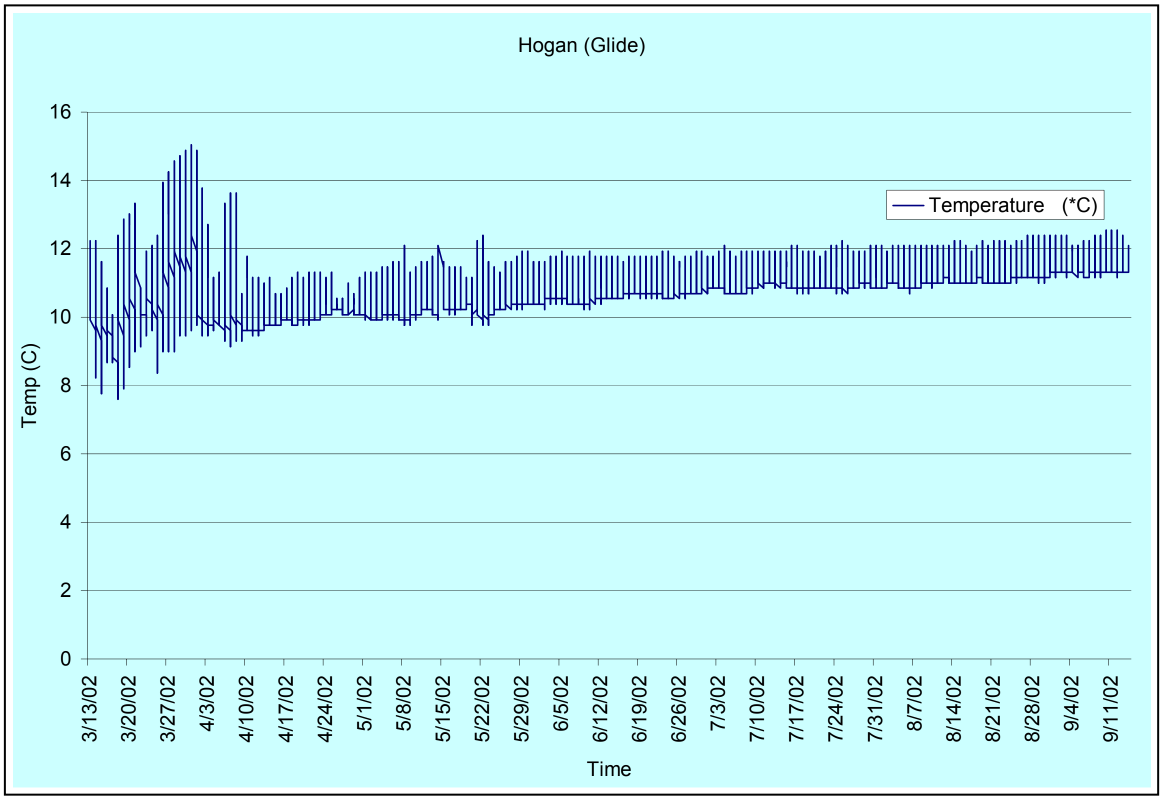
In 2002 the Fishery Foundation conducted several surveys to provide background information on fish habitat of the Calaveras River. The surveys included water temperature, carcass counts of salmon and steelhead, and salmonid redd distribution. This report covers the water temperature survey.

Water temperature was collected continuously from March 2002 to February 2003 at six locations in the lower Calaveras River below New Hogan Reservoir.

Hogan Reach

Temperature recorders were placed in the Hogan Reach in a pool (Hogan Pool) and riffle (Hogan Glide) location from March 2002 into February 2003. The Hogan Pool recorder was lost after replacement in September 2002. Water temperature was slightly higher early in the spring because of lower flows from the New Hogan Reservoir. Thereafter water temperature was lower and more consistent with bottom releases from the reservoir.




Hogan (Glide)
16
14
12
10
8
6
4
2
0
Temp (C)
Temperature (*C)
3/13/02
3/20/02
3/27/02
4/3/02
4/10/02
4/17/02
4/24/02
5/1/02
5/8/02
5/15/02
5/22/02
5/29/02
6/5/02
6/12/02
6/19/02
6/26/02
7/3/02
7/10/02
7/17/02
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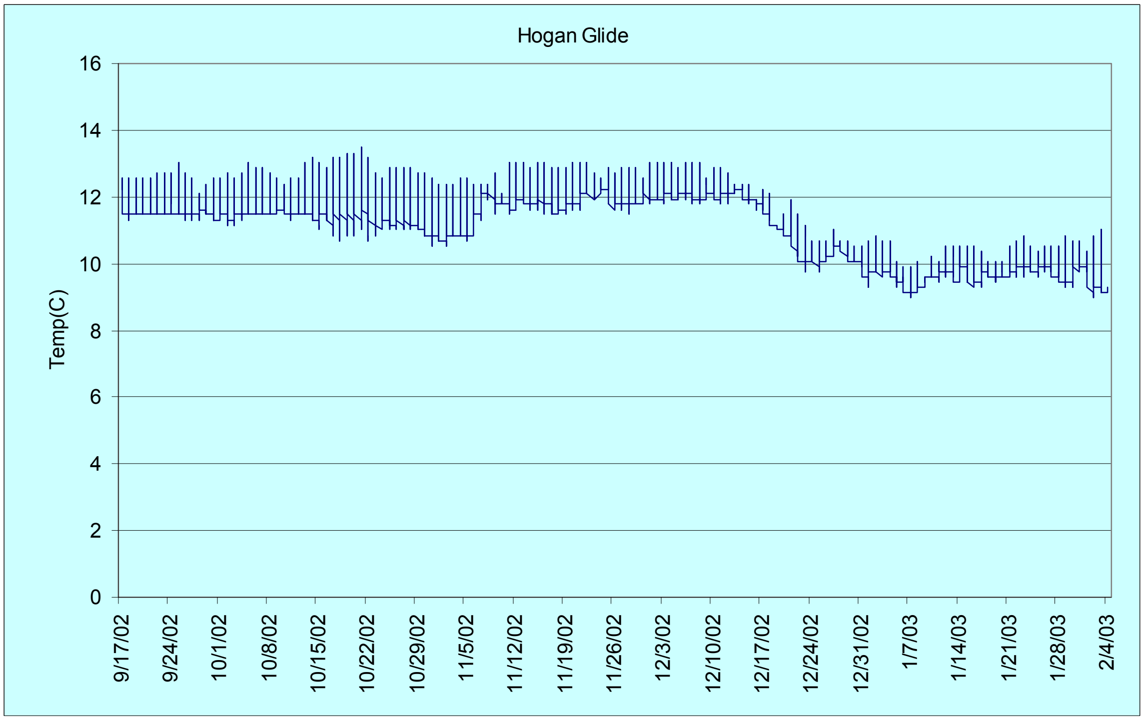
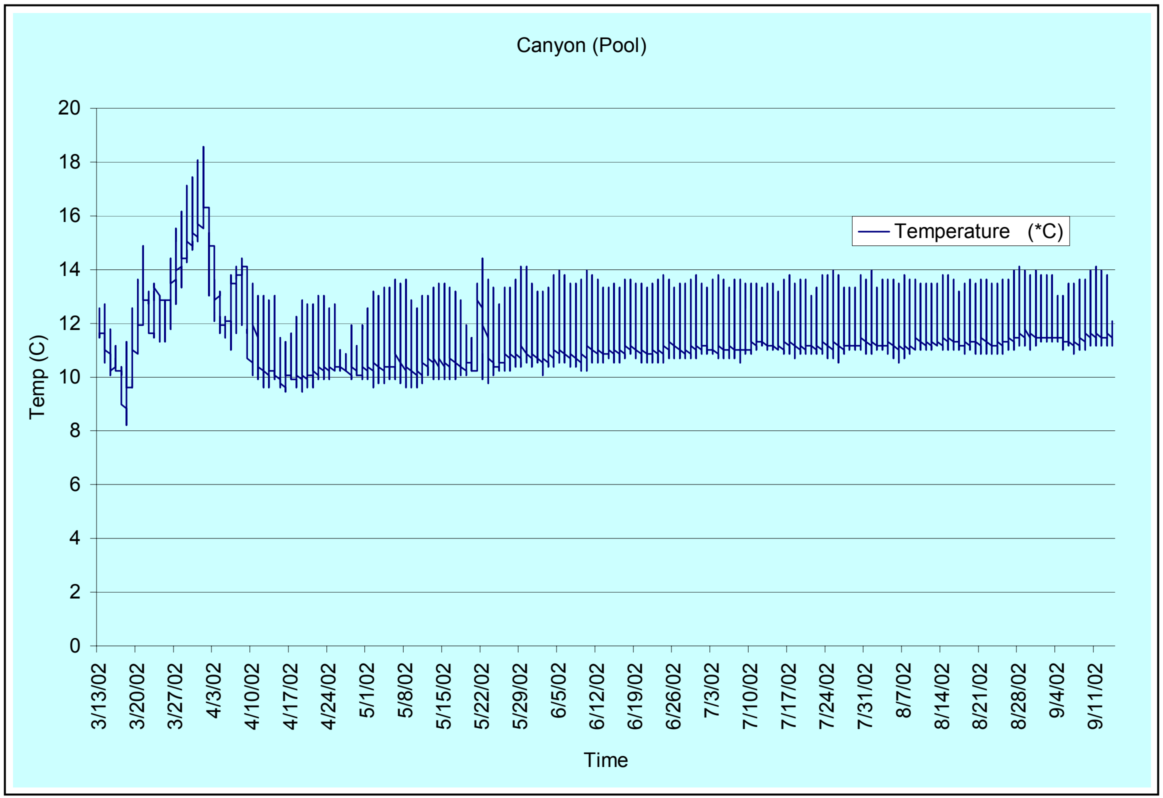
9/4/02
9/11/02
Time


Hogan Glide
16
14
12
10
8
6
4
2
0
Temp(C)
9/17/02
9/24/02
10/1/02
10/8/02
10/15/02
10/22/02
10/29/02
11/5/02
11/12/02
11/19/02
11/26/02
12/3/02
12/10/02
12/17/02
12/24/02
12/31/02
1/7/03
1/14/03
1/21/03
1/28/03
2/4/03

Canyon Reach

Temperature recorders were also placed in a pool and riffle area of the Canyon Reach from March 2002 into February 2003. Water temperature was slightly higher early in the spring because of lower flows from the New Hogan Reservoir. Thereafter water temperature was lower and more consistent. Temperature was slightly higher than that recorded upstream in the Hogan Reach. Water temperature was very similar between the pool and glide areas.


Canyon (Pool)
Temperature (*C)
Temp (C)
0
2
4
6
8
10
12
14
16
18
20
3/13/02
3/20/02
3/27/02
4/3/02
4/10/02
4/17/02
4/24/02
5/1/02
5/8/02
5/15/02
5/22/02
5/29/02
6/5/02
6/12/02
6/19/02
6/26/02
7/3/02
7/10/02
7/17/02
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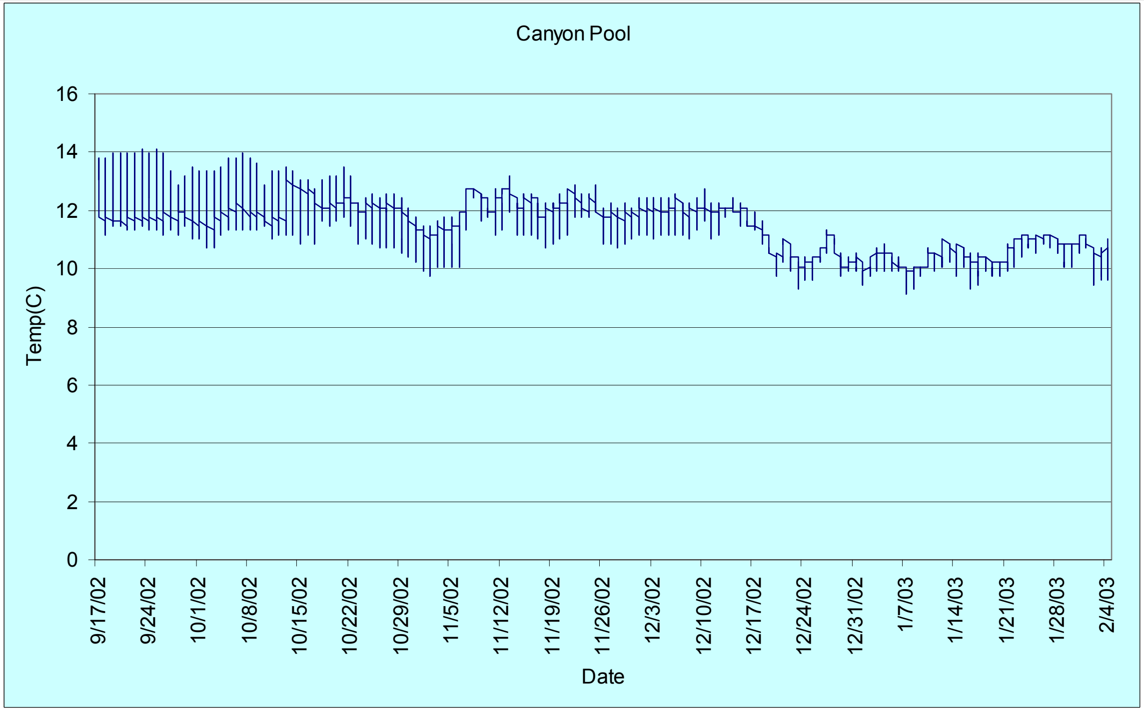
9/4/02
9/11/02
Time


Canyon Pool
Temp(C)
0
2
4
6
8
10
12
14
16
9/17/02
9/24/02
10/1/02
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10/15/02
10/22/02
10/29/02
11/5/02
11/12/02
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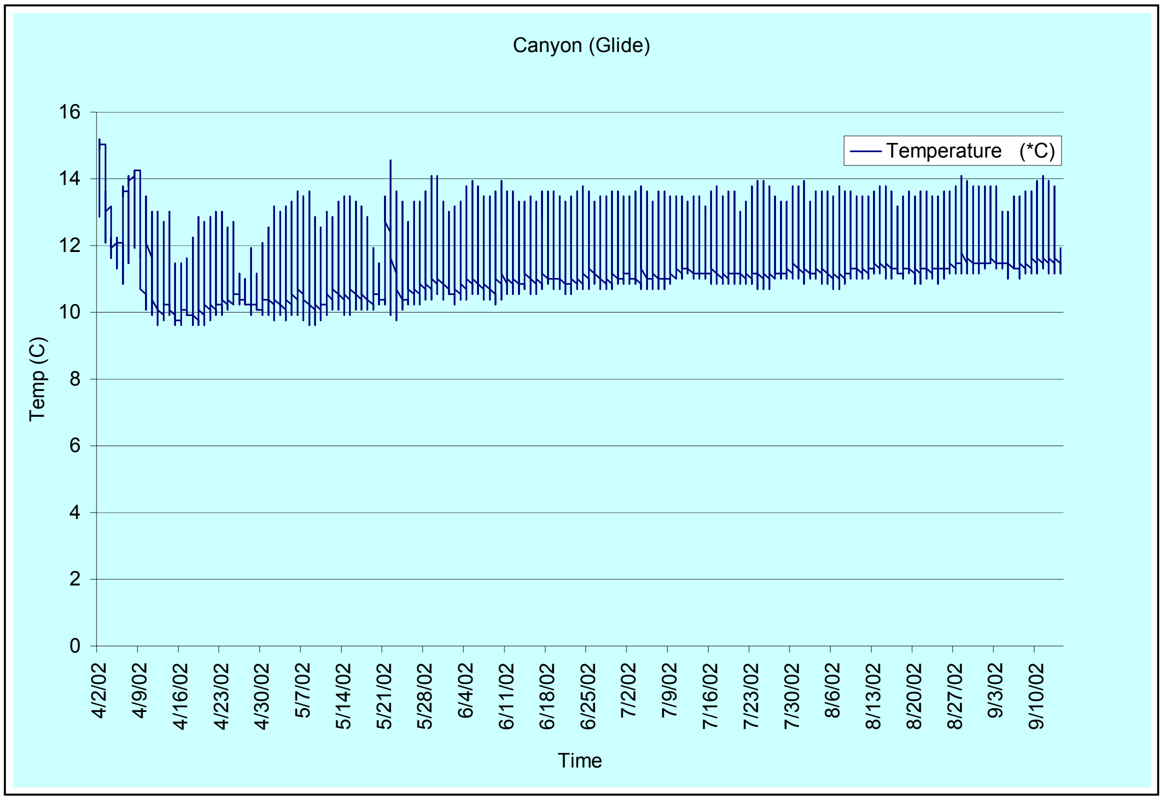
11/26/02
12/3/02
12/10/02
12/17/02
12/24/02
12/31/02
1/7/03
1/14/03
1/21/03
1/28/03
2/4/03
Date


Canyon (Glide)
Temperature (*C)
Temp (C)
0
2
4
6
8
10
12
14
16
4/2/02
4/9/02
4/16/02
4/23/02
4/30/02
5/7/02
5/14/02
5/21/02
5/28/02
6/4/02
6/11/02
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6/25/02
7/2/02
7/9/02
7/16/02
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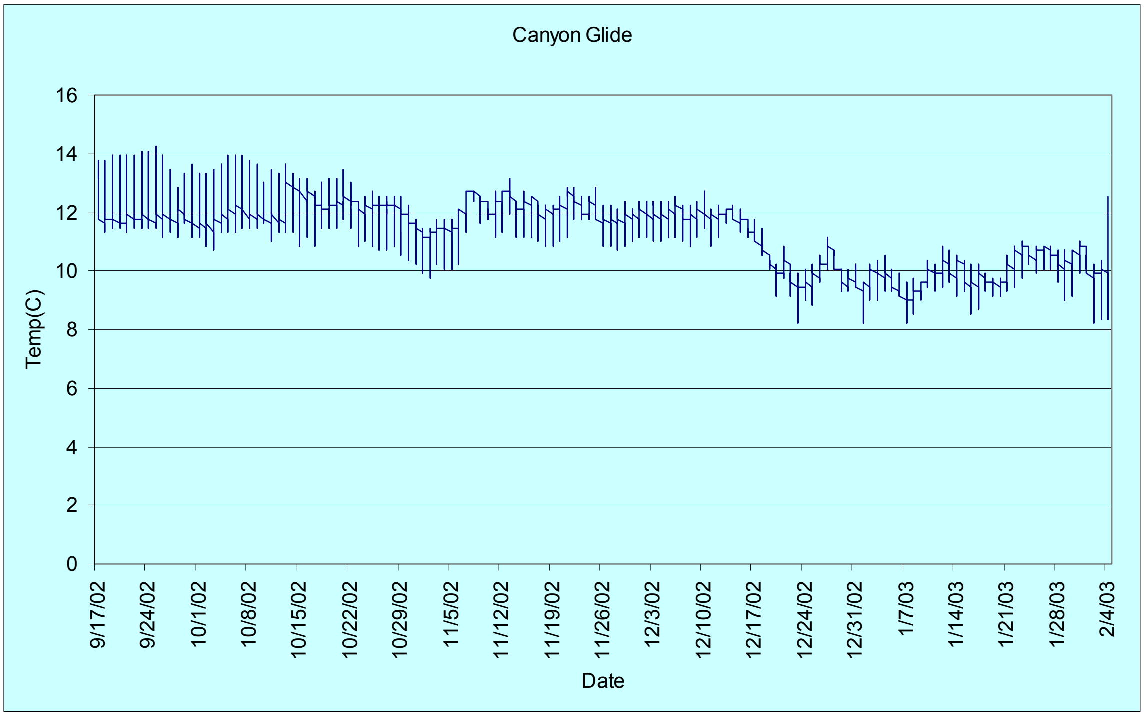
9/3/02
9/10/02
Time


Canyon Glide
Temp(C)
0
2
4
6
8
10
12
14
16
9/17/02
9/24/02
10/1/02
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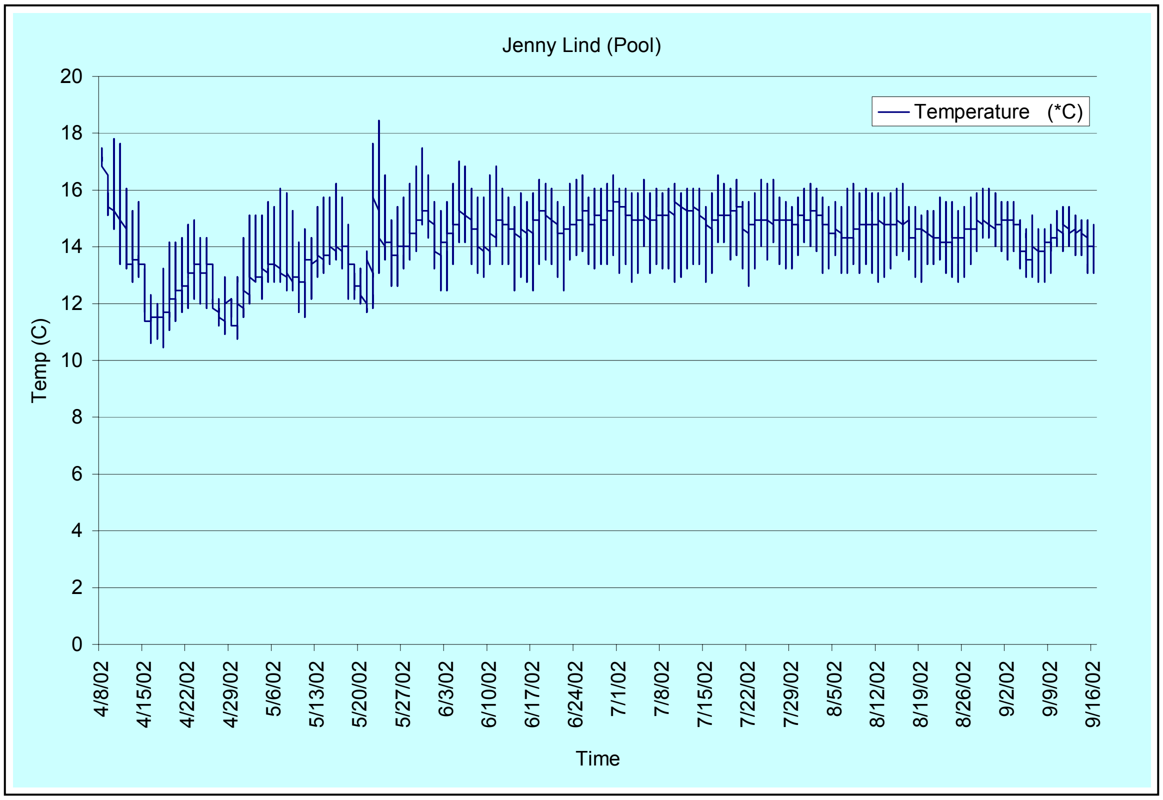
10/15/02
10/22/02
10/29/02
11/5/02
11/12/02
11/19/02
11/26/02
12/3/02
12/10/02
12/17/02
12/24/02
12/31/02
1/7/03
1/14/03
1/21/03
1/28/03
2/4/03
Date

Jenny Lind Reach

Temperature recorders were also placed in a pool and riffle area of the Jenny Lind Reach from April 2002 into January 2003. Water temperature was slightly higher early in the spring because of lower flows from the New Hogan Reservoir. Thereafter water temperature was lower and more consistent. Temperature was slightly higher than that recorded upstream in the Hogan and Canyon Reaches. Water temperature was very similar between the pool and glide areas.


Jenny Lind (Pool)
Temperature (*C)
Temp (C)
0
2
4
6
8
10
12
14
16
18
20
4/8/02
4/15/02
4/22/02
4/29/02
5/6/02
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7/22/02
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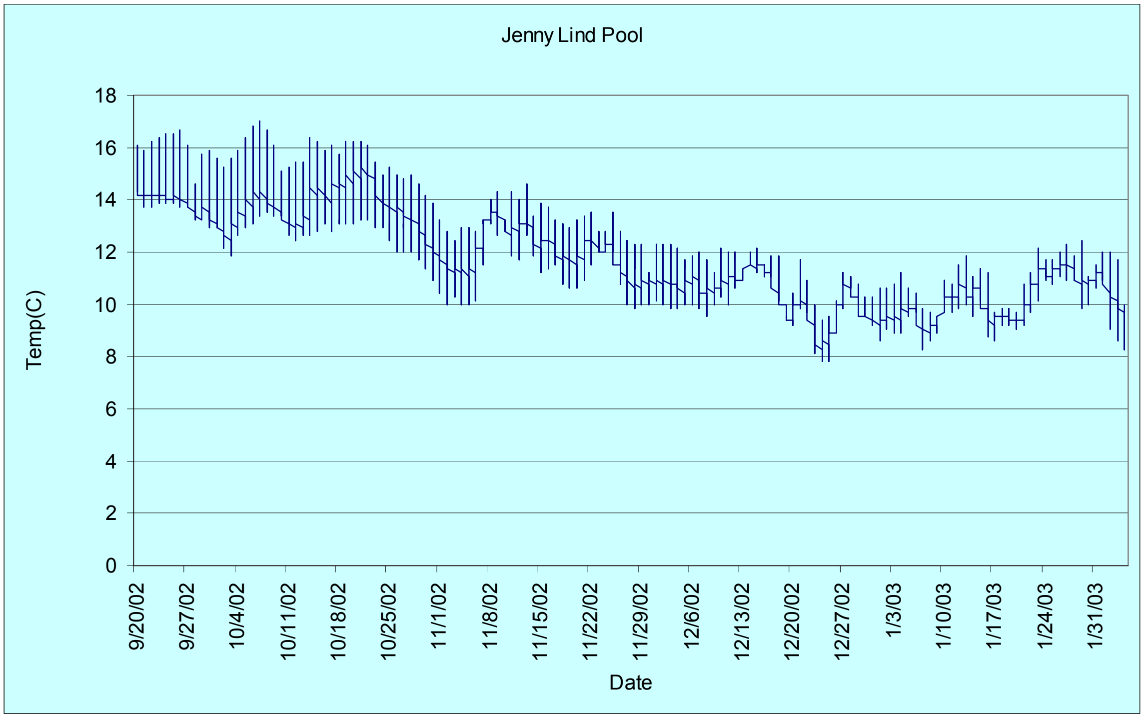
9/9/02
9/16/02
Time


Jenny Lind Pool
Temp(C)
0
2
4
6
8
10
12
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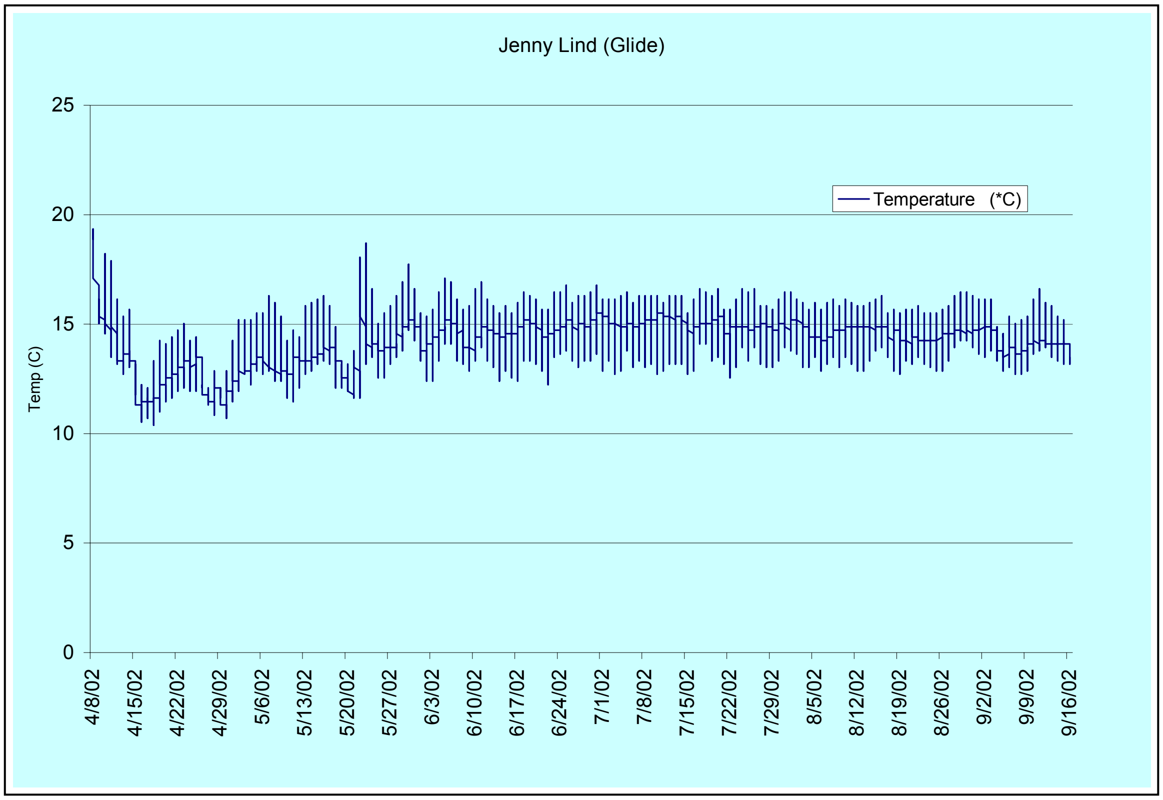
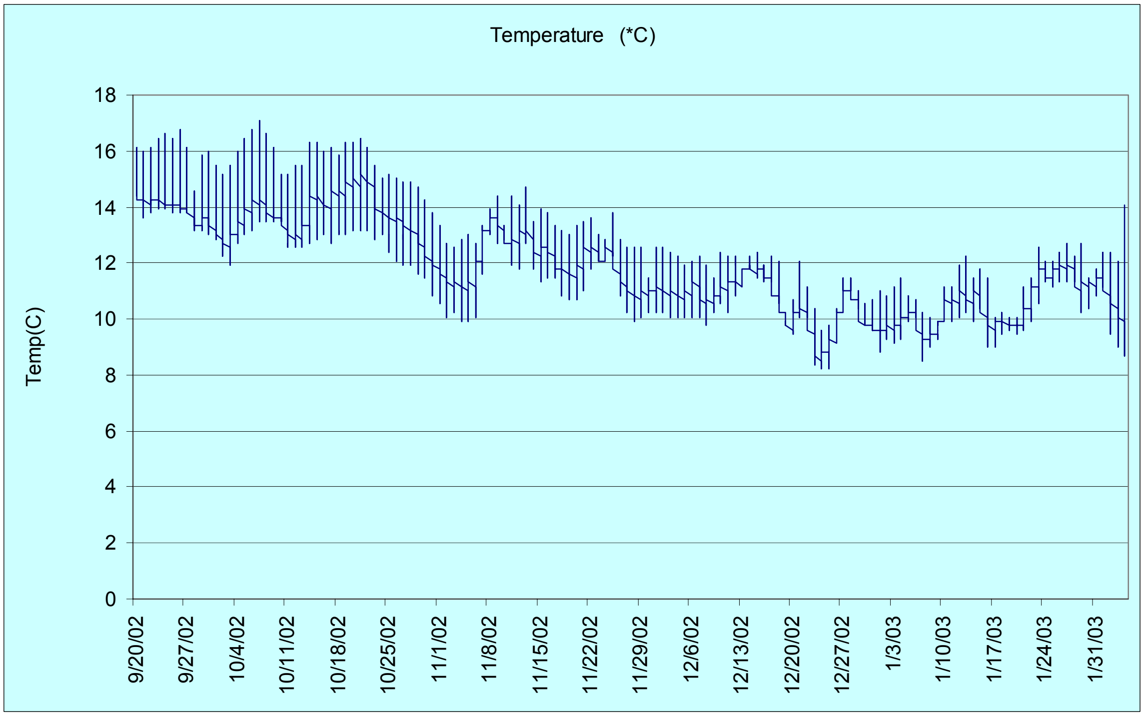
16
18
9/20/02
9/27/02
10/4/02
10/11/02
10/18/02
10/25/02
11/1/02
11/8/02
11/15/02
11/22/02
11/29/02
12/6/02
12/13/02
12/20/02
12/27/02
1/3/03
1/10/03
1/17/03
1/24/03
1/31/03
Date


Jenny Lind (Glide)
Temperature (*C)
Temp (C)
25
20
15
10
5
0
4/8/02
4/15/02
4/22/02
4/29/02
5/6/02
5/13/02
5/20/02
5/27/02
6/3/02
6/10/02
6/17/02
6/24/02
7/1/02
7/8/02
7/15/02
7/22/02
7/29/02
8/5/02
8/12/02
8/19/02
8/26/02
9/2/02
9/9/02
9/16/02


Temperature (*C)
Temp(C)
18
16
14
12
10
8
6
4
2
0
9/20/02
9/27/02
10/4/02
10/11/02
10/18/02
10/25/02
11/1/02
11/8/02
11/15/02
11/22/02
11/29/02
12/6/02
12/13/02
12/20/02
12/27/02
1/3/03
1/10/03
1/17/03
1/24/03
1/31/03