



Lagunitas Limiting Factors Analysis Limiting Factors for Coho Salmon and Steelhead

Prepared for
Marin Resource Conservation District
P.O. Box 1146
Point Reyes Station, CA 94956

Prepared by
Stillwater Sciences
2855 Telegraph Avenue, Suite 400
Berkeley, CA 94705

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Appendix A.	Detailed methods and results.
Appendix B.	Report comments and responses.

1 INTRODUCTION

1.1 Background

The Marin Resource Conservation District, along with the Tomales Bay Watershed Council, Point Reyes National Seashore, Marin Municipal Watershed District (MMWD), Salmon Protection and Watershed Network (SPAWN), Trout Unlimited, and Marin County sponsored the Lagunitas Creek Watershed Limiting Factors Analysis as part of a Proposition 13, Coastal Non-point Source Control Program grant. The overall purpose of the grant is to fill information gaps related to physical and biological factors controlling salmonid population dynamics within the watershed. The project was completed in two phases. Because of the high level of public support and interest within the watershed, a number of studies and monitoring programs have been implemented in recent years. Much of the focus of Phase I work was to review and synthesize this existing information in order to develop hypotheses and identify information gaps concerning salmonid population dynamics. Phase II consisted of implementing focused field studies to fill key information gaps identified during Phase I and synthesizing the results of these studies with analyses that were based on existing information. This report combines the results from both phases of study.

Two focal species were selected by Marin Resource Conservation District and the Lagunitas Advisory Group for consideration during the limiting factors analysis—coho salmon (*Oncorhynchus kisutch*) and steelhead (*O. mykiss*). Although other species/indicators were considered for inclusion in the analysis (freshwater bivalves, California freshwater shrimp, California red-legged frog, aquatic macroinvertebrates), it is believed that a wide variety of ecosystem attributes important to these species and the aquatic community as a whole would be reasonably addressed by focusing on the needs of these two anadromous salmonid species throughout their freshwater life histories.

1.2 Objectives

There were four major objectives for the Lagunitas Creek watershed limiting factors analysis:

1. Develop conceptual models and test hypotheses about factors potentially limiting populations of the focal species using the available literature and data;
2. Refine conceptual models based on the Phase I analysis of available data;
3. Test conceptual models and hypotheses through focused field studies during Phase II;
4. Develop restoration recommendations based on the results of focused field studies and analysis of existing information.

1.3 Approach

Our approach to stream and salmonid restoration is based primarily on restoring or reinitiating geomorphic and ecological processes to achieve the goal of self-sustaining target populations. A key objective is to link land-use activities with their effects on salmonid populations. Human activities affect watershed inputs (e.g., water, sediment), leading to a cascade of changes in important geomorphic processes, habitat characteristics, species abundance, and population dynamics (Figure 1-1).

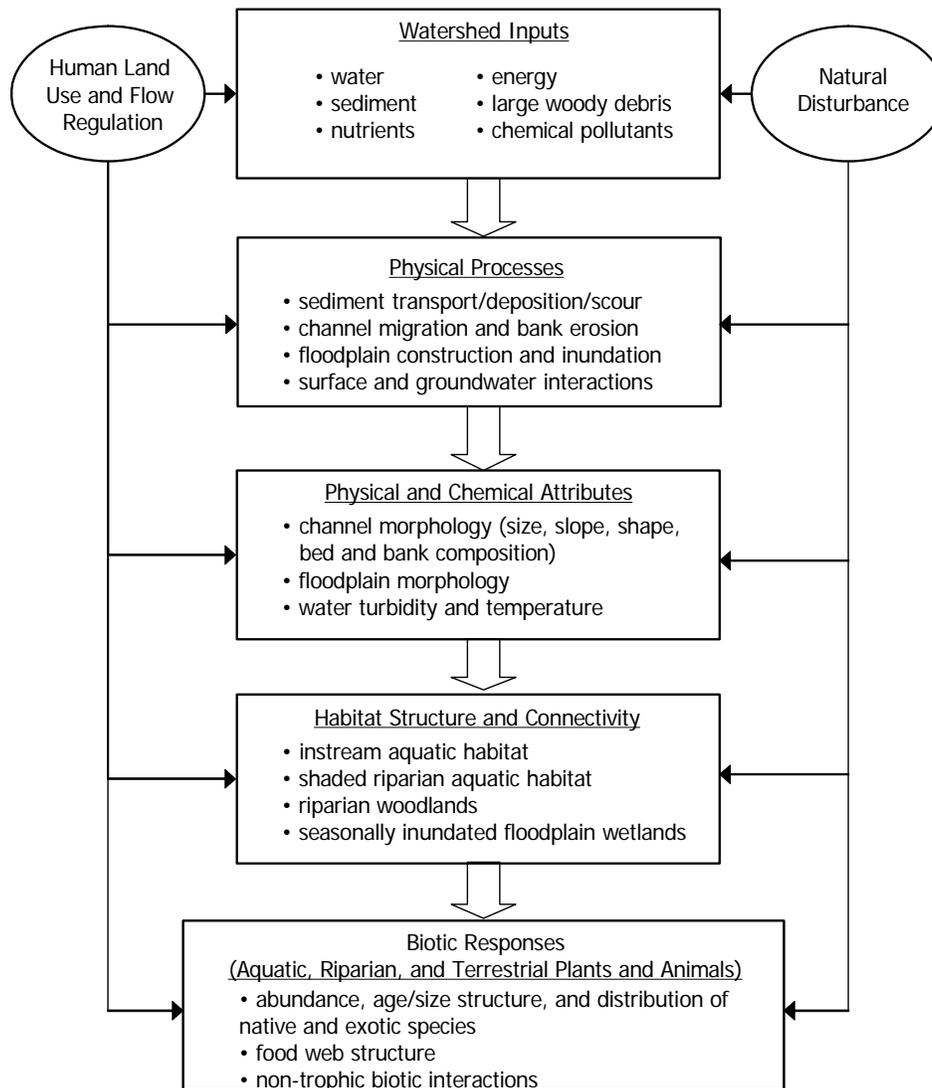


Figure 1-1. A simple conceptual model of the physical and ecological linkages used in developing biotic response indices of river ecosystem health.

A limiting factors analysis integrates the effects of habitat carrying capacity and density-independent mortality across the entire life cycle of an organism to determine mechanisms regulating population growth. Our approach to identifying limiting factors began with a general conceptual model describing the life history of the focal species and identifying habitat constraints most likely to affect survival of key life stages. This general formulation provided a starting point for reviewing available data for the Lagunitas watershed and developing hypotheses about mechanisms controlling salmonid abundance under contemporary conditions. We then tested these hypotheses with existing information and results of focused field studies. The results of these studies were synthesized in multi-stage stock recruitment models that estimate carrying capacities and density-independent mortality at different life stages, with the goal of reaching a mechanistic understanding of how mortality at one or more life stages may limit population size.

The iterative process of hypothesis development, testing, and refinement provided an adaptive and efficient process for identifying priority restoration strategies for salmonid populations.

1.4 Study Area

The study area included stream reaches of Lagunitas Creek, San Geronimo Creek, Devils Gulch, and Olema Creek, in western Marin County, California accessible to anadromous salmonids (Figure 1-2). Peters Dam (Kent Lake) and Nicasio Dam (Nicasio Reservoir) prevent passage of anadromous fish on Lagunitas Creek and Nicasio Creek, respectively.

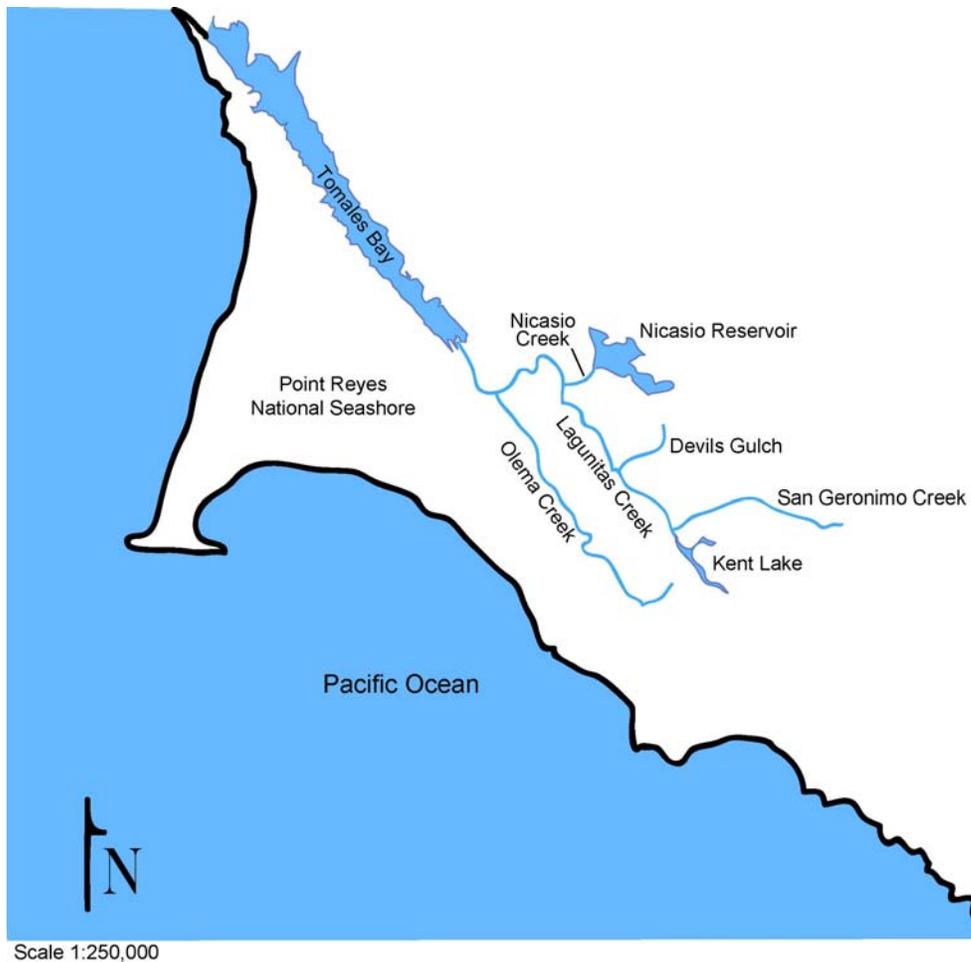


Figure 1-2. Map of the study area.

2 FOCAL SPECIES

In the following sections, we provide a biological overview, a conceptual life history model, and an evaluation of the conceptual model based on existing information and focused field studies for both coho salmon and steelhead.

2.1 Coho Salmon Status and Biological Overview

Coho salmon found in the Lagunitas Creek watershed belong to the Central California Coast evolutionarily significant unit (ESU) (NMFS 1997), which includes coastal drainages from Punta Gorda in northern California south to and including the San Lorenzo River in central California, the drainages of San Francisco and San Pablo bays, excluding the Sacramento-San Joaquin River basin. This ESU is federally listed as endangered under the Endangered Species Act (NMFS 2005, 1996). Critical habitat is designated to include all river reaches and estuarine areas accessible to coho salmon within the ESU's geographic area (NMFS 1999).

Coho salmon populations in California have generally declined and the species no longer occupies many of the streams in California where they used to occur (Hassler et al. 1991, Brown et al. 1994). Brown et al. (1994) estimated that coho salmon populations in California have decreased to less than 6% of 1940 numbers. Coho populations in the southern part of the species' range appear to have shown the greatest declines, with few coho occupying coastal streams near or south of San Francisco Bay. In the Central California Coast ESU, where historical populations are estimated to have numbered between 50,000 and 125,000 naturally spawning fish, current abundance is estimated to be less than 5,000 fish, many of which are considered to be of hatchery origin (Brown and Moyle 1991, Bryant 1994, CDFG 1994).

Although the species is in decline throughout the ESU, the Lagunitas Creek population of coho salmon, including fish spawning the tributary streams of Oleman Creek, San Germonimo Creek, and Devil's Gulch, is the largest and most stable south of the Noyo River within the Central California Coast ESU (Ketcham et al. 2004). Coho salmon are also known to occur in neighboring watersheds such as Pine Gulch and Redwood creek (Ketcham et al. 2004). A summary of the life history and habitat requirements of coho salmon is provided below and the general coho salmon lifecycle is presented in Figure 2-1.

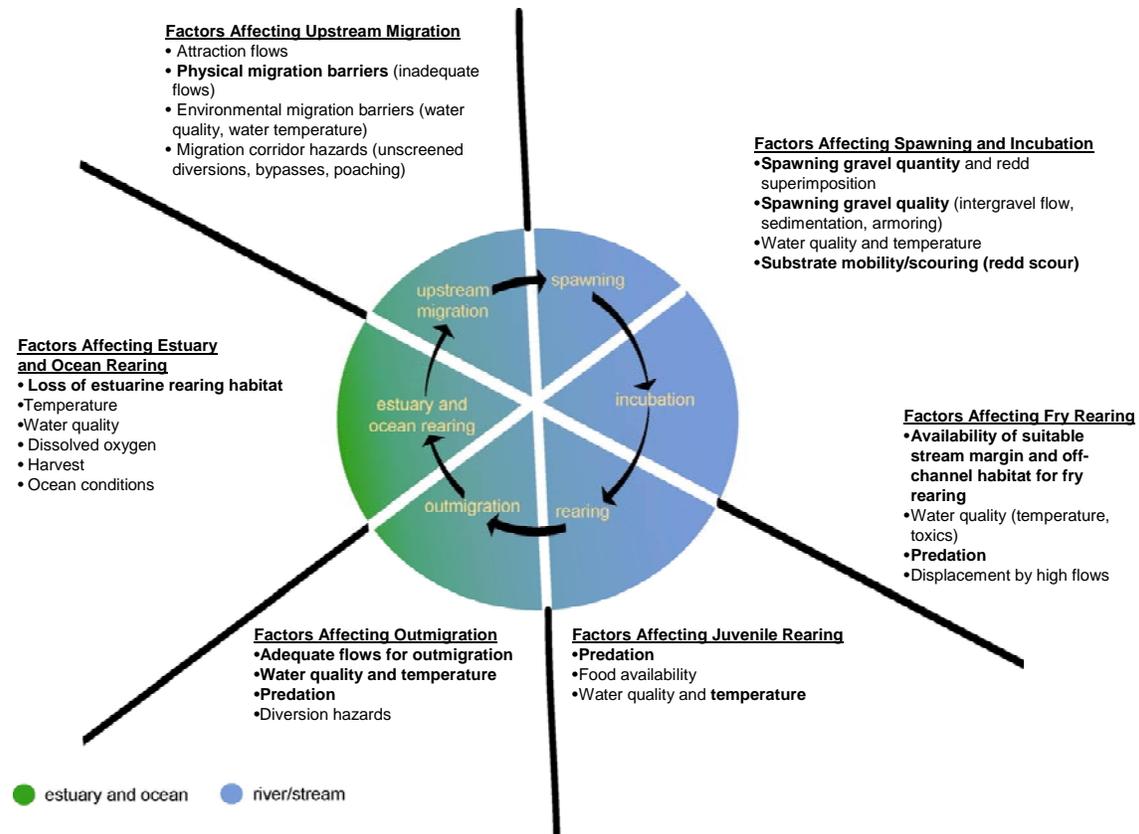


Figure 2-1. Coho salmon life cycle with potential factors affecting each life stage.

2.1.1 Life history overview

Adult coho salmon typically migrate to the vicinity of their natal stream during the fall of their third year (Sandercock 1991). These three-year-old adults have spent one winter in fresh water and one winter in the ocean. Coho salmon do not enter the stream system all at the same time, but instead arrive throughout the spawning season in a pattern that reflects storms that increase flow in the spawning streams (Shapovalov and Taft 1954). There may be some selective advantage to spawning later in the season, since the redds of earlier-spawning fish may be subsequently disturbed by the redd-building activities of later-arriving females (redd superimposition). The early part of a coho salmon run tends to be dominated by males, with females returning in greater numbers during the latter part of the run (Shapovalov and Taft 1954, Moyle et al. 1989).

Spawning sites are typically in areas where there are beds of loose, silt-free, coarse gravel, and nearby cover for adults (Moyle et al. 1989). Redds are usually located in the transitional area at the downstream end (or tail) of pools as they feed into riffles where the water changes from a smooth to a turbulent flow (Hazzard 1932, Hobbs 1937, Smith 1941, Briggs 1953, Stuart 1953). Redd construction may last as long as five days, during which time the female will dig up to seven egg pockets in succession, progressing in an upstream direction (Shapovalov and Taft 1954, Tautz 1977, van den Berghe and Gross 1984). Following deposition in the gravel, coho salmon eggs incubate for 35–50 days at temperatures of approximately 9 to 11°C (48.2 to 51.8°F) (Shapovalov and Taft 1954), with incubation time being inversely related to water temperature. After hatching, salmon larvae (alevins) remain in the gravel while undergoing further

development and absorption of the yolk sac. Emergence begins 2–3 weeks after hatching, and may continue for an additional 2–7 weeks (Shapovalov and Berrian 1940).

Upon emergence from the gravels, coho salmon fry seek low-velocity areas along shallow stream margins (Shapovalov and Taft 1954). As they grow, juvenile coho move to deeper habitats, although they continue to prefer low-velocity habitat throughout the rearing period. Juvenile coho establish territories or form hierarchical groups in pools based on optimal foraging positions (Dolloff and Reeves 1990, Fausch 1993).

During winter, both instream cover and off-channel areas providing slow water are essential for protection against displacement by high flows, and for cover from predation (Bustard and Narver 1975, Mason 1976, Hartman et al. 1982). Deep (>45 cm [>18 in]), slow (<15 cm/s [0.5 ft/s]) areas within or near (<1 m [3.2 ft]) cover of roots, large wood, and flooded brush appear to constitute preferred habitat (Hartman 1965, Bustard and Narver 1975), especially during freshets (Tschaplinski and Hartman 1983, Swales et al. 1986, McMahon and Hartman 1989). Following winter peak flows, juvenile coho salmon emerge from winter hiding areas and feed heavily to grow in size in preparation for downstream migration.

Coho smolt outmigration generally occurs in the spring approximately one year after they emerge from gravels (an age referred to as “1+”). A smaller portion of the outmigration is made up of age-0+ fish migrating downstream as fry, but these fish are believed to have low probability of surviving to adulthood (Otto 1971, Crone and Bond 1976, Hartman et al. 1982). Size at smolting has been correlated with ocean survival of anadromous salmonids (Peterman 1982, Bilton et al. 1982, Ward et al. 1989) and studies have associated higher smolt survivals with juvenile coho salmon migrating at sizes of at least 100 mm fork length (Drucker 1972, Crone and Bond 1976). Shapovalov and Taft (1954) found the average size of outmigrating smolts to range from 103 to 116 mm (4.1 to 4.6 in) in Waddell Creek, California.

2.2 Coho Salmon Conceptual Model

In this section we describe a general conceptual model linking the life history and habitat requirements of coho salmon. The general model combines hypotheses that are well supported by the literature with elements that are the subject of ongoing research. We expect that there will be cases where our general conceptual model does not hold up, requiring subsequent modification and refinement to fit the conditions of particular watersheds. However, the general conceptual model provides a useful starting point for developing and testing hypotheses specific to contemporary conditions within the Lagunitas Creek watershed.

Because juvenile coho salmon generally smolt at age 1+¹ (Randall et al. 1987, Sandercock 1991) and must spend at least one summer and winter in fresh water prior to outmigrating to the sea, they tend to establish territories² in suitable rearing habitat soon after emergence (as opposed to fall Chinook, chum, pink, and sockeye salmon, which only spend a few weeks or months in the rearing stream) (Mason 1966). Territories are established to ensure access to sufficient food supply (Kalleberg 1958). The role of territories in regulating individual growth is an important

¹ We follow conventional methods for assigning fish ages to year classes. Age 0+ refers to fish in their first year of life, sometimes called young-of-the-year; age 1+ to fish in their second year of life, and so on. A fish changes from age 0+ to age 1+ based on the time of hatching, which in the case of steelhead occurs in the spring

² We use the term territory and territory size not only in its traditional sense—as a particular defended area—but also in cases where defense of a particular area may not occur but agonistic behavior by dominant individuals (e.g., nips, fin extensions, charges) effectively determine the maximum density of rearing juvenile coho in a pool.

mechanism for partitioning a finite food resource among juvenile coho salmon (especially in summer when low stream flows reduce invertebrate production and higher temperatures increase metabolic demand). Larger coho salmon smolts may have a higher probability of returning as adults, especially when ocean conditions are less than optimal (Holtby et al. 1990). If territories were not established and defended by individuals, theoretically the result would be either mortality due to starvation or a large number of small smolts that would have very poor ocean survival. The size of individual territories (and thus rearing density) may vary from location to location as a function of food availability and temperature, with territories becoming smaller in more productive or physically complex habitats or colder streams (Mason 1976, Dill et al. 1981).

The maximum number of juvenile coho salmon that even very good summer habitat can support is usually small relative to the number of fry that even a few successful redds can produce. Because of this, spawning gravel availability and egg mortality (e.g., as a result of poor gravel quality, redd dewatering, fungal infections, redd scour) rarely have an important effect on coho salmon population dynamics. In other words, any density-dependent mortality that might result from redd superimposition and density-independent mortality resulting from redd scour and poor gravel quality (among other factors) are usually irrelevant because, despite these sources of mortality, far more fry are typically produced than can be supported by the available rearing habitat (although this may not be the case with depressed populations). Typically, the density-dependent mortality or emigration that occurs when juvenile coho salmon establish territories sets the carrying capacity for juvenile rearing and overshadows other sources of mortality affecting eggs and juveniles. Therefore, the availability of suitable juvenile rearing habitat (either in the summer or winter) is the factor that usually governs the number of coho salmon smolts produced from a stream.

During winter, juvenile coho salmon are typically associated with low-velocity habitats (Hartman 1965, Mundie 1969, Lister and Genoe 1979, Shirvell 1990). When temperatures drop and base flows rise, juvenile coho may make seasonal or temporary shifts to off-channel habitats (Scarlett and Cederholm 1984). This type of winter habitat provides foraging opportunities at base flows and refuge from displacement by high flows (Bell 2001). Since coho salmon tend to spawn and rear in small- or medium-size streams in reaches with moderate gradients (i.e., <3%), the coarse cobble and boulder substrates that are often used as winter cover by other salmonids, such as steelhead and coastal cutthroat trout, are frequently not available. Over-wintering coho salmon, therefore, are often found in slower velocity habitats such as floodplains, sloughs, off-channel water bodies, beaver ponds, and complex in-channel habitats associated with large wood. We postulate that such habitats were abundant in many streams in northern California and the Pacific Northwest under historical conditions.

Under historical conditions, rearing habitat may have been more limited during the summer than winter, because territorial behavior largely disappears in winter, particularly where winter temperatures are very cold, and because floodplains and off-channel habitats were more extensive prior to human disturbance. If winter habitat was even moderately abundant under historical conditions, greater habitat limitations would be expected during the summer when low flows and warmer temperatures would restrict habitat area and food availability would limit a stream's carrying capacity. However, because of the profound changes that have occurred in streams throughout coastal California and the Pacific Northwest, such as large-scale removal of in-channel wood, loss of large wood input through logging in riparian areas, channelization of previously complex drainage patterns, and the construction of levees disconnecting floodplains from the channel, the availability of suitable winter habitat has been greatly diminished. While summer habitat conditions have also deteriorated due to land management activities, it is likely that impacts in many watersheds have disproportionately affected winter habitat. Thus, in our

conceptual model for coho salmon, we initially assume that under current conditions, winter habitat is in shorter supply than summer habitat.

2.3 Evaluation of the Coho Salmon Conceptual Model

In this section we test and refine hypotheses suggested by our general conceptual model through synthesizing existing data (primarily collected by local agencies and groups from 1996 to present) and the results of focused field studies conducted by Stillwater Sciences between November 2004 and June 2006. Three different field studies were conducted to investigate the following: (1) coho salmon early life stage mortality, (2) response of juvenile salmonids to winter floods, and (3) relative production of salmonid smolts from discrete reaches within the Lagunitas Creek watershed. The general methods and major findings of each focused study are presented here, along with analyses of existing information, in order to refine our understanding of the major factors influencing the focal species' population dynamics. Detailed descriptions of study methods and results are included as Appendix A to this report.

2.3.1 Winter habitat limitations

In this section we evaluate evidence for winter habitat limitations for coho salmon, first using evidence from existing fisheries information available from Lagunitas Creek and tributaries, and second using the results from focused field studies. As described in our conceptual model for coho salmon, we initially assume that coho salmon populations are limited by juvenile rearing habitat and that winter habitat under current conditions is typically in shorter supply than summer habitat.

2.3.1.1 Evidence from existing information

In this section we test the hypothesis posited by our general conceptual model that under current conditions winter habitat is typically more limiting than summer habitat for juvenile coho. The first step in assessing the importance of winter carrying capacity would be to compare the available data for summer juvenile coho salmon abundance to the number of juveniles surviving to smolt the following spring. If winter habitat did not limit coho salmon populations, we would expect smolt production to be similar to the number of juvenile coho salmon alive at the end of their first summer. Limited information in Bratovich and Kelley (1988) suggests that this was in fact the case during the early 1980s. At the very low population levels studied during this period, juvenile coho salmon experienced high overwinter survival during years with low winter peak flows. For example, the fall 1983 estimate of 900 juveniles produced 744 age-1+ smolts in spring 1984; the fall 1984 estimate of 2,500 juveniles produced 1,922 age-1+ smolts in spring 1985³.

When we began the limiting factors assessment for Lagunitas Creek, ten years had passed since the last smolt outmigrant data had been collected (Bratovich and Kelley 1988). Redd counts and late-summer juvenile abundance data were available for a roughly 10-year period prior to our analysis, however, and we were able to use this data to indirectly estimate smolt production. We can roughly estimate smolt production by calculating the number of smolts that would be necessary to produce the observed annual adult returns. To do this we must first make assumptions about ocean survival rates and the sex ratio of the adult return. Ocean survival for coho salmon is thought to be density-independent. Assuming that sex ratios of returning adult

³ Furthermore, we suspect that Bratovich and Kelley (1988) underestimated the number of smolts produced in those years because their trapping location at Nicasio Creek is upstream of reaches known to support winter rearing of coho salmon (see Section 2.3.1.2). Therefore, overwinter survival may have been even higher than reported.

coho salmon are approximately 1:1 (a relatively safe assumption; Sandercock 1991) and that redd counts approximate the total number of female coho returning to Lagunitas Creek (a less safe assumption, but the numbers may be reasonable considering the frequency of redd surveys, which are generally conducted weekly, and the attempt to account for redd superimposition), then the total adult return for coho salmon in the Lagunitas watershed is roughly twice the annual redd count. Since nearly all adult female coho along the central California coast return after 2 years at sea and are the product of age 1+ smolts, dividing the total adult return estimated from the redd counts by a range of typical ocean survival rates from the literature gives an approximate estimate of smolt production for a given cohort.

Mean ocean survival rates for coho salmon typically range from 4 to 11% (reviewed in Sandercock 1991). Shapovalov and Taft (1954) documented ocean survival rates ranging from 1 to 8%, with an average of 5%, for coho in central California coastal streams over the four years from 1935 through 1938. Although we recognize that ocean survival will vary from year to year depending upon ocean productivity, we can roughly calculate coho smolt production by using a series of plausible mean ocean survival values. Table 2-1 presents coho smolt production estimates for Lagunitas cohorts spawned in water years (WY) 1994 through 2005, assuming ocean survival rates of 5% and 8%.

Table 2-1. Smolt production estimates for Lagunitas coho salmon.*

WY	Number of juveniles	Redds (WY+2)	5% ocean survival		8% ocean survival	
			Smolt production estimate	Smolt/juv ratio	Smolt production estimate	Smolt/juv ratio
1994	7,788	86	3,440	0.4	2,150	0.3
1995	31,350	254	10,160	0.3	6,350	0.2
1996	5,164	239	9,560	1.9	5,975	1.2
1997	8,480	184	7,360	0.9	4,600	0.5
1998	16,962	203	8,120	0.5	5,075	0.3
1999	4,394	191	7,640	1.7	4,775	1.1
2000	5,724	240	9,600	1.7	6,000	1.0
2001	4,281	134	5,360	1.3	3,350	0.8
2002	23,581	311	12,440	0.5	7,775	0.3
2003	33,625	372	14,880	0.4	9,300	0.3
2004	14,031	134	5,360	0.4	3,350	0.2
2005	21,925	277	11,080	0.5	6,925	0.3

* In this table, watershed totals for redds may deviate from values reported by MMWD. The reason for this discrepancy is that we include redd counts for Lagunitas and San Geronimo creeks and Devil's Gulch, but not for six tributary streams that have been added to the MMWD surveys at various times during the last ten years. Due to the addition of survey areas, adult returns, as indexed by redd counts, may have been underestimated during the first years of sampling. Therefore, we standardized the redd counts used in our analysis to include only redds built in reaches that have been surveyed every year. For most years, this makes little difference; in some years the difference is more dramatic; but, for the sake of hypothesis testing both data sets would yield a similar pattern of smolt:juvenile ratios.

From Table 2-1, it appears that using an ocean survival rate of 5% overestimates smolt production from Lagunitas Creek, as the back-calculated smolt estimates are much higher than the previous summer's juvenile estimates in many years. At an ocean survival rate of 8%, smolt estimates are still slightly higher than the previous summer's juvenile estimates in a few years. They are similar enough, however, to be well within sampling error in either the redd counts and/or the summer juvenile abundance estimates (see Section 2.3.2, Figure 2-9).

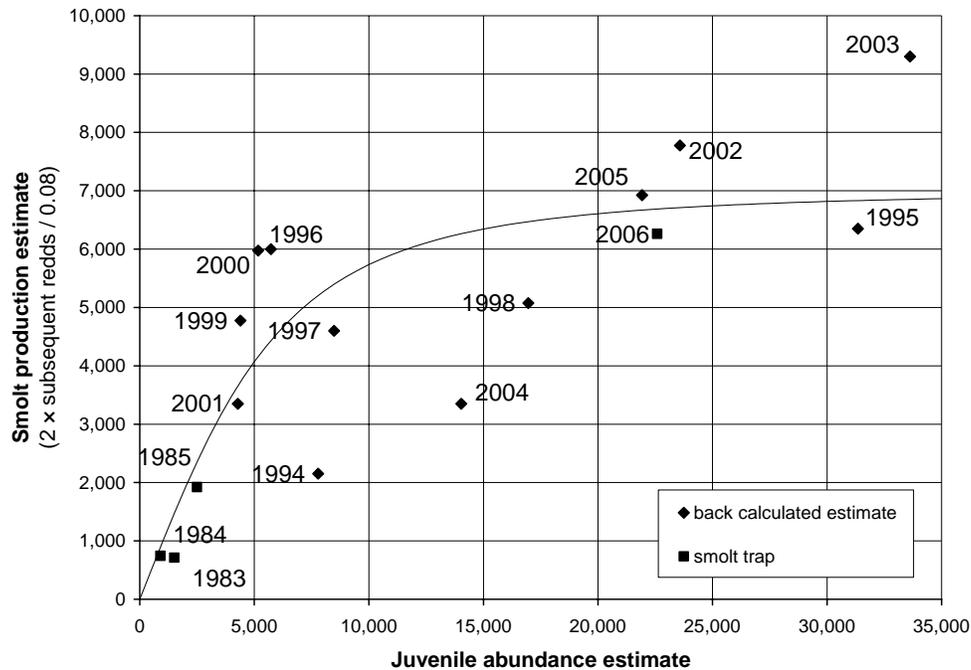


Figure 2-2. The relationship between juvenile coho salmon abundance and smolt production in the Lagunitas watershed. Data labels correspond to the year of smolt outmigration.

It should be noted that the purpose of this exercise was not to precisely estimate ocean survival for coho salmon, which is expected to vary annually and which could only be calculated by comparing smolt abundance estimates with adult returns for each cohort. Rather, the purpose was to roughly estimate smolt production in order to compare it with the previous fall's juvenile abundance to look for evidence of winter habitat limitations. We did, however, want to use a mean ocean survival rate that was both realistic and conservative. Several lines of evidence suggest that an ocean survival of 8% is realistic for the Lagunitas Creek coho salmon population. First, a minimum ocean survival rate can be calculated by comparing juvenile abundance to adult returns for a given cohort. Winter mortality must be negligible for this comparison to yield ocean survival, otherwise actual ocean survival would be even higher. This may not be a reasonable assumption in most years, but it may be true during years of low late-summer juvenile coho abundance (e.g., <6,000 fish). Minimum ocean survival rates averaged 9% for years in which late-fall juvenile abundance was estimated at less than 6,000 fish (1995, 1998, 1999, and 2000). Second, since the initiation of this project, we have been able to measure ocean survival of one cohort by comparing smolt abundance (see Section 2.3.1.2) with adult returns. Ocean survival for this cohort was estimated to be 5% during a period when ocean productivity was believed to be low. In addition, as mentioned previously, 8% is consistent with both the observed juvenile and adult abundance in Lagunitas Creek and values reported in the literature. Finally, for the purposes of analyzing potential winter habitat limitations, our use of 8% for ocean survival is conservative, since at higher ocean survival rates fewer smolts are necessary to produce the observed adult returns. Therefore, if mean ocean survival is actually greater than 8%, smolt estimates would represent an even smaller fraction of the previous fall's juvenile population, which we would interpret as evidence of even greater winter habitat limitations.

Using 8% as a rough measure of mean ocean survival, and estimating smolt production by dividing adult returns by the ocean survival rate, we then took a closer look at the relationship between summer abundance and smolt production to determine whether there was evidence for winter habitat limitations. In Figure 2-2 we plotted both the back-calculated smolt estimates assuming a constant ocean survival rate of 8% and the measured smolt abundance from Bratovich and Kelley (1988) against juvenile abundance estimates from the previous fall to see if a density-dependent relationship can be discerned. The data in Figure 2-2 show an approximately linear increase in smolts with increasing juvenile abundance at low densities (<6,000 juveniles). The generalized Beverton-Holt curve shown in Figure 2-2 represents this type of density-dependent mortality and suggests that winter carrying capacity falls between about 6,000 to 7,000 fish. We would initially hypothesize that the variability around the relationship is due to variation in ocean survival rates or from sampling error in the redd counts or juvenile estimates. The furthest outliers are 1994, 2003, and 2004, but the ocean survival rates necessary to produce such deviations are well within the natural range of variability. For example, for 6,500 smolts (our initial estimate of winter carrying capacity) to result in 372 redds or 744 spawners (the number observed for the cohort smolting in 2003), only a small increase in ocean survival from 8% to 11.5% would be required.

In years when late-summer juvenile abundance is below the estimated winter carrying capacity of 6,000 to 7,000 fish our analysis suggests relatively high winter survival, so that the number of smolts produced increases linearly with increases in the previous fall's juvenile population. In years of higher summer abundance (>6,000 to 7,000 fish), the large discrepancy between late-summer juvenile abundance and estimated smolt production provides strong evidence for winter habitat constraints on smolt production.

Despite winter habitat limitations, the number of smolts is relatively high for the size of the Lagunitas watershed. If ocean survival is similar to the highest survival observed by Shapovalov and Taft (1954), then approximately 2,000 to 7,000 smolts must be produced annually to account for the adult escapement observed during the 1990s (if ocean survival is lower, an even higher number of smolts would be expected; Table 2-1). The relatively high smolt production in the Lagunitas watershed indicates that winter habitat quality may be high relative to other California streams.

2.3.1.2 Field evaluation

Because of relatively strong preliminary evidence for winter habitat limitations for coho salmon, we performed two complementary field studies to determine the habitat characteristics influencing persistence of coho salmon through the winter period and the subsequent production of smolts in the spring. Understanding the characteristics and distribution of high-quality winter habitat and protecting or enhancing those habitats may be important to the long-term productivity of salmonid populations in the Lagunitas Creek watershed. Overwintering habitats for coho salmon in the Lagunitas Creek watershed vary from small tributary streams to larger, mainstem habitats. Based on observations made during reconnaissance field visits, there appear to be areas of floodplain with abundant woody debris, side channels, and sloughs near Tocaloma that could provide excellent winter refuge habitat for juvenile coho. Elsewhere in the watershed, winter habitat quality varies dramatically over short distances. For example, field reconnaissance in Devil's Gulch during the fall of 2004 indicated that pools thought to provide relatively high quality winter habitat were interspersed with pools with seemingly little winter habitat value. High-quality habitat in Devil's Gulch is provided by pools with structural complexity due to the presence of large woody debris, or unembedded coarse (large cobble or boulder) substrates. The field studies included a detailed study to determine the persistence of juvenile salmonids from

habitat units in Devil's Gulch with different winter habitat quality, to quantify the number of steelhead and coho salmon smolts produced in the Lagunitas Creek watershed, and to determine the relative contribution of high-quality winter habitats in the Tocaloma Reach to overall smolt production in the watershed.

Smolt abundance estimates have not been conducted in the Lagunitas Creek watershed since the early 1980s (Bratovich and Kelley 1988). Because the production of salmonid smolts may be limited by factors that occur after late-summer population monitoring (e.g., winter habitat limitations for age 1+ steelhead and age 0+ coho salmon), estimates of smolt production provide important information on winter carrying capacity and fill gaps in the knowledge of salmonid population dynamics in the Lagunitas watershed. Quantifying smolt production from the habitats described above would determine the relative importance of certain areas (e.g., the Tocaloma Reach) to overall salmonid production and provide insight into the habitat characteristics that increase persistence of juvenile salmonids during the winter.

Devil's Gulch experimental design

Here we present the general methods, most pertinent results, and our interpretations of field studies conducted as part of the limiting factors assessment. Descriptions of the specific study methods and detailed results are provided as an appendix to this report. In October 2005 we captured and tagged fish from 28 pool and run study units with varying amounts of woody debris and unembedded coarse (≥ 10 cm [3.9 in]) substrate in an approximately 1.3-km [0.8-mi] study reach of Devil's Gulch. The experiment included a total of 23 pools and 5 runs, which represented about 80% of the pool habitat and 20% of the run habitat within the study reach.

To describe physical conditions at the beginning of the study, we measured cover, depth, and the dimensions of each study unit. All woody debris and unembedded coarse substrate cover within the 0.75 bankfull channel was measured using methods similar to those described in Kinsolving and Bain (1990). We chose the 0.75 bankfull width to represent the extent of channel inundated during winter storms that would cause fish to seek flow refuge. Stream stage within the study reach was measured by a pressure transducer and stream temperature was measured with a thermograph that recorded data at 15-minute intervals.

We used multiple-pass electrofishing to capture fish from all study units. All fish greater than 60 mm FL were tagged with individually coded passive integrated transponder (PIT) tags. Fish were allowed to recover and then were released into their original habitat unit. We relocated fish at monthly intervals from October through February using a hand-held, submersible PIT-tag reader during base flow periods between winter storms. The reader consisted of a sealed antenna coil mounted on a pole and was designed to be moved over the streambed to search for tagged fish. Similar to electrofishing, study units were blocked with netting at their upstream and downstream ends and three passes with the reader were made through each study unit. In addition, the entire study reach was surveyed with a single pass of the mobile tag reader to relocate any fish that had moved outside of the study units. Coincident with the monthly relocations of PIT-tagged fish, a subset of habitat units were electrofished to compare sampling efficiency with the mobile tag reader. Sampling was conducted according to the methods described above, with three passes of electrofishing following three passes with the mobile tag reader within each study unit. Over three sampling events, a total of 13 study units were surveyed using both methods. We also conducted exploratory field surveys to attempt to relocate PIT-tagged salmonids with the hand-held antenna during peak winter flow events. To complete the experiment in late February 2007, we again employed multiple-pass electrofishing in the study units to recapture tagged fish and to obtain late-winter densities of juvenile salmonids.

Devil's Gulch results

We tagged 1,142 coho salmon in 28 study pools and runs in Devil's Gulch during October 2005. Following the initial tagging effort in October, we observed an approximately 30% reduction in the abundance of PIT-tagged coho in study pools by the first relocation survey in November (Figure 2-3). This period preceded the first winter storms, so the initial reduction in overall abundance was unrelated to hydrologic conditions in Devil's Gulch. Instead, the initial decline in PIT-tagged fish was attributable to several factors: (1) differences in detection efficiency between the capture method of electrofishing and relocations using the hand-held reader; (2) redistribution of tagged fish from the study units to other habitat units not sampled within the study reach; and (3) emigration from the study reach.

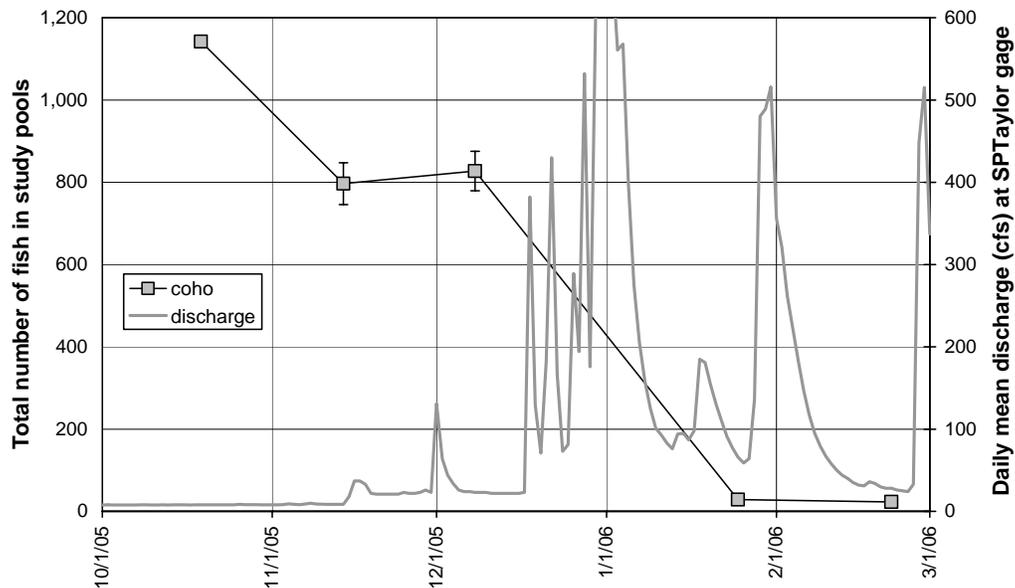


Figure 2-3. Abundance of PIT-tagged coho salmon in study pools within Devil's Gulch and discharge patterns in Lagunitas Creek during winter of 2005-2006.

Differences in detection efficiency were observed for pools in which both mobile reader and electrofishing surveys were conducted. Although these comparisons were limited, the mobile reader underestimated the number of tagged coho in some cases (Figure 2-4).

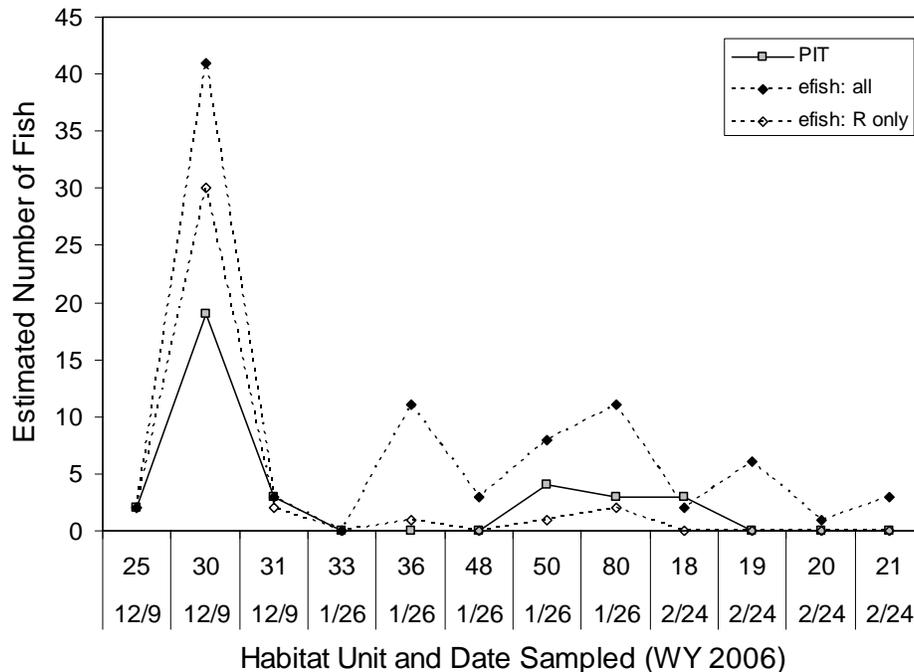


Figure 2-4. Comparison of the estimated number of juvenile coho salmon in Devil's Gulch study pools sampled by the hand held PIT-tag reader and electrofishing. "PIT" refers to coho detected with the tag reader; "efish: R only" refers to tagged coho captured via electrofishing; "efish: all" refers to all coho captured during electrofishing.

Following the initial decline in fish abundance, no significant change in the estimated number of tagged coho occurred between relocation surveys in November and December. During this period the stream experienced two small freshets (maximum of 131 cfs mean daily flow at the SP Taylor gage), but the magnitude of these storms was not sufficient to cause significant emigration of coho salmon from Devil's Gulch.

Beginning on 22 December 2005 and continuing through mid-January 2006, winter storms caused a series of floods in Devil's Gulch culminating in an approximately 15–25 year flow event on December 30, 2005. The SP Taylor stream gage recorded a peak instantaneous discharge of 7,080 cfs on this date, which is the highest recorded flow since the gage was installed in 1983. This storm caused a significant reduction in the abundance of tagged coho, which declined from approximately 800 fish in November to approximately 30 fish in February (a 96% reduction).

A final fish relocation survey was conducted in February 2006. Despite the large winter flood between the January and February relocation surveys, no significant reduction in the abundance of PIT-tagged coho was observed between the January and February sampling.

The 27 tagged coho recaptured at the end of the study were distributed across 15 individual habitat units. Of these fish, 14 were recaptured downstream of their fall capture location, 9 fish were recaptured at their original capture location, and 4 were recaptured upstream of their original capture location. Because so few of the tagged coho remained in the stream over the winter, we were not able to detect the influence of habitat complexity on their retention. Major changes in the characteristics of study pools as a result of extremely high stream flows also

complicated our ability to relate fish retention to cover. However, prior to major habitat changes caused by the storm on December 30, 2005, we conducted exploratory field studies to relocate PIT-tagged fish from a subset of habitat units during peak winter storm flows. Our field observations suggest that during winter floods, juvenile coho salmon used slackwater habitats either along the stream margin or in the lee of debris jams. It appeared that complex debris jams that spanned from the winter base flow channel up through the bankfull channel provided low-velocity habitat through all stages of the hydrograph.

Juvenile coho salmon abundance declined 98% in Devil's Gulch between late October 2005 and late February 2006. The reduction is consistent with our initial hypothesis that winter habitat availability limits the production of coho within the Lagunitas watershed. This result is also consistent with our conceptual model of coho habitat use that assumes winter survival to be highest in stream channels with off-channel habitat, such as alcoves, backwaters, and side-channels—features that are absent from the confined channel of Devil's Gulch.

The fate of the majority of fish initially tagged in Devil's Gulch is not known. Most California streams no longer have high-quality winter rearing in downstream, low-gradient reaches above the estuary. Coho displaced from summer rearing areas in these streams are not likely to survive to smolt. They either become exhausted while attempting to seek refuge habitat and die, become prey due to lack of cover, or are swept downstream to sea before they are physiologically prepared for the saltwater environment. As will be discussed in the following section, we found evidence that at least some fish emigrating from Devil's Gulch during the winter were able to survive to smolt by residing in the mainstem Lagunitas Creek, primarily the Tocaloma Reach.

Lagunitas downstream migrant trapping methods

Downstream migrant trapping was conducted at three locations in the Lagunitas Creek watershed from mid-March through early June 2006 to estimate the production of coho salmon and steelhead smolts from stream reaches that varied in their channel characteristics. Downstream migrant traps included a rotary screw trap (the "Lower" trap) installed at the upstream extent of tidal influence in lower Lagunitas Creek approximately 2.1 miles above the Highway 1 bridge crossing in Point Reyes Station. A second rotary screw trap (the "Upper" trap) was installed 5.6 miles upstream of Highway 1. The third trap ("San Geronimo trap") consisted of a fyke net installed by SPAWN near the mouth of San Geronimo Creek, approximately 11.2 miles upstream of the Highway 1 bridge (Appendix A, Figure A-21).

The lower and upper traps were monitored beginning on March 20, the San Geronimo trap beginning on April 21, and continuing at all traps through June 9, 2006. Flows were highly variable, and monitoring was suspended for short periods due to high flows and/or debris accumulation (see Appendix A). No interruptions to monitoring occurred at the San Geronimo trap.

Fish were collected daily from the traps. All juvenile salmonids captured in the traps were anesthetized, fork length (FL) was measured to the nearest millimeter, and wet weight to the nearest 0.01 g. All salmonids were examined for indications of smolting (e.g., deciduous scales, silver coloration). To estimate trap efficiency, up to 25 fish per day of each species were marked using fin clips indicating the location and the week captured. Marked fish were subsequently released 200 to 300 meters above their point of capture. All captured fish were checked for marks and were scanned with hand held PIT-tag detectors to identify any fish that were previously tagged in the Devil's Gulch companion study.

Lagunitas downstream migrant trapping results

A total of 6,261 coho smolts were estimated to emigrate from Lagunitas Creek during spring 2006. This total falls within the winter carrying capacity of 6,000 to 7,000 fish predicted by our analysis of historical juvenile numbers and adult returns (Figure 2-2). The majority of coho salmon smolts captured in downstream migrant traps in the Lagunitas watershed emigrated during the period between April 15 and May 15, 2006 (Figure 2-5), consistent with the timing of emigration observed in other regional studies (e.g., Shapovalov and Taft 1954). Fish captures at the three downstream migrant traps within the Lagunitas watershed indicate that stream reaches were not uniformly productive in terms of coho salmon smolt abundance. An estimated 2,268 coho smolts were captured at the San Geronimo trap; 2,397 smolts were captured at the upper Lagunitas trap; and 6,261 smolts were captured at the lower Lagunitas trap (Table 2-2). We would expect more smolts to be captured at downstream locations, independent of habitat quality, simply because a greater extent of potentially occupied habitat is present above downstream traps compared to upstream traps. However, when the number of smolts captured in stream reaches between each trap are expressed in terms of reach length, the value of the Tocaloma Reach for coho salmon smolt production is evident. Over half of the 6,261 coho salmon smolts were produced in the 7.2-km Tocaloma Reach, which is roughly equivalent to a linear density of approximately 530 fish/km. This compares to linear densities of 10 fish/km in the reach between the Upper Lagunitas trap (includes Lagunitas Creek from the Upper Lagunitas trap to Peters Dam and Devil's Gulch) and 300 fish/km in San Geronimo Creek. These results are consistent with our initial hypothesis that the Tocaloma Reach, bracketed by the Upper and Lower Lagunitas traps, provides high-quality winter habitat for coho salmon. Qualitative observations made during the winter indicated numerous off-channel habitats such as large debris jams, backwaters, side-channels, sloughs, and inundated floodplains that form during winter freshets. These habitats, illustrated in photographs in Appendix A, Figure A-22 and A-23, contrast with the typically confined channel conditions of the drainage network upstream of the Tocaloma Reach. Photographs in Appendix A, Figures A-24 and A-25 illustrate the lack of refuge habitat during a moderately high flow event typical of the drainage network above the Tocaloma Reach.

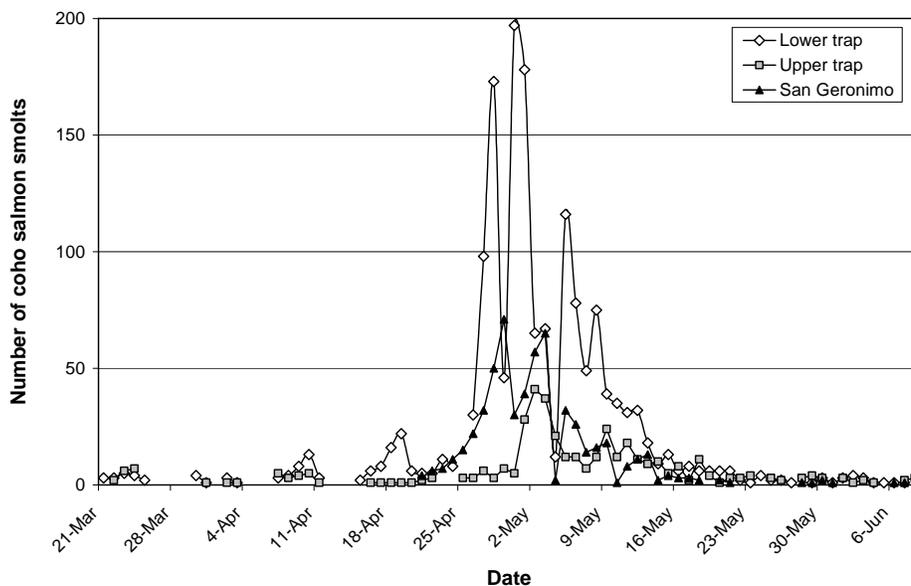


Figure 2-5. Coho salmon smolts captured by calendar date at downstream migrant traps in the Lagunitas Creek watershed, 2006.

Table 2-2. Estimate abundance and capture efficiency of coho salmon smolts at downstream migrant traps in San Geronimo Creek and upper and lower Lagunitas Creek, spring 2006.

Trap	Abundance		Trap efficiency	
	Estimate	95% conf. int.	Estimate	95% conf. int.
San Geronimo Creek	2,268	1,849–2,812	0.22	0.18–0.26
Upper Lagunitas Creek	2,397	1,937–3,018	0.15	0.12–0.19
Lower Lagunitas Creek	6,261	5,282–7,499	0.24	0.20–0.29

Although not achieving the production of the Tocaloma Reach, smolt production from San Geronimo Creek was relatively high despite its confined channel. The majority of coho smolts produced from the drainage network above the Tocaloma Reach originated in San Geronimo Creek (Table 2-2). According to our earlier observations stemming from the initial reconnaissance surveys of the Lagunitas Creek watershed, we did not expect San Geronimo to be a large producer of coho salmon smolts. This hypothesis was based on the lack of woody debris, and a relatively incised and confined stream channel. However, other watershed characteristics may result in high-quality winter habitat for coho salmon. We hypothesize that many of the small intermittent tributaries to San Geronimo Creek provide suitable refuge habitat when they become inundated during the winter. Other researchers have documented winter use of intermittent and small tributaries by juvenile coho salmon. Wigington et al. (2006) found that coho salmon immigrated from mainstem channels into intermittent stream habitats once flow resumed in the fall. In their study, coho salmon using the intermittent tributaries experienced higher winter survival and attained larger sizes than counterparts rearing in mainstem habitat.

The size of coho smolts captured at the Lower Lagunitas trap was larger, on average, than for smolts captured at both upstream traps. Appendix A includes length frequencies of coho summarized by week of capture. At all traps, we observed an initial increase in mean smolt size, followed by a gradual decline through the emigration period. This result is similar to trends of earlier migrating smolts being larger than later migrants that have been observed for coho salmon by Shapovalov and Taft (1954) and for sockeye salmon by Crawford et al. (1992). The difference in mean smolt size among the three downstream migrant traps suggests that growth opportunities are greater for fish that reared in the winter and spring in the Tocaloma Reach. Although in most cases we can not definitively identify the winter location of individual fish, two lines of evidence suggest that variability in smolt size reflects differences in growth achieved in the respective stream reaches separated by the traps prior to the emigration period. First, once fish initiated their downstream migration, emigration to the estuary proceeded relatively quickly. For example, of the 92 coho smolts that were originally marked at the San Geronimo trap and then recaptured at the Lower trap, 94% were recaptured the week following their initial marking period (Figure 2-6). Second, the size distribution of fish marked at upstream traps and recaptured at the Lower trap is similar to the size distribution at their first point of capture (Figure 2-7). Since size at smolting heavily influences ocean survival, the Tocaloma Reach is an important rearing reach not only because it produces large numbers of coho smolts, but also because it provides good growth opportunities.

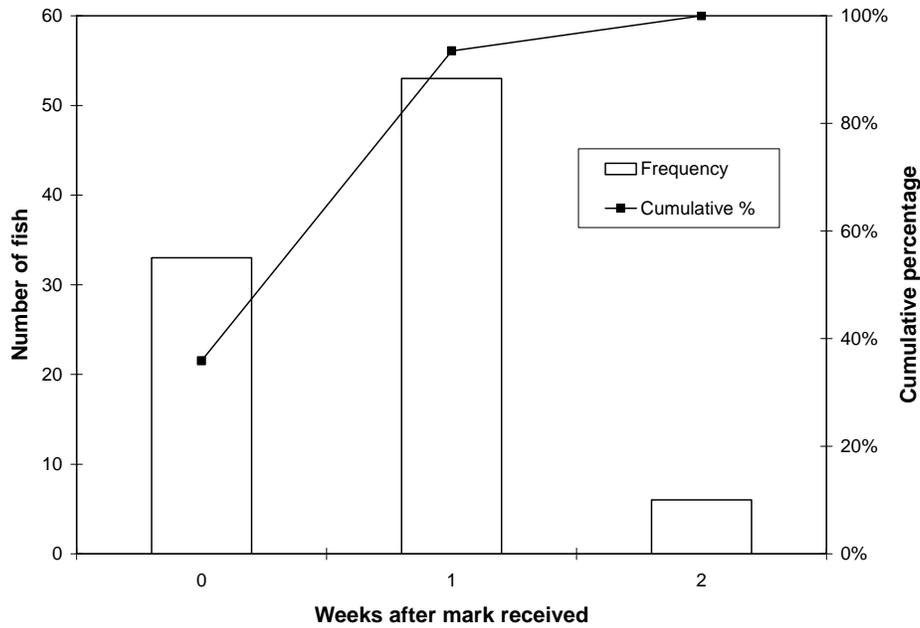


Figure 2-6. Weeks until recaptured of juvenile coho originally marked at the San Geronimo trap and recaptured at the lower Lagunitas rotary screw trap.

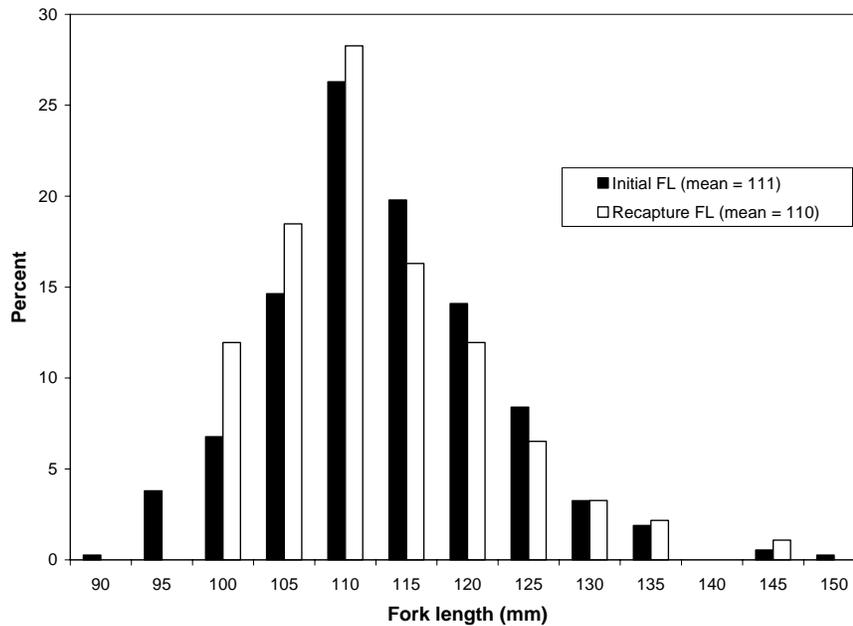


Figure 2-7. Size distribution of marked juvenile coho salmon at their initial capture in San Geronimo Creek and at their subsequent recapture at the lower Lagunitas rotary screw trap.

Recapture rates at the Lower trap were consistent across groups of coho smolts marked and released at each of the three trap locations (Table 2-3), suggesting that mortality was low during

emigration. If significant mortality occurred during emigration, we would expect much lower recapture rates for fish initially marked and release at upstream trap locations. The most common source of mortality of outmigrating smolts is predation. High turbidity during outmigration and lack of predatory fish large enough to eat coho smolts in Lagunitas Creek probably account for the apparently low mortality rate.

Table 2-3. Mark and recapture histories of coho captured in San Geronimo Creek (SG) and upper and lower Lagunitas Creek, 2006.*

Trap		Mark/recapture histories			Efficiency estimates		
		SG coho	Upper coho	Lower coho	SG coho	Upper coho	Lower coho
SG	marked	365					
	recaptured	79			0.22		
Upper	marked		262				
	recaptured	55	30		0.15	0.11	
Lower	marked			509			
	recaptured	88	97	152	0.24	0.37	0.30

During smolt trapping, we recaptured a total of 32 PIT-tagged juvenile coho that were originally marked during the fall of 2005 in the Devil’s Gulch study. Of the tagged fish, 30 were recaptured at the lower trap and two were recaptured at the upper trap. For the majority of these fish, their last known relocation within Devil’s Gulch occurred during December surveys preceding the large winter storms (Figure 2-8). This result suggests that these fish emigrated from Devil’s Gulch during or right before the large winter storms occurred and found suitable winter refuge in downstream reaches of Lagunitas Creek. Although their exact winter locations are not known, the much higher catch rate of tagged fish at the lower trap suggests that the majority of these fish emigrated from Devil’s Gulch to the Tocaloma Reach of Lagunitas Creek.

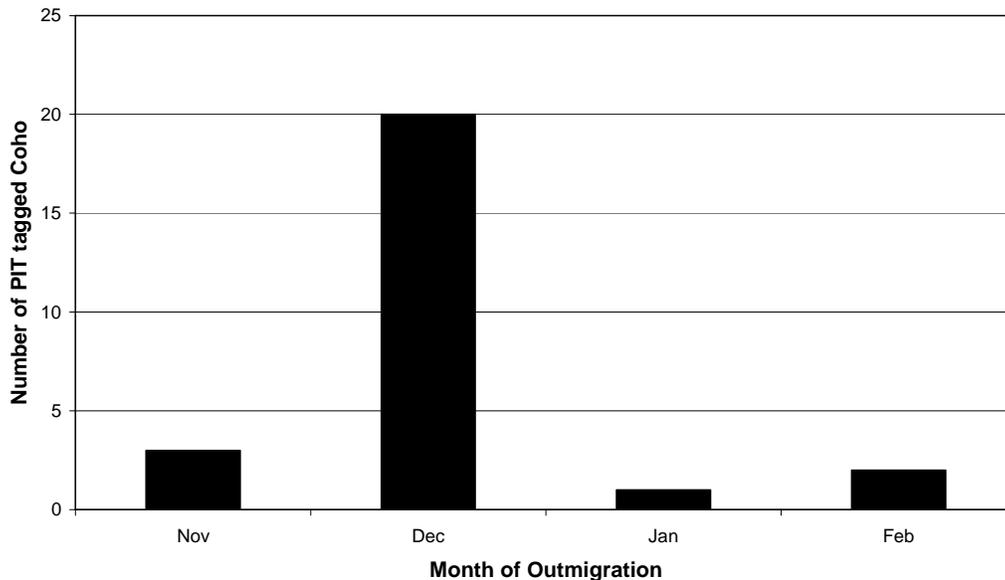


Figure 2-8. Date of last known relocation within Devil’s Gulch of PIT-tagged juvenile coho salmon recaptured at the upper or lower Lagunitas rotary screw trap.

Summary of winter habitat investigations

Both the review of existing fisheries information and the focused field studies suggest that winter habitat limits the coho population of Lagunitas Creek during years when the late-summer juvenile abundance is above approximately 6,000 to 7,000 fish. During this study, we observed very low winter survival in the confined channel of Devil's Gulch, while the majority of smolt production occurred in the unconfined Tocaloma reach of Lagunitas Creek. The implications of these findings for potential management and restoration activities are discussed in Section 3.1.

2.3.2 Early lifestage mortality

Analyses of both the existing fish population data and results of field studies described above suggest that in years where juvenile coho abundance exceeds approximately 6,000 – 7,000 in the fall, winter habitat conditions limit the number of smolts produced. However, in some years fall abundance drops below this hypothesized winter carrying capacity (Figure 2-9), indicating that factors occurring prior to winter may constrain smolt production in some years. In this section we use our general conceptual model (Section 2.2) to evaluate the most likely causes of low fall abundance, first by examining existing data, and subsequently through focused field studies.

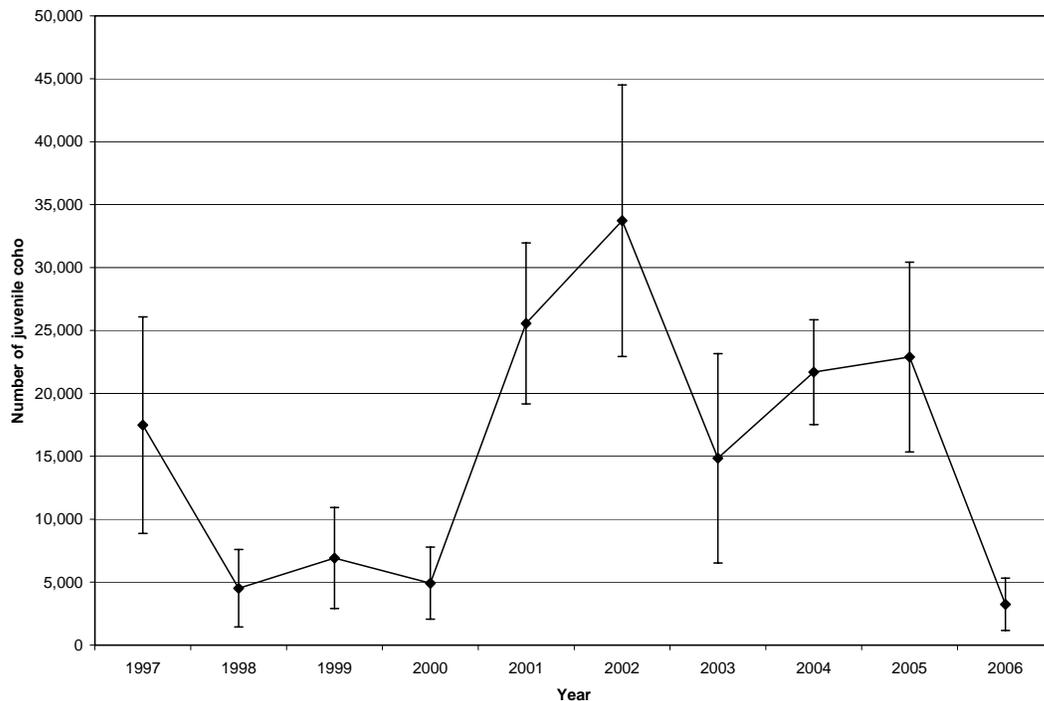


Figure 2-9. Juvenile coho salmon population estimates for the Lagunitas watershed with 95 percent confidence intervals (± 1.96 standard deviations). Sample site data prior to 1997 was not available to calculate error associated with the extrapolated estimate.

Within Section 2.2, we hypothesize that even under conditions of low reproductive success, such as low escapements or high incubation mortality, there should be sufficient fry in most years to seed available juvenile rearing habitat to carrying capacity. If this hypothesis is true, we would

expect to see little variation in late-summer juvenile densities (i.e., the densities after any territorial behavior has regulated juvenile abundance) between years in watersheds with relatively consistent summer rearing conditions. If late-summer juvenile densities were relatively consistent across years with differing adult returns we would conclude that, consistent with our conceptual model, mortality during the egg, alevin, and fry life stages does not affect coho population dynamics. Conversely, if juvenile densities varied dramatically across years with similar adult returns, contradicting our conceptual model, we would expect that early life stage mortality may be an important factor affecting population dynamics. Therefore, the first step in evaluating this aspect of our conceptual model was to examine recent trends in late-summer juvenile coho abundance in relation to annual adult returns.

2.3.2.1 Evidence from existing information

In examining the historical fisheries data, we discovered that there is considerable variation in year-to-year juvenile coho abundance, contrary to our conceptual model, (Figure 2-10). For example, similar redd counts in the years 2000 and 2001 resulted in very different juvenile abundance the following summer (Table 2-4). This contradicts our presumption that late-summer juvenile abundance should be relatively consistent from year to year, and led us to explore the following hypotheses:

1. The quality of late-summer abundance data varies from year to year due to inconsistent field or analytical methods, *or* the population estimates are not sufficiently precise to statistically differentiate between years with high and low juvenile abundance.
2. In some years, but not all, high density-independent mortality of juvenile coho salmon occurs *after* summer densities have been established through territorial behavior.
3. In some years, but not all, extremely high mortality during early life stages (i.e., incubating eggs, developing alevins, and/or early emergent fry) results in juvenile populations below summer carrying capacity.

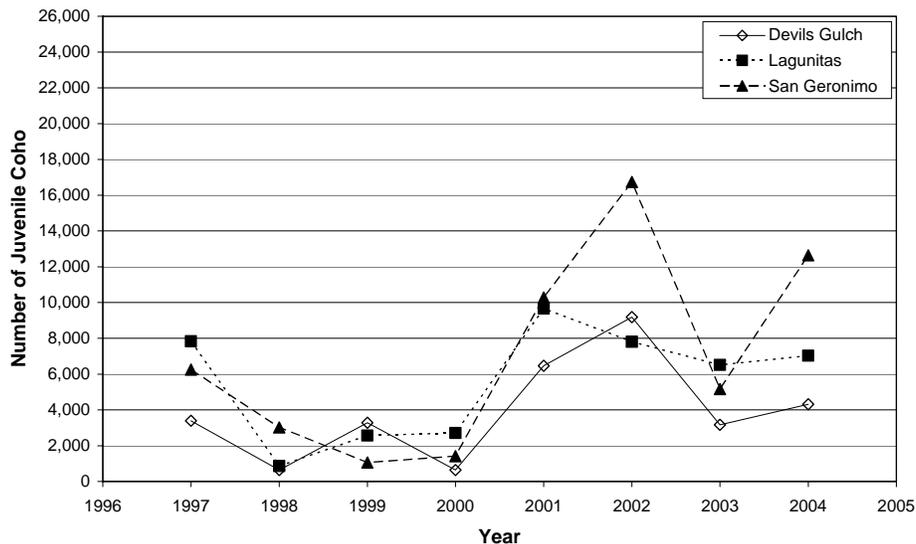


Figure 2-10. Juvenile coho salmon population estimates for the Lagunitas Creek, San Geronimo Creek, and Devil's Gulch.

To evaluate the first hypothesis, we reviewed the sampling methods used to derive late-summer population estimates. Detailed methods on the sampling techniques used by MMWD to estimate juvenile salmonid populations are available in annual reports (e.g., Ettlinger et al. 2006, available at <http://www.marinwater.org/>). In summary, stream reaches are surveyed every three to five years to determine the relative abundance of pool, run, and riffle habitats. A number of sample sites comprising several habitat units each and which are distributed throughout the watershed are selected and sampled annually. Juvenile fish densities (fish/length of stream) for each habitat unit are estimated using multiple-pass electrofishing, or occasionally snorkeling, and are reported by fish species and age class. Three steps are then necessary to calculate a streamwide population estimate using information from the individual sample sites. First, fish densities from each habitat type sampled (e.g., all pool habitats) are averaged. Second, the average density for each habitat type is multiplied by the total length of stream comprised of that habitat type. Finally, the product of the average fish density and habitat length is summed for all habitat types (i.e., number of fish in pool habitat + number of fish in riffle habitat + number of fish in runs) to arrive at a streamwide population estimate.

After reviewing the available data, the hypothesis that data quality varied from year to year seems unlikely. Fish population monitoring has been conducted by the same agency (MMWD) and, with a few exceptions to adjust for changing channel conditions, sampling has occurred at the same sites since 1996. Ettlinger et al. (2003) demonstrated that the habitat composition of sample sites was representative of habitat composition within the Lagunitas watershed as a whole and that sampling effort was similar in surveys from 1996 to 2003.

Furthermore, trends in juvenile abundance within the Lagunitas watershed (including San Geronimo Creek and Devil's Gulch) are very similar to trends in nearby streams (i.e., Olema Creek, Redwood Creek and Pine Gulch; Ketcham et al. 2004), suggesting that the variations in juvenile abundance are not artifacts of the sampling techniques employed.

Next, in order to evaluate the precision of the annual juvenile coho estimates, we calculated the error associated with the extrapolated population estimate. While error estimates for individual sample sites are available, MMWD had not previously calculated the potential error associated with their extrapolated estimates. In Figure 2-9 the annual estimates are plotted with 95% confidence intervals, demonstrating that the sampling precision was at least sufficient enough to differentiate years of low juvenile abundance (e.g., 1998, 1999, 2000) from years with moderately high abundance.

The second hypothesis, that high mortality occurs during the summer in some years, also seems unlikely for the Lagunitas watershed. The most likely source of mortality that could vary from summer to summer and that would occur after summer densities had been established through territorial behavior would be high water temperatures in years with low flows and/or high summer air temperatures. The quantity of summer rearing habitat for coho salmon within California watersheds can be limited by high water temperatures. However, evidence for temperature limitations on juvenile coho salmon abundance in the Lagunitas watershed is lacking. Summer releases of cool water from Kent Lake required under the 1995 SWRCB order and shading provided by well-developed riparian vegetation typically maintain summer water temperatures below 14.4°C (Prunuske Chatham 1997). Juvenile coho abundance fluctuated dramatically from 1996 to 2006 (e.g., 4,281 fish in 2000 to 33,625 fish in 2002), a period with consistent and relatively high minimum summer flows (~7–8 cfs) in the main stem of Lagunitas Creek. Temperature data was not available for the unregulated tributaries San Geronimo Creek and Devil's Gulch. However, fall abundance of coho salmon in San Geronimo Creek and Devil's Gulch show no relationship with annual low flows (Figure 2-11), a variable that is correlated with

summer temperature (Beschta et al. 1987). The annual variation in juvenile coho abundance, therefore, does not appear to be related to variation in summer habitat availability.

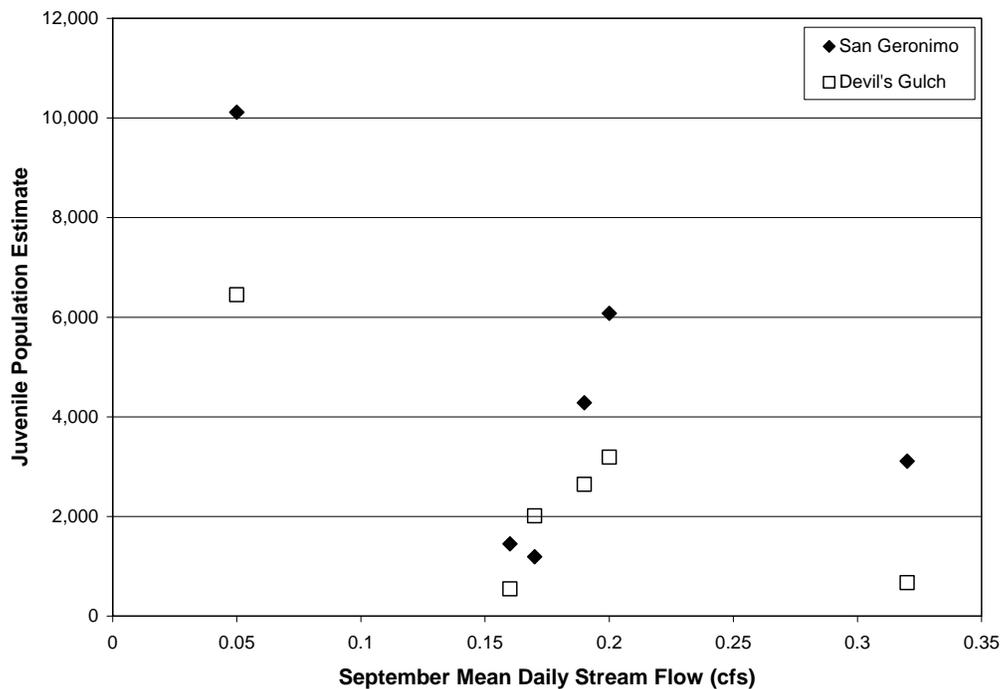


Figure 2-11. Relationship between juvenile coho salmon estimates in San Geronimo and Devil's Gulch and September streamflow in San Geronimo Creek from 1996 to 2001.

A variety of evidence appears to contradict our general conceptual model and supports the third hypothesis, that high mortality during the early life stages in some years affects coho population dynamics in the study area. First, as previously discussed, there is considerable annual variation in the abundance of juvenile coho that does not appear to be related to either sampling error or summer habitat availability. Second, adult returns during years of extremely low juvenile coho abundance (e.g., 1998, 1999, and 2000) are comparable to adult returns in years of moderate-to-high juvenile abundance (Table 2-4). This suggests that reproductive success may differ between these years and warrants a more detailed investigation of the existing data.

In order to estimate reproductive success, we first estimated the annual reproductive effort for the coho population. This estimate was derived by multiplying the annual redd counts by an average fecundity of 2,600 eggs per female (Shapovalov and Taft 1954) to calculate total egg deposition within the study area. Reproductive success for each cohort was then roughly estimated as survival from egg deposition until the end of the first summer, the first time for which there is existing abundance information (e.g., Ettliger et al. 2006). Using this method, survival estimates since 1996 range from <1% to 4.5% (Table 2-4), providing evidence for extremely high mortality during several of the last ten years⁴.

⁴ During years of relatively high juvenile abundance (i.e., >20,000 fish; Table 2-4), the actual survival of egg and early emergent fry may be higher than we have calculated because of density-dependent factors occurring after fry emergence. However, we are mainly concerned with explaining years of extremely low survival, the years 1998, 1999, and 2000 in particular, rather than years of relatively good juvenile production.

Table 2-4. Survival of coho salmon from egg deposition to summer juvenile stage.

Water year	Redd count ¹	Number of eggs deposited ²	End-of-summer juveniles ²	Egg-to-late-summer fry survival ³
1996	86	223,600	8,480	3.79
1997	254	660,400	16,962	2.57
1998	253	657,800	4,394	0.67
1999	184	478,400	5,724	1.2
2000	203	527,800	4,281	0.81
2001	205	533,000	23,581	4.42
2002	286	743,600	33,625	4.52
2003	158	410,800	14,031	3.42
2004	311	808,600	21,925	2.71
2005	372	967,200	22,590	2.34
2006	134	348,400	3,067	0.88

¹ Redd counts and estimates of juvenile coho salmon are based on results of annual MMWD surveys.

² Eggs deposited = 2,600 eggs/female x redd count

³ Survival = (juveniles/eggs deposited) * 100

A third line of evidence in support of the hypothesis for high mortality of coho salmon in the early life stages is based on differences in the annual trends of juvenile coho salmon and steelhead abundance. The steelhead population does not appear to be affected by the same factors responsible for years of low juvenile coho abundance, and in fact, there is some evidence that age 0+ steelhead increase in abundance during years when juvenile coho numbers are low. Age 0+ steelhead and age 0+ coho salmon are potential competitors for space in streams where both species are found, and their behavioral interactions are primarily determined by fish size, with larger fish having a competitive advantage. In contrast to coho salmon, which spawn in the late fall and emerge early in the spring, peak steelhead spawning typically occurs in March (Shapovalov and Taft 1954), with emergence in late spring. Consequently, steelhead fry emerge later in the year than coho salmon and are typically much smaller than the juvenile coho, which have fed for weeks or months prior to steelhead emergence. Since coho salmon prefer pool habitat over other habitat types and are competitively dominant over steelhead of the same year class due to their larger size, they tend to displace or reduce the density of age 0+ steelhead within pools. Therefore, if steelhead populations are unaffected by the factors that reduce juvenile coho salmon abundance in some years, we would expect the density of age 0+ steelhead in pools to increase as the density of juvenile coho salmon decreases. In fact, an inverse relationship in the density of age 0+ steelhead and coho salmon in pools is evident in data from the Lagunitas watershed, especially within Devil's Gulch (Figure 2-12) and San Geronimo Creeks (Figure 2-13). In these streams, the abundance of age 0+ steelhead appears to respond positively to increased space available in pools during years of lower juvenile coho abundance and negatively in years of high juvenile coho abundance. In pools within Lagunitas Creek the pattern is not as strong (Figure 2-14). However, in Lagunitas Creek the mean density of coho salmon in pools is more uniform across years compared to densities in San Geronimo Creek and Devil's Gulch. Nevertheless, the available data suggests that age 0+ steelhead respond positively to decreased competition with juvenile coho in pools, and that they are not necessarily vulnerable to the same factors causing early lifestage mortality of coho salmon.

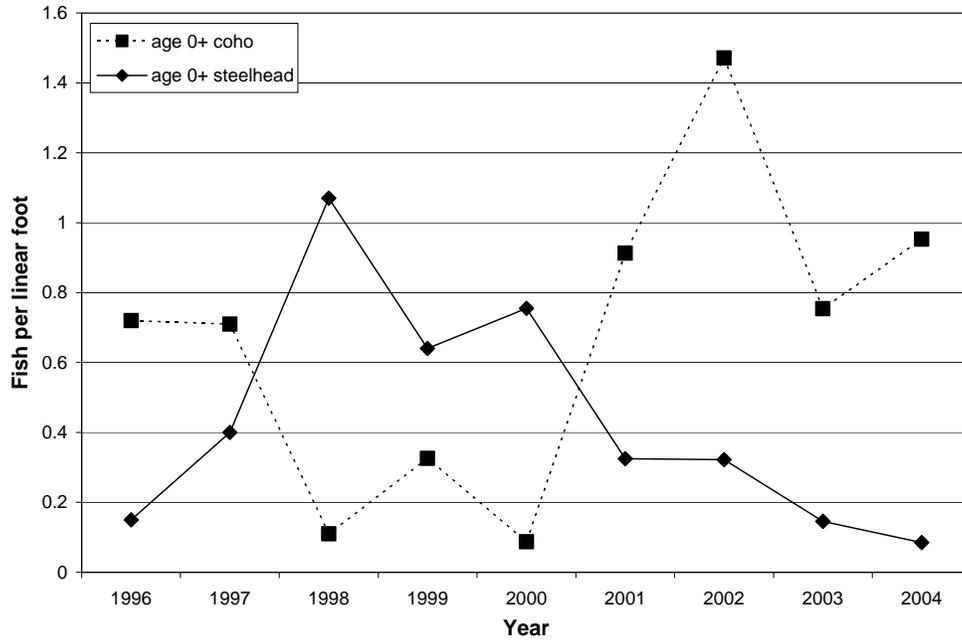


Figure 2-12. Density of juvenile salmonids in pool habitats in Devil's Gulch, 1996-2004.

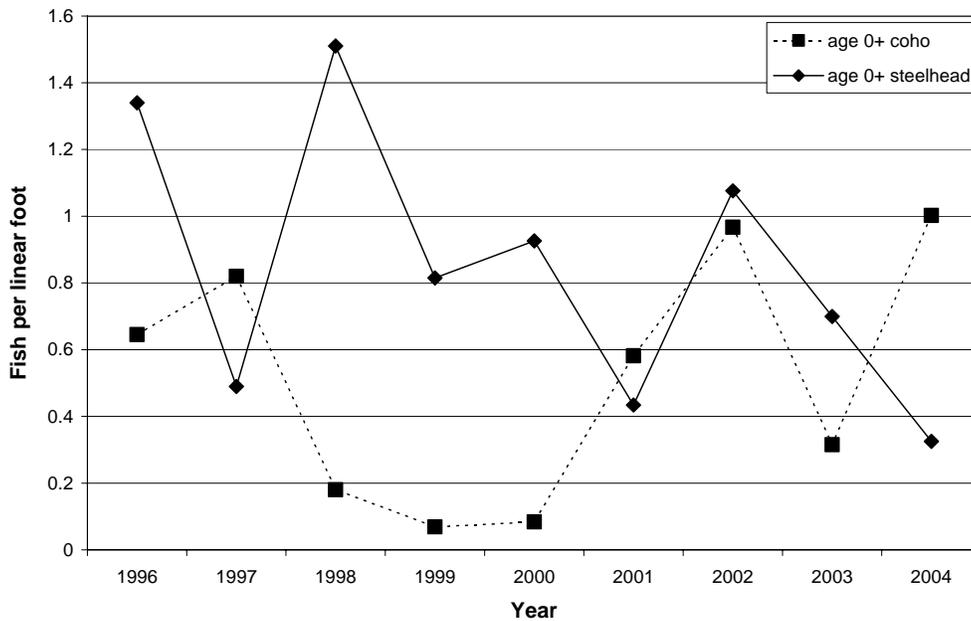


Figure 2-13. Density of juvenile salmonids in pool habitats in San Geronimo Creek, 1996-2004.

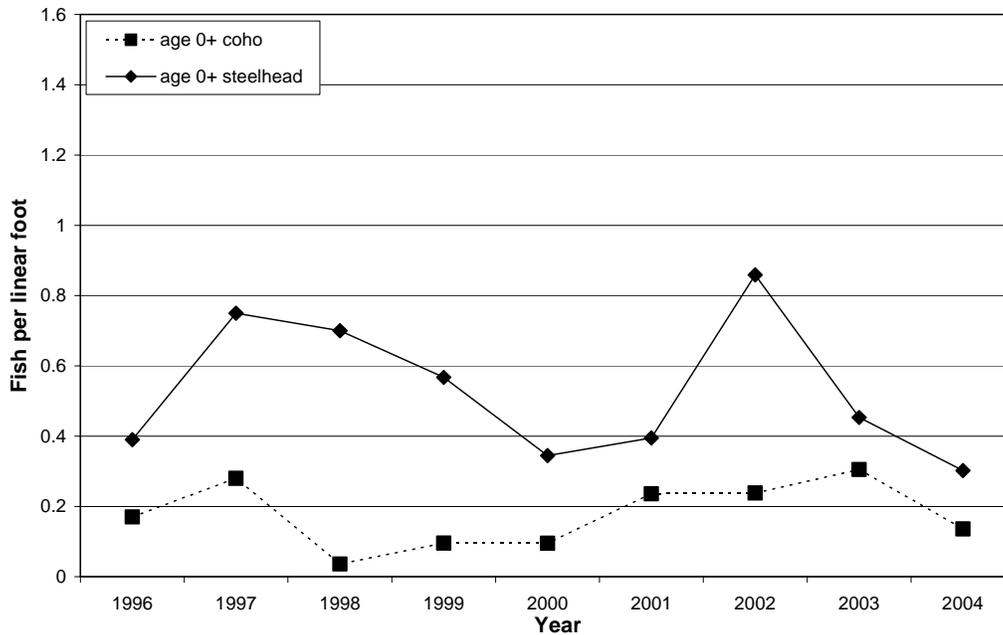


Figure 2-14. Density of juvenile salmonids in pool habitats in Lagunitas Creek, 1996–2004.

The most likely explanation for the inverse correlation of juvenile coho salmon and steelhead abundance is related to differences in the timing of reproduction for the two species. Because coho salmon spawn at the beginning of the wet season in California, developing eggs and alevins may be vulnerable to mortality related to high stream flows and sediment flux during winter storms. In addition, newly emerged fry are vulnerable to displacement during late winter and spring freshets. Steelhead, on the other hand, may be less affected by these sources of mortality because they spawn later in the year (Montgomery et al. 1999).

In summary, by reviewing the existing fisheries information we found:

1. evidence of extremely high early lifestage mortality of coho salmon in some years,
2. no apparent relationship between summer rearing habitat availability (as represented by annual summer low flow) and annual variation in juvenile coho abundance, and
3. an inverse correlation between juvenile abundance of coho salmon and steelhead.

These findings lead us to conclude that density-independent mortality during the early life stages of coho salmon may affect late-summer juvenile abundance in some years. Density-independent mortality during the early life stages is most likely due to either redd scour, deposition of fine sediments into redds leading to entombment of eggs and alevins, displacement of newly emerged fry, or some combination of the three. Support for these potential mechanisms is provided by Ettliger (2004) who found a negative correlation between instantaneous peak flows and juvenile coho abundance within the Lagunitas watershed. There have been no reports of other sources of mortality (e.g., disease, redd dewatering) that might otherwise account for high egg, alevin, or fry mortality.

It is critical that the mechanism for the apparently high early lifestage mortality be understood in order to identify management activities that could ameliorate this mortality. If redd scour is the primary source of mortality, restoration should focus on measures which will lead to coarser gravels in the redds or reducing shear stress during storms (e.g., increasing connection of the

channel to the floodplain). If redd entombment is shown to be the primary mechanism for the mortality, then management actions to enhance coho salmon populations should reduce the input of fine sediments (sand, silt, and clay) into the stream channel. If downstream displacement of early emergent fry is the mechanism, then increasing channel complexity to increase velocity refuge may be warranted. An initial evaluation and ranking of hypotheses related to redd scour, entombment of eggs and alevins, and displacement of newly emerged fry is provided below.

Redd scour

Along the central California coast, the incubation period for coho typically coincides with the highest stream flows of the year. In streams where winter discharge may exceed the flow necessary to mobilize the surface layer of bed particles (the critical entrainment flow, Q_c), mortality of incubating eggs and alevins may occur if the streambed is scoured to below the egg burial depth. Egg burial depths for coho salmon typically range from 15 to 35 cm (5.9 to 13.8 in) (Devries 1997). Upon hatching, alevins remain in the gravel for two to four weeks, but may move deeper within the stream bed (Sandercock 1991) and thus effectively increase the depth of scour necessary to cause mortality after hatching.

Ordinarily, we would not expect high flows that occur annually or several times annually to scour the stream bed to a depth that would affect a significant portion of coho salmon redds. In undisturbed streams, egg burial depths of salmon are thought to exceed the depth of stream bed scour during commonly recurring peak flows (Montgomery et al. 1996). Bed scouring events have likely exerted strong selective pressure on salmonids in terms of the timing of spawning and egg burial depth. The redd depth for a given species is presumably the result of an evolutionary trade-off between scour mortality and fecundity. Deeper redds reduce potential for mortality due to scour, but require energy that might otherwise be used to produce eggs; at some point the energy required for a female salmon to dig a deeper redd would be better spent, in terms of reproductive success, on producing more eggs. Chinook salmon, which tend to spawn in mainstem habitats where bed scour is relatively deep, typically dig the deepest redds and use the largest spawning substrate of any of the Pacific salmon. Similarly, over an evolutionary time-scale, we would expect coho salmon to have adjusted their egg burial depths to at least exceed the depth of scour for floods that have a high probability of occurring, such as bankfull discharge (defined as the peak flow with a 1.5- to 2-year return interval).

In Lagunitas Creek, however, previous research has suggested that bed scour may occur more frequently than expected (several times each year), indicating that the stream substrate is currently finer than it was historically, peak flows are higher, or both. In their study of Lagunitas Creek from the early 1980s, Bratovich and Kelley (1988) concluded that redd scour may occur as a result of a single storm event that greatly raises stream flows for a short period, or as a result of the cumulative effects of multiple moderately-sized storms (e.g., 75–500 cfs mean daily flow) occurring throughout the egg incubation period. If either scenario were true, then flows sufficient to create bed scour appear to occur more frequently than once per year, since bankfull discharge is approximately 1,600 to 1,800 cfs. Increased sediment supply following the onset of land use in the mid-to-late 19th century could have reduced the grain size in Lagunitas Creek. Bed fining is a typical channel response to increased sediment supply, including both coarse and fine sediment⁴, and this is further exacerbated by the small grain size of sediment eroded from the banks of San Geronimo Creek (the primary sediment source for the reach of Lagunitas Creek through Samuel P. Taylor State Park [Hecht 1992, Prunuske Chatham 1997]). The potential for redd scour may also increase if there is a relatively coarse armor layer over a layer of smaller gravels and fine sediments, such as has been observed in the Shafter Reach of Lagunitas Creek. If this is the case,

⁴ We define coarse sediment as gravels or larger (≥ 2 mm) and fine sediment as sand or smaller (< 2 mm).

then redd construction may fine the bed surface by mixing the layers. Under this scenario, the relatively finer particles on the redd surface may be more easily mobilized than the surrounding bed. Scour within the redd may occur rapidly because the smaller particles are more easily mobilized and little or no upstream sediment is transported to replace the scoured material.

To evaluate the hypothesis that redd scour is the cause of the low juvenile coho abundance in some years, fundamental issues of scour extent and timing of scour need to be considered. To achieve the magnitude of mortality apparent in years of low juvenile coho abundance, nearly every redd would need to be destroyed, since successful emergence from only a small number of redds would be sufficient to supply the numbers of juveniles observed in those years. If the source of mortality was redd scour, the scouring flows would have to occur after all coho spawning had occurred and before emergence from the earliest redds had begun. Therefore, if redd scour is the cause of mortality, we would expect unequivocal results from a study examining scour in Lagunitas Creek. In other words, if most redds are not destroyed by a high flow (e.g., >1,500 cfs), then redd scour would not explain the low juvenile abundance observed in some years.

Entombment

Entombment (infiltration of fines into redds that impedes the emergence of fry) is a potential source of mortality for coho salmon. Because of the large proportion of sand in the bed of Lagunitas Creek, transport of sand bedload is common even at relatively low flows. Between 1979 and 1982, sediment transport rates of greater than 1 ton/day were observed at flows as low as 80–90 cfs, and still-measurable transport was observed at flows as low as 60 cfs (Hecht 1983). High flows would be expected to move large amounts of sand and fine sediment. If these flows occur after redd construction, the sand can intrude into the redd. Bratovich and Kelley (1988) monitored 17 coho salmon redds throughout the incubation period and sampled redd substrate at the end of the emergence period. Using measurements of intragravel dissolved oxygen (to estimate survival to hatching), and percentage of fine material less than 3 mm diameter (to estimate egg-to-emergence survival), Bratovich and Kelley (1988) estimated that survival from egg deposition through fry emergence averaged 59% in Lagunitas Creek. Significant mortality of alevins can occur if fine sediment forms a seal preventing fry emergence, even when fine sediment does not comprise a large percentage of the substrate within a redd (Phillips et al. 1975). When the mortality of alevins is caused by this form of entombment, bulk samples (the method used by Bratovich and Kelley [1988] to estimate fines) overestimate survival-to-emergence values based on the percentage of fine sediment.

Entombment would also be related to high stream flows during the incubation period but not, as in the case of redd scour, directly to peak flows. Fine sediment intrusion could occur during sustained flows above base levels, or during a series of moderately high flow events. Entombment is likely when there is a large source of fine sediment available for transport, for which there is some evidence in San Geronimo Creek (Stillwater Sciences 2007). Because fine sediment transport may occur over a range of higher flows, entombment would be more likely to affect a large percentage of the redds than scour, which would require that a higher peak flow occurred after spawning in order to affect most redds.

Downstream displacement of newly emerged fry

Alternatively, or in addition to redd scour and/or entombment, downstream displacement of fry during winter or spring freshets can lead to high mortality prior to the summer rearing period. Although no direct information is available to assess mortality of early emergent fry in the study area, changes in land use within the watershed have likely reduced channel complexity, which may increase fry displacement by reducing the availability of velocity refuge. The timing of

spawning has been strongly selected so that fry emergence generally occurs when survival and growth conditions tend to be optimal (Quinn 2005). Within salmon populations, the timing of spawning may vary slightly from year to year in response to stream flow patterns or other correlated environmental variables such as stream temperature. Even within years, spawning will occur over a period of months, resulting in a naturally protracted period of fry emergence. In the Lagunitas watershed, spring freshets may occur unpredictably and, in some years, freshets occur during or just after peaks in fry emergence. Newly emerged salmonid fry are known to be poor swimmers and high flows that occur during or shortly after emergence (not necessarily the annual peak flows, which usually occur much earlier in the year) may displace fry downstream (Ottaway and Clark 1981, Heggenes and Traaen 1988). As both the timing and magnitude of spring flows may vary considerably from year to year, annual variation in mortality due to displacement may be high.

Displacement of fry during late-winter or spring freshets can lead to high mortality prior to the summer rearing period. However, fry are only vulnerable to displacement for a few weeks before they reach a size at which they can maintain position at low water velocities (Harvey 1987, Heggenes and Traaen 1988). Because emergence from any one redd may extend for several weeks and emergence from a population of redds may occur over an extended period due to differences in spawning dates and local stream temperatures, frequent events may be necessary throughout the emergence period to displace a large percentage of fry. Of course, very high flows, such as are common in winter but that also occasionally occur in spring, can displace juvenile coho salmon of all sizes if there is insufficient velocity refuge. Therefore, several moderate freshets during the emergence period or one large freshet occurring shortly after the majority of fry have emerged from redds could cause substantial displacement of age 0+ salmon.

Alternatively, volitional downstream dispersal (as opposed to involuntary displacement) may increase with higher spring flows. During years with relatively high spring base flows, less low-velocity habitat is available for coho salmon fry. If higher base flows increase mid-channel velocities in pools—the preferred habitat of juvenile coho salmon—their carrying capacity may be reduced through territorial competition.

2.3.2.2 Field evaluation

Uncertainty about the mechanisms behind the potentially high early lifestage mortality led us to investigate the above hypotheses through field experiments conducted during the winters of 2004 and 2005. In order to make the best use of available resources, we first performed pilot or exploratory studies designed to rapidly evaluate the multiple hypotheses, instead of conducting a statistically rigorous test of any one hypothesis. This approach involved an iterative process of study development, field data collection, rapid analysis of results, and refinement of our original hypotheses based on our interpretations of the analysis. An alternative approach would have been to conduct a very thorough test of the effects of a potential mechanism, such as redd scour, to precisely estimate egg survival (e.g., to the nearest 10%), but this would likely have required the entire budget available. If redd scour was subsequently found not to be an important source of mortality using this approach, we would not be very far in our analysis. Below we describe these pilot studies and their implications for early lifestage mortality of coho salmon in the Lagunitas Creek watershed.

Experimental design

Spawning surveys were conducted weekly beginning on 1 December to select potential study redds in target stream reaches. A total of ten coho salmon redds distributed across four sites within the Lagunitas watershed were selected for study (Appendix A; Figure A-1). Once potential study redds were identified, frequent surveys (daily or every other day) were conducted to verify spawning had occurred and to obtain length estimates of females, which were used to estimate fecundity. Redds were identified as to the individual female that constructed it and date of construction, and their locations were flagged so that instruments measuring bed scour and fine sediment infiltration could be installed after spawning had occurred and the female had left the redd. Up to four scour chains and two infiltration bags were installed at each redd. Scour chains were placed directly upstream, downstream, and on either side of the redds. Cross section profiles over the egg pockets of each study redd were also constructed. The scour chains provided data on both maximum instantaneous scour during storm events and net scour of the streambed immediately adjacent to the study redds for the period of study; the cross section measurements provided information on the net change in bed elevation on the redd mound and scour and deposition of particles on the redds. Both maximum instantaneous scour and net scour are important measures of redd scour. Maximum instantaneous scour determines whether a single flow event scours the streambed to a depth that would affect the egg pocket. Maximum scour for any particular flood event is measured against the elevation of the streambed prior to that event. Net scour determines whether the rate of scour and deposition of particles over the period of study would result in cumulative scouring to a depth that would affect the egg pocket. Net scour is measured against the elevation of the streambed at the time of redd construction. Infiltration bags were buried in the stream bed adjacent to egg pockets to measure fine sediment intrusion into spawning gravels. In addition, pebble counts were made to characterize particle size distributions at spawning locations. Particle size distributions, scour, and infiltration of fine sediment were monitored before and after each storm event during the period between egg deposition and fry emergence. At the end of this period, emergence traps were placed on a subset of the study redds (7 of 10 redds) to monitor fry emergence. Following emergence, freeze core samples were taken of the egg pocket areas to look for evidence of fine sediment layers capable of entombing fry. As mentioned above, these investigations were not meant to estimate egg or emergence survival with a high degree of precision, but were conducted to determine if either scour or infiltration of fine sediment was worth pursuing further as a limiting factor hypothesis. Below we present the most pertinent results and our analysis. Descriptions of the specific study methods and detailed results are provided in Appendix A to this report.

Results and discussion

Redd scour

After the initial bed elevation measurements and deployment of instruments in the study redds, Lagunitas Creek experienced an approximately bankfull flood followed by a series of storms of smaller magnitude (Figure 2-15). The bankfull event reached approximately 1,800 cfs on December 27, 2005 (USGS gage 11460400 at S.P. Taylor State Park). This peak flow was similar in magnitude to those observed during years of reduced juvenile coho salmon abundance in the past and provided an excellent opportunity for examining the potential for egg and alevin mortality to result from redd scour.

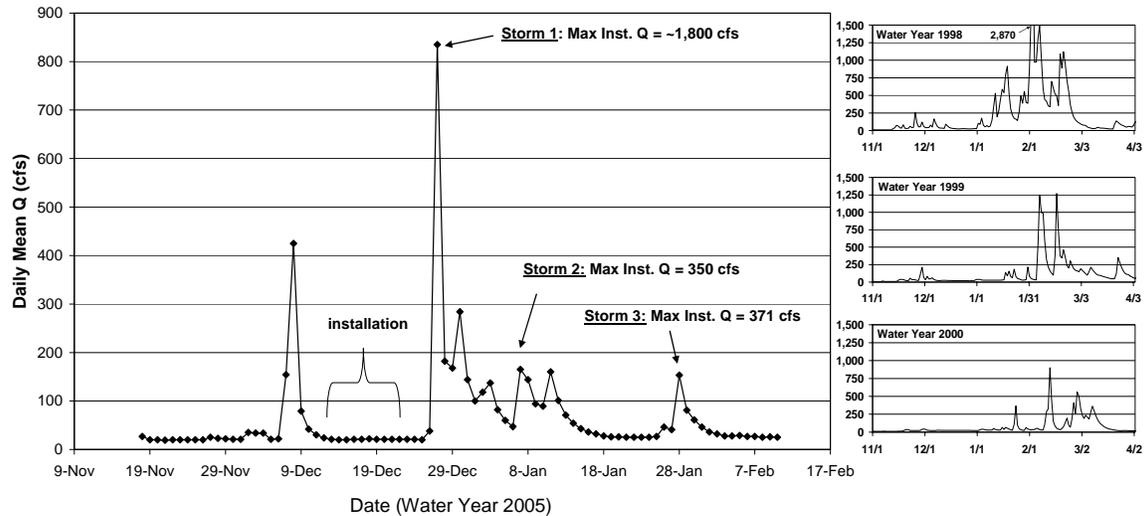


Figure 2-15. Daily mean discharge at S.P. Taylor State Park (USGS gage 11460400), Lagunitas Creek during the survival-to-emergence study period. Mean daily discharge is also shown for water years 1998, 1999, and 2000 to show similarities between hydrographs for all years.

Results of monitoring this flood event indicated a low magnitude of scour relative to the egg burial depth of coho salmon. Scour chain data showed that average scour at study redd locations was less than 4 cm [1.6 in] for the majority of redds (7 of 9 redds) (Figure 2-16). Scour approaching the egg burial depth was recorded at only one of 32 scour chains during this event (Figure 2-16).⁵ Limited scour was observed during subsequent smaller storms (see Appendix A).

⁵ The chain that recorded high scour was located at Olema Redd 2, and although there was the potential for some egg mortality due to scour at this site, we documented a *minimum* survival-to-emergence of ~10% using emergence traps (see “Observed fry emergence” below). This indicated that scour did not result in total mortality of developing embryos even when it approached the 15-cm threshold.

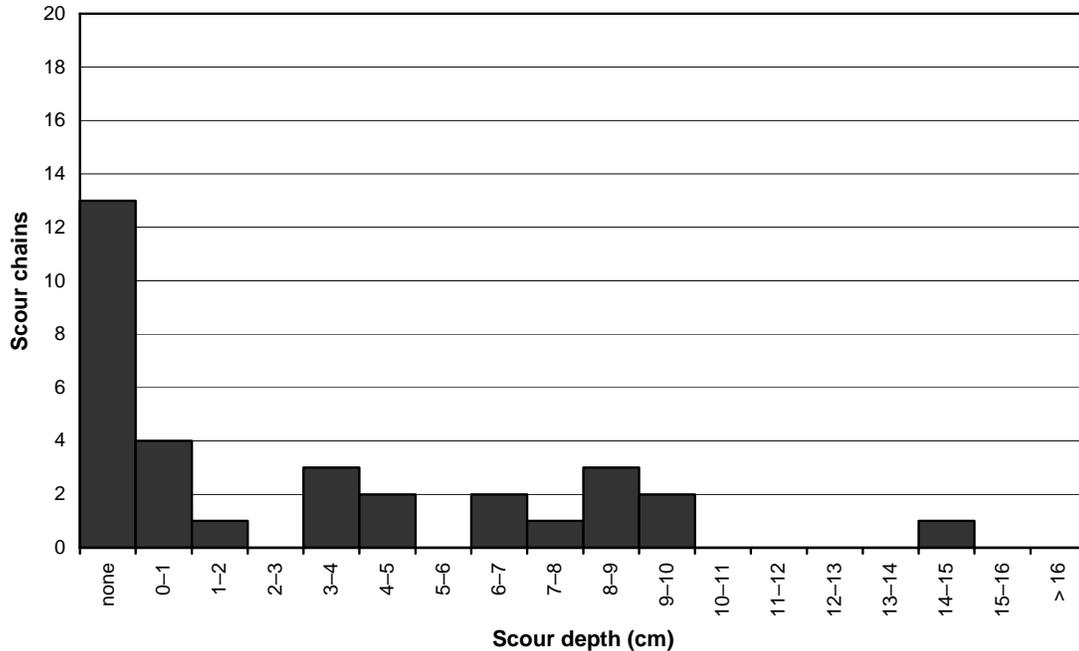


Figure 2-16. Frequency of the depth of scour recorded by 32 scour chains during a bankfull flow event.

Cross section surveys, which documented the net change in bed elevation, demonstrated some ability for the bed to “reset” its elevation due to the combination of both scour and deposition of bed material during high flows. Redd mound elevation, as measured by cross section surveys, showed relatively little net change on average when compared to the pre-Storm 1 elevation. The net change in average elevation (i.e., net scour/aggradation) of the redd surface ranged from -8.5 to 2.1 cm [-3.4 to 0.8 in], with the majority of redds (6 of 9) showing a change of ± 2 cm [0.8 in] (Figure 2-17). Even though 14 of 32 scour chains recorded scour over 3 cm [1.2 in], only 2 of 9 redds had net elevation losses over 3 cm, and neither of these redds showed net losses approaching the egg burial depth. These results suggest a low potential for cumulative scour from multiple, moderately-sized flows to cause egg mortality.

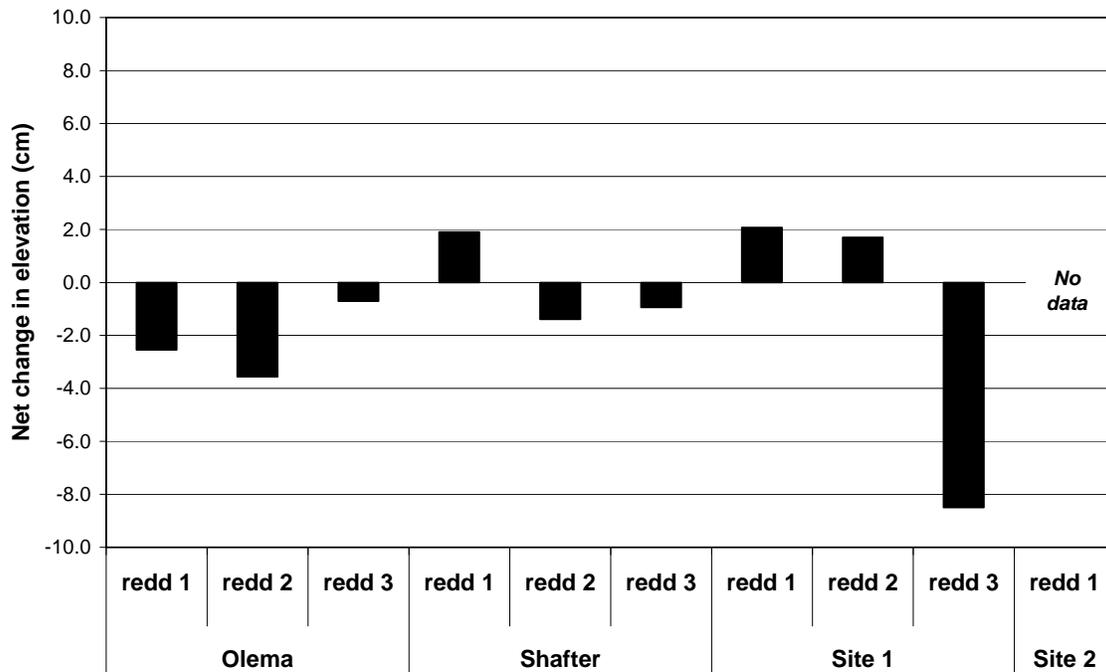


Figure 2-17. Mean change in redd elevation resulting from a bankfull flow event.

These results are consistent with empirical observations of bed mobility in gravel-bedded alluvial systems where the bed has not become less coarse as a result of anthropogenic increases in sediment input. In a gravel-bedded stream, mobilization of coarser bed material, such as median-sized particles, tends to begin at bankfull discharge (Andrews 1983). Therefore, we would expect the depth of scour to reflect D_{50} at redd study sites as flows approach bankfull discharge. Relating depth of scour to pre-Storm 1 median particle size for the monitored redds shows that the depth of redd scour was less than the D_{50} for the majority of redds monitored (6 of 9 redds) (Figure 2-18). These data support the idea that sediment is being transported within the studied spawning reaches within Lagunitas Creek and Olema Creek in accordance with empirical observations within gravel-bed alluvial systems. The instances in which average scour depth was greater than D_{50} were influenced by localized hydraulic effects. For instance, Olema Redd 2 and Shafter Redd 1 were downstream from large woody debris that was submerged during high flow, causing local flow constriction and downstream erosion, and Site 1 Redd 2/3 was on the crest of a riffle, which is where local erosion of sediment would be expected during a high-flow event.

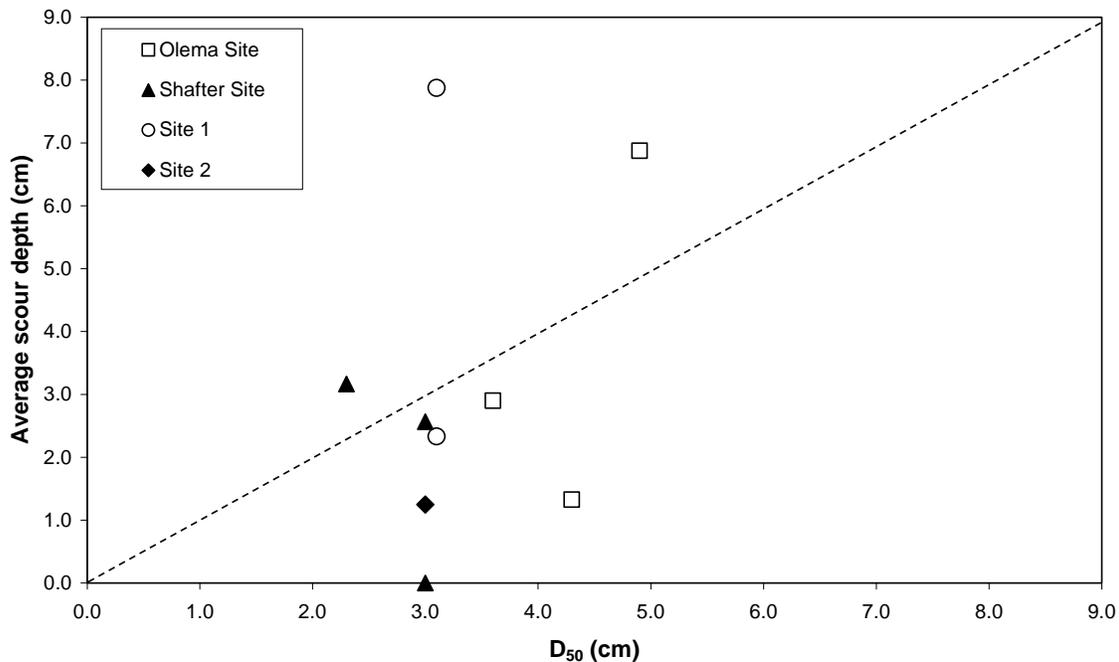


Figure 2-18. Relationship between average scour depth and D_{50} for a bankfull event.

The lack of scour observed during our study apparently contradicts results from Bratovich and Kelley (1988), which caused us to conduct a more detailed analysis of their data. During a 2,620-cfs flood in 1983 (a flood with a recurrence interval of 2.75 to 3 years), Bratovich and Kelley (1988) describe “severe scouring” to a depth apparently exceeding 20 cm, the depth at which they had anchored their scour gages. However, since none of the gages were recovered at the end of winter they were not able to quantify the extent of scour. In 1984, Bratovich and Kelley (1988) monitored eight scour gages during an approximately bankfull event (1,840 cfs)—a magnitude very similar to that observed during our study (1,790 cfs). Although they recorded slightly higher scour depths, in only one case did scour exceed our assumed egg burial depth for coho salmon of 15 cm. The slightly greater depth of scour is not surprising given evidence that particle sizes at their redd locations were smaller than we observed during our study. The substrate surrounding the redds that were monitored by Bratovich and Kelley (1988) during the 1983/84 incubation period had D_{50} values that ranged from 10 mm to 22 mm, with an average value of 15 mm, and the particle size within the redds studied had an average D_{50} of 22 mm. The pre-Storm 1 D_{50} for the substrate adjacent to the redds in this study ranged from 16 mm to 49 mm (average 31 mm), therefore, less scour would be anticipated for the conditions within our study than conditions during the 1983/84 incubation period for the same flow magnitude. After monitoring scour across two smaller subsequent storms, Bratovich and Kelley (1988) concluded based on the total additive scour that multiple storms within a season, or one storm of great magnitude places coho salmon redds at risk and increases egg mortality to “unacceptable levels.” However, differences in streambed conditions between the study period of Bratovich and Kelley (1988) and our study notwithstanding, if we are correctly interpreting the results of Bratovich and Kelley (1988) they may have overestimated the impact of scour on egg survival since they do not appear to have not accounted for deposition of sediment after scour events. Adding the maximum instantaneous scour for all sampling intervals may not be a reliable indicator of redd scour if the scour is not measured against the elevation of the streambed at the time of egg deposition. If a storm induces

8 cm of scour but also results in 8 cm of sediment deposition, returning the bed to its original elevation, and a subsequent storm induces 8 cm of scour, adding maximum instantaneous scour for these two events results in 16 cm even though the streambed is only 8 cm below its original elevation. For example, Table 2-5 includes results from their 1984 study in terms of maximum instantaneous redd scour (the maximum scour observed for during a single sampling interval), the amount of sediment deposition at each redd, and the cumulative redd scour over multiple sampling intervals measured against the elevation of the streambed at the beginning of the study (i.e., the elevation of the streambed when eggs would have been deposited), and compares these values to total additive scour one would calculate without accounting for deposition.⁶ Based on this analysis, it appears that scour at only one of eight study redds monitored exceeded 15 cm after accounting for sediment deposition.

Table 2-5. Scour and deposition in eight simulated¹ coho salmon redds during 1984. Modified from Table 6-3 in Bratovich and Kelley (1988).²

Sampling date	Measurement ⁴	Lagunitas Creek simulated redd number ³							
		1	2	3	4	5	6	9	10
5-Jan-84	max inst scour	-17	-11	-7	-10	-10	-6	-6	-13
	deposition	0	0	0	7	0	6	8	5
	net change	-17	-11	-7	-3	-10	0	2	-8
24-Feb-84	max inst scour	-2	0	-1	-10	0	0	-11	-6
	deposition	2	0	1	1	0	1	4	7
	cumulative scour	-18	-11	-8	-12	-10	0	-10	-13
	net change	-17	-11	-8	-11	-10	1	-6	-6
5-Apr-84	max inst scour	-2	0	0	-1	-1	1	-4	-1
	deposition	0	0	0	1	0	0	1	0
	cumulative scour	-18	-11	-8	-11	-11	2	-10	-8
	net change	-18	-11	-8	-11	-11	2	-8	-8
	total additive scour	-20	-11	-8	-20	-11	-5	-21	-20

¹ Redds were constructed in December 1983.

² Shaded cells indicate events where scour is greater than or equal to egg burial depth.

³ Simulated redds 7 and 8 were not recovered on the January 5th sampling date.

⁴ Max inst scour = maximum instantaneous scour observed for during a single sampling interval;

Net change = change in streambed elevation after scour and deposition;

Cumulative scour = maximum depth of scour relative to streambed elevation at time of redd construction;

Total additive scour = the sum of maximum instantaneous scour from all sample intervals.

In both Bratovich and Kelley's (1988) and our study of scour in Lagunitas Creek, a small number of redds were monitored, adding some uncertainty to our conclusions based on these small sample sizes. However, if redd scour is the mechanism resulting in such low survival to emergence, we would expect nearly every redd to show significant scour, since the 4,000 to 5,000 juveniles estimated during the years of lowest abundance could have resulted from a very few successful redds that escaped significant scour (e.g., 5 to 10 redds even at low survival-to-emergence rates). It is very unlikely that the redds we monitored would show no scour if, in fact, scour was widespread and 99% of the eggs had died as a result. We could conduct a statistical

⁶ The table includes only simulated redds that were monitored during the approximately bankfull flood occurring in late December 25, 1983. Bratovich and Kelley (1988) also monitored scour at eight simulated redds installed in Devil's Gulch and San Geronimo Creek (four each) in January 1984. Scour at one of the eight simulated redds exceeded 15 cm.

test of this probability, but it hardly seems necessary. The sampling locations were chosen with members of the Lagunitas Advisory Group to be representative of typical spawning locations, and there was a relatively large flow event during the study period (approximate bankfull); it does not seem likely that the redds that were monitored during this study were the only redds within Lagunitas Creek and Olema Creek that were not significantly scoured.

Although our data suggest that redd scour is not a significant source of coho salmon mortality in the study area, if no other sources of mortality sufficiently explain low juvenile population estimates, it could be worth revisiting the redd scour hypothesis, critically reviewing our assumptions, and conducting a follow-up field investigation. A follow-up study design could include increasing the redd sample size, or choosing redds that are most likely to scour (if those redds do not scour to the extent expected, it would increase confidence in rejecting the redd scour hypothesis).

Entombment of eggs and alevins

As with the redd scour study, our goal was to determine if fine sediment intrusion could be a substantial source of mortality, either by suffocating developing embryos, or by entombing alevins within the redd, and was not intended as a way to precisely estimate entombment mortality. The initial objective of the fine sediment portion of this study was to examine infiltration of fines into the bed adjacent to the study redds using infiltration bags (Lisle and Eads 1991) and to document whether a layer of infiltrated fines within the redds had the potential to entomb eggs and alevins using freeze cores. However, before samples from the infiltration bags or freeze cores were analyzed, we discovered that fry emergence estimated from a subsample of study redds (see below) was greater than expected if mortality during the egg and alevin stage was responsible for years with low juvenile coho abundance. Because sediment transport dynamics did not appear to be the mechanism responsible for the years of low juvenile abundance, we decided to redirect resources from analysis of sediment samples to other investigations.

Observed fry emergence

Survival-to-emergence rates measured from a subsample of study redds appeared to be sufficient to fully seed available juvenile rearing habitat in Lagunitas Creek. Environmental conditions made monitoring fry emergence challenging during the study year. Stream flow varied considerably during the emergence period, resulting in days when the traps could not be checked safely. Additionally, high levels of fine sediment were transported during storm events and accumulated in some of the traps. Several traps were removed during a portion of the emergence period to prevent further accumulation of fine sediment and potential mortality of emerging fry. Therefore, the number of fry captured in the emergence traps should be considered a *minimum* measure of survival-to-emergence since the traps were only in place for a portion of the emergence period and sediment accumulation caused by the traps may have reduced emergence success (Table 2-6). Mean minimum survival-to-emergence from seven study redds was 15% and ranged from 0 to 36%. In the redd with zero coho fry emergence, we suspect that superimposition by a steelhead disturbed the egg pocket since one steelhead fry was captured near the end of monitoring for coho emergence. The number of fry captured from the six remaining study redds totaled 2,372 fish. Despite sampling problems, the observed minimum survival-to-emergence appeared to be more than sufficient to fully seed the available coho rearing habitat. For example, given the number of redds observed during the year of study (372), an average fecundity of 2,600 eggs, and conservatively assuming survival-to-emergence rates between 10 and 20% (bracketing our observed minimum rates for emergence), we would expect between 97,000 and 193,000 fry to have been produced in the Lagunitas watershed. This total far exceeds the maximum number of juvenile coho salmon ever observed in the Lagunitas watershed (Table

2-4). The magnitude and pattern of winter flows during this study was similar to the years 1999 and 2000, which had low juvenile coho abundance (although peak flows in 1998 were considerably higher than any other years). Based on these results, survival-to-emergence does not appear to be a factor limiting production of coho salmon. Therefore, we decided to redirect resources from further analysis of sediment samples from infiltration bags and freeze cores and focus on potential mortality of newly emerged fry.

Table 2-6. Coho fecundity and minimum observed emergence at seven study redds in Lagunitas Creek.

Site number	Redd number	Female Length (cm)	Estimated Fecundity	Minimum emergence	Minimum survival (%)
Shafter	2	58	1,765	202	11
	3	63.5	2,304	242	11
Lagunitas site 1	1	61	2,304	837	36
Lagunitas site 2	1	66	2,586	219	8
Olema	1	60	1,950	0	0
	2	60	1,950	173	9
	3	65	2,468	699	28
Average across all sites		62	2,190	338	15

Displacement of newly emerged fry

Although not originally included in our scope of work, we redirected our resources towards a preliminary investigation of the potential for displacement of fry due to high spring flows. Spring 2005 was a particularly good year to examine the effects of spring flows and juvenile salmon abundance due to the relatively high adult salmon return and high spring flows. Initially, we looked for evidence of a relationship between spring flow patterns and juvenile coho abundance using the existing data. Figure 2-19 shows a negative correlation between spring stream flow and juvenile coho abundance. The pattern is clearest when plotted with April flows, but March flows exhibit a similar pattern.

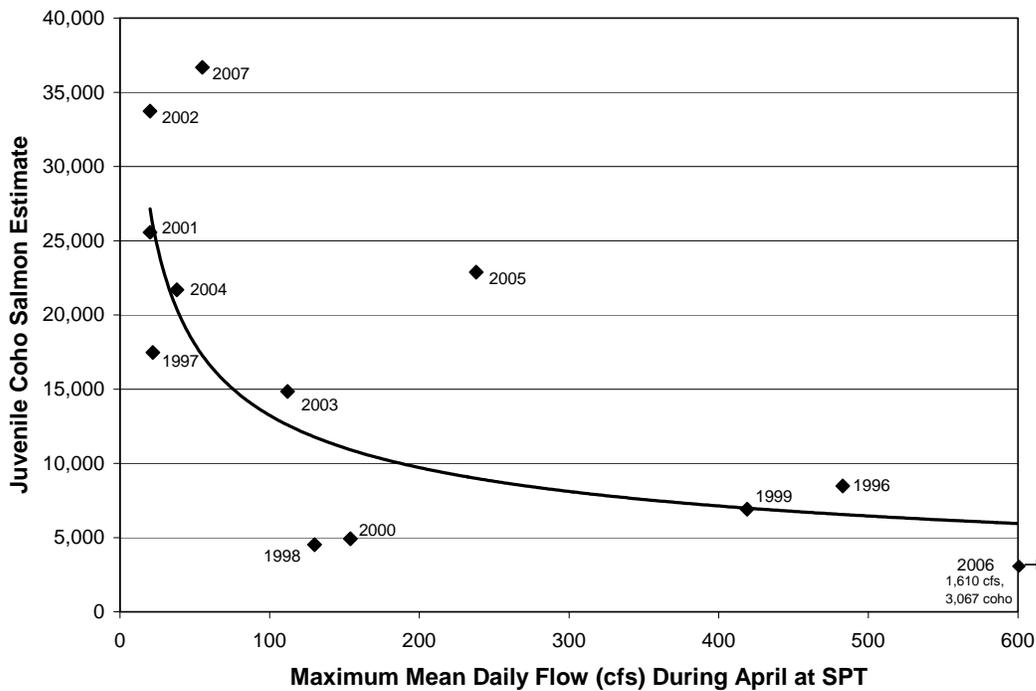


Figure 2-19. Relationship between spring flow and fall juvenile coho population estimates in the Lagunitas Creek watershed, 1996-2007.

This pattern and a lack of evidence for low survival-to-emergence led us to hypothesize that spring flows may reduce juvenile coho abundance either due to displacement during high peak flows or due to a reduction in rearing habitat in pools during sustained high base flows. We conducted a series of direct observation dives during June 2005 in Devil's Gulch and Lagunitas Creek at sites regularly sampled by MMWD during juvenile salmonid monitoring (sites in San Geronimo Creek were not sampled because of water quality concerns). During spring snorkel sampling we observed longitudinal trends in the abundance of coho salmon in Lagunitas Creek. Compared to historical snorkel surveys conducted by MMWD, our observations were low at four sample sites above the confluence of Devil's Gulch, which is consistent with a displacement hypothesis (Figure 2-20). However, our counts at two sites below Devil's Gulch were much higher than in previous years of sampling (Figure 2-21).

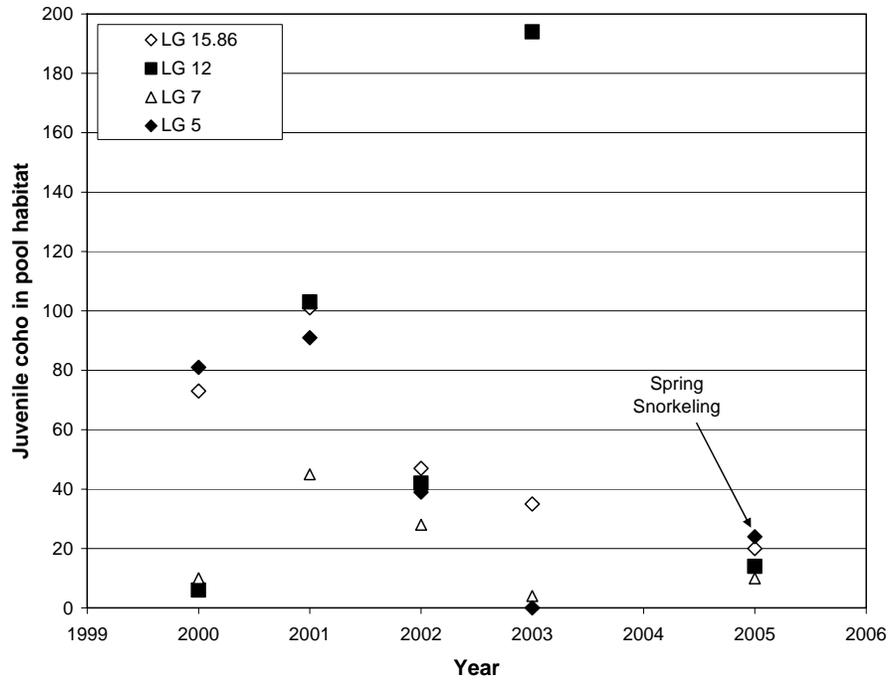


Figure 2-20. Number of juvenile coho salmon observed at sample sites monitored by MMWD in Lagunitas Creek above the confluence with Devil's Gulch, 2000-2005.

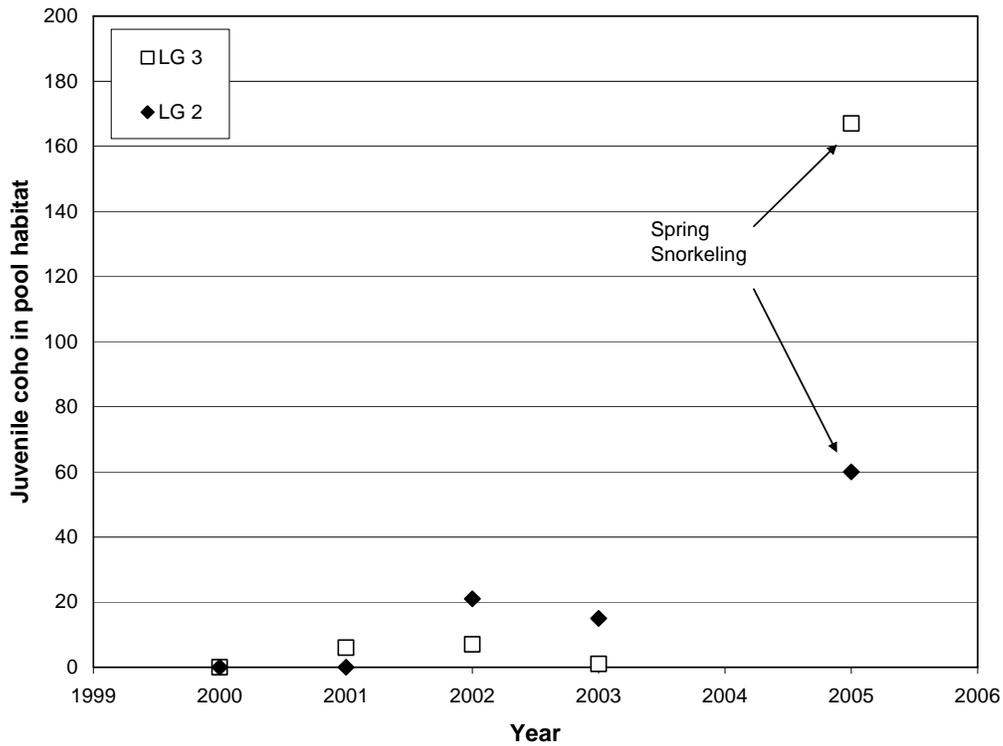


Figure 2-21. Number of juvenile coho salmon observed at sample sites monitored by MMWD in Lagunitas Creek below the confluence with Devil's Gulch, 2000-2005.

We used habitat data from MMWD paired with estimated juvenile densities from our snorkel surveys to extrapolate a rough population estimate for spring 2005 for comparison with previous years' population estimates. We initially speculated that the density of fish in downstream habitat units would decline over the summer to levels similar to those observed in previous years. We anticipated that this decline would be a response to warming stream temperatures in the lower reaches of Lagunitas Creek. If this were true, the extrapolated population estimate based on our observations would be approximately 13,400⁷ and would approach the trend line in Figure 2-19. If this decline were not observed, the population estimate would be approximately 29,400 fish and would be much higher than predicted based on a negative relationship with spring flows, suggesting that the relationship between juvenile coho abundance and spring flows is not causal. In fact, a decline in abundance at downstream sites was not observed. During fall electrofishing surveys, MMWD documented patterns of coho abundance that were very similar to our snorkel observations (Figure 2-22). The extrapolated population estimate for the Lagunitas Creek watershed from MMWD sampling is similar to our rough estimate based on spring snorkeling observations (compare MMWD's estimate of 22,590 based on fall electrofishing [Ettlinger et al. 2006] with the 29,400 fish we estimated from snorkel surveys). Therefore, the results from the 2005 snorkel surveys did not fit the overall relationship between spring flow and fall juvenile abundance.

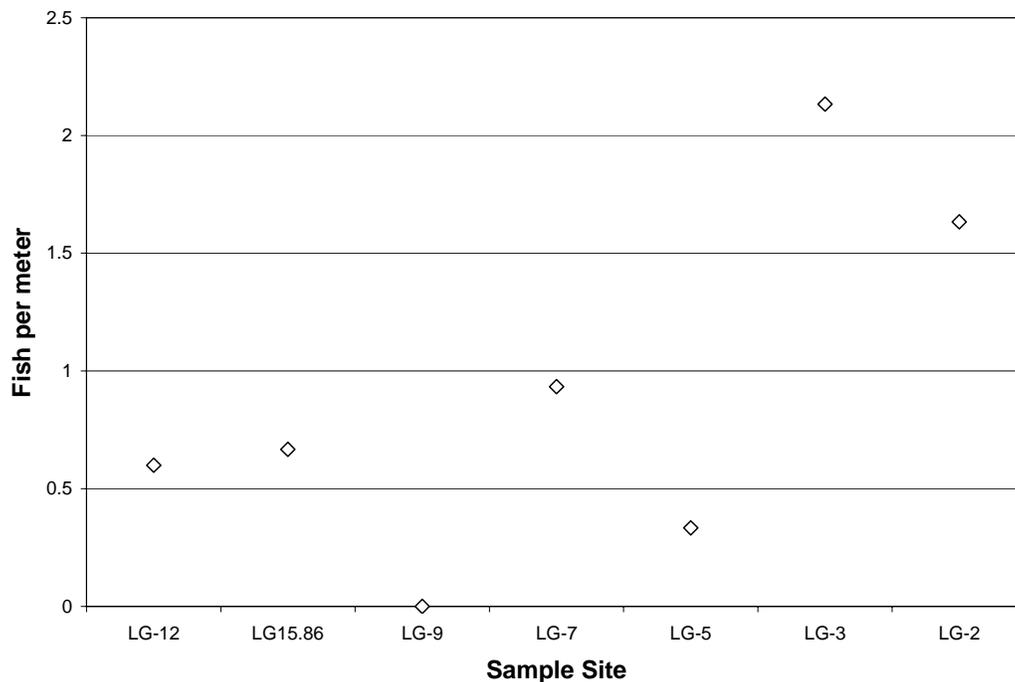


Figure 2-22. Linear abundance of juvenile coho captured by MMWD at Lagunitas Creek sample sites during fall 2005.

⁷ Although we do not have spring snorkel data for sites in San Geronimo, estimates for San Geronimo typically constitute one-third to one-half of the total coho population estimate for Lagunitas Creek. If you double the low snorkel estimate of 6,700 fish based only on observed densities from upstream sample sites the result is 13,400 fish. If you double the high estimate of 14,700 fish based on the observed densities of all sample sites, the result is 29,400 fish.

Subsequent juvenile estimates made in 2006 and 2007 fit the overall pattern of high spring flows resulting in low juvenile abundance (Figure 2-19). One possible reason for the discrepancy seen in 2005 is the record high adult return for that brood year. Recent analyses have shown that a combination of the number of returning adults, flow conditions during incubation, and flow conditions during the spring can explain a great deal of the variation in fall juvenile coho abundance. For example, Ettlenger (2007) found a strong relationship between the number of redds built in San Geronimo Creek, flows above a threshold of 1,300 cfs during incubation, and flows above a threshold of 90 cfs during April (Table 2-7). In this formulation, called the “incremental” model,” fall juvenile coho abundance in the Lagunitas watershed declines linearly with increases in flow above either the incubation or spring-flow thresholds, the values for which were selected through trial and error to achieve the best fit to the observed juvenile coho abundance. As Ettlenger (2007) indicates, certain parameters are important for explaining fall coho abundance only in certain years. For example, incubation discharge may only have a strong influence on fall coho abundance in years with very high winter flows. This led us to examine whether fall coho abundance could be explained with an “all or nothing” model. Under this formulation, once a threshold value for incubation or spring flow is surpassed, the effect on the coho population is the same regardless of the absolute flow. Below that threshold, there is no effect on the coho population (thus the effect of the model parameters can be considered to be all or nothing). This type of model formulation would indicate that either incubation discharge or spring flow can be important in any given year, and that in years where thresholds for both incubation and spring flow are exceeded, the impact on the coho population is greater than in years when only one threshold is exceeded. The threshold for the “all or nothing” model incubation flow was selected in part to reflect a discharge at which significant redd scour might be likely—3,200 cfs is roughly twice bankfull discharge. The threshold for the spring flow, 120 cfs, was selected by trial and error to achieve the best fit with observed juvenile coho abundance.

Table 2-7. Juvenile coho model for the Lagunitas Creek watershed (Ettlenger 2007).*

Year	San Geronimo Creek Redds	Peak Incubation Flow	April Daily Flow	Juvenile Coho Estimate
1998	121	5,830	130	4,394
1999	60	1,860	417	5,724
2000	61	1,760	154	4,281
2001	74	504	20	23,581
2002	148	1,617	20	33,625
2003	63	776	112	14,133
2004	205	3,230	38	21,899
2005	254	1,770	238	22,590
2006	102	10,200	1,610	3,067
2007	143	650	55	36,680

*Numbers in bold are significant factors explaining below-average coho population estimates.

We found that both the Incremental model and the all-or-nothing model had equal power to explain fall juvenile coho abundance (Figure 2-23). Both models suggest that there may be a relationship between the number of returning adults, and incubation or spring discharge. However, the management implications of the two models can be very different. For example, the all-or-nothing model predicts that optimal smolt production can still occur at a peak incubation flow of 3,000 cfs and maximum daily flow in April of 100 cfs, whereas the Incremental model predicts that production will be less than 40% of optimum at the same

combination of flows. As can be seen in Figure 2-24, the two models give very different impressions of how flows affect fall coho abundance. The fact that these two models with the same variables have equal explanatory power but very different interpretations indicates that additional research is needed to clarify the effects of incubation flow and spring flow on fall juvenile coho abundance. Both models suggest that redd scour occurs in some years, but the all-or-nothing model suggests that it would occur relatively infrequently in years with very high flows, whereas the Incremental model would suggest that redd scour increases over a broader range of winter flows. This could be tested fairly easily with further scour studies or emergence trapping in years with flows above the incremental threshold, but below the all-or-nothing threshold.

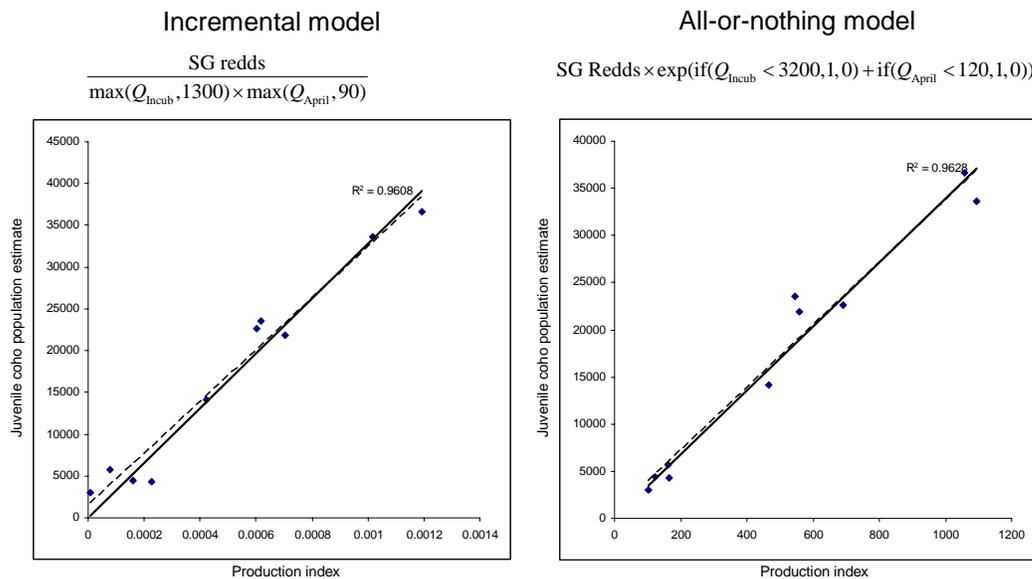


Figure 2-23. Two two-parameter models based on San Geronimo redds, peak incubation flow (Q_Incub), and maximum daily April flow (Q_April). The R-squared values reported above are for fitted lines through the origin; for unconstrained lines, the R-squared values are 0.966 and 0.933 for the Incremental and all-or-nothing models respectively.

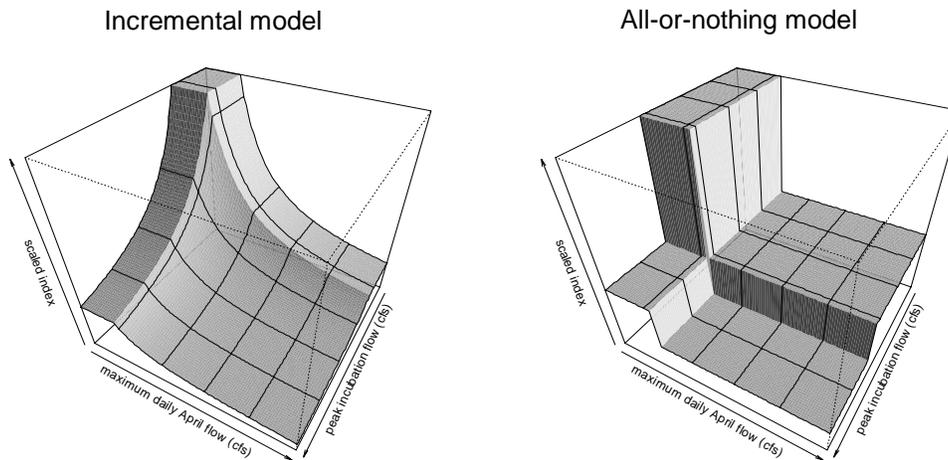


Figure 2-24. Production index for fixed number of redds, scaled by maximum production index. Gridlines show increments in maximum daily April flow of 100 cfs, and increments in peak incubation flow of 1,000 cfs.

A possible mechanistic explanation for the relationship between high spring flows and numbers of redds is that the displacement flow must occur after essentially all fry have emerged, otherwise, the later-emerging fry would reseed the summer rearing habitat. In most years, all the fry would have emerged and set up territories prior to April. However, in years with high escapements there is a greater probability of fish spawning later, and therefore, a greater probability that fry would emerge late in the season, thereby ameliorating the effects of high flows in April. This may be what happened in 2005, a year with record adult returns and which had high juvenile densities despite high April flows. Clearly, additional hypothesis-driven research needs to be conducted to evaluate how high spring flows effect coho summer rearing densities.

Summary of coho salmon investigations

Consistent with our conceptual model for coho salmon, we found evidence of winter habitat constraints on smolt production in both the analysis of existing information and through subsequent field studies. Based on these analyses, we suggest that there may be a winter carrying capacity of 6,000 to 7,000 juveniles. Our winter habitat field studies occurred during a year with exceptionally high flows (a flood with an approximately 25-year flood recurrence interval), and consequently our results were likely influenced by the magnitude of winter storms. Nevertheless, smolt numbers (as estimated in the outmigrant study) approached our hypothesized carrying capacity, largely due to production from the Tocaloma Reach. These results suggest that high quality winter habitat within the Tocaloma Reach buffers the coho population against rare and extreme flow events. In some years, fall juvenile abundance is below 6,000 fish. In these years, contrary to our conceptual model, there is evidence for high mortality during the early life stages of coho salmon. Through field studies, we have ruled out redd scour and entombment of eggs and alevins as likely factors limiting production during most years. Extreme flow events during some years (e.g., 1998, 2006) may result in redd scour, but these events are relatively infrequent compared to the three-year coho salmon life cycle. During more frequent flow events, such as the bankfull flood experienced during this study, redd scour appears minimal. Likewise, entombment of eggs and alevins does not appear sufficient to affect late-summer juvenile abundance.

Although there appears to be indirect evidence for displacement of fry during late-winter and spring freshets, the mechanisms for this mortality have not yet been tested. Further tests of this hypothesis are proposed in subsequent sections of this report.

Conclusions regarding the limiting factors affecting this coho salmon population are based on current conditions in the Lagunitas Creek watershed. If restoration of winter habitat is undertaken, at some point summer rearing habitat would become limiting. Evaluation of potential means of increasing summer rearing habitat would then be warranted, although there is a limit to how much summer habitat (e.g., pools) can or should be increased (i.e., if the pool/riffle ratio becomes too skewed towards pools there may be insufficient food supply from the riffles). Additionally, other factors may become limiting if changes occur to the watershed. For example, if riparian tree cover is reduced, water temperatures may rise to a point that summer rearing habitat is reduced. Likewise, the coho population currently appears resilient to mortality of eggs and alevins. However, if the mean size of spawning gravel were to decrease (due to a large influx of smaller gravel, for example), redd scour could increase. If summer rearing habitat becomes limiting and egg survival-to-emergence falls to lower than 3 or 4 percent due to a massive influx of fine sediment, then gravel quality may become limiting. Potential changes in watershed management that might alter the sediment, nutrient, or thermal inputs or flow regimes should be evaluated to see if the change is great enough to affect coho limiting factors.

2.4 Steelhead Status and Biological Overview

Steelhead found in the Lagunitas Creek watershed belong to the Central California Coast ESU (NMFS 1997), which includes coastal drainages from the Russian River to Aptos Creek and the drainages of San Francisco and San Pablo Bays, excluding the Sacramento-San Joaquin River basin. This ESU is federally listed as threatened under the Endangered Species Act (NMFS 2000).

Accurate adult population size estimates for Lagunitas Creek and other Bay Area watersheds are not available. In general, steelhead stocks throughout California have declined substantially. The most current estimate of the population of steelhead in California is approximately 250,000 adults, which is roughly half the population that existed in the mid-1960s (McEwan and Jackson 1996). A summary of the life history and habitat requirements of steelhead is provided below and the general steelhead life cycle is presented in Figure 2-25.

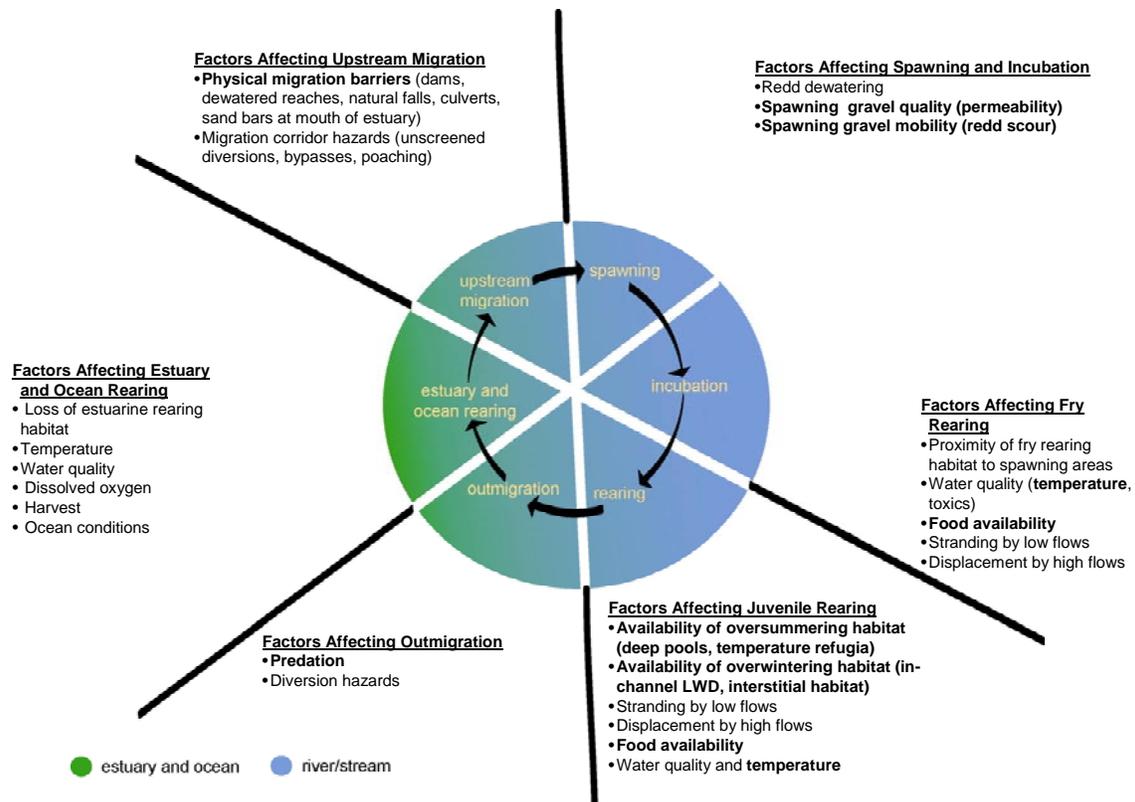


Figure 2-25. Steelhead life cycle with potential factors affecting each life stage.

2.4.1 Life history overview

Steelhead is the term commonly used for the anadromous life history form of *O. mykiss*. Both resident and anadromous life histories may be expressed within the same watershed, although detailed information on the relative proportion of each ecotype is rarely available. The relationship between anadromous and resident life history forms of this species is the subject of ongoing research. Current evidence suggests that the two forms are capable of interbreeding and that, under some conditions, either life history form can produce offspring that exhibit the alternate form (*i.e.*, resident rainbow trout can produce anadromous progeny and vice-versa) (Shapovalov and Taft 1954, Burgner et al. 1992, Hallock 1989). The fact that little to no genetic difference has been found between resident and anadromous life history forms inhabiting the same basin supports this hypothesis (Busby et al. 1993, Nielsen 1994, but see Zimmerman and Reeves 2001).

Steelhead return to spawn in their natal stream, usually in their fourth or fifth year of life, with males typically returning to fresh water earlier than females (Shapovalov and Taft 1954, Behnke 1992). A small percentage of steelhead may stray into streams other than their natal stream. Based on variability in the timing of their life histories, steelhead are broadly categorized into winter and summer reproductive ecotypes. Only the winter ecotype (winter-run) occurs in Lagunitas Creek. Winter-run steelhead generally enter spawning streams from late fall through spring as sexually mature adults, and spawn in late winter or spring (Roelofs 1985, Meehan and Bjornn 1991, Behnke 1992). Spawning occurs primarily from January through March, but may begin as early as late December and may extend through April (Hallock et al. 1961).

Female steelhead construct redds in suitable gravels, often in pool tailouts and heads of riffles, or in isolated patches in cobble-bedded streams. Steelhead eggs incubate in the redds for 3–14 weeks, depending on water temperatures (Shapovalov and Taft 1954, Barnhart 1991). After hatching, alevins remain in the gravel for an additional 2–5 weeks while absorbing their yolk sacs, and then emerge in spring or early summer (Barnhart 1991).

After emergence, steelhead fry move to shallow-water, low-velocity habitats, such as stream margins and low-gradient riffles, and forage in open areas lacking instream cover (Hartman 1965, Fontaine 1988). As fry grow and improve their swimming abilities in the late summer and fall, they increasingly use areas with cover and show a preference for higher velocity, deeper mid-channel areas near the thalweg (the deepest part of the channel) (Hartman 1965, Everest and Chapman 1972, Fontaine 1988).

Juvenile steelhead (parr) rear in fresh water before outmigrating to the ocean as smolts. The duration of time parr spend in fresh water appears to be related to growth rate, with larger, faster-growing members of a cohort smolting earlier (Peven et al. 1994). Steelhead in northern and central California typically spend two years in freshwater prior to smolting (Shapovalov and Taft 1954). Steelhead in warmer areas, where feeding and growth are possible throughout the winter, may spend a shorter period in fresh water before smolting, while steelhead in colder, more northern, and inland streams may require three or four years before smolting (Roelofs 1985).

Juvenile steelhead occupy a wide range of habitats, using deep pools as well as higher-velocity riffle and run habitats (Bisson et al. 1982, Bisson et al. 1988). During periods of low temperatures and high flows that occur in winter months, steelhead prefer low-velocity pool habitats with large rocky substrate or woody debris for cover (Hartman 1965, Raleigh et al. 1984, Swales et al. 1986, Fontaine 1988). During high winter flows, juvenile steelhead seek refuge in interstitial spaces in cobble and boulder substrates (Bustard and Narver 1975).

Juvenile emigration typically occurs from March through June. Emigration appears to be more closely associated with size than age, with 15–20 centimeters (6–8 inches) being most common for downstream migrants. Depending partly on growing conditions in their rearing habitat, steelhead may migrate downstream to estuaries as age 0+ juveniles or may rear in streams for up to four years before outmigrating to the estuary and ocean (Shapovalov and Taft 1954). Steelhead migrating downstream as juveniles may rear for one month to a year in the estuary before entering the ocean (Shapovalov and Taft 1954, Barnhart 1991).

2.5 Steelhead Conceptual Model

Coho salmon and steelhead share several life history traits that influence factors potentially limiting their populations. Perhaps the most important aspect for understanding their population dynamics is that the average fecundity is high relative to the amount of suitable juvenile rearing habitat usually available within a stream. This means that rather than reproductive success, their population growth tends to be limited by physical habitat constraints during the juvenile freshwater rearing stage.

Steelhead can smolt at a variety of ages, but most frequently smolt at age 2+. ⁸ Because juvenile steelhead must spend at least one summer and winter in freshwater prior to outmigrating to the

⁸ We follow conventional methods for assigning fish ages to year classes. Age 0+ refers to fish in their first year of life, sometimes called young-of-the-year; age 1+ to fish in their second year of life, and so on. A fish changes from age 0+ to age 1+ based on the time of hatching, which in the case of steelhead occurs in the spring.

sea, they tend to establish territories in suitable rearing habitat soon after emergence from the gravel. The maximum densities of overwintering age 0+ steelhead that a reach of stream can support are determined by territorial behavior, both intraspecific and interspecific with other salmonids when they are present.

Steelhead smolts tend to have much greater survival to adulthood if they outmigrate as age 2+ or older smolts because the older fish are generally larger. Although they are sometimes common, age 1+ smolts may contribute little to the numbers of returning adults.⁹ This differential survival is likely due to the advantages that larger fish have in evading predation, either through superior swimming ability or by growing larger than the gape of potential fish predators can accommodate. In considering steelhead life histories, it is important to distinguish between age 1+ smolts and age 1+ downstream migrants. It is a common life history strategy for juvenile steelhead to migrate downstream in the spring but rear for an additional year in an estuary before smolting when one is present. This is true of all age classes of juvenile steelhead but especially common at age 1+. Age 1+ steelhead that rear in the estuary will then smolt at age 2+ the following spring and, because they may be larger as a result of greater food supply in the estuary, they may experience similar if not higher survival to adults as stream-reared age 2+ smolts. Therefore, in instances of both stream and estuary rearing, production of adult steelhead depends greatly on the size of the smolts produced, and advantageous smolt size is most often reached by age 2+.

The relatively extended freshwater rearing of steelhead has important consequences for the species' population dynamics. The maximum number of steelhead that a stream can support is limited by food and space through territorial behavior, and this territoriality is necessary to produce steelhead smolts that are large enough to have a reasonable chance of ocean survival. Because of these habitat requirements, the number of age 0+ fish that a reach of stream can support is typically small relative to the average fecundity of an adult female steelhead. For example, a female steelhead may produce, on average, about 5,000 eggs. Typical age 0+ densities in some of the most productive California steelhead streams (e.g., tributaries to South Fork Eel River) are approximately 0.10 fish/ft² (1.1 fish/m²) (Connor 1996). Therefore, with survival-to-emergence as low as 25%, the number of fry produced from one female (5,000 x 0.25 = 1,250) may be sufficient to fully seed the available rearing capacity of nearly 0.25 miles (0.4 km) of Lagunitas Creek at some of the highest densities observed in California. Therefore, the availability of suitable juvenile rearing habitat (either in the summer or winter) is the factor that usually governs the number of steelhead smolts produced from a stream.

Within the freshwater rearing stages of their life histories, the physical habitat requirements for different age classes of steelhead are relatively similar, except that as fish age and grow they require more space for foraging. We postulate that age 0+ steelhead rearing habitat did not typically limit steelhead production under historical conditions in either winter or summer, and does not currently. Age 0+ steelhead can use shallower habitats and finer substrates (e.g., gravels) than age 1+ steelhead, which, because of their larger size, need coarser cobble/boulder substrate for velocity cover while feeding and as escape cover from predators. Because age 0+ steelhead can generally utilize the habitats suitable for age 1+ steelhead, but age 1+ steelhead can not use the shallower and/or finer substrate habitats suitable for age 0+ steelhead, it is unlikely that summer habitat will be in shorter supply for age 0+ than age 1+ steelhead. There may be stream systems or reaches where all available habitat is suitable for both age 0+ and age

⁹ Patterns described here are typical of North Coast and Central Valley populations, but may not necessarily reflect life histories of steelhead in southern California. South of San Francisco Bay, where warmer stream temperatures and longer photoperiods may lead to higher steelhead growth opportunities in some seasons, fish may achieve a suitable size for smolting at age 1+.

1+ steelhead, but even in these instances the density of age 0+ steelhead that the habitat will support will be higher than for the larger age 1+ steelhead simply due to allometric increases in territory size. In situations where summer habitat is suitable for both age classes, competition for space between age 0+ and age 1+ steelhead may restrict the numbers of age 0+ steelhead that the habitat will effectively support. But in general, a reach of stream would commonly support far fewer age 1+ than age 0+ steelhead in the summer.

As with summer habitat, a reach of stream will typically support far fewer age 1+ than age 0+ steelhead in the winter. In watersheds where temperatures become cold in winter (*i.e.*, < 45°F), predation risk becomes much greater because the fish become slower, sluggish, and less able to escape predators. Refuge from high flows requires a similar type of habitat as concealment cover, but may require access deeper into the streambed to avoid turbulent conditions near the surface or even within first layer of substrate (the implications of this for embeddedness are discussed later). During winter juvenile steelhead will often hide within the substrate (or other cover) during the day, emerging only at night. In colder regions, juvenile steelhead may remain concealed in the substrate all winter. Because steelhead tend to spawn in higher gradient reaches (*i.e.*, >3%) with confined stream channels, off-channel water bodies such as sloughs and backwaters are typically rare. As a result, steelhead show less propensity than other species (*e.g.*, coho salmon) for using off-channel slackwater habitats in winter, and a greater propensity for using in-channel cover provided by cobble and boulder substrates, which are typically common and usually immobile at all but the highest flows in these areas. Because age 0+ steelhead are smaller and can utilize a wider range of substrate than age 1+ steelhead, it will often be the case that there is more winter habitat available for age 0+ than for age 1+ fish.

In watersheds where, as a result of anthropogenic disturbance, there are increased inputs of coarse and fine sediment to the stream channel and decreased large woody debris, there is often greater disparity between the amount of summer habitat for age 0+ and age 1+ steelhead. Pool frequency is reduced with the removal of large woody debris, especially in forced pool-riffle and plane-bed stream reaches. The remaining pools may become shallower as a result of aggradation and the lack of scour-forcing features such as large woody debris. The filling of interstitial spaces of cobble/boulder substrates by gravels and sand can affect summer habitat for both age 0+ and age 1+ steelhead. But because of the larger size and more secretive nature of age 1+ steelhead, their habitat will be reduced at lower levels of embeddedness than for age 0+ steelhead.

Likewise, in the winter, habitat may often become unsuitable for age 1+ steelhead at lower magnitudes of sedimentation than for age 0+ steelhead. At higher levels of embeddedness, substrate will become unsuitable for both summer and winter rearing, but it will often be more limiting in winter because refuge from entrainment during winter freshets typically occurs deeper within the substrate. Thus, as for coho salmon, we initially assumed that winter rearing habitat limits steelhead populations in the study area.

2.6 Evaluation of Steelhead Conceptual Model

In this section we test and refine hypotheses suggested by our conceptual understanding of steelhead through synthesizing existing data (primarily collected by local agencies and groups from 1996 to present) and the results of focused field studies conducted by Stillwater Sciences between November 2004 and June 2006.

2.6.1 Winter habitat limitations

In this section we evaluate evidence for winter habitat limitations for steelhead, first using evidence from existing fisheries information available from Lagunitas Creek, and second using the results from focused field studies.

2.6.1.1 Evidence from existing information

Similar to our evaluation of the coho salmon conceptual model, our analysis of steelhead population dynamics begins with a comparison of the relative abundance of steelhead at different life stages. Because we believe it is essential for the maintenance of the population to produce age 2+ or older smolts, and that habitat suitable for producing them (age 1+ summer and/or winter habitat) was historically limiting, and under disturbed conditions would become even more so, the initial focus was to look at ratios of abundance of different life stages. If the number of age 1+ steelhead during the fall is high relative to the number of age 2+ smolts, then an initial hypothesis would be that age 1+ winter habitat is limiting. If the number of age 1+ steelhead is high during the late spring relative to the number of age 1+ steelhead during the fall, then it would indicate that age 1+ summer habitat is limiting. Finally, if the fall abundance of age 0+ is high relative to the spring abundance of age 1+ fish then winter habitat is likely limiting. Each of these hypotheses are further addressed below.

To assess the importance of winter habitat for age 1+ steelhead, we compared numbers of age 2+ steelhead smolts to numbers of age 1+ juvenile steelhead in fall. Bratovich and Kelley (1988) captured outmigrants for three years—1983, 1984, and 1985—the total number of smolts varied from approximately 340 to 700 fish. (These numbers may underestimate smolt production because the outmigrant trap washed out during portions of the emigration period during all three years. The degree to which this influences our interpretation of the existing data is discussed below.) Bratovich and Kelley (1988) provide estimates of the proportion of these smolts that are age 0+, 1+, or 2+ based on scales collected from a subsample of the fish captured. However, because the size range used to classify age 1+ fish is atypical for steelhead based on our professional judgment, there may be reasons to doubt that the proportions of age 1+ and 2+ smolts reported are accurate. A re-analysis of the data presented in Bratovich and Kelley (1988) using Shapovalov and Taft's (1954) length-at-age ranges shows very high proportions of steelhead smolting at age 2+ and a low number emigrating at age 1+ (Table 2-8). In other stream systems (e.g., Waddell Creek, Santa Cruz County), there are far more age 1+ downstream migrants than 2+ smolts. We have two hypotheses to explain these results:

1. In Lagunitas Creek, the estuary is no longer suitable for rearing large numbers of age 1+ fish through the summer; therefore, the life history strategy of migrating downstream at age 1+ is no longer viable and has been selected against, resulting in the Lagunitas population not having a strong age 1+ downstream migrant life history.
2. Overwinter survival of age 0+ steelhead is sufficiently low that the density of age 1+ fish is not sufficient to trigger significant density-dependent downstream migration of age 1+ steelhead in the spring.

Table 2-8. Estimated number and age composition of steelhead smolts captured in Lagunitas Creek during each spring, 1983-1985. Age composition was determined using length at age breaks given by Shapovalov and Taft (1954).

Year	Number and Percent Composition of Steelhead smolts captured by age						Total captured
	Age 0+		Age 1+		Age 2+		
	n	%	n	%	n	%	
1983	15	4	40	10	350	86	405
1984	5	1	10	3	322	96	337
1985	0	0	64	9	635	91	699
Total	20	1	114	8	1,307	91	1,441

To compare the estimated number of age 2+ smolts with previous life stages for the years 1983–1985, we need to estimate the number of age 1+ steelhead present during the fall. The summer/fall juvenile steelhead abundance data presented in Trihey & Associates (1995) for various years between 1970 and 1994, including the years 1982–1984, is aggregated over all age classes. It appears that the abundance of age 1+ fish could be estimated, as length data were collected. However, we have yet to acquire the length data for these electrofishing surveys. The reports produced by MMWD on late-summer/fall sampling for the years 1995 through 2005 do include separate estimates for age 0+ and 1+ steelhead (Table 2-9). If we assume that the abundance of age 1+ fish was similar in the years 1983–1985 (a potentially incorrect assumption), then roughly 3,000 to 4,000 age 1+ steelhead resulted in roughly 300–600 smolts—a survival of approximately 10 to 20 percent. This would indicate that winter habitat for age 1+ steelhead is limiting the number of 2+ smolts produced in the Lagunitas watershed.

Table 2-9. Extrapolated age 0+ and age 1+ steelhead population estimates for the Lagunitas watershed (data from MMWD).

Year	Age 0+	Year	Age 1+	Percent survival
1995	40,480	1996	4,179	10.32
1996	26,398	1997	2,325	8.81
1997	45,522	1998	3,224	7.08
1998	66,611	1999	3,376	5.07
1999	53,867	2000	4,097	7.61
2000	51,010	2001	3,975	7.79
2001	39,409	2002	2,437	6.18
2002	63,625	2003	3,562	5.6
2003	42,435	2004	2,562	6.04
2004	46,011	2005	2,816	6.12
2005	40,814	2006	2,697	6.61

* Data from Marin Municipal Water District

In the fall, there are generally 40,000 to 60,000 age 0+ juvenile steelhead in the Lagunitas watershed, compared to only 2,000 to 5,000 age 1+ steelhead (Table 2-9). Figure 2-26 through Figure 2-28 show the number of age 0+ steelhead present in a given year plotted against the resulting number of age 1+ steelhead present the following year for the Lagunitas watershed. The relationship between age 0+ and age 1+ steelhead abundance makes a very strong case for density-dependent mortality between the late-summer age 0+ life stage and late-summer age 1+

life stage (i.e., regardless of the number of age 0+ juveniles, roughly the same number of age 1+ steelhead are present each year). If we believe our re-analysis of Bratovich and Kelley's (1988) data and assume it is applicable to the 1995 to 2003 time period, then only a small fraction of the 90% loss of age 0+ fish is due to age 1+ emigration in the spring. (Even if we use the analysis by Bratovich and Kelley [1988] the number of age 1+ smolts is not high enough to account for the large discrepancy between the number of age 0+ and age 1+ juveniles present during late fall). This would lead us to hypothesize that either winter habitat for age 0+ fish or summer habitat for age 1+ fish is limiting the abundance of age 1+ fish in the fall. Because spring juvenile abundance data are not available, we can not conclusively determine which may be the case. As asserted earlier, the low number of age 1+ downstream migrants (based on our re-analysis of the length-at-age data presented in Bratovich and Kelley [1988]) may indicate that numbers of age 1+ fish are not sufficient to trigger substantial density-dependent downstream migration of age 1+ steelhead in the spring. If this were indeed true, we would hypothesize that winter habitat for age 0+ fish is limiting for age 1+ juveniles, but that the age 0+ winter carrying capacity is approximately 10 times greater than that for age 1+, which is consistent with our initial conceptual model.

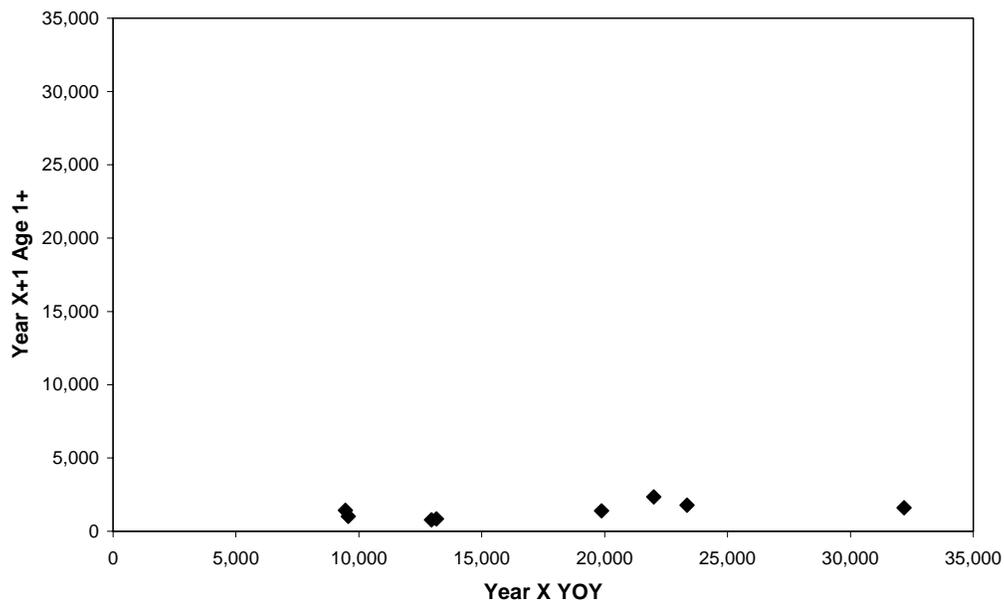


Figure 2-26. The relationship between age 0+ and age 1+ steelhead abundance during the fall in San Geronimo Creek.

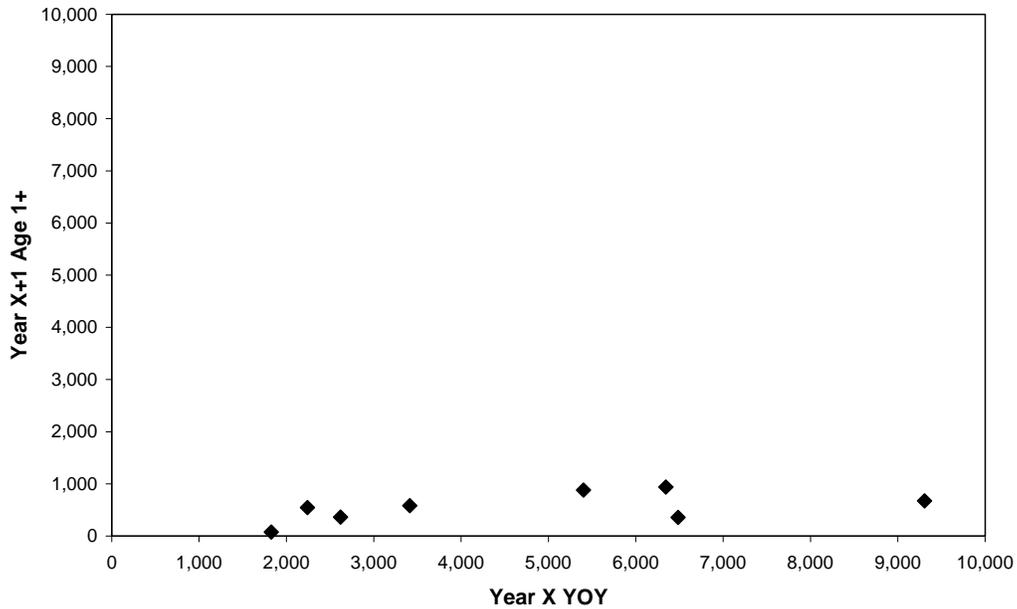


Figure 2-27. The relationship between age 0+ and age 1+ steelhead abundance during the fall in Devil's Gulch.

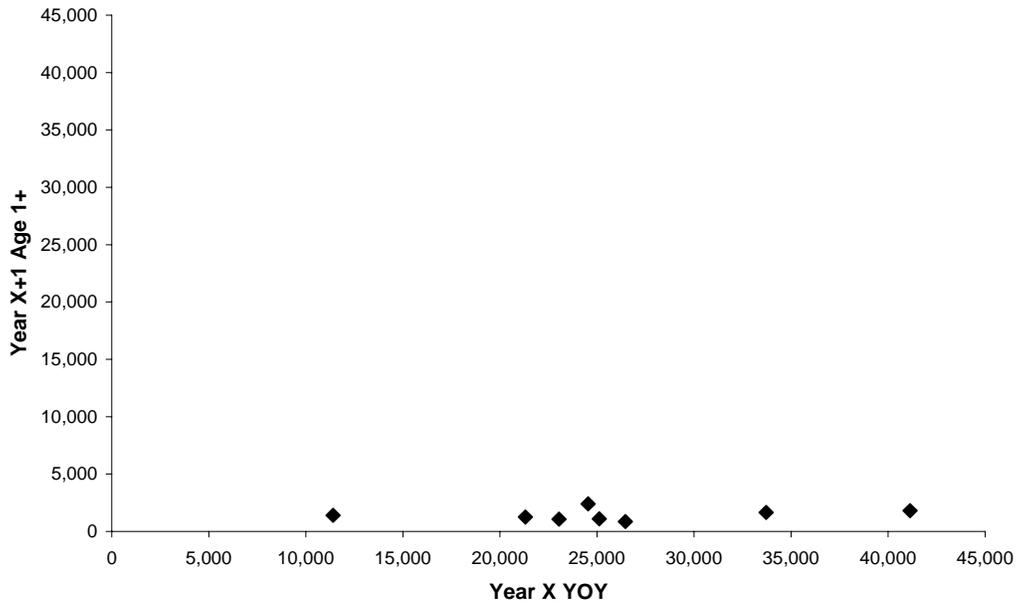


Figure 2-28. The relationship between age 0+ and age 1+ steelhead abundance during the fall in Lagunitas Creek.

A lack of information on recent steelhead smolt numbers and adult returns adds a great deal of uncertainty to our analysis of steelhead population dynamics in the Lagunitas watershed. Beginning in the winter of 2001/2002, MMWD survey crews began counting steelhead redds

during coho salmon spawning surveys. A total of 38 steelhead redds were observed in 2001/2002, and 15 redds were observed in 2002/2003. Because these surveys ended in late January or early February, they likely missed a large number of redds constructed after this period; in other streams (e.g., Waddell Creek), steelhead spawning typically peaks in mid-March and can extend into May. However, taking these redd counts as a minimum, and assuming a 1:1 sex ratio, at least 76 and 30 adult steelhead returned to the watershed in 2001/2002 and 2002/2003, respectively. Unlike for coho salmon, we cannot predict the number of smolts necessary to produce this return because steelhead may return to spawn another year. The relationship between annual smolt production and returning adults is further complicated by the fact that steelhead exhibit greater variation than coho in the number of years they may spend in the ocean before spawning. Although the redd counts certainly underestimate the number of returning adults, if they in fact represented the total run, this number of fish would be sufficient to seed available juvenile habitat to densities within the range reported for the years 1995-2003 in the Lagunitas watershed. In fact, assuming an average fecundity of 5,500 eggs and 50% survival-to-emergence, in theory only 25 females (or a total run of 50 fish) are necessary to seed the watershed at the highest densities of age 0+ juveniles that have been reported.

This leads us to two important conclusions. First, because of the high fecundity of female steelhead, adult steelhead escapement could reach very low numbers before late-summer abundance of juvenile steelhead would decline to a noticeable degree. Second, because winter habitat for age 1+ steelhead appears to limit the production of age 2+ smolts, which we believe are critical to the production of adult steelhead, but recent trends in age 2+ smolt numbers are unknown, the response of the steelhead population to habitat degradation could go unnoticed until the population was extremely small.

In summary, based on the best available evidence, winter habitat for age 1+ steelhead appears to limit the production of age 2+ smolts in the Lagunitas watershed. Although it is difficult to assess the strength of the steelhead population given the current available information, data presented in Bratovich and Kelley (1988) suggest that the number of age 2+ or older smolts produced in the Lagunitas watershed is relatively small. According to our conceptual model for steelhead, winter habitat for age 1+ or older steelhead is the first to degrade in the face of anthropogenic disturbance. Therefore, understanding the conditions that provide suitable winter habitat for age 1+ steelhead and maintaining or enhancing the quality of those habitats will be critical to maintaining steelhead production in the Lagunitas watershed.

2.6.1.2 Field evaluations

Because of relatively strong preliminary evidence for winter habitat limitations for coho and steelhead, we performed two complementary field studies to determine the habitat characteristics influencing persistence of juvenile salmonids through the winter and subsequent production of smolts in the spring. We undertook a detailed study of retention of individually marked fish in habitats with varying degrees of cover complexity in habitat units within Devil's Gulch and also conducted smolt trapping at three locations within the Lagunitas Creek watershed. The rationale and general methods for these studies was described in Section 2.3.1.2. In this section we describe the results of the two studies that are pertinent to evaluating our steelhead conceptual model. Detailed descriptions of the study methods are provided in Appendix A.

Devil's Gulch results

We tagged 767 age 0+ and 213 age 1+ steelhead in 28 study pools and runs in Devil's Gulch during October 2005. Following the initial tagging effort in October, we observed an approximately 20% reduction in age 0+ and a 40% reduction of age 1+ PIT-tagged steelhead in

study pools by the first relocation survey in November (Figure 2-29). This initial reduction in overall abundance was similar to the reduction observed for coho salmon and was unrelated to hydrologic conditions in Devil's Gulch. Instead, the initial decline in PIT-tagged fish is attributable to several factors: (1) differences in detection efficiency between the capture method of electrofishing and relocations using the hand-held reader; (2) redistribution of tagged fish from the study units to other habitats within the study reach; and (3) emigration from the study reach.

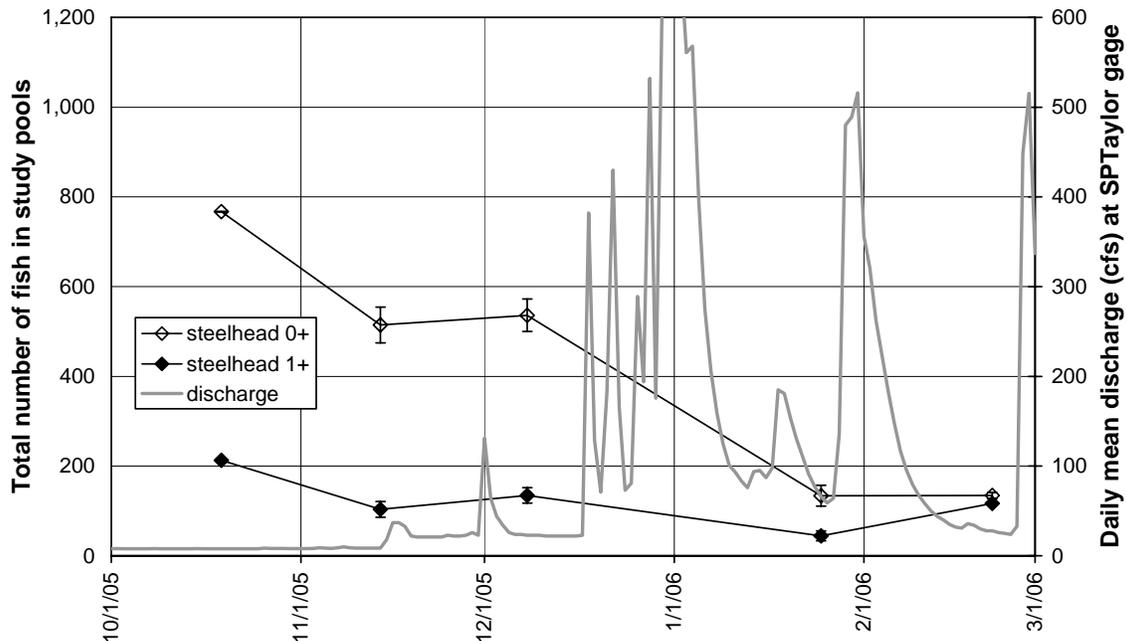


Figure 2-29. Abundance of PIT-tagged juvenile steelhead in study pools within Devil's Gulch and discharge patterns in Lagunitas Creek during winter of 2005-2006.

Differences in detection efficiency were observed for steelhead in pools in which both mobile tag reader and electrofishing surveys were conducted. Although these comparisons were limited, the mobile reader tended to produce higher estimates for tagged age 0+ steelhead compared to multiple-pass electrofishing (Figure 2-30). For age 1+ steelhead, the PIT-tag reader tended to underestimate the number of tagged fish captured during electrofishing (Figure 2-31).

Following the initial decline in fish abundance, no significant change in the estimated number of tagged steelhead occurred between relocation surveys in November and December. During this period the stream experienced two small freshets (maximum of 131 cfs mean daily flow at the SP Taylor gage), but the magnitude of these storms was not sufficient to cause significant emigration from Devil's Gulch.

Similar to coho salmon, age 0+ steelhead declined dramatically in response to the winter storms occurring during December 2005 and early January 2006. Numbers of age 0+ steelhead declined approximately 73% between December and February when storms were occurring. The abundance of age 1+ steelhead remained approximately the same from November until the end of the study in February.

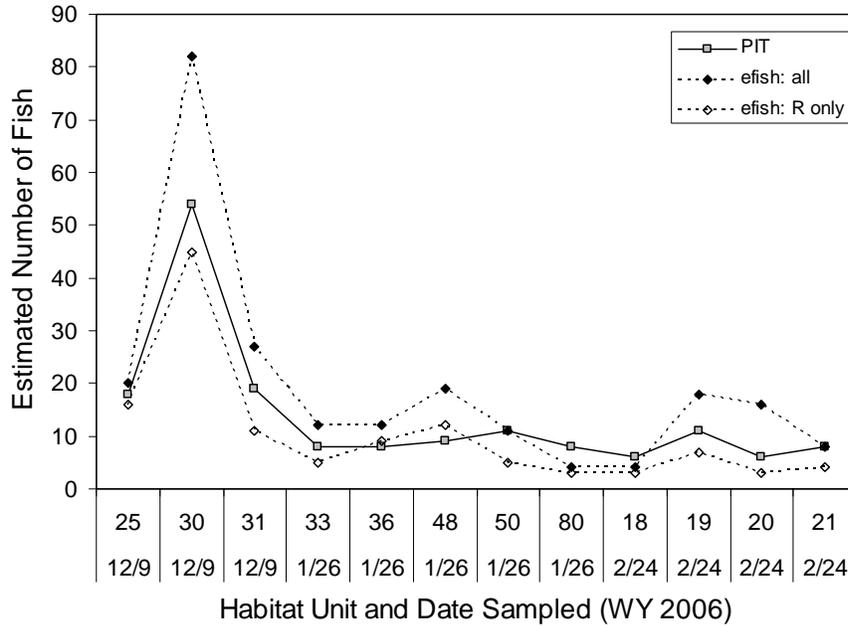


Figure 2-30. Comparison of the estimated number of age 0+ steelhead in Devil's Gulch study pools sampled by hand held PIT tag reader and electrofishing. "PIT" refers to steelhead detected with the reader; "efish: R only" refers to tagged steelhead captured via electrofishing; efish: all refers to all steelhead captured during electrofishing.

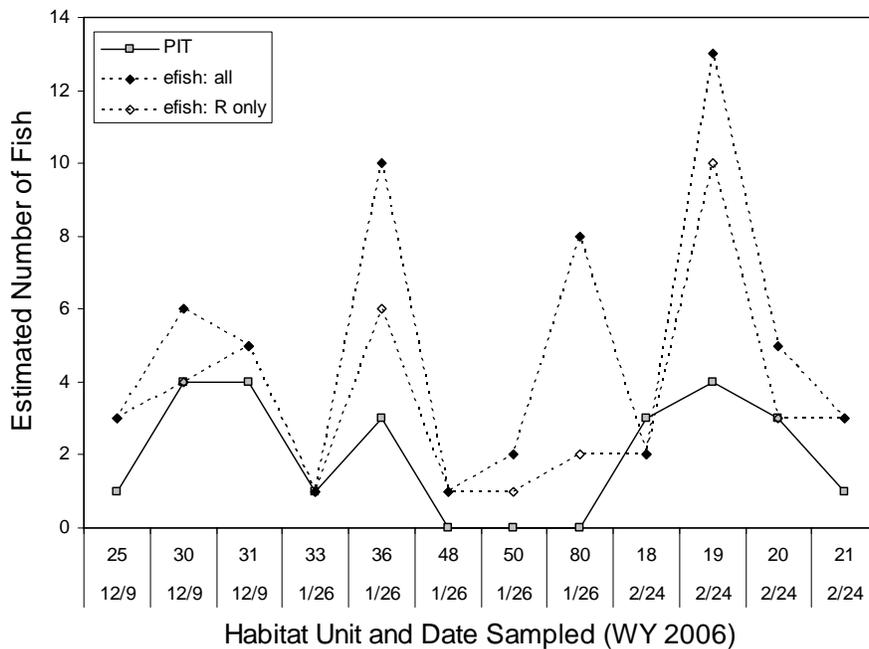


Figure 2-31. Comparison of the estimated number of age 1+ steelhead in Devil's Gulch study pools sampled by hand held PIT tag reader and electrofishing. "PIT" refers to steelhead detected with the reader; "efish: R only" refers to tagged steelhead captured via electrofishing; efish: all refers to all steelhead captured during electrofishing.

The decline in age 0+ fish (2005 cohort) over the study period brought their numbers to about the same as age 1+ fish present during the previous fall. The abundance of the 2005 steelhead cohort remained relatively constant until the population survey conducted by MMWD in fall 2006. As mentioned in the review of existing fisheries information, the relationship between age 0+ and age 1+ steelhead abundance in the Lagunitas Creek watershed makes a very strong case for density-dependent mortality between these life stages (i.e., regardless of the number of age 0+ juveniles, roughly the same number of age 1+ steelhead are present each year). We hypothesized that the reduction in abundance between life stages was due to a lack of winter high-flow refuge due, in part, to embeddedness of coarse substrate. Results from this study suggest that the large reduction in abundance between age 0+ and age 1+ life stages observed in the Lagunitas Creek watershed is related to mortality or emigration during winter storms. In contrast, winter mortality appears relatively low for age 1+ juveniles. Contrary to our conceptual model, these results suggest that winter habitat for age 0+ steelhead is limiting production of steelhead in the Lagunitas Creek watershed. Further evidence that winter habitat constraints on age 0+ steelhead are limiting steelhead production in the study area comes from the smolt trapping results discussed below.

Lagunitas downstream migrant results

An estimated 4,738 steelhead smolts emigrated from Lagunitas Creek during spring 2006. Similar to coho salmon, the peak in smolt emigration for steelhead occurred in late April and early May (Figure 2-32). However, the peak in steelhead emigration was less pronounced than for coho salmon. Steelhead smolt production was more evenly spread among stream reaches than was observed for coho salmon. An estimated 721 steelhead smolts were produced above the San Geronimo trap. However, we expect that a large portion of the steelhead emigration was missed at the San Geronimo trap because it wasn't installed until late April, and that steelhead smolt production above this trap was underestimated. Approximately 2,567 smolts were produced above the upper Lagunitas trap, and 4,738 smolts were produced above the lower Lagunitas trap (Table 2-10). When the number of steelhead smolts captured in stream reaches above the upper Lagunitas trap and between the upper and lower Lagunitas traps are expressed in terms of reach length, the linear abundance is 126 smolts/km produced above the upper Lagunitas trap, and 301 smolts/km produced in the Tocaloma Reach. From these results it appears that the Tocaloma Reach is important for steelhead production, as it was for coho. However, because of low recapture rates at both rotary screw traps, there is considerable variability in the steelhead smolt estimates, and differences in steelhead smolt production between the reaches may be overestimated.

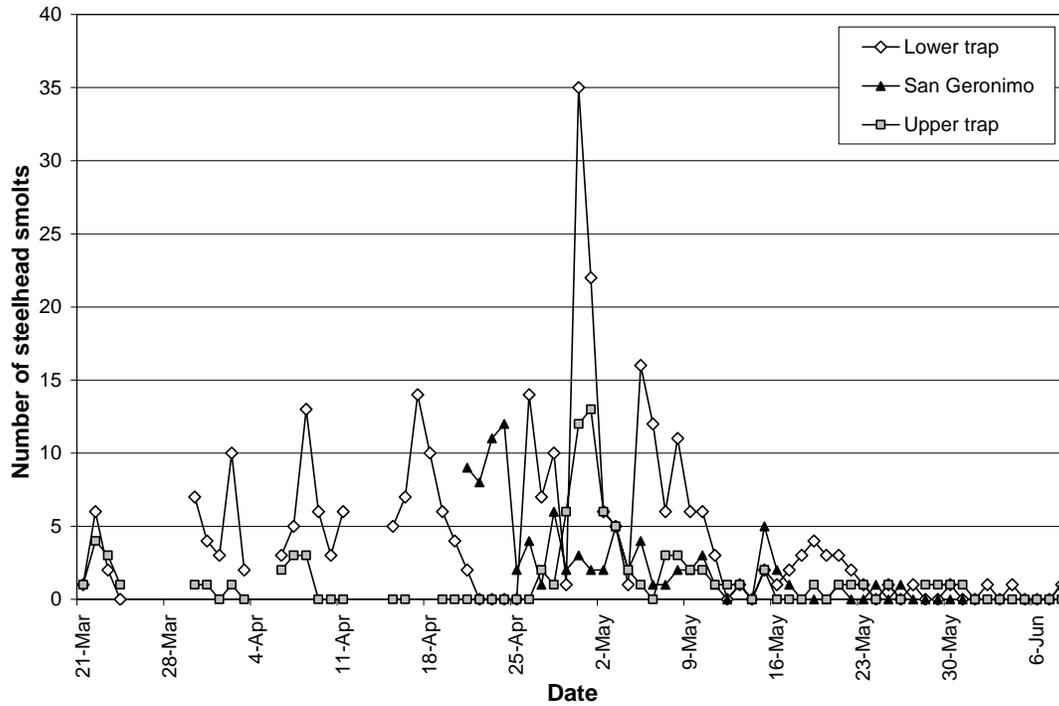


Figure 2-32. Steelhead smolts captured by calendar date at downstream migrant traps in the Lagunitas Creek watershed, 2006.

Table 2-10. Estimated abundance and capture efficiency of steelhead smolts at downstream migrant traps in San Geronimo Creek, and upper and lower Lagunitas Creek, spring 2006.

Trap	Abundance		Trap efficiency	
	Estimate	95% conf. int.	Estimate	95% conf. int.
San Geronimo Creek	721	404–1,366	0.12	0.06–0.20
Upper Lagunitas Creek	2,567	1,017–7,460	0.04	0.01–0.10
Lower Lagunitas Creek	4,738	2,261–11,601	0.06	0.02–0.12

Steelhead smolts captured at the Lower Lagunitas trap were larger, on average, than smolts captured at the upstream traps. Appendix A includes length frequencies of steelhead captured at the three traps summarized by week of capture. At all traps, we observed an initial increase in mean smolt size, followed by a gradual decline through the emigration period. This result is similar to trends of earlier migrating smolts being larger than later migrants that has been observed for coho salmon by Shapovalov and Taft (1954) and sockeye salmon by Crawford et al. (1992). As with coho, the difference in mean smolt size among the three downstream migrant traps suggests that growth opportunities are greater for fish that rear in the Tocaloma Reach.

Because steelhead can smolt at a variety of ages, we conducted a preliminary age composition analysis of steelhead smolts captured in spring 2006 using the length-at-age size thresholds calculated by Shapovalov and Taft (1954). According to this analysis, age 2+ smolts dominate the total smolt catch, with age 1+ fish comprising approximately 13% of the total (Table 2-11). This result is similar to the age composition of smolts we estimated from data presented in

Bratovich and Kelley (1988) using the same length-at-age size thresholds (see Table 2-8). One preliminary hypothesis, based on review of the limited data presented by Bratovich and Kelley (1988), was that the low number of age 1+ downstream migrants reflects changes to the estuary from historical conditions. If the estuary is no longer suitable for rearing large numbers of age 1+ fish through the summer, the life history strategy of migrating downstream at age 1+ is not viable and has been selected against, resulting in the Lagunitas population not having a strong age 1+ downstream migrant life history component. However, results from the Devil's Gulch study, and more recent steelhead population estimates suggest that our alternative hypothesis was true: overwinter survival of age 0+ steelhead is sufficiently low that numbers of age 1+ fish are not sufficient to trigger significant density-dependent downstream migration of age 1+ steelhead in the spring.

Table 2-11. Estimated number and age composition of steelhead smolts captured in Lagunitas Creek during spring 2006. Age composition was determined using length-at-age thresholds in Shapovalov and Taft (1954).

Year	Age 1+		Age 2+		Total captured
	n	%	n	%	
2006	34	14	250	86	284

The age 2+ smolt estimate from spring 2006 (4,122) is similar to the total estimated abundance of age 1+ steelhead present in the Lagunitas creek watershed during the previous fall (2,816). This result indicates high survival of age 1+ steelhead over the winter. Although we have only one year of recent smolt data, the estimated abundance of age 2+ smolts in 2006 is also consistent with previous estimates of age 1+ abundance in the Lagunitas Creek watershed, which typically range from approximately 2,000 to 4,000 fish.

3 SYNTHESIS AND RECOMMENDATIONS

The next step in the limiting factors approach to enhancing coho and steelhead in Lagunitas Creek is to develop a restoration and adaptive management plan with site-specific designs. As an example of what might be included in such a plan, Figure 3-1 shows a design for two wood jams in East Fork Rock Creek in the North Umpqua River watershed of Oregon. The East Fork Rock Creek program includes site-specific designs for 30 locations and a detailed monitoring protocol to determine which designs were most effective at increasing coho overwintering survival. The recommendations below would serve as the basis for developing such a detailed plan.

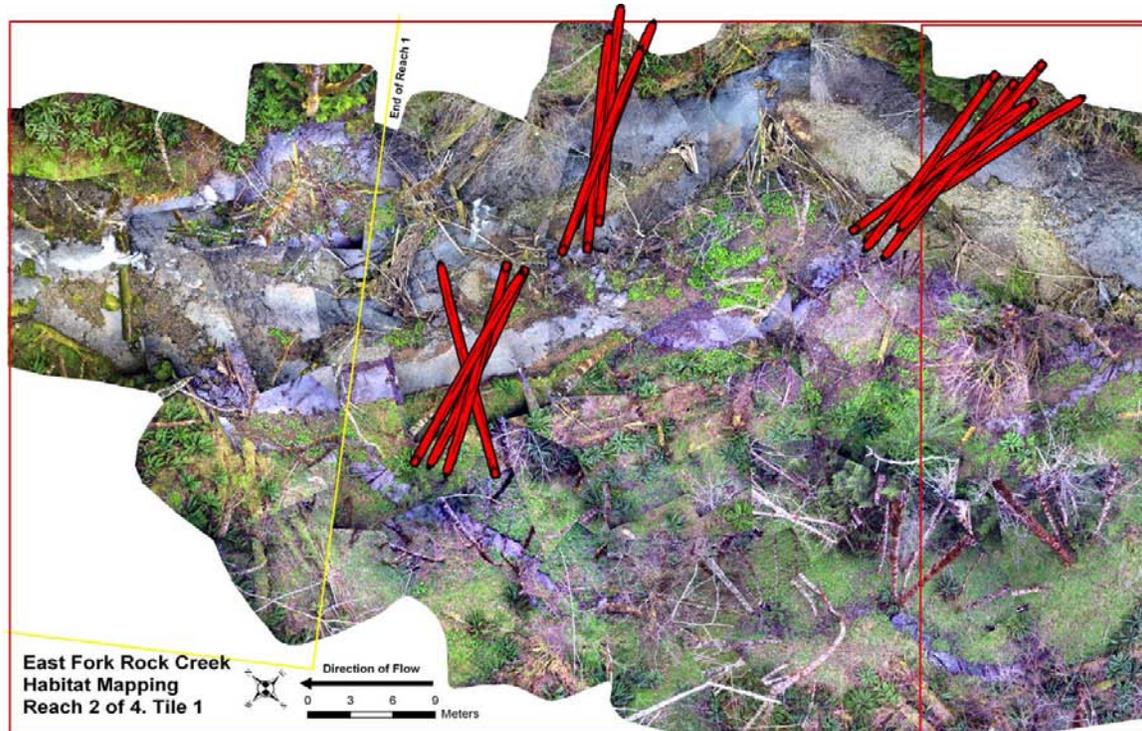


Figure 3-1. Site specific designs for two wood jams in East Fork Rock Creek.

3.1 Coho Salmon

For coho salmon in the Lagunitas Creek watershed there are two probable chronic constraints to smolt production, high spring flows and winter habitat availability, the influence of which will vary annually according to seasonal patterns of high-flow events. Evidence for winter habitat constraints on population growth comes from the large discrepancy between late-summer abundance of juveniles and smolt production estimates and from the results of focused field studies conducted as part of this limiting factors assessment. The available evidence suggests that smolt production may typically be limited to between 6,000 and 7,000 fish, although actual smolt production may vary somewhat depending on winter severity. In 2006, the majority of coho smolt production occurred in San Geronimo Creek or in the Tocaloma Reach of Lagunitas Creek, with very little production observed in the confined channel of Devil's Gulch and upper reaches of Lagunitas Creek. In San Geronimo Creek, we recommend maintaining or restoring connectivity between the main channel and its low-gradient tributaries. We hypothesize that many of the small, low-gradient tributaries to San Geronimo Creek provide winter refuge habitat

during periods of high stream flow. The value of these tributaries to juvenile salmonids should be confirmed by further studies.

In confined channel types within Devil's Gulch, San Geronimo Creek, and the upper reaches of Lagunitas Creek, constructed wood jams could increase winter carrying capacity. We witnessed a net loss of woody debris from Devil's Gulch as a result of export to the Lagunitas Creek channel during winter storms in 2006. Because flows during these storms were extremely high, they may have removed much of the large wood that had collected and persisted through previous lower-magnitude flood events. Before the loss of woody debris occurred, we conducted exploratory field sampling with the PIT-tag reader during high flow events. Our field observations suggest that the larger and more complex jams create the best winter refuge habitat because they provide slackwater habitat throughout all stages of the hydrograph. Refuge habitat utilizing live trees may also be feasible. Woody debris additions of various configurations to improve winter habitat should be tested and monitored in a pilot study reach to develop effective design criteria. We recommend that woody debris addition proceeds adaptively, with monitoring of fish retention at sites with different configurations. Once various designs have been evaluated for effectiveness, the same types of structures could be used throughout similar channel types within the watershed.

Currently, the most important reach for coho salmon smolt production appears to be the Tocaloma Reach of Lagunitas Creek. Floodplain habitat in this reach should be protected from development or disturbance to preserve the winter habitat that this reach provides. Studies to document habitat utilization within the Tocaloma Reach during the winter would provide information on the specific characteristics of off-channel habitats that are effective as overwinter habitat. Further years of smolt trapping above and below this reach would increase confidence in our assessment of the importance of this reach for coho smolt production.

During years of low fall abundance of juvenile coho, such as occurred in 1998, 1999, and 2000, winter habitat does not appear to limit smolt production. In these years, early lifestage mortality appears to limit production of coho from the watershed. There is uncertainty regarding the mechanisms responsible for low fall juvenile abundance during these years. Results from the redd scour and emergence trapping field studies indicate that downstream transport of sediment is not currently affecting the coho salmon population during years with low-recurrence interval high flow events (e.g., bankfull floods occurring every 1.5 to 2 years). However, larger-magnitude high flows, such as occurred in water years 1998 and 2006, may cause redd scour. The existing data suggests that displacement of fry during spring freshets may explain low juvenile abundance in some years. However, our results from 2005 snorkel surveys were inconclusive. Future investigations could be used to determine whether summer flow patterns, cooler than average stream temperatures, or other habitat conditions enabled juvenile coho to reach such high densities in the lower reaches of Lagunitas Creek during 2005. Specific management recommendations to reduce early lifestage mortality should be contingent on further evaluation of the potential for displacement of newly emerged coho fry. However, restoration actions aimed at improving overwinter habitat by increasing large woody debris cover and complexity within confined reaches of Lagunitas Creek, San Geronimo Creek, and Devil's Gulch are also likely to improve fry retention during spring freshets.

Finally, ocean survival is a contributing factor to coho salmon productivity in the Lagunitas Creek watershed. The high apparent ocean survival of coho salmon over the last ten years may be related to the relatively large size of smolts produced in the watershed, and from the Tocaloma Reach in particular. In addition, Tomales Bay may improve ocean survival of coho salmon smolts relative to other watersheds by providing an ecotone in which smolts can grow rapidly

before entering the near-shore ocean environment. Low adult returns of coho salmon in 2007/2008 over a large part of their range (including Lagunitas Creek) have been attributed in part to poor ocean conditions in 2006 and 2007 (MacFarlane et al. 2008). It is unclear whether the recent decline in near-shore ocean productivity is part of a trend which could reduce ocean survival of coho salmon over the long term. If so, more extensive habitat restoration efforts may be necessary to produce enough smolts to maintain the numbers of returning adults that have been observed over the last ten years. An increased understanding of coho salmon use of Tomales Bay, the near-shore ocean environment, and the influence of both freshwater and ocean conditions on survival rates would add greatly to the understanding of coho population dynamics in the Lagunitas Creek watershed.

3.2 Steelhead

As with coho salmon, winter habitat appears to limit the steelhead population in the Lagunitas Creek basin. However, contrary to our original hypothesis that age 1+, rather than age 0+ winter habitat, is typically limiting for steelhead, our results suggest that winter mortality for the younger age class may limit production of steelhead in Lagunitas Creek. In Devil's Gulch, numbers of age 0+ steelhead (2005 cohort) declined dramatically over the winter study period (~93% reduction) to about the numbers of age 1+ fish present the previous fall. The abundance of the 2005 steelhead cohort remained relatively constant through fall of 2006, when MMWD conducted their juvenile salmonid population survey. In contrast, age 1+ fish (2004 cohort) had high survival over the winter study period. Further evidence for constraints on the younger age class came from the smolt trapping study. The age 2+ smolt estimate from spring 2006 (4,122; 95% CI: 1,944 and 9,977) is similar to the total estimated abundance of age 1+ steelhead present in the Lagunitas Creek watershed during the previous fall (2,816)¹⁰. This result indicates high survival of age 1+ steelhead over the winter. In contrast to coho salmon, production of steelhead smolts appears more evenly distributed across the Lagunitas watershed. Because of their propensity for using unembedded cobble and boulder substrate as refuge during high winter flows, we recommend looking for opportunities to adjust the configuration of coarse cobble and boulder substrates in reaches where they are naturally present to improve winter habitat. As with woody debris additions, we suggest that coarse substrate enhancements proceed adaptively by incorporating monitoring to determine the effectiveness of different habitat improvement techniques.

Increasing winter carrying capacity for age 0+ steelhead may increase the abundance of juvenile fish until summer habitat for age 1+ steelhead becomes limiting. After winters of high age 0+ survival an age 1+ summer habitat bottleneck may develop if pool habitat becomes limiting. However, behavioral emigration of "excess" age 1+ steelhead surviving the winter could increase production if suitable habitat can be provided through restoration of the Lagunitas estuary. Besides the ocean life stages, utilization of the Lagunitas Creek estuary is perhaps the least understood component of salmonid population dynamics and ecology in the watershed.

¹⁰ Although the age 2+ smolt estimate in spring 2006 is larger than the age 1+ estimate from the previous fall, the discrepancy between values is within the error associated with either estimate.

4 LITERATURE CITED

- Andrews, E. D. 1983. Entrainment of gravel from naturally sorted riverbed material. Geological Society of America Bulletin 94: 1225-1231.
- Barnhart, R. A. 1991. Steelhead *Oncorhynchus mykiss*. Pages 324-336 in J. Stolz and J. Schnell, editors. Trout. Stackpole Books, Harrisburg, Pennsylvania.
- Behnke, R. J. 1992. Native trout of western North America. American Fisheries Society, Bethesda, Maryland.
- Bell, E. 2001. Survival, growth and movement of juvenile coho salmon (*Oncorhynchus kisutch*) over-wintering in alcoves, backwaters, and main channel pools in Prairie Creek, California. Master's thesis. Humboldt State University, Arcata, California.
- Beschta, R. L., R. E. Bilby, G. W. Brown, L. B. Holtby, and T. D. Hofstra. 1987. Stream temperature and aquatic habitat: fisheries and forestry interactions. Pages 191-232 in E. O.Salo and T. W. Cundy, editors. Streamside management: forestry and fishery interactions. Contribution No. 57. College of Forest Resources, University of Washington, Seattle.
- Bilton, H. T., D. F. Alderdice, and J. T. Schnute. 1982. Influence of time and size at release of juvenile coho salmon (*Oncorhynchus kisutch*) on returns at maturity. Canadian Journal of Fisheries and Aquatic Sciences 39: 426-447.
- Bisson, P.A., J.L. Nielsen, R.A. Palmason, and L.E. Grove. 1982. A system of naming habitat types in small streams, with examples of habitat utilization by salmonids during low streamflow. In N.B. Armantrout (ed.) Acquisition and Utilization of Aquatic Habitat Inventory Information: Proceedings of the Symposium. Portland, OR, October 1981.
- Bisson, P. A., J. L. Nielsen, and J. W. Ward. 1988. Summer production of coho salmon stocked in Mount St. Helens streams 3-6 years after the 1980 eruption. Transactions of the American Fisheries Society 117: 322-335.
- Bisson, P. A., K. Sullivan, and J. L. Nielsen. 1988. Channel hydraulics, habitat use, and body form of juvenile coho salmon, steelhead trout, and cutthroat trout in streams. Transactions of the American Fisheries Society 117: 262-273.
- Bratovich, P. M., and D. W. Kelley. 1988. Investigations of salmon and steelhead in Lagunitas Creek, Marin County, California. Volume I: migration, spawning, embryo incubation and emergence, juvenile rearing, and emigration. Prepared by D. W. Kelley and Associates, Newcastle, California for Marin Municipal Water District, Corte Madera, California.
- Briggs, J. C. 1953. The behavior and reproduction of salmonid fishes in a small coastal stream. Fish Bulletin No. 94. California Department of Fish and Game, Marine Fisheries Branch.

- Brown, L. R., and P. B. Moyle. 1991. Status of coho salmon in California. Prepared by Department of Wildlife and Fisheries, University of California, Davis for National Marine Fisheries Service, Terminal Island, California.
- Brown, L. R., P. B. Moyle, and R. M. Yoshiyama. 1994. Historical decline and current status of coho salmon in California. *North American Journal of Fisheries Management* 14: 237-261.
- Bryant, G. J. 1994. Status review of coho salmon populations in Scott and Waddell creeks, Santa Cruz County, California. National Marine Fisheries Service, Southwest Region, Protected Species Management Division, Santa Rosa, California.
- Burgner, R. L., J. T. Light, L. Margolis, T. Okazaki, A. Tautz, and S. Ito. 1992. Distribution and origins of steelhead trout (*Oncorhynchus mykiss*) in offshore waters of the North Pacific Ocean. *International North Pacific Fisheries Commission Bulletin* 51: 92 p.
- Busby, P. J., O. W. Johnson, T. C. Wainwright, F. W. Waknitz, and R. S. Waples. 1993. Status review for Oregon's Illinois River winter steelhead. NOAA Technical Memorandum NMFS-NWFSC-10. National Marine Fisheries Service, Seattle, Washington.
- Bustard, D. R., and D. W. Narver. 1975. Aspects of the winter ecology of juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Salmo gairdneri*). *Journal of the Fisheries Research Board of Canada* 32: 667-680.
- CDFG (California Department of Fish and Game). 1994. Coho salmon habitat impacts. Qualitative assessment techniques for registered professional foresters. Draft Report No. 2. Prepared for the California Board of Forestry.
- Connor, E. J. 1996. Comparative evaluation of Pacific giant salamander and steelhead trout populations among streams in old-growth and second-growth forests of northwest California. Doctoral dissertation. University of California, Davis.
- Crawford, C., G. Jenkins, and G. Edgar. 1992. Water column trophodynamics in Port Phillip Bay. CSIRO, Port Phillip Bay Environmental Study. Internal report, No. 1. Victoiran Institute of Marine Science, Queenscliff.
- Crone, R. A., and C. E. Bond. 1976. Life history of coho salmon, *Oncorhynchus kisutch*, in Sashin Creek, southeastern Alaska. *Fishery Bulletin* 74: 897-923.
- DeVries, P. 1997. Riverine salmonid egg burial depths: review of published data and implications for scour studies. *Canadian Journal of Fisheries and Aquatic Sciences* 54: 1685-1698.
- Dill, L. M., R. C. Ydenburg, and A. H. G. Fraser. 1981. Food abundance and territory size in juvenile coho salmon (*Oncorhynchus kisutch*). *Canadian Journal of Zoology* 59: 1801-1809.

- Dolloff, C. A., and G. H. Reeves. 1990. Microhabitat partitioning among stream-dwelling juvenile coho salmon, *Oncorhynchus kisutch*, and Dolly Varden, *Salvelinus malma*. Canadian Journal of Fisheries and Aquatic Sciences 47: 2297-2306.
- Drucker, B. 1972. Some life history characteristics of coho salmon of the Karluk River system, Kodiak Island, Alaska. Fisheries Bulletin 70: 79-94.
- Ettlenger, E. 2004. Salmonid trends in the Lagunitas Creek watershed. PowerPoint presentation. Prepared for Marin Municipal Water District, Fairfax, California.
- Ettlenger, E. 2007. Juvenile coho population model for the Lagunitas Creek watershed. Unpublished memorandum from MMWD.
- Ettlenger, E., C. Kranz, F. Rohr, and G. Andrew. 2006. Juvenile salmonid population monitoring report, Lagunitas Creek, Marin County, California, fall 2005. Marin Municipal Water District, Corte Madera, California.
http://www.marinwater.org/documents/MMWD_Juv_Report_2005.pdf.
- Ettlenger, E., J. Riley, and G. Andrew. 2003. Juvenile salmonid population monitoring report, Lagunitas Creek, Marin County, California, Fall 2002. Marin Municipal Water District, Corte Madera, California.
- Everest, F. H., and D. W. Chapman. 1972. Habitat selection and spatial interaction by juvenile Chinook salmon and steelhead trout in two Idaho streams. Journal of the Fisheries Research Board of Canada 29: 91-100.
- Fausch, K. D. 1993. Experimental analysis of microhabitat selection by juvenile steelhead (*Oncorhynchus mykiss*) and coho salmon (*O. kisutch*) in a British Columbia stream. Canadian Journal of Fisheries and Aquatic Sciences 50: 1198-1207.
- Fontaine, B. L. 1988. An evaluation of the effectiveness of instream structures for steelhead trout rearing habitat in the Steamboat Creek basin. Master's thesis. Oregon State University, Corvallis.
- Hallock, R. J. 1989. Upper Sacramento River steelhead (*Oncorhynchus mykiss*), 1952-1988. Prepared for U. S. Fish and Wildlife Service, Sacramento, California.
- Hallock, R. J., W. F. Van Woert, and L. Shapovalov. 1961. An evaluation of stocking hatchery-reared steelhead rainbow trout (*Salmo gairdnerii gairdnerii*) in the Sacramento River system. Fish Bulletin 114. California Department of Fish and Game.
- Hartman, G. F. 1965. The role of behavior in the ecology and interaction of underyearling coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Salmo gairdneri*). Journal of the Fisheries Research Board of Canada 22: 1035-1081.
- Hartman, G. F., B. C. Andersen, and J. C. Scrivener. 1982. Seaward movement of coho salmon (*Oncorhynchus kisutch*) fry in Carnation Creek, an unstable coastal stream in British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 39: 588-597.

- Harvey, B. C. 1987. Susceptibility of young-of-the-year fishes to downstream displacement by flooding. *Transactions of the North American Fisheries Society* 116: 851-855.
- Hassler, T. J., C. M. Sullivan, and G. R. Stern. 1991. Distribution of coho salmon in California. Final Report, Contract No. FG7292. Prepared by U. S. Fish and Wildlife Service, California Cooperative Fishery Research Unit, Humboldt State University, Arcata for California Department of Fish and Game, Sacramento.
- Hazzard, A. S. 1932. Some phases of the life history of the eastern brook trout, *Salvelinus fontinalis* Mitchill. *Transactions of the American Fisheries Society* 62: 344-350.
- Hecht, B. 1983. Substrate enhancement/sediment management study, Lagunitas Creek, Marin County. Phase IIIb: sediment transport and bed conditions, 1979-1982. Prepared by HEA, Berkeley, California for Marin Municipal Water District, Corte Madera, California.
- Hecht, B. 1992. Sediment overview report: development of an initial sediment management plan for Lagunitas Creek, Marin County, California. Prepared by Balance Hydrologics, Inc., Berkeley, California for Marin Municipal Water District, Corte Madera, California.
- Heggenes, J., and T. Traaen. 1988. Downstream migration and critical water velocities in stream channels for fry of four salmonid species. *Journal of Fish Biology* 32: 717-727.
- Hobbs, D. F. 1937. Natural reproduction of quinnat salmon, brown trout and rainbow trout in certain New Zealand waters. *Fisheries Bulletin* 6. New Zealand Marine Department.
- Holtby, L. B., B. C. Andersen, and R. K. Kadowaki. 1990. Importance of smolt size and early ocean growth to interannual variability in marine survival of coho salmon (*Oncorhynchus kisutch*). *Canadian Journal of Fisheries and Aquatic Sciences* 47: 2181-2194.
- Kalleberg, H. 1958. Observations in a stream tank of territoriality and competition in juvenile salmon and trout (*Salmo salar* L. and *S. trutta* L.). *Annual Report of the Institute of Freshwater Research, Drottningholm* 39: 55-98.
- Ketcham, B. J., G. G. Brown, and O. G. Wolff. 2004. Index reach monitoring program summary - Olema Creek, Marin County, California: 1999-2003. PORE/NR/WR/04-04.
- Kinsolving, A. D., and M. B. Bain. 1990. A new approach for measuring cover in fish habitat studies. *Journal of Freshwater Ecology* 5: 373-378.
- Lisle, T. E., and R. E. Eads. 1991. Methods to measure sedimentation of spawning gravels. Research Note PSW-411. USDA Forest Service, Pacific Southwest Research Station, Berkeley, California.
- Lister, D. B., and H. S. Genoe. 1970. Stream habitat utilization of cohabiting underyearlings of Chinook (*Oncorhynchus tshawytscha*) and coho (*O. kisutch*) salmon in the Big Qualicum River, British Columbia. *Journal of the Fisheries Research Board of Canada* 27: 1215-1224.

- MacFarlane, R. B., S. Hayes, and B. Wells. 2008. Coho and Chinook salmon decline in California during the spawning seasons of 2007/2008. Internal memorandum. NOAA Fisheries Service, Southwest Fisheries Science Center, Santa Cruz, California.
- Mason, J. C. 1976. Response of underyearling coho salmon to supplemental feeding in a natural stream. *Journal of Wildlife Management* 40: 775-788.
- Mason, J. E. 1966. The migrant dipper: a trap for downstream-migrating fish. *The Progressive Fish-Culturist* 28: 96-102.
- McEwan, D., and T. A. Jackson. 1996. Steelhead restoration and management plan for California. Management Report. California Department of Fish and Game, Inland Fisheries Division, Sacramento.
- McMahon, T. E., and G. F. Hartman. 1989. Influence of cover complexity and current velocity on winter habitat use by juvenile coho salmon (*Oncorhynchus kisutch*). *Canadian Journal of Fisheries and Aquatic Sciences* 46: 1551-1557.
- Meehan, W. R., and T. C. Bjornn. 1991. Salmonid distributions and life histories. Pages 47-82 in W. R. Meehan, editor. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication No. 19. Bethesda, Maryland.
- Montgomery, D. R., E. M. Beamer, G. R. Pess, and T. P. Quinn. 1999. Channel type and salmonid spawning distribution and abundance. *Canadian Journal of Fisheries and Aquatic Sciences* 56: 377-387.
- Montgomery, D. R., J. M. Buffington, N. P. Peterson, D. Schuett-Hames, and T. P. Quinn. 1996. Stream-bed scour, egg burial depths, and the influence of salmonid spawning on bed surface mobility and embryo survival. *Canadian Journal of Fisheries and Aquatic Sciences* 53: 1061-1070.
- Moyle, P. B., J. E. Williams, and E. D. Wikramanayake. 1989. Fish species of special concern of California. Final Report. Prepared by Department of Wildlife and Fisheries Biology, University of California, Davis for California Department of Fish and Game, Inland Fisheries Division, Rancho Cordova.
- Mundie, J. H. 1969. Ecological implications of the diet of juvenile coho in streams. Pages 135-152 in T. G. Northcote, editor. Symposium on salmon and trout in streams. H. R. MacMillan Lectures in Fisheries, University of British Columbia, Vancouver.
- Nielsen, J. 1994. Invasive cohorts: impacts of hatchery reared coho salmon on the trophic, developmental, and genetic ecology of wild stocks. USDA Forest Service, Pacific Southwest Research Station, Albany, California.
- NMFS (National Marine Fisheries Service). 1996. Endangered and threatened species; threatened status for central California coast coho salmon Evolutionarily Significant Unit (ESU). *Federal Register* 61: 56138-56149.

- NMFS. 1997. Endangered and threatened species: threatened status for southern Oregon/northern California coast evolutionarily significant unit (ESU) of coho salmon. Federal Register 62: 24588-24609.
- NMFS. 1999. Designated critical habitat; central California coast and southern Oregon/northern California coast coho salmon. Federal Register 64: 24049-24062.
- NMFS. 2000. California coastal salmon and steelhead current stream habitat distribution table. NMFS, Southwest Region, Long Beach, California. <http://swr.ucsd.edu/hcd/Mendocsonoma.PDF>
- NMFS. 2005. Endangered and threatened species; final listing determinations for 16 ESUs of west coast salmon, and final 4(d) protective regulations for threatened salmonid ESUs. Federal Register 70: 37160-37204.
- Ottaway, E. M., and A. Clarke. 1981. A preliminary investigation into the vulnerability of young trout (*Salmo trutta* L.) and Atlantic salmon (*S. salar* L.) to downstream displacement by high water velocities. Journal of Fish Biology 19: 135-145.
- Otto, R. G. 1971. Effects of salinity on the survival and growth of pre-smolt coho salmon (*Oncorhynchus kisutch*). Journal of the Fisheries Research Board of Canada 28: 343-349.
- Peterman, R. M. 1982. Model of salmon age structure and its use in preseason forecasting and studies of marine survival. Canadian Journal of Fisheries and Aquatic Sciences 39: 1444-1452.
- Peven, C. M., R. R. Whitney, and K. R. Williams. 1994. Age and length of steelhead smolts from the mid-Columbia River basin, Washington. North American Journal of Fisheries Management 14: 77-86.
- Phillips, R. W., R. L. Lantz, E. W. Claire, and J. R. Moring. 1975. Some effects of gravel mixtures on emergence of coho salmon and steelhead trout fry. Transactions of the American Fisheries Society 104: 461-466.
- Prunuske Chatham. 1997. San Geronimo bedload sediment reduction program 1997 monitoring report. Prepared by Prunuske Chatham, Occidental, California for Marin County Resource Conservation District, Point Reyes Station and Marin Municipal Water District, Corte Madera, California.
- Quinn, T. P. 2005. The behavior and ecology of Pacific salmon and trout. First edition. American Fisheries Society, Bethesda, Maryland and University of Washington Press, Seattle.
- Raleigh, R. F., T. Hickman, R. C. Solomon, and P. C. Nelson. 1984. Habitat suitability information: rainbow trout. FWS/OBS-82/10.60. U. S. Fish and Wildlife Service, Fort Collins, Colorado.
- Randall, R. G., M. C. Healey, and J. B. Dempson. 1987. Variability in length of freshwater residence of salmon, trout, and char. Pages 27-41 in M. J. Dadswell, R. J. Klauda, C. M. Moffitt, R. L. Saunders, R. A. Rulifson and J. E. Cooper, editors. Common strategies of

- anadromous and catadromous fishes: American Fisheries Society Symposium 1. American Fisheries Society.
- Roelofs, T. D. 1985. Steelhead by the seasons. The News-Review, 31 October, A4; A8.
- Sandercock, F. K. 1991. Life history of coho salmon (*Oncorhynchus kisutch*). Pages 397-445 in C. Groot and L. Margolis, editors. Pacific salmon life histories. University of British Columbia Press, Vancouver, B. C.
- Scarlett, W. S., and C. J. Cederholm. 1984. Juvenile coho salmon fall-winter utilization of two small tributaries of the Clearwater River, Jefferson County, Washington. Pages 227-242 in J. M. Walton and D. B. Houston, editors. Proceedings of the Olympic Wild Fish Conference. Peninsula College, Port Angeles, Washington.
- Shapovalov, L., and A. C. Taft. 1954. The life histories of the steelhead rainbow trout (*Salmo gairdneri gairdneri*) and silver salmon (*Oncorhynchus kisutch*) with special reference to Waddell Creek, California, and recommendations regarding their management. Fish Bulletin 98. California Department of Fish and Game.
- Shapovalov, L., and W. Berrian. 1940. An experiment in hatching silver salmon (*Oncorhynchus kisutch*) eggs in gravel. Transactions of the American Fisheries Society 69: 135-140.
- Shirvell, C. S. 1990. Role of instream rootwads as juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*O. mykiss*) cover habitat under varying streamflows. Canadian Journal of Fisheries and Aquatic Sciences 47: 852-861.
- Smith, O. R. 1941. The spawning habits of cutthroat and eastern brook trouts. Journal of Wildlife Management 5: 461-471.
- Stillwater Sciences. 2007. Upper Lagunitas Creek watershed sediment delivery analysis. Prepared for Department of Public Works, Marin County, California by Stillwater Sciences, Arcata and Berkeley, California.
- Stuart, T. A. 1953. Spawning migration, reproduction and young stages of the loch trout (*S. trutta* L.). Freshwater and Salmon Fisheries Research Report 5. Scottish Home Department, Edinburgh.
- Swales, S., R. B. Lauzier, and C. D. Levings. 1986. Winter habitat preferences of juvenile salmonids in two interior rivers in British Columbia. Canadian Journal of Zoology 64: 1506-1514.
- Tautz, A. F. 1977. Effects of variability in space and time on the production dynamics of salmonid fishes. Doctoral dissertation. University of British Columbia, Vancouver.
- Trihey & Associates. 1995. Trends and abundance for steelhead and coho salmon in Lagunitas Creek, Marin County, California. Prepared by Trihey and Associates, Concord, California for Marin Municipal Water District, Corte Madera, California.

- Tschaplinski, P. J., and G. F. Hartman. 1983. Winter distribution of juvenile coho salmon (*Oncorhynchus kisutch*) before and after logging in Carnation Creek, British Columbia, and some implications for overwinter survival. *Canadian Journal of Fisheries and Aquatic Sciences* 40: 452-461.
- van den Berghe, E. P., and M. R. Gross. 1984. Female size and nest depth in coho salmon (*Oncorhynchus kisutch*). *Canadian Journal of Fisheries and Aquatic Sciences* 41: 204-206.
- Ward, B. R., P. A. Slaney, A. R. Facchin, and R. W. Land. 1989. Size-biased survival in steelhead trout (*Oncorhynchus mykiss*): back-calculated lengths from adults' scales compared to migrating smolts at the Keogh River, British Columbia. *Canadian Journal of Fisheries and Aquatic Sciences* 46: 1853-1858.
- Wigington, P. J., Jr., J. L. Ebersole, M. E. Colvin, S. G. Leibowitz, B. Miller, B. Hansen, H. R. Lavigne, D. White, J. P. Baker, M. R. Church, J. R. Brooks, M. A. Cairns, and J. E. Compton. 2006. Coho salmon dependence on intermittent streams. *Frontiers in Ecology and the Environment* 4: 513-518.
- Zimmerman, C. E., and G. H. Reeves. 2001. Population structure of sympatric anadromous and nonanadromous *Oncorhynchus mykiss*: evidence from spawning surveys and otolith microchemistry. *Canadian Journal of Fisheries and Aquatic Sciences* 57: 2152-2162.

Appendices

Appendix A

Detailed Field Study Methods and Results

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1 EARLY LIFE STAGE MORTALITY INVESTIGATIONS

1.1 Redd Identification and Selection

Spawning surveys were conducted weekly beginning on 1 December to select potential study redds in target stream reaches. The spawning periods of Chinook salmon and steelhead partially overlap with that of coho salmon in Lagunitas Creek. Although redds built by these species may differ in size and shape, they are similar enough that there is the potential for misidentifying redds when they are not occupied by a representative female. Therefore, only redds that were occupied by female coho salmon during spawning surveys were selected for the field study. During spawning surveys, females were observed either digging redds, paired with males over a constructed redd, or guarding completed redds after the spawning act. Once potential study redds were identified at four sites within the watershed (Figure A-1), more frequent surveys (daily or every other day) were conducted to ensure that spawning had occurred and to obtain length estimates of females. Redds were identified by the individual fish, date of construction, and the location was flagged so that scour chains and infiltration bags could be installed in the area surrounding the redds.

For each study redd, the length of the female salmon was measured to estimate its fecundity. Lengths were obtained after spawning had occurred by temporarily disturbing the female from her redd. Upon approach the female typically moved to an area in the vicinity of the redd and held in the current. Length estimates were obtained by noting identifiable features on the streambed (i.e., lightly colored rocks, woody debris, or other distinguishing features) at the nose and tail of the female. When the fish returned to the redd, the distance between streambed features was measured to the nearest 2 cm using a meter stick. Fish length was used to estimate fecundity values using a linear regression of total length on egg volume from a central California coho salmon population (Waddell Ck latitude 37° 6' N, longitude 122° 17' W; approximately 105 km south of Lagunitas Creek) (Shapovalov and Taft 1954):

$$\text{Number of eggs} = 0.01153 \times \text{female length (cm)}^{2.9403}$$

1.2 Instrument Installation/Monitoring

1.2.1 Elevation measurements

1.2.1.1 Bed elevation

Cross-sections were surveyed at the locations of the monitored redds to document storm-induced changes in bed elevation within and adjacent to the redds. For the Olema Site, Shafter Site, and Site 1, cross-sections were surveyed by two-person crews using an automatic level and stadia rod to an accuracy of 0.01 ft. For each of the cross-sections surveyed, rebar endpins on each bank were driven to a secure depth, capped, and marked. The rebar endpins served as cross-section monuments and were the starting and ending elevations recorded for each cross-section. A tape was strung between the endpins and elevations were taken every 3 ft within the active channel and floodplain, and every 1 ft within the boundary or the surveyed redd, to ensure that small-scale elevation changes and microtopographic bedforms were accurately captured. A ladder catwalk was used when surveying across the redds to avoid redd disturbance. Bed substrate was noted at each elevation station, and the water level elevation was recorded on each bank. Cross-sections

were then resurveyed following Storm 1 to document any net aggradation/erosion of sediment. Compiled cross-section surveys are shown in Figures A-2 through A-11.

In addition to cross-sections, a longitudinal profile was also surveyed at each of the monitored reaches. The total length of each longitudinal profile was determined as a function of the presumed length required to accurately assess reach-average slope, as well as a function of any upstream and/or downstream obstructions. At the Olema site, Shafter site, and Site 1, a longitudinal profile was surveyed during the cross-section effort prior to Storm 1. A measuring tape was stretched along the length of the monitored site and the bed surface elevation and water depth recorded along the thalweg approximately every 5 to 7 ft (more frequently where there were significant breaks in elevation). At Site 2, the longitudinal profile following Storm 1 was constructed by connecting the thalweg elevation from each surveyed cross-section. Compiled longitudinal profiles are shown in Figures A-12 through A-15. Compiled plan views showing cross-section locations, thalweg location, and locations of study redds and associated monitoring equipment (explained below) are shown in Figures A-16 through A-19.

1.2.1.2 High flow water surface elevation

Crest gages were installed at each site to record maximum stage for each storm event monitored. The crest gages were installed at an elevation appropriate to capture maximum stage for both lower intensity and higher intensity storms within Lagunitas Creek and Olema Creek. Crest gages were constructed of 4 ft piece of 2 inch diameter PVC pipe encasing a 4 ft long, 1 inch x 2 inch piece of wood and crushed cork. Maximum stage for each storm monitored was recorded by crush cork level on the piece of wood. A datum on each crest gage coinciding with the bottom of the piece of wood was surveyed and tied to the local surveyed benchmark so that the cork level provided water surface elevation relative to the local bed surface elevation. Crest gages were installed at the upstream and downstream portions at the Olema site, Shafter site, and Site 1 (2 gages per site). To better capture local water surface topography during high flow, 4 crest gages were installed along the length of Site 2 (see Figure A-17).

1.2.2 Local bed scour measurements

1.2.2.1 Scour chains

Scour chains were installed to give a measure of maximum scour depth for each storm event monitored. Scour chains were approximately 45 cm long heavy gage link chains installed with a standpipe to a depth of 30 cm, which was considered to be below the depth of anticipated scour for the monitoring period. The chains were installed as close to the monitored redds as possible without actually causing redd disturbance (see Lisle and Eads 1991 for complete discussion of methodology). Data collected recently by Rennie and Millar (2000) show that scour measured adjacent to redds is similar to scour within the actual egg pocket, suggesting that the methodology used for this study was adequate to quantify the effects of scour on egg mortality. In general, scour chains were installed at the upstream, downstream, left, and right side of each monitored redd (4 chains per redd) (see Figure A-20). At the Shafter Site, scour chains installed such that the downstream chain for redd 1 was the upstream chain for redd 2, and the downstream chain for redd 2 was the upstream chain for Redd 3. At Site 1, the proximity of redd 2 and redd 3 caused them to be considered a single 'redd complex,' therefore 4 chains total were installed around both redds. After installation and following each storm event monitored, the length of chain exposed above the bed was and the bed elevation adjacent to the chain was measured. Maximum instantaneous scour was determined by comparing chain length before and after each monitored storm, and the net erosion/aggradation at each chain location was determined by comparing bed

elevation before and after each storm monitored. Compiled scour chain data and bed elevation data for the study redds are given in Table A-1.

Table A-1. Average and maximum scour measurements near redd locations in the Lagunitas Watershed, December 2004.

Site	Redd	AVERAGE Storm 1 scour depth (cm)	MAXIMUM Storm 1 scour depth (cm)	Average change in bed elevation following Storm 1 (cm)
Shafter	1	3.2	9.5	1.9
	2	2.6	7.7	-1.4
	3	0	0	-0.9
Site 2	1	1.3	4.0	--
Site 1	1	2.3	6.8	2.1
	2	7.9	8.7	1.7
	3			-8.5
Olema	1	2.9	4.5	-2.5
	2	6.9	15.0	-3.6
	3	1.3	5.0	-0.7

1.2.2.2 Tracers

In an effort to quantify scour within the monitored redds, small tracer washers (approx 38 mm in diameter) were inserted into the redd mound surface particles (after Konrad et al. 2002). Tracers were placed into the redd mounds from a ladder catwalk to minimize disturbance to the redds monitored. Four tracers (spaced 10 cm apart) were placed within each redd mound: 2 tracers were placed so that the top of the tracer was flush with the bed surface (bottom of washer at approximately 40 mm), 2 washers were placed so that the top of the washer was at a depth of approximately 40 mm (not sure if you are using a fig for this or not). The tracers at each redd were tagged with color flagging to indicate burial depth. To determine the degree of bed particle mobility within the redds, tracer presence or absence for each monitored redd was noted following each storm. Tracers were then reinstalled as needed following the monitored storm events.

1.2.3 Sediment characterization

1.2.3.1 Bed particle size distribution

Particle size distribution data was measured within the substrate adjacent to the monitored redds during instrument installation and following the monitored storms. The particle size distributions were determined by conducting pebble counts (Wolman 1954) in which the intermediate axis of 100 surface bed particles were measured. When discrete bed sediment facies units were evident (Site1 and Site 2), pebble counts were done for the entire facies unit instead of for the area just adjacent to the redds. Particle size distribution data before and after the storms was then compared to get the relative degree of local storm-induced bed particle fining or coarsening. Compiled bed particle size distribution data (D_{16} , D_{50} , and D_{84}) are given in Table A-2.

Table A-2. Particle size distribution near redd locations in the Lagunitas Watershed, December 2004.

Site	Description	Pre- and Post-Storm Dates	D ₁₆ (mm)	D ₅₀ (mm)	D ₈₄ (mm)
Shafter	Around Redd 1	12/16/2004	9	23	52
		1/3/2005	10	26	56
	Around Redd 2	12/16/2004	13	30	67
		1/3/2005	10	27	48
	Around Redd 3	12/16/2004	6	30	51
		1/3/2005	2	23	50
Site 2	Facies 1	12/23/2004	3	31	79
		1/5/2005	15	26	61
	Facies 2 (Around Redd 1)	12/23/2004	9	30	54
		1/5/2005	15	44	88
	Facies 3	12/23/2004	4	18	42
		1/5/2005	12	25	55
Site 1	Facies 1	12/17/2004	6	16	39
		1/5/2005	15	26	61
	Facies 2 (Around Redds 1, 2, and 3)	12/17/2004	18	31	60
		1/5/2005	32	50	61
Olema	Around Redd 1	12/18/2004	10	36	55
		1/4/2005	16	28	56
	Around Redd 2	12/20/2004	24	49	71
		1/4/2005	11	28	50
	Around Redd 3	12/20/2004	24	43	64
		1/4/2005	9	25	50

1.2.3.2 Infiltration bags

Infiltration bags were installed at each monitored site to give indication of infiltration of fine sediment for each storm event and net infiltration/accumulation of fine sediment for the entire study period. Each site had 2 sets of infiltration bags installed: redd bags and site bags. Redd bags were installed adjacent to each monitored redd (sampled after each storm), and site bags were installed at the upstream and downstream portions of each site (sampled at the end of the monitoring period). Site 2 was then exception in that it only one site bag and it was installed adjacent to the redd. The installation of the infiltration bags followed the procedure outline in Lisle and Eads (1991). Bags were installed by digging a pit approximately 30 cm in diameter in bed sediments to a depth of 30 cm (below assumed depth of the egg pocket). The excavated sediment was then sorted to remove all sediment finer than 8 mm. A collapsed infiltration bag was then placed at the bottom of the pit and the sorted sediment placed on top of the bag so that the sediment above the bag was flush with adjacent bed surface. String was attached to the bags and pulled up to the bed surface (with the bag collapsed) for identification and to be used for bag removal following storm events. Following installation, the elevation of bed surface at infiltration bag location was surveyed for post-storm comparison. After each storm monitored, the redd bags were removed, the sediment sample was collected, and reinstalled following the above procedure. At the end of the monitoring period, the site bags were removed and the sediment was collected.

1.2.3.3 Freeze core sampling

Freeze cores samples were taken at the end of the incubation period (DATE) at each of the 6 redds monitored for emergence. To obtain the freeze cores, perforated standpipes (see Terhune 1958) were driven into each redd egg pocket to a depth of 30 cm and liquid nitrogen was poured into the tube for approximately 10 minutes (time that ensured adequate freezing of sediment adjacent to buried standpipe). After completion of delivery of the liquid nitrogen, the frozen sediment sample was removed from the streambed by lifting the standpipe (with the sample attached).

After extraction, the standpipe and sample were placed upon an open-top box that was portioned into discrete bins. The sample was inspected for evidence of an infiltrated sand seal, evidence of trapped eggs and/or aelvin, and general particle size sorting and stratification. The information from this initial field investigation was then recorded for each sample. The bin sizes within the open-top box were then adjusted to match the thickness of distinct sediment layers (i.e., sand seal, finer layers, coarser layers), and the sediment from the distinct layers was then transferred to the bins by melting the sample with portable blowtorches. The sediment samples were then marked and saved for future particle size distribution determination.

1.2.4 Emergence Monitoring

Emergence traps were installed at locations within each of the four monitoring locations (Figure A-21). The emergence date for each redd was predicted using a degree-day (defined as the sum of the number of degrees over 0 °C accumulated daily) model that predicts egg development as a function of the total heat requirement for incubation in gravel (spawning to emergence). Stream temperatures were monitored at each study site using Stowaway Tidbit thermographs (Onset Computer Corporation, Bourne, MA). Prior to installation, calibration checks were performed to confirm the manufacturer's specified accuracy (± 0.2 °C) using measurements from United States National Institute of Standards and Technology (NIST) certified thermographs in water and ice baths. Thermographs passing calibration checks were set for data logging at 15-minute intervals.

Water temperature data from each study site was input into a model to predict the approximate dates of hatching and fry emergence and to help schedule emergence trap deployment. Emergence timing predictions were initially based on estimated upper and lower daily values that were assumed to bracket the true water temperatures for the period. Emergence predictions were updated with real temperature observations from the thermographs as they became available.

The emergence of fry from study redds was measured using emergence traps placed over the redd areas. These traps consisted of a metal frame fit with a nylon cover and a trailing nylon sleeve and collection bottle. Trap frames were tear-drop shaped, with a length of 2.4 m, and width of 1.8 m which was large enough to cover the mound area of each redd. Trap covers consisted of 3 mm nylon mesh material bordered by a 30 cm-wide, solid nylon skirt. Collection bottles were 2 liter plastic bottles with mesh side vents to allow water flow. Bottles were fitted with plastic funnels that directed fry from the trap sleeve into the collection bottle and that acted as a baffle that provided velocity shelters for fry.

Emergence traps were placed over the top of each redd approximately 10 days prior to the predicted date of emergence. The timing of trap placement varied between sites due to differences in the dates of redd construction and stream temperatures. In three cases, study redds were partially superimposed or had other redds built adjacent to them which prevented installation of emergence traps. Emergence traps were aligned with stream flow and placed on

the river bottom over the remaining study redds. To facilitate placement of the emergence traps, the egg pocket area was identified on cross-section profiles of the channel through the redd mound and photographs of the redds taken before the first storms. Once in place, the trap was secured to the stream bed by driving rebar stakes around the trap's perimeter and fastening the stakes to the trap frame. Around the entire perimeter, the nylon skirt was buried by hand to a depth of 30 cm to prevent alevins from migrating laterally around the trap. All excavated material was inspected to ensure that no eggs or alevins were disturbed and the apron was then buried and the streambed surrounding the redd was rebuilt to its original level.

Emergence trap monitoring began immediately following installation of the traps and was conducted every other day until the first fry emerged and, with few exceptions, daily thereafter. Emergence traps were typically checked in the morning. Collection bottles were removed from the traps and fry were transferred to 5-gallon buckets for measurement. A maximum of 50 fry per trap per day were measured; any additional fry were counted but not measured. Fork length was measured to the nearest millimeter, sac condition was observed, and any mortality was noted. After being counted, all fry were released in calm areas with cover along the stream margin.

The condition of each trap was also monitored daily. The skirts on the trap covers were checked to ensure they remained buried. Trap covers were cleaned with a long-handled brush or push broom as often as necessary to remove any accumulated algae or debris.

Stream flow varied considerably during the emergence period, resulting in some days when the traps could not be checked safely. Additionally, high levels of fine sediment were transported during storm events and accumulated in some of the traps. Several traps were removed during a portion of the emergence period to prevent further accumulation of fine sediment and potential mortality of emerging fry. All traps were removed by 6 March, 2005. Photos of the trap locations and representative channel conditions during high flows can be found in Figures A-22 through A-25.

Coho fry emergence was observed at all but one study redd. At Olema redd 1, no coho fry were observed to emerge, but we suspect that a steelhead had superimposed this redd since we captured one steelhead fry near the end of the monitoring period. Appendix Figures A-26 through A-31 show daily emergence totals for the remaining redds during the spring 2004 sampling period. Emergence totals from most study redds should be considered minimum counts since the emergence traps were only in place for a portion of the emergence period and sediment accumulation caused by the traps may have resulted in unnaturally low fry emergence.

2 DEVIL'S GULCH WINTER HABITAT METHODS

In October 2005, we selected 28 pool and run study units with varying amounts of woody debris and unembedded coarse (≥ 10 cm) substrate along an approximately 1.3 km study reach of Devil's Gulch. During February 2006, two new pools were added to the original study units. The experiment included a total of 25 pools and 5 runs, which represented about 80 percent of the pool habitat and 20 percent of the run habitat within the study reach. Overall, units averaged 14.5 m in length (range 6.9–27.2) and 50.3 m² in area (range 18.5–103.6).

We used multiple-pass electrofishing to capture fish from all study units. The upstream and downstream ends of each unit were blocked with netting prior to electrofishing. All juvenile salmonids captured were anesthetized and the fork length (FL) to the nearest millimeter and wet weight to the nearest 0.01 g were recorded. All fish greater than 60 mm FL were tagged with sterilized passive integrated transponder (PIT) tags. Two tag types were used based on fish size. Full-duplex (FD) PIT tags measuring 11 mm were used for fish from 60 - 99 mm FL, which included age 0 (young of year) steelhead and all juvenile coho salmon. The FD tags have the advantage of small size, enabling tagging of smaller fish, but they have a smaller detection range than larger tags. Half-duplex (HD) PIT tags measuring 23 mm, were used for all fish ≥ 100 mm FL to take advantage of the larger detection range. We chose the 60 mm and 100 mm thresholds for tagging to minimize tag-related mortality and because scale analysis indicated that 100 mm FL is a size break separating age 0 and age 1 steelhead at the end of the growing season in Devil's Gulch (Ettlinger et al. 2005). All tags were inserted into the body cavity anterior to the pelvic fin with a 12-gauge hypodermic needle. Fish were allowed to recover and then were released into their original habitat unit. To complete the experiment in late February 2007, we again employed multiple-pass electrofishing in the study units to recapture tagged fish and to obtain late winter densities of juvenile salmonids.

During the study period monthly relocations of PIT-tagged fish were made using a submersible PIT tag reader during base flow periods between winter storms. The reader consisted of a sealed antenna coil mounted on a pole and was designed to be moved over the streambed to search for tagged fish. The reader had a detection range of approximately 15 cm and automatically recorded the unique code for each tagged fish encountered and the time and date of detection. Surveys were conducted after dark when juvenile salmonids were less likely to be concealed in cover and detection probabilities were greater. Study units were blocked with netting at their upstream and downstream ends and three passes with the reader were made through each study unit. In addition, the entire study reach was surveyed with a single pass of the mobile tag reader to relocate any fish that had moved outside of the study units.

Coincident with the monthly relocations of PIT tagged fish a subset of habitat units were electrofished to compare sampling efficiency with the mobile tag reader. Sampling was conducted according to the methods described above, with three passes of electrofishing following three passes with the mobile tag reader within each study unit. Over three sampling events, a total of 13 study units were surveyed using both methods.

Fish movement during the study period was further documented with an array of stationary PIT tag monitoring stations within the study reach. Each monitoring station consisted of an Oregon RFID transceiver powered by three deep-cycle batteries. A rectangular antenna was positioned perpendicular to the stream channel spanning the bankfull channel. Tagged fish passing through the antenna field were recorded (PIT tag identification number, date, and time) continuously by a

palm pilot attached to the transceiver. Stationary antenna were operable between their installation in late November until January 1, 2006 when high flows destroyed the array. Antenna function was tested at least weekly by floating a PIT tagged drone through the antenna loop and confirming its record within the palm pilot. However, PIT antenna efficiencies were not estimated. Periodically, individual antenna were disabled when debris accumulation and storm flows damaged instream portions of the antenna loops. Stationary antenna were installed at seven locations within the lower 600 m of the study reach and were arranged to bracket study units with contrasting habitat characteristics.

To describe physical conditions at the beginning of the study, we measured cover, depth, and the dimensions of each study unit. At 4 – 10 equally spaced orthogonal transects within each unit we measured the wetted width, three depths at equally spaced points across the wetted channel, and the width of the 0.75 bankfull channel. We chose the 0.75 bankfull width to represent the extent of channel inundated when winter storms forced fish to seek refuge. The total length, maximum depth, and the tail crest depth were also recorded for each unit. We measured cover within the 0.75 bankfull channel using methods similar to those described in Kinsolving and Bain (1990) by counting the number of object surfaces in a 0.25-m-wide cross-sectional cell. Solid objects ≥ 10 cm in any cross-sectional dimension and >3 cm from the stream substrate (woody debris and unembedded boulders and cobbles) were considered three surfaces. Objects ≥ 10 cm that did not provide overhead cover for fish (e.g., embedded boulders) and objects <10 cm in any cross-sectional dimension but >3 cm from the substrate were considered single surfaces. Surface counts were categorized as wood, cobble/boulder, or other (e.g., undercut bank). During the study, high flows altered the habitat characteristics within the study units so each unit was remapped after the study period to document the extent of habitat change. From these habitat data we calculated the area of cover, expressed as both absolute area and a percentage of the unit area (cover density), and the mean of the cover values (cover complexity).

Hydrologic conditions within the study reach were measured by a pressure transducer and stream temperature was measured with a thermograph that recorded data at 15 min intervals.

3 LAGUNITAS DOWNSTREAM MIGRANT TRAPPING METHODS

Downstream migrant trapping was conducted at three locations in the Lagunitas Creek watershed from mid-March through early June, 2006 to estimate the production of coho salmon and steelhead smolts from stream reaches which varied in their channel characteristics. Downstream migrant traps included a rotary screw trap (lower trap) installed at the upstream extent of tidal influence in lower Lagunitas Creek approximately 2.1 miles above the Highway 1 bridge crossing in Point Reyes Station. A second rotary screw trap (upper trap) was installed at 5.6 miles above Highway 1. The third trap (San Geronimo) consisted of a fyke net installed and monitored in conjunction with SPAWN near the mouth of San Geronimo Creek, approximately 11.2 miles upstream of the Highway 1 bridge (Figure A-21).

We monitored the lower and upper traps beginning on March 20 and the San Geronimo trap beginning on April 21 and continued monitoring at all traps through June 9, 2006. Flows were highly variable during the trapping period, and monitoring was suspended for short periods due to high flows and/or debris accumulation. At the lower trap, monitoring was suspended on dates. At the upper trap, monitoring was suspended on dates (Table A-3). No interruptions to monitoring occurred at the San Geronimo trap.

Table A-3. Number of operational days for three outmigrant traps on Lagunitas Creek.

Trap	Installation Date	Number of Days from Trap Installation to Removal	Number of Days Operational	Number of Days Non-Operational
San Geronimo	5/21/2006	50	50	0
Upper Lagunitas Trap	3/20/2006	82	66	16
Lower Lagunitas Trap	3/20/2006	82	71	11

Fish were collected daily from the traps. All juvenile salmonids captured in the traps were anesthetized with tricaine methanesulfonate (MS-222) and the fork length (FL) to the nearest millimeter and wet weight to the nearest 0.01 g were recorded. The condition of all salmonids was examined for indications of smolting (e.g., deciduous scales, silver coloration, etc.). To estimate trap efficiency, up to 25 fish per day of each species were marked using fin clips that signified the location and the week captured. Marked fish were subsequently released 200 to 300 meters above their point of capture. All captured fish were checked for marks and were scanned with hand held PIT tag detectors to identify any fish that were previously tagged in the Devil's Gulch companion study. Length frequency histograms for fish captured at all traps are provided in Figures A-32 through A-59.

4 REFERENCES

- Kinsolving, A. D., and M. B. Bain. 1990. A new approach for measuring cover in fish habitat studies. *Journal of Freshwater Ecology* 5: 373-378.
- Konrad, C. P., D. B. Booth, S. J. Burges, and D. R. Montgomery. 2002. Partial entrainment of gravel bars during floods. *Water Resources Research* 38: 10.1029/2001WR000828.
- Lisle, T. E., and R. E. Eads. 1991. Methods to measure sedimentation of spawning gravels. Research Note PSW-411. USDA Forest Service, Pacific Southwest Research Station, Berkeley, California.
- Rennie, C. D., and R. G. Millar. 2000. Spatial stability of stream bed scour and fill: a comparison of scour depth in chum salmon (*Oncorhynchus keta*) redds and adjacent bed. *Canadian Journal of Fisheries and Aquatic Sciences* 57: 928-938.
- Shapovalov, L., and A. C. Taft. 1954. The life histories of the steelhead rainbow trout (*Salmo gairdneri gairdneri*) and silver salmon (*Oncorhynchus kisutch*) with special reference to Waddell Creek, California, and recommendations regarding their management. Fish Bulletin 98. California Department of Fish and Game.
- Wolman, G. M. 1954. A method of sampling coarse river-bed material. *Transactions of the American Geophysical Union* 35: 951-956.

Appendix A
Figures

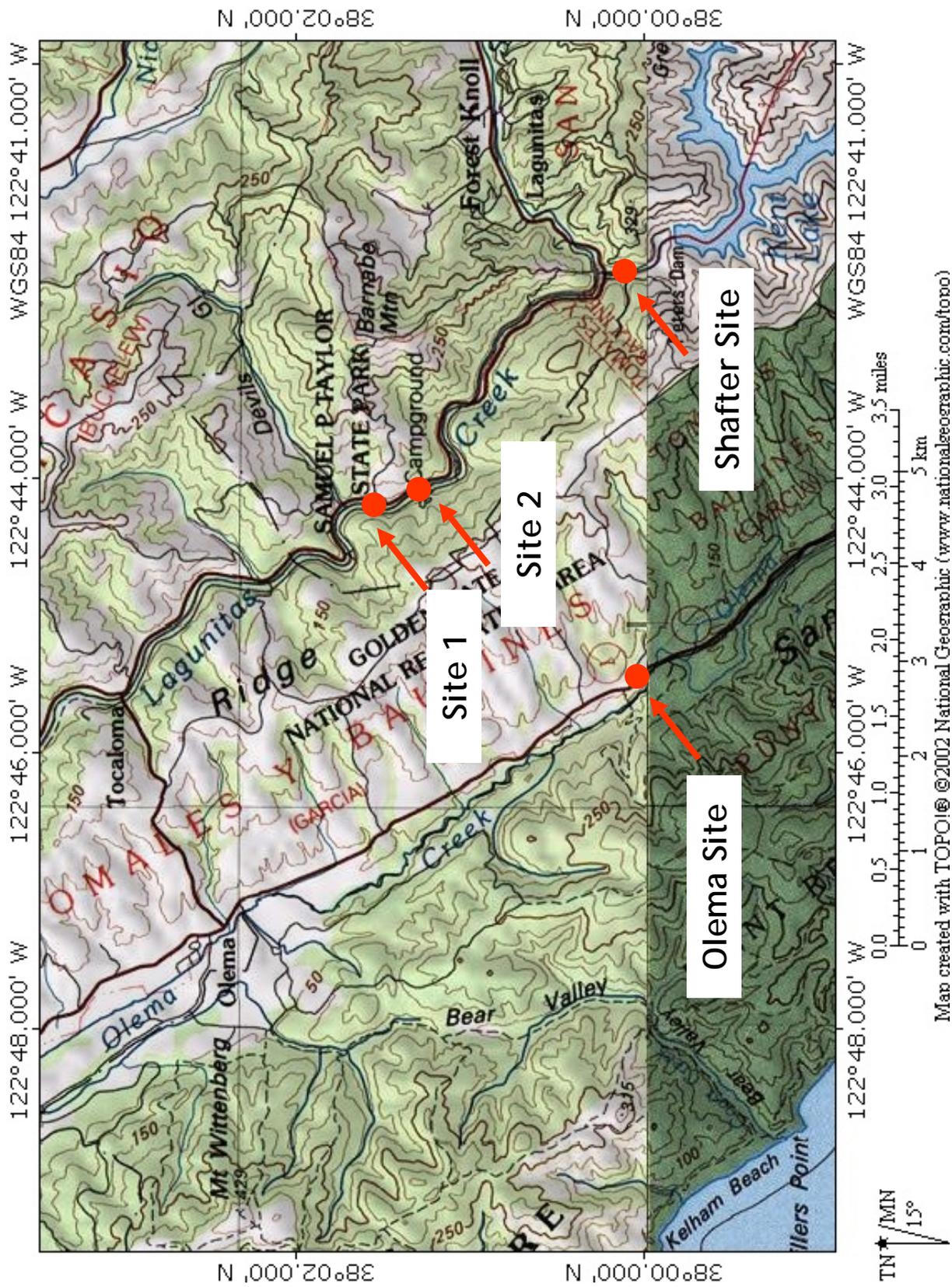


Figure A-1. Sites of study redd locations within the Lagunitas Watershed.

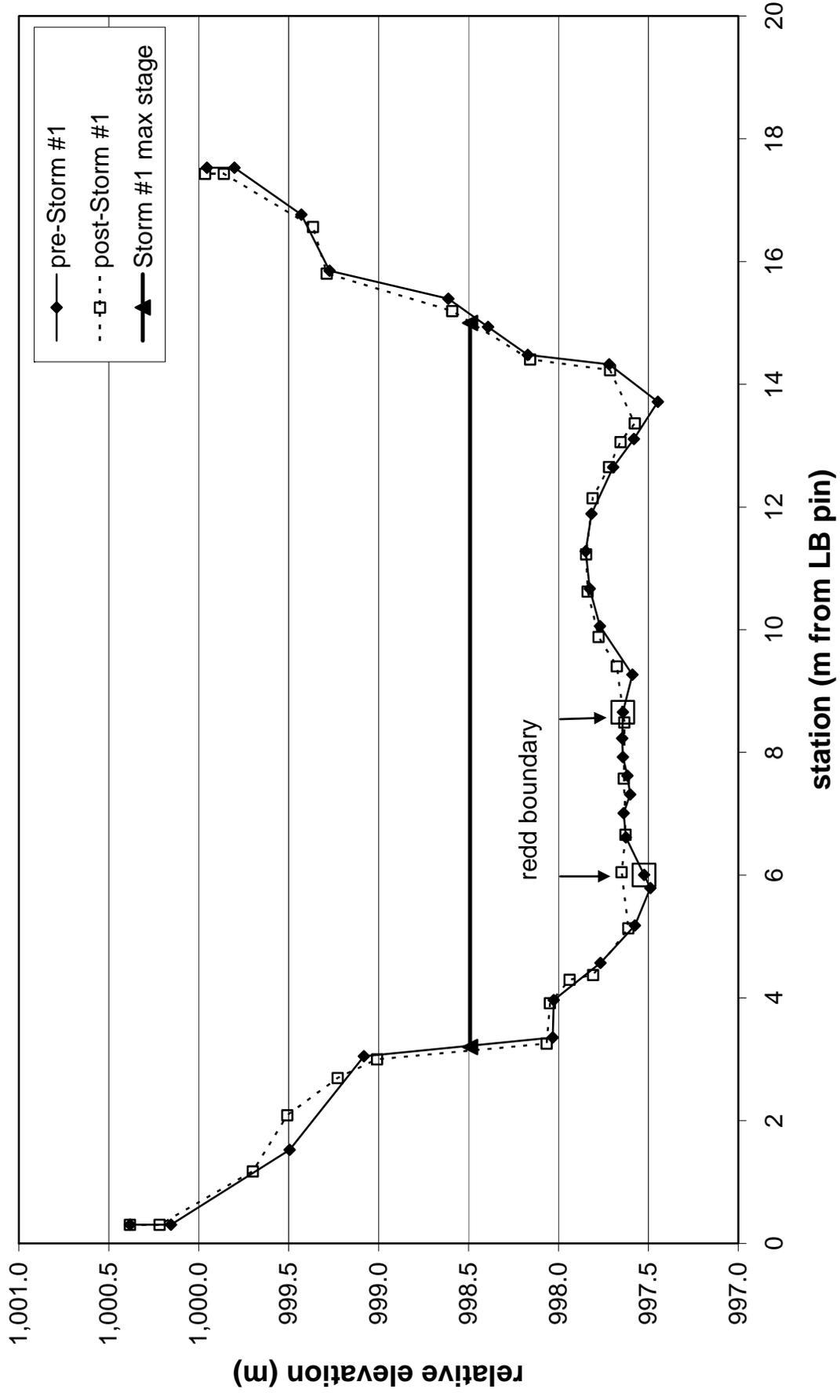


Figure A-2. Cross-section survey at Redd #1 at the Shafter site, Lagunitas Creek, including redd boundary locations.

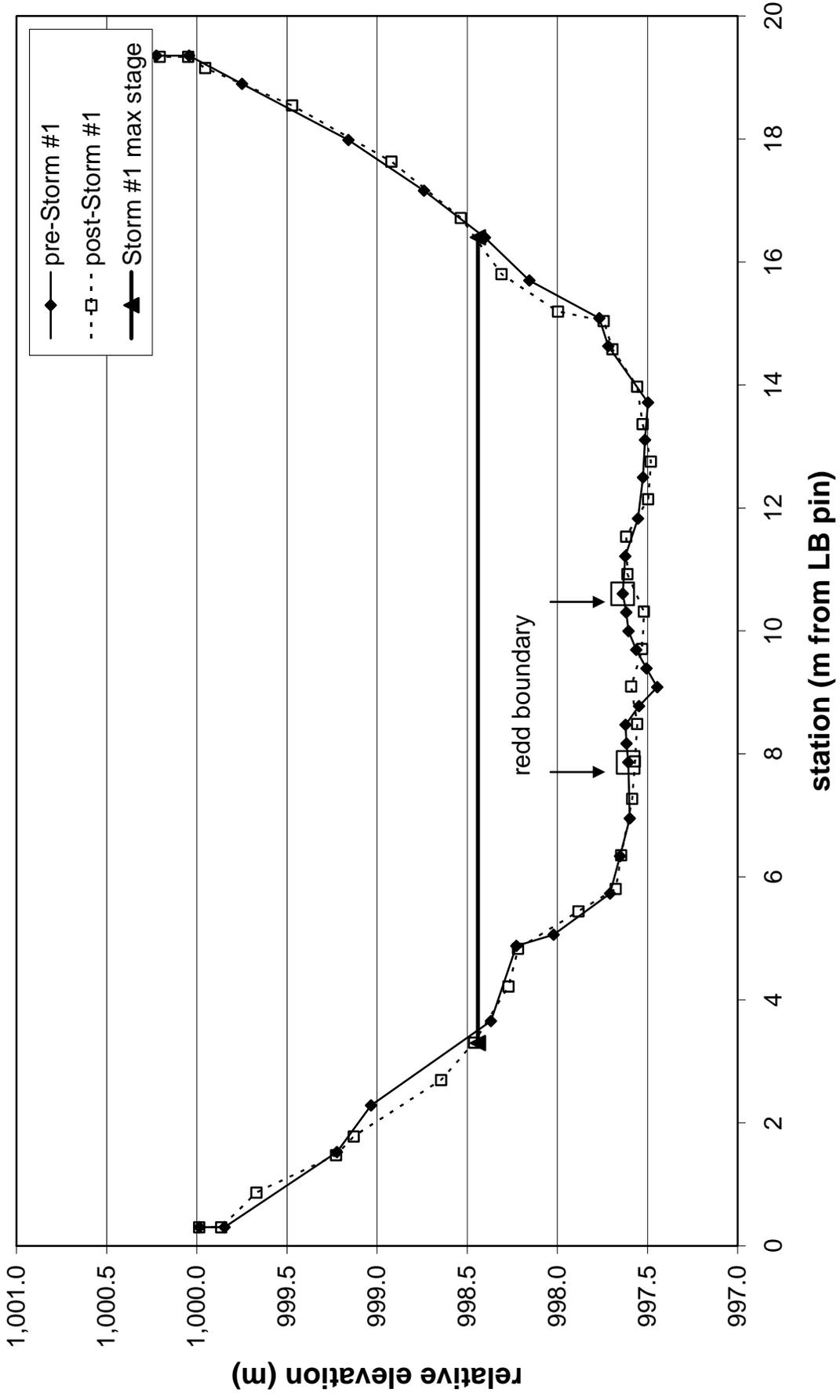


Figure A-3. Cross-section survey at Redd #2 at the Shafter site, Lagunitas Creek, including redd boundary locations.

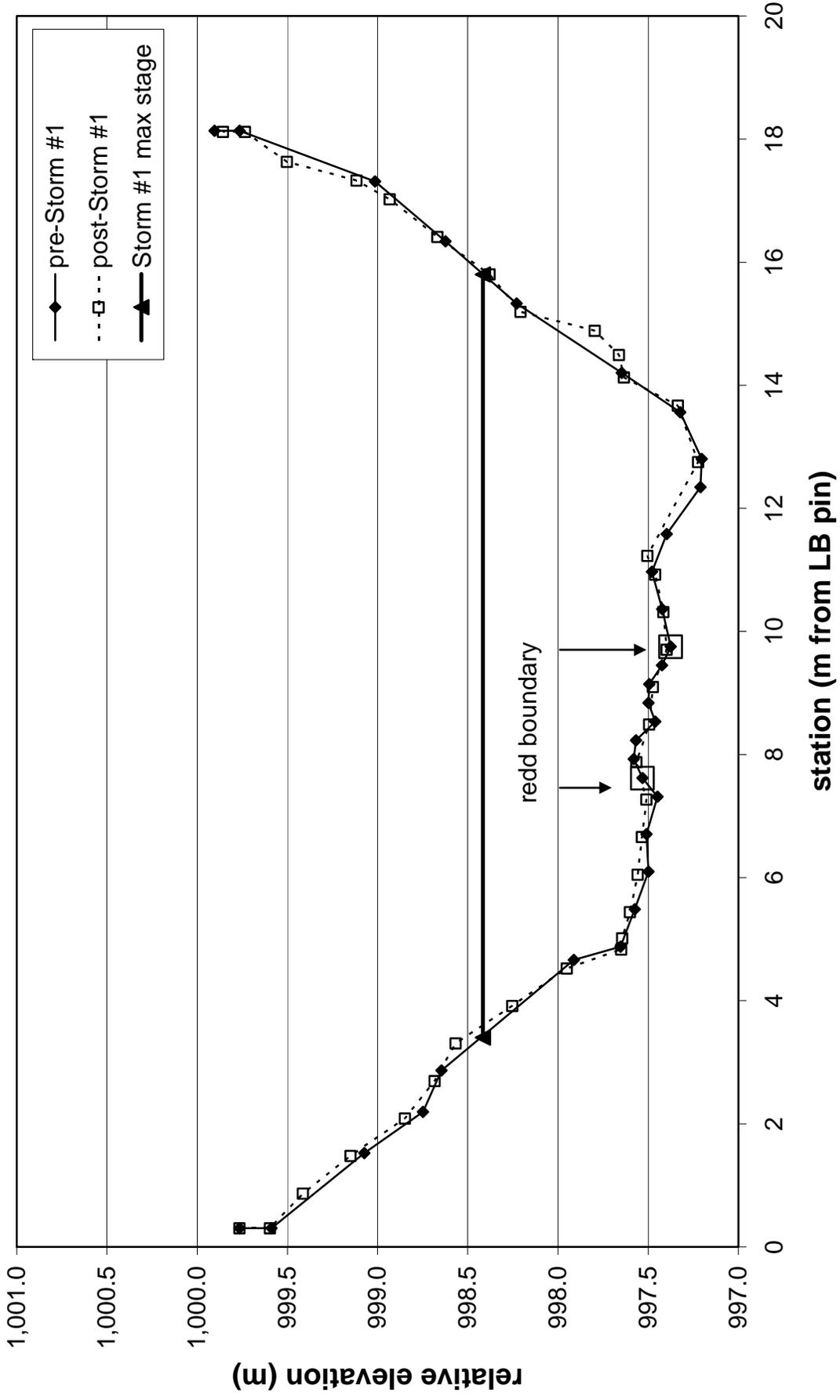


Figure A-4. Cross-section survey at Redd #3 at the Shafter site, Lagunitas Creek, including redd boundary locations.

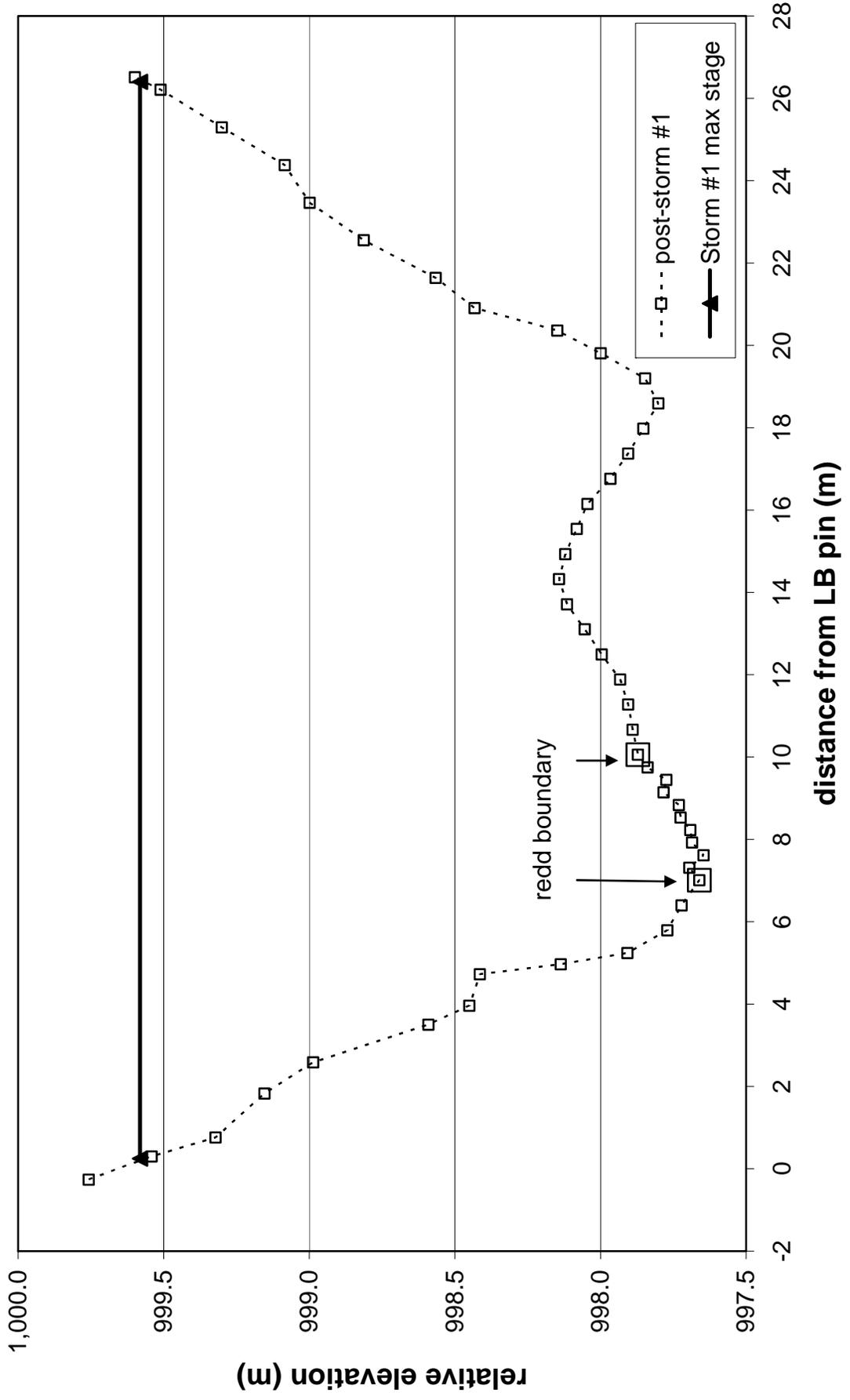


Figure A-5. Cross-section survey at the study redd at Site 2, Lagunitas Creek, including redd boundary locations.

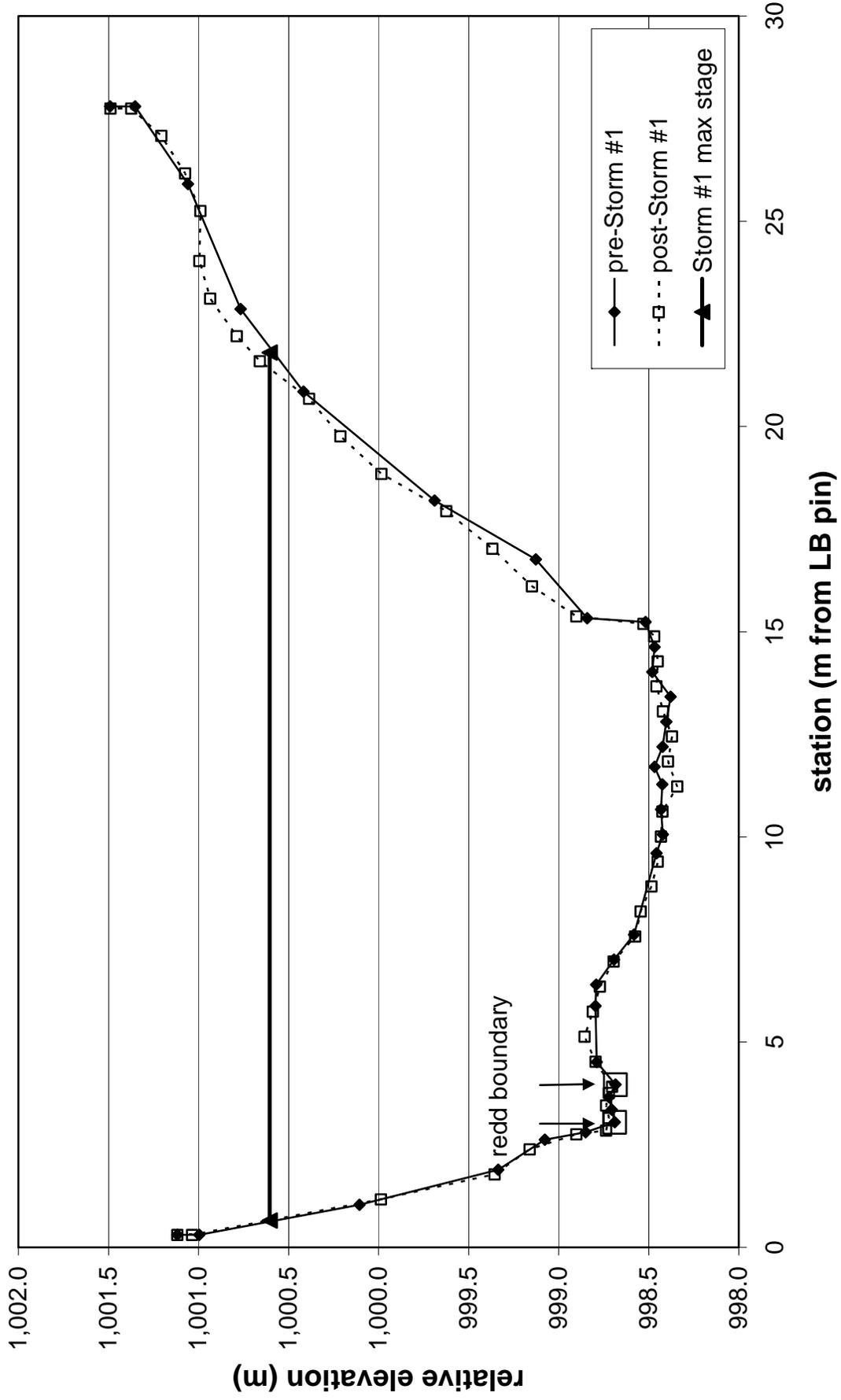


Figure A-6. Cross-section survey at Redd #1 at Site 1, Lagunitas Creek, including redd boundary locations.

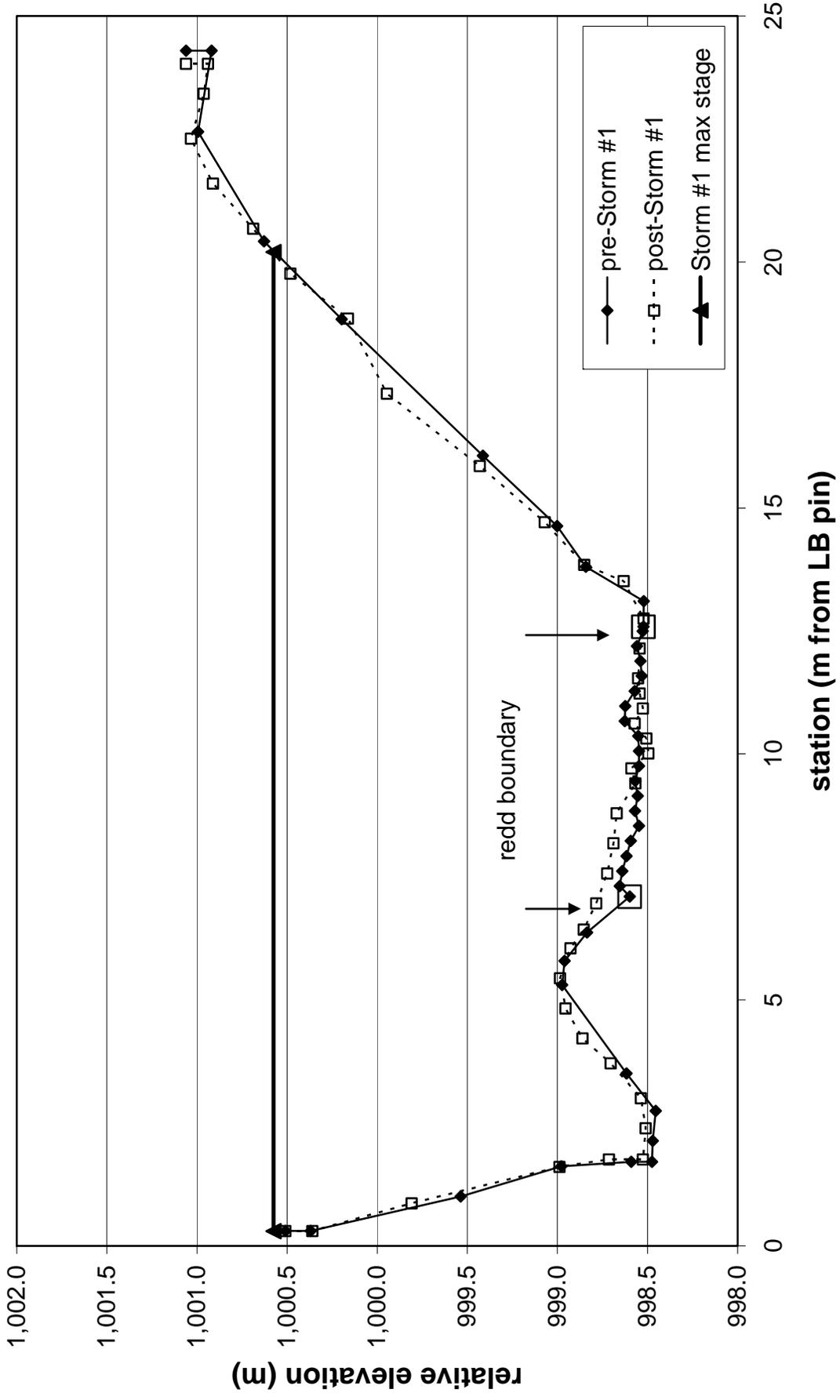


Figure A-7. Cross-section survey at Redd #2 at Site 1, Lagunitas Creek, including redd boundary locations.

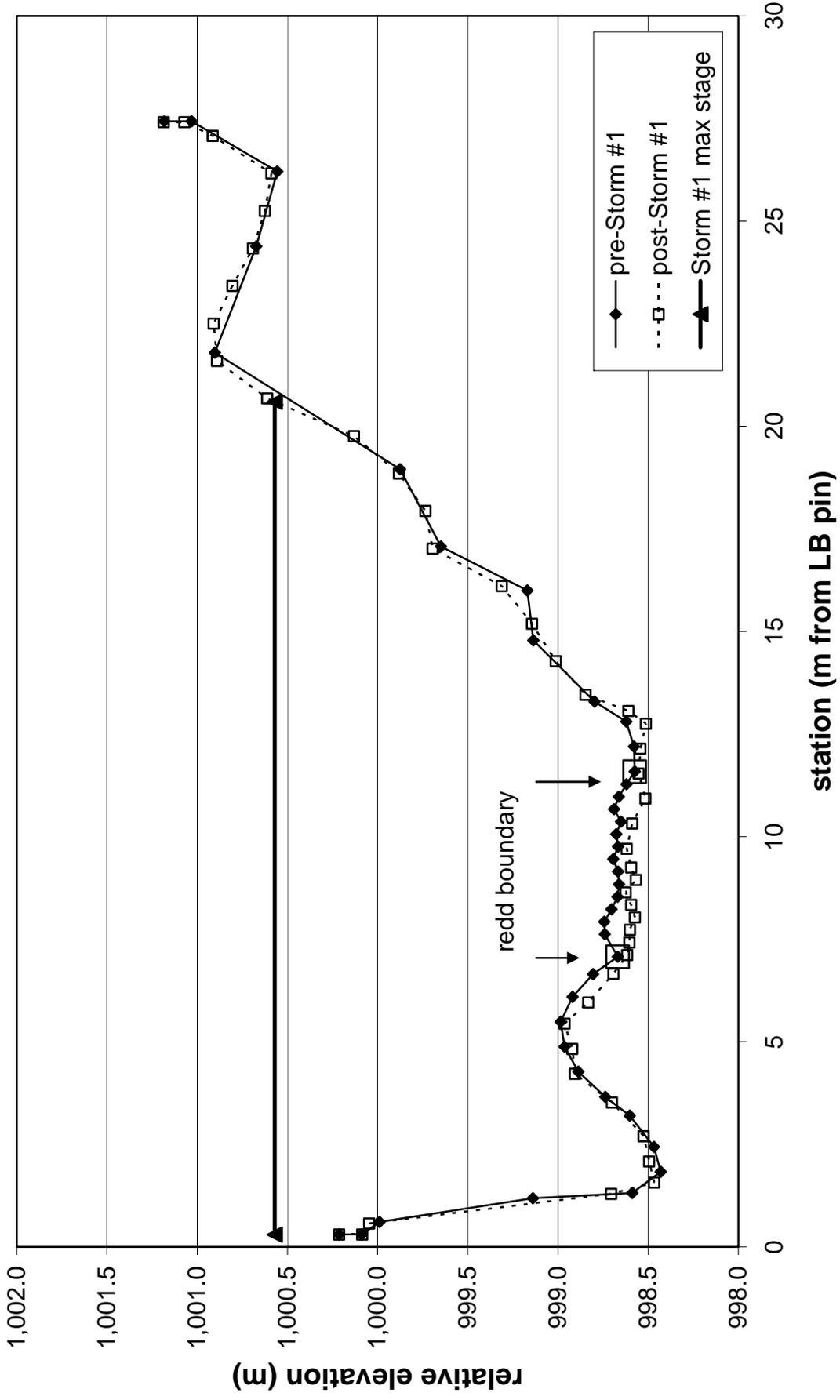


Figure A-8. Cross-section survey at Redd #3 at Site 1, Lagunitas Creek, including redd boundary locations.

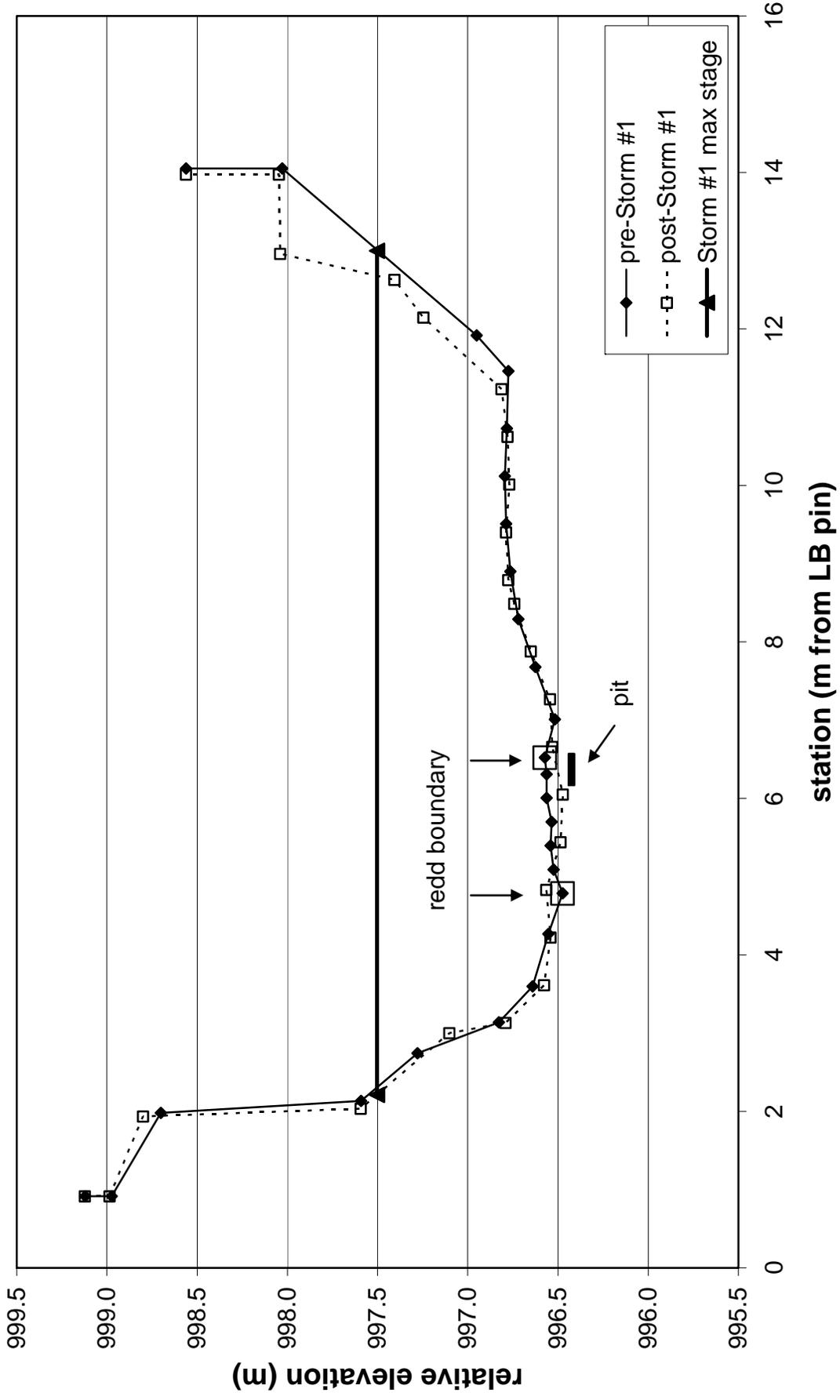


Figure A-9. Cross-section survey at Redd #1 at Olema Creek, including redd boundary locations.

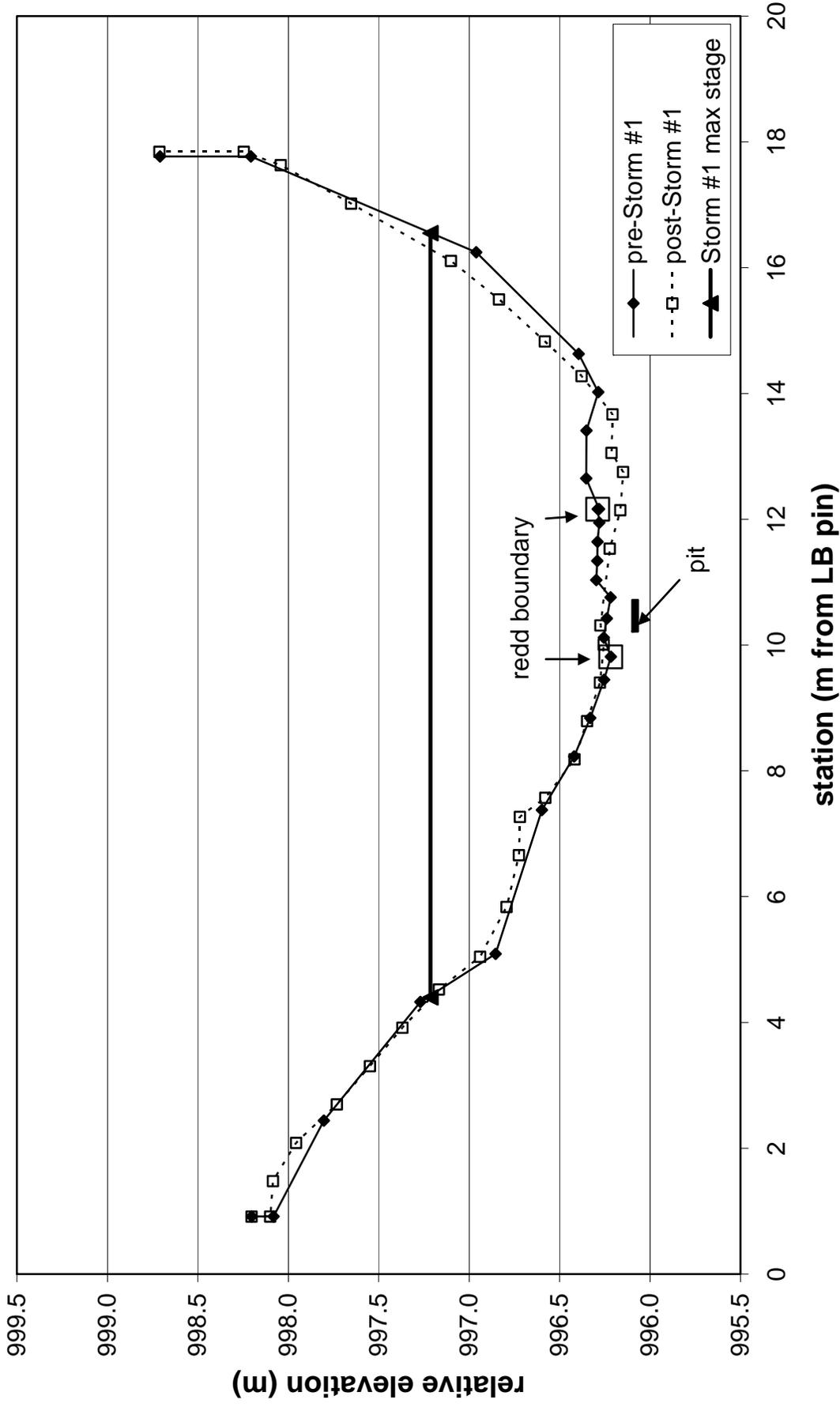


Figure A-10. Cross-section survey at Redd #2 at Olema Creek, including redd boundary locations.

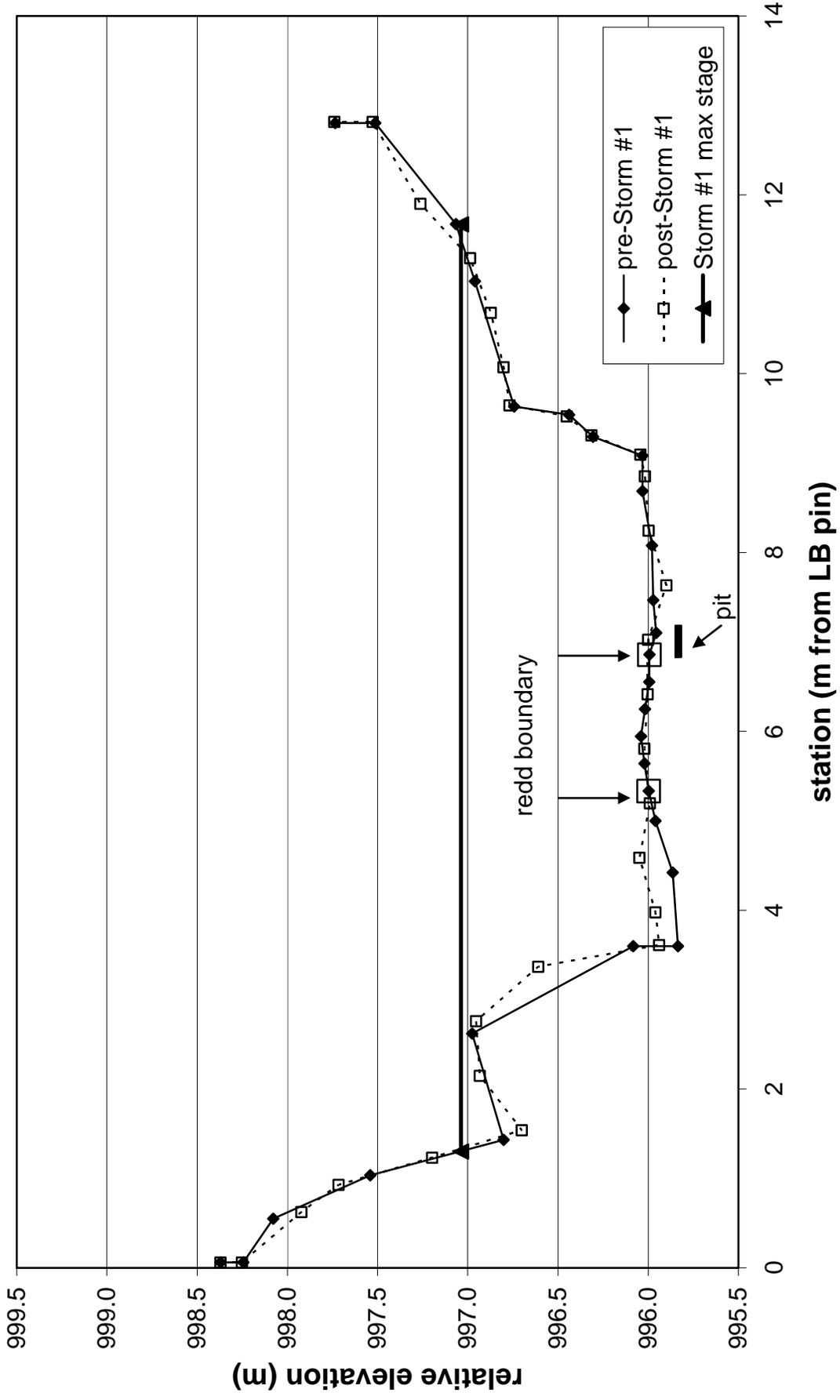


Figure A-11. Cross-section survey at Redd #3 at Olema Creek, including redd boundary locations.

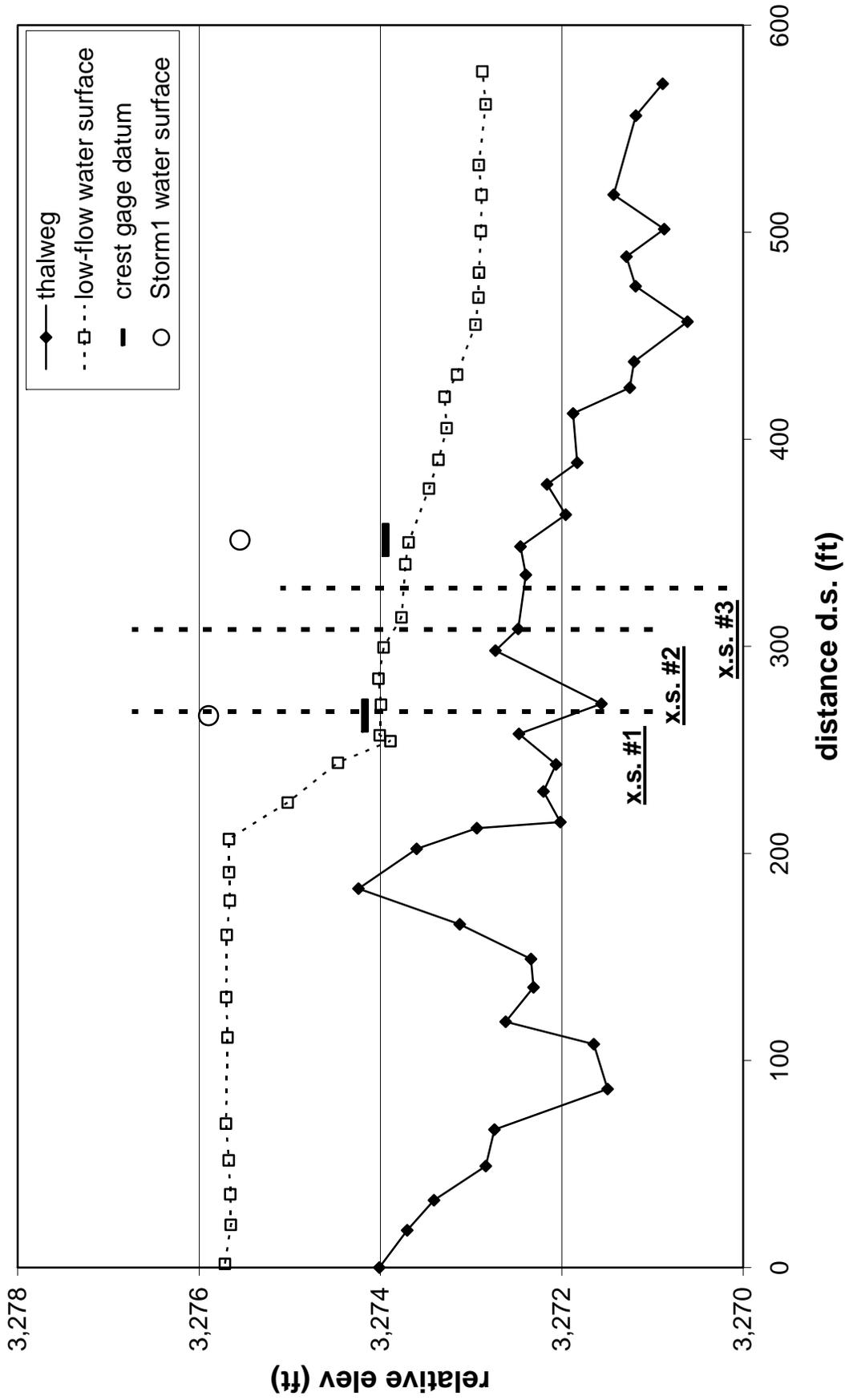


Figure A-12. Long profile at the Shafter site, including cross-section and crest gage locations.

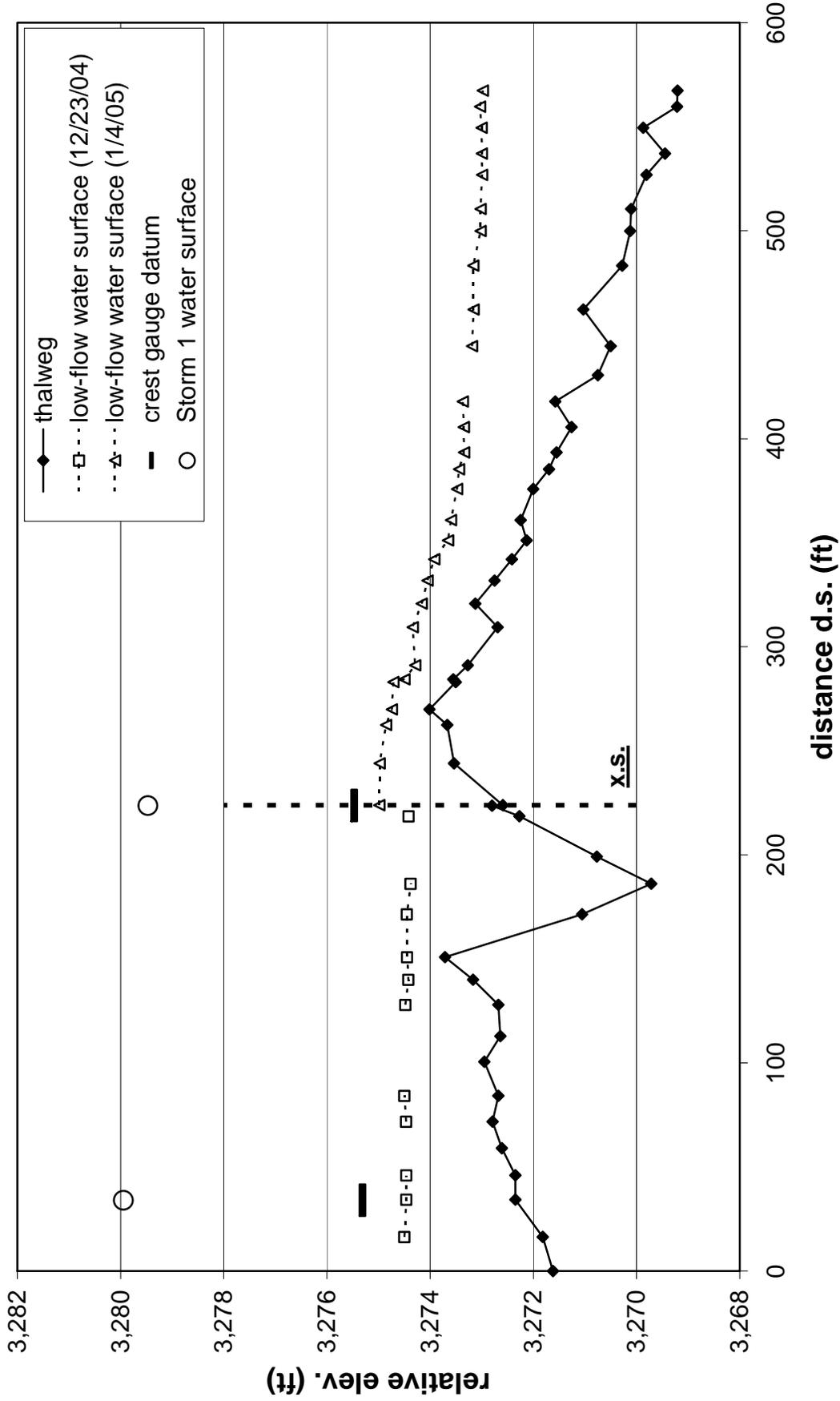


Figure A-13. Long profile at Site 2, including cross-section and crest gage locations.

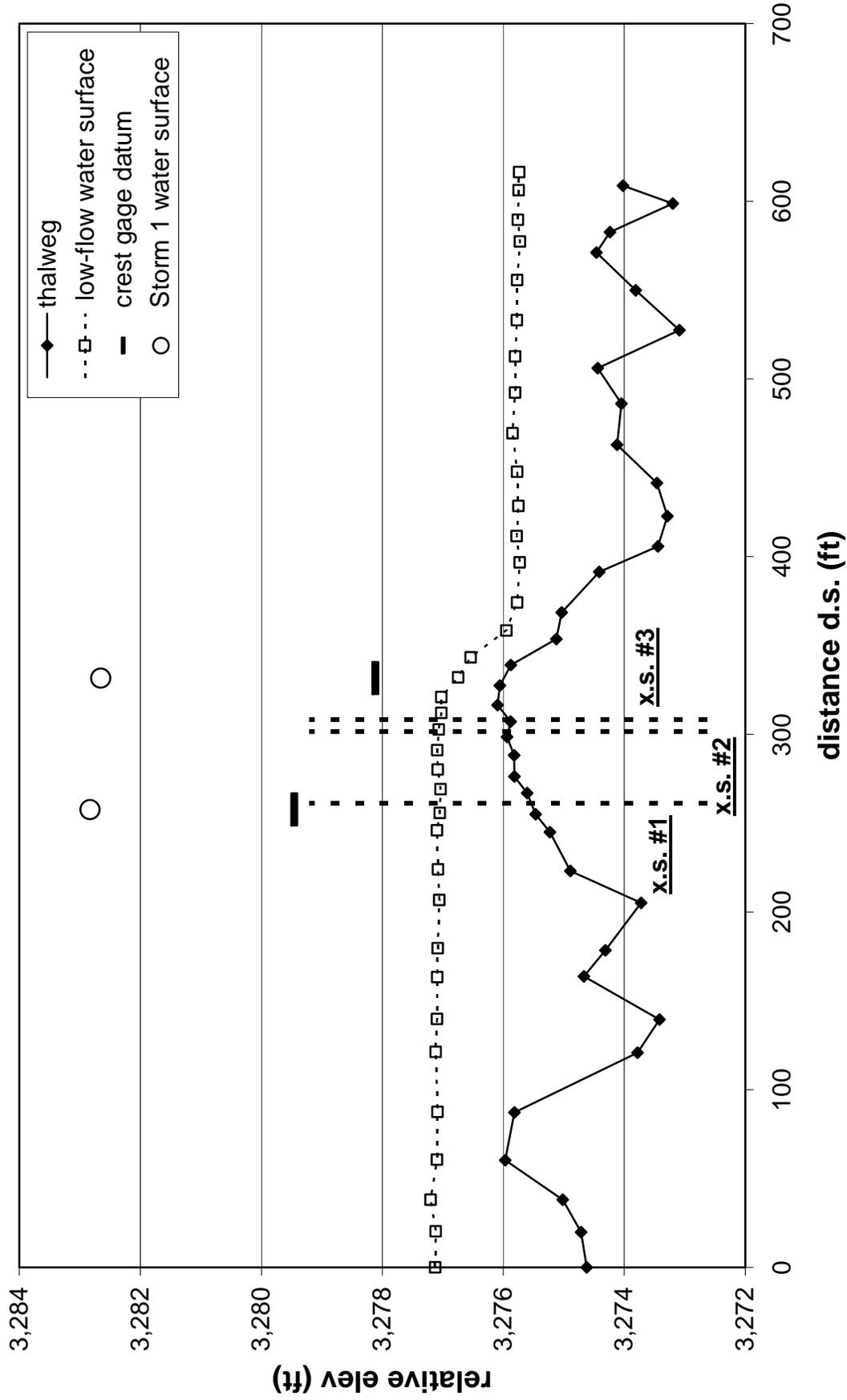


Figure A-14. Long profile at Site 1, including cross-section and crest gage locations.

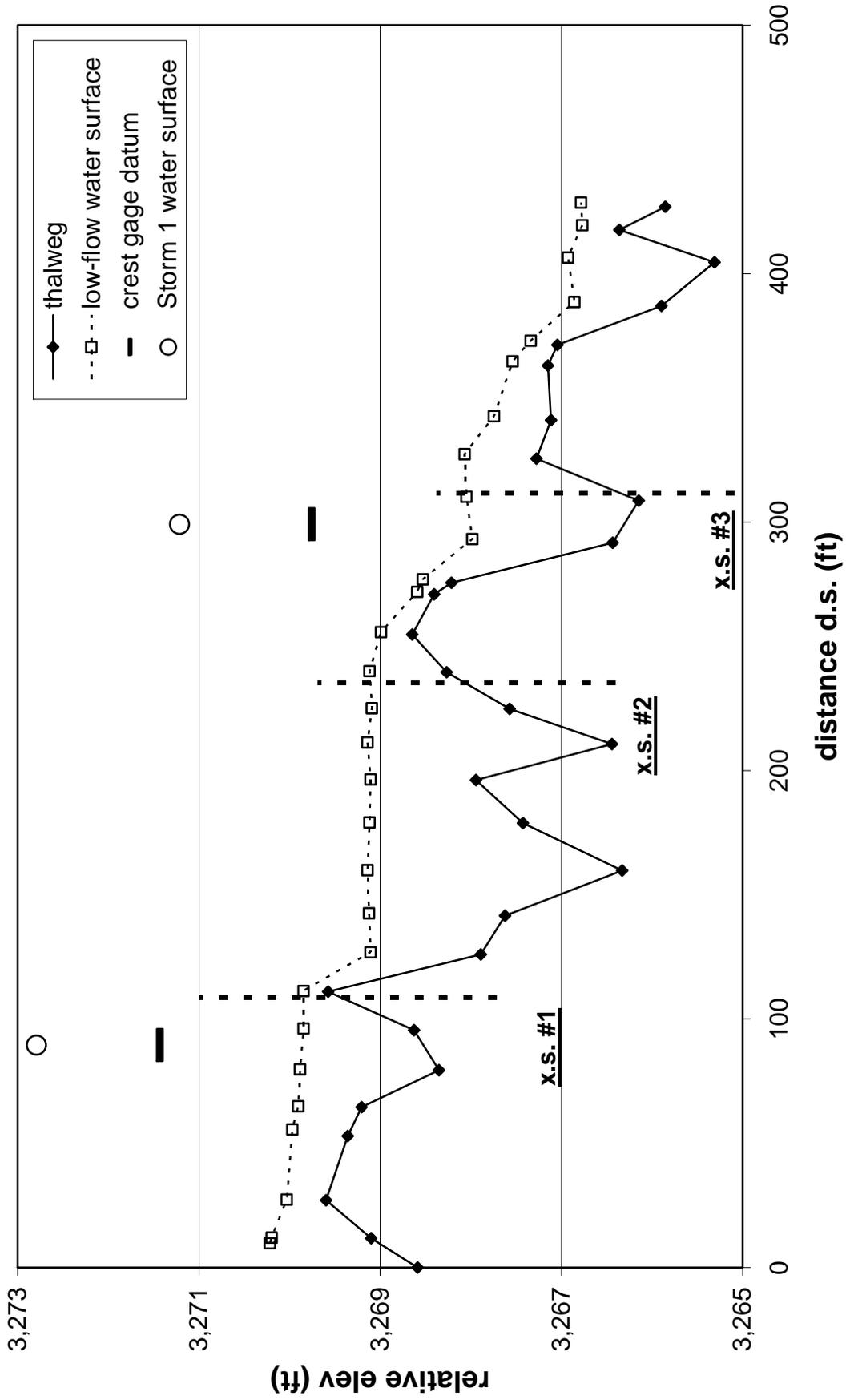


Figure A-15. Long profile at Olema Creek, including cross-section and crest gage locations.

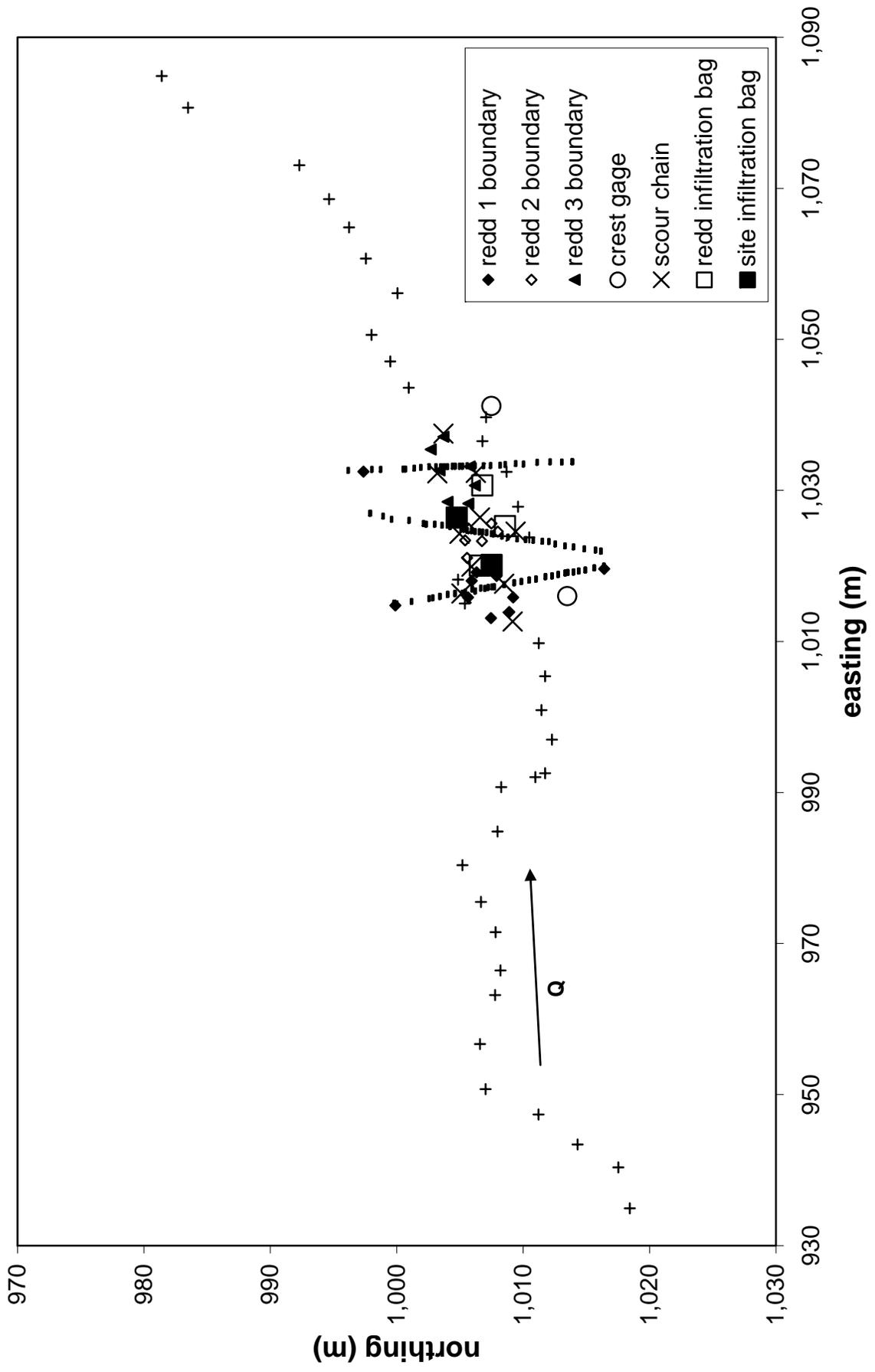


Figure A-16. Plan view for the Shafter site, including cross-section, crest gage, and monitoring equipment locations.

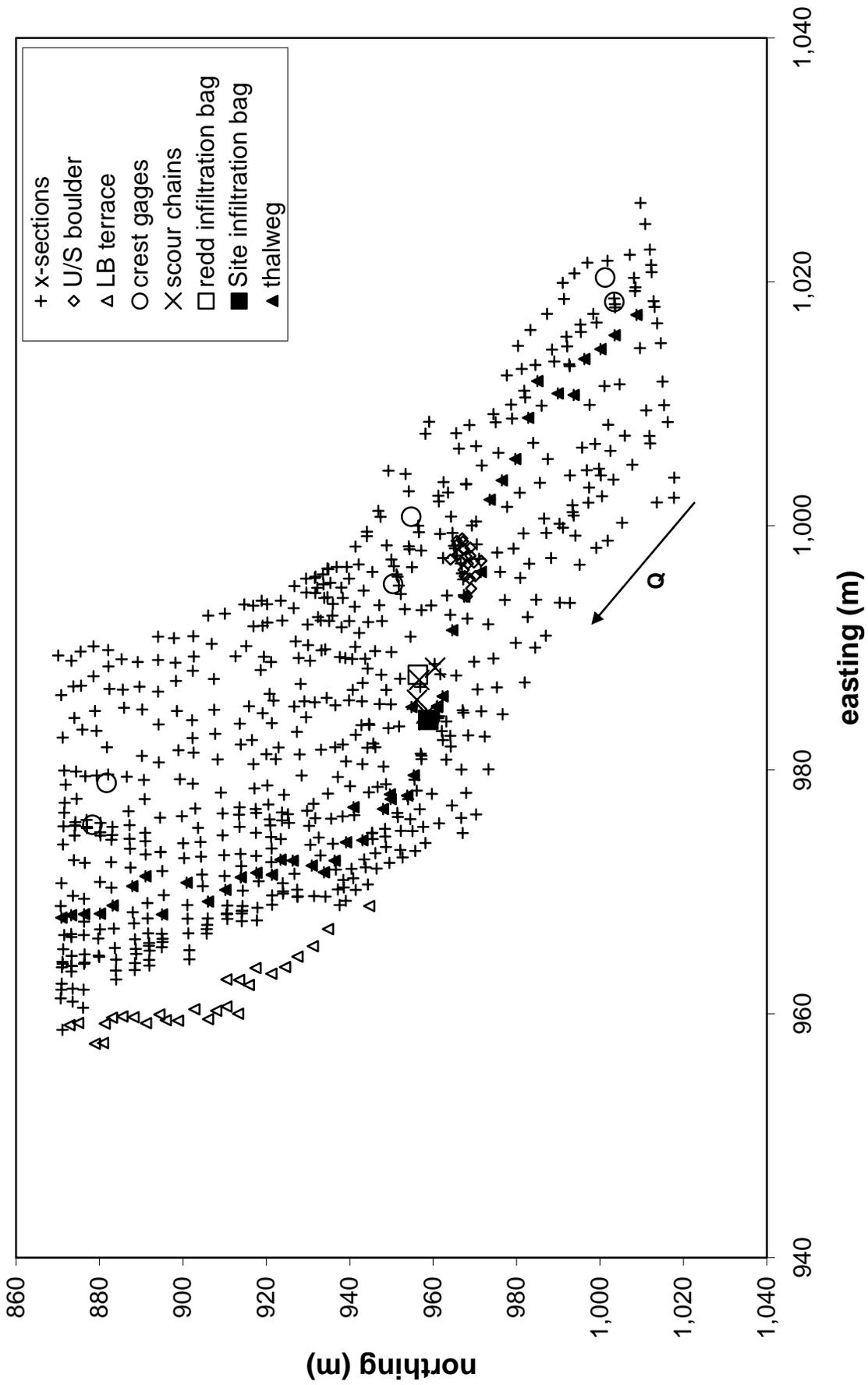


Figure A-17. Plan view for intensive Site 2, including cross-section, crest gage, and monitoring equipment locations.

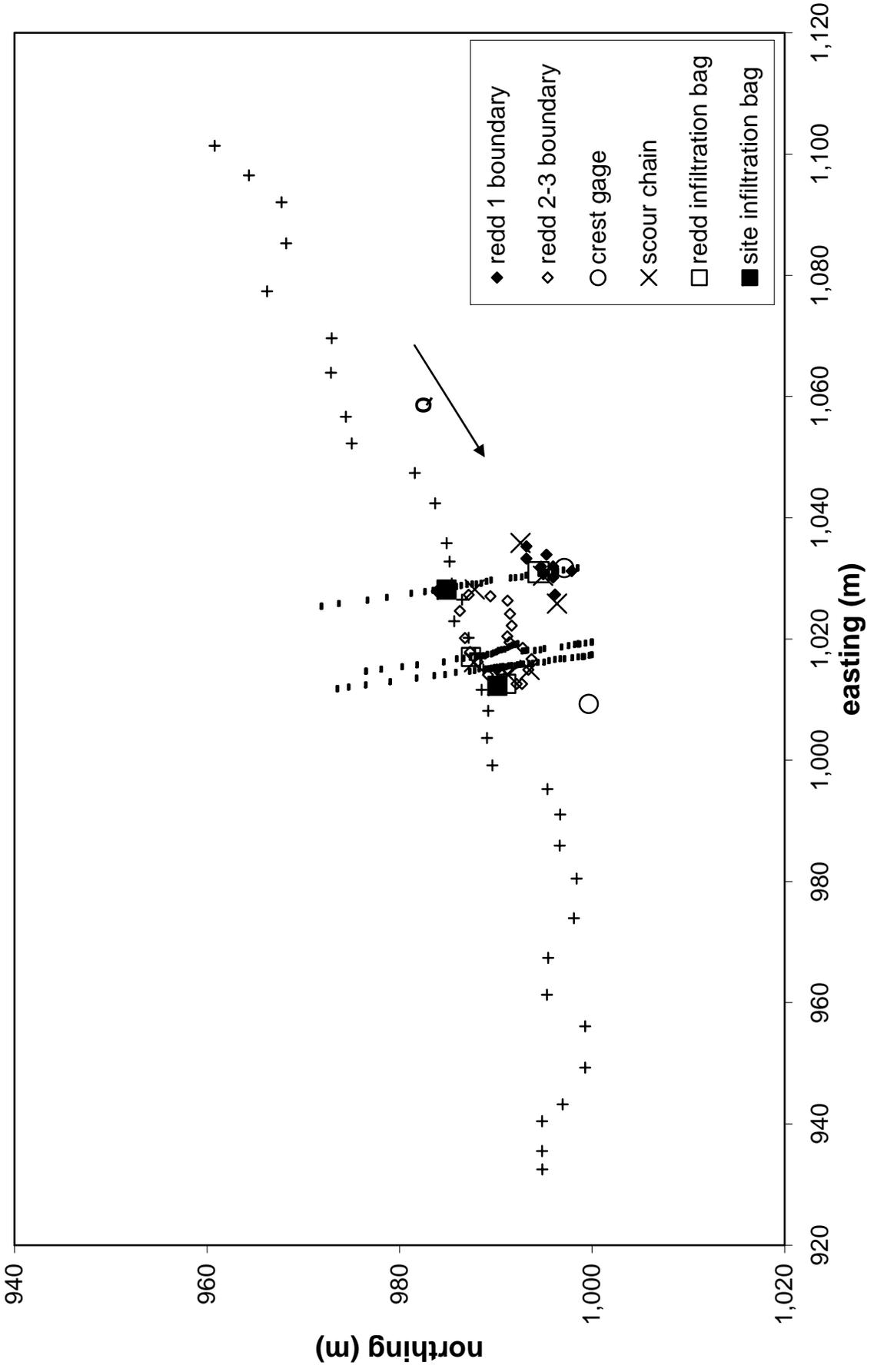


Figure A-18. Plan view for Site 1, including cross-section, crest gage, and monitoring equipment locations.

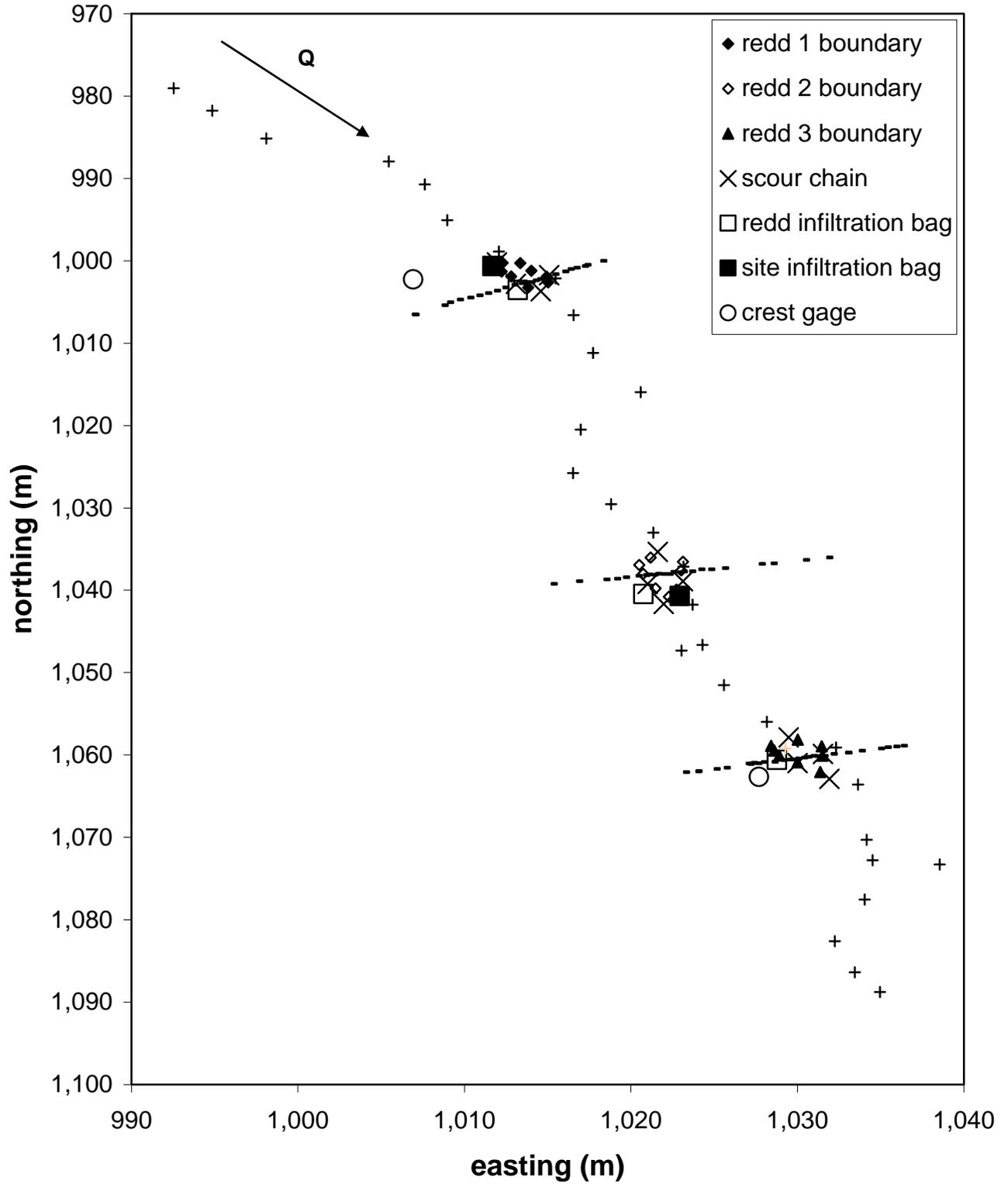


Figure A-19. Plan view for Olema Creek, including cross-section, crest gage, and monitoring equipment locations.

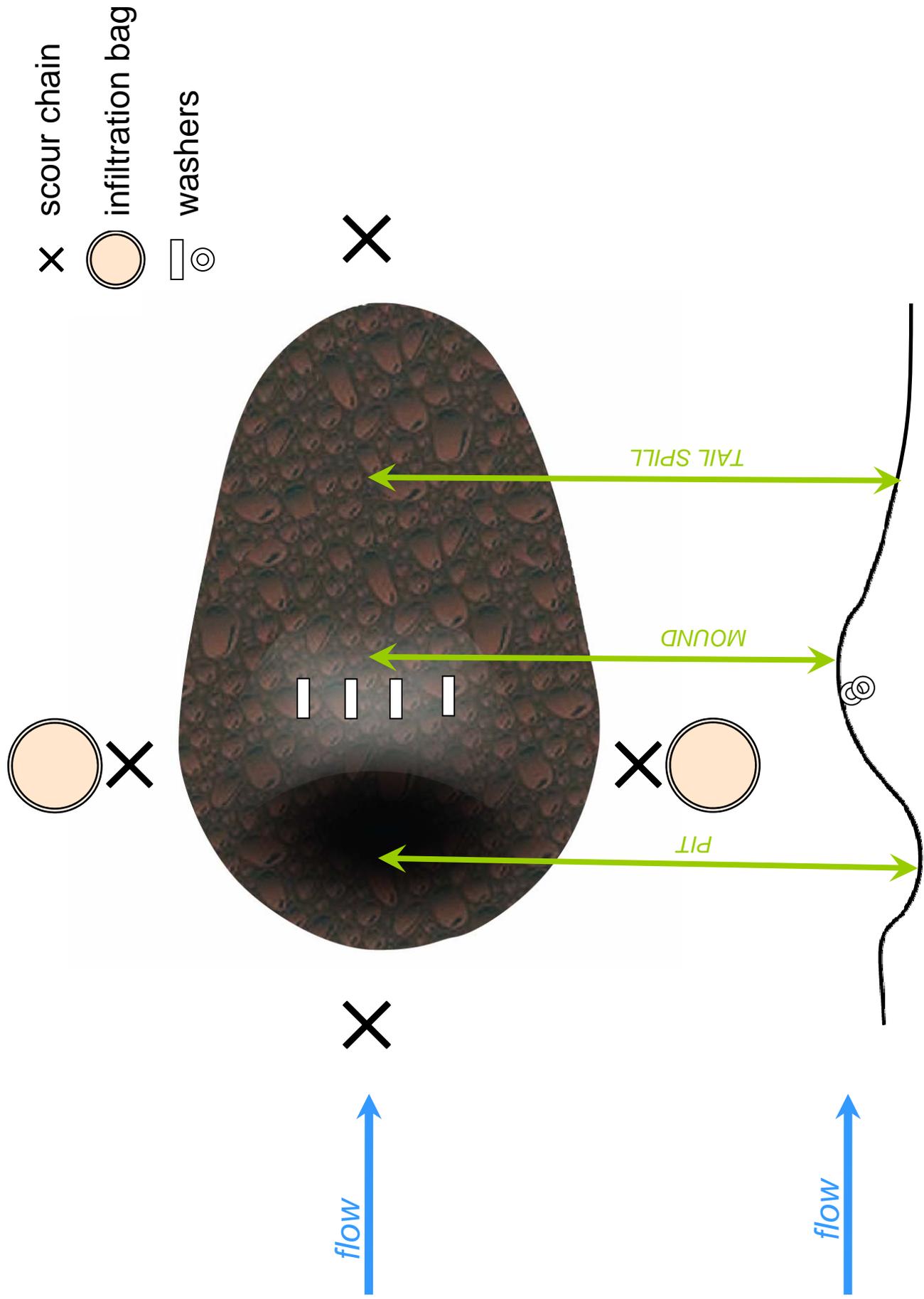
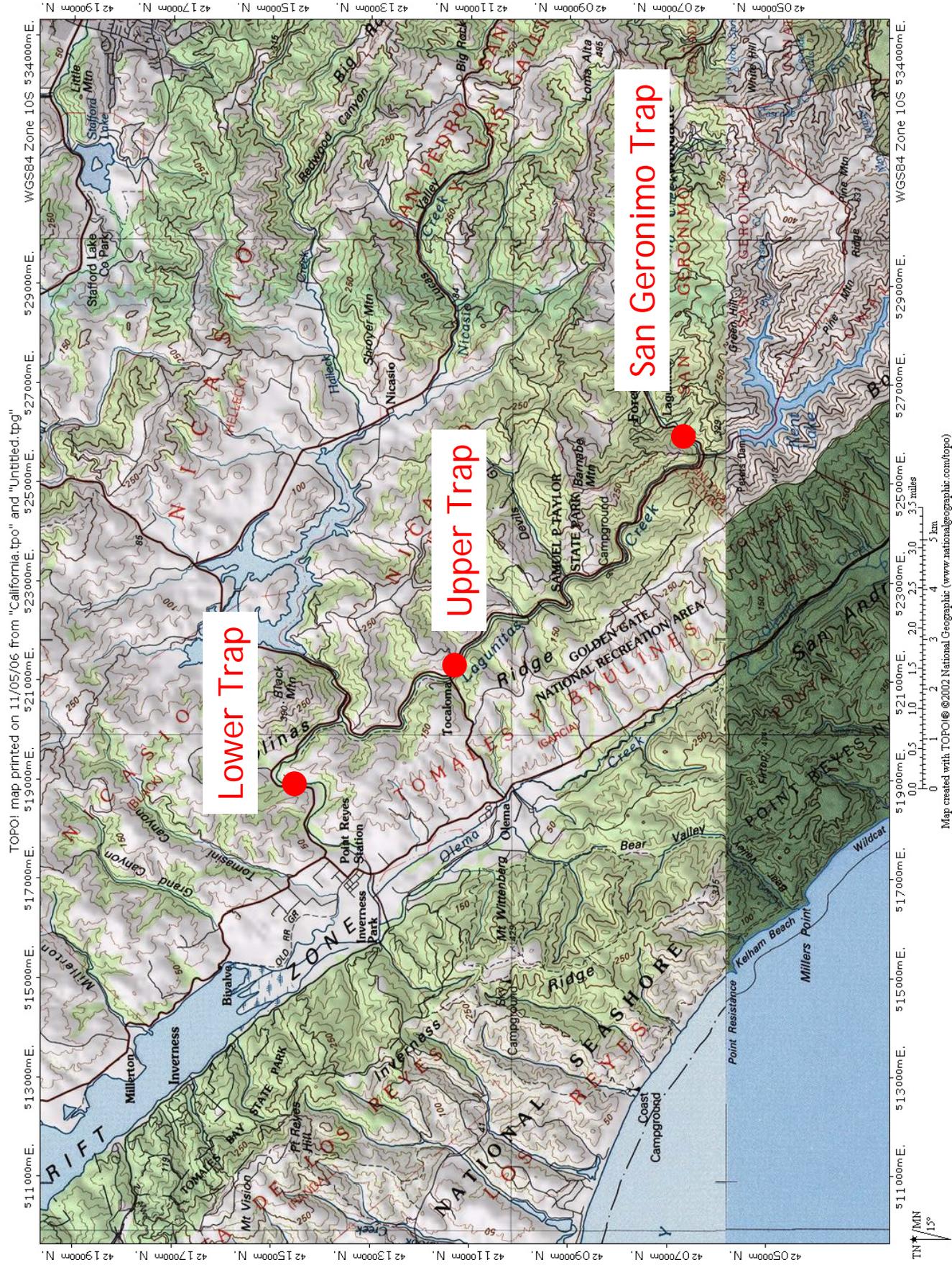


Figure A-20. Redd diagram and location of monitoring equipment used for the redd study.



Lower Trap

Upper Trap

San Geronimo Trap

Figure A-21. Locations of downstream monitoring trap locations in the Lagunitas Creek watershed, 2006.



Figure A-22. Aerial photo of the Lower Trap location in Lagunitas Creek.



Figure A-23. Photo of off-channel habitat in the Tocaloma Reach of Lagunitas Creek during high flows.

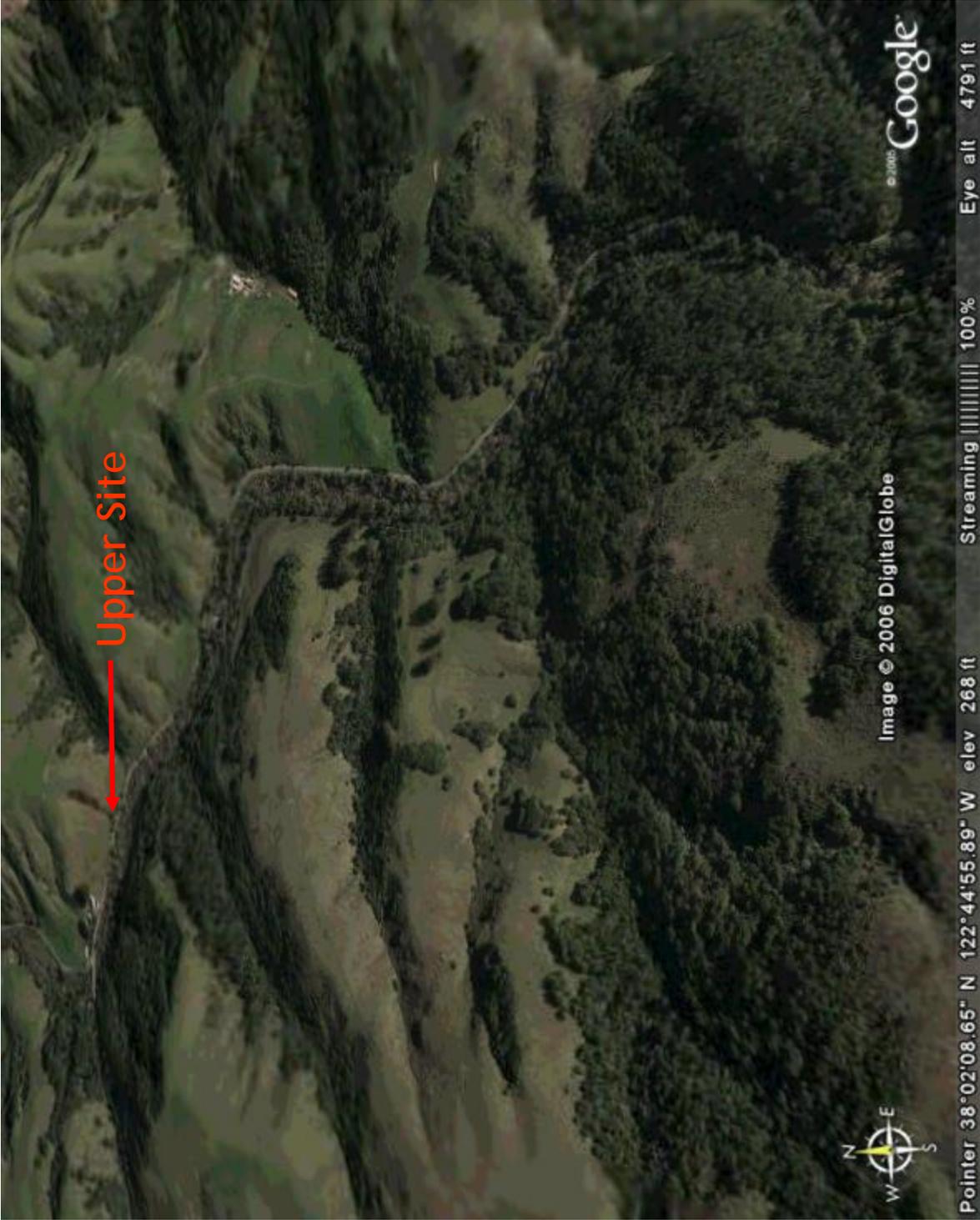


Figure A-24. Aerial photo of the Upper Trap location in Lagunitas Creek.



Figure A-25. Photo of confined reach of upper Lagunitas Creek during high flows.

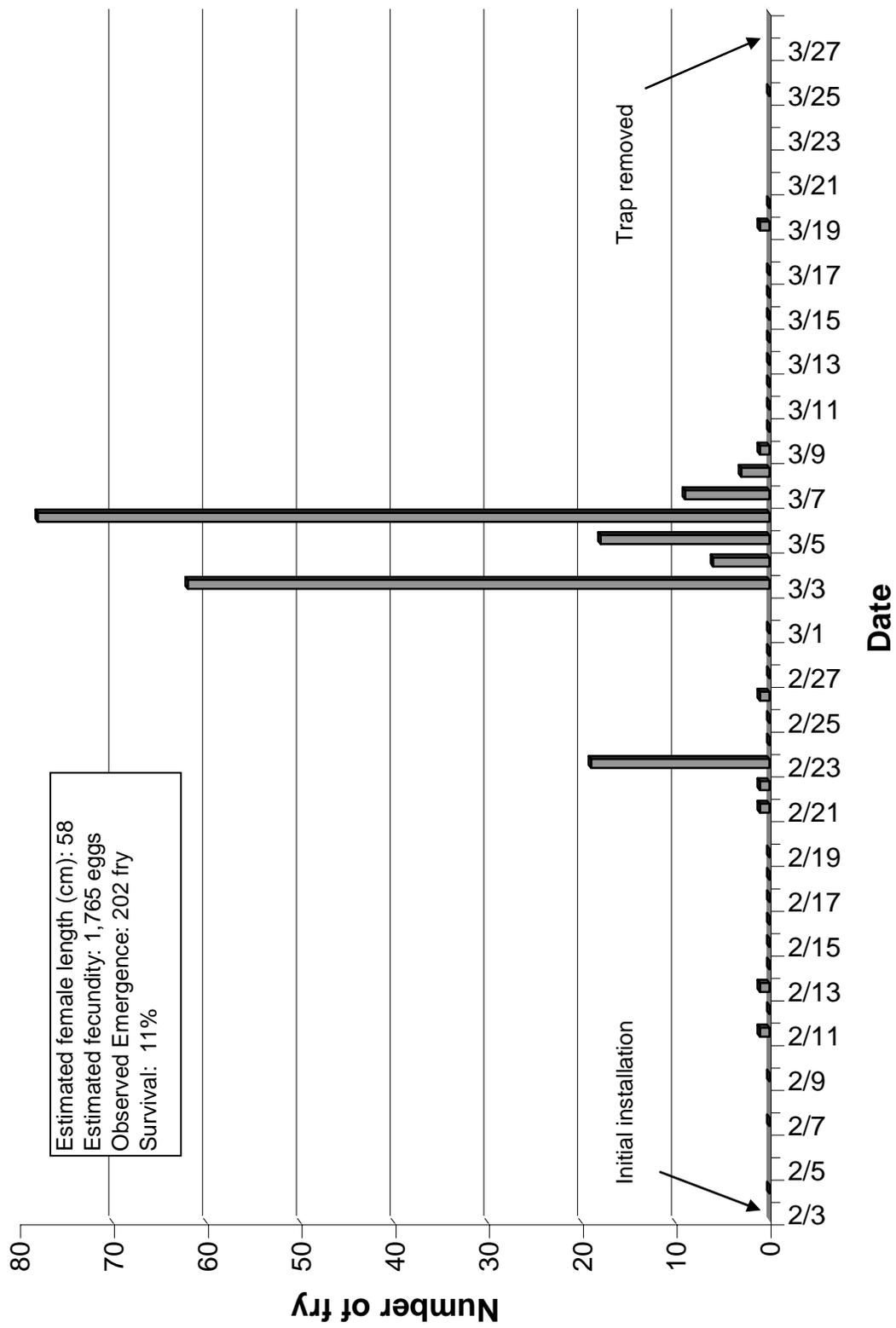


Figure A-26. Daily emergence totals at the Shafter site, Redd #1.

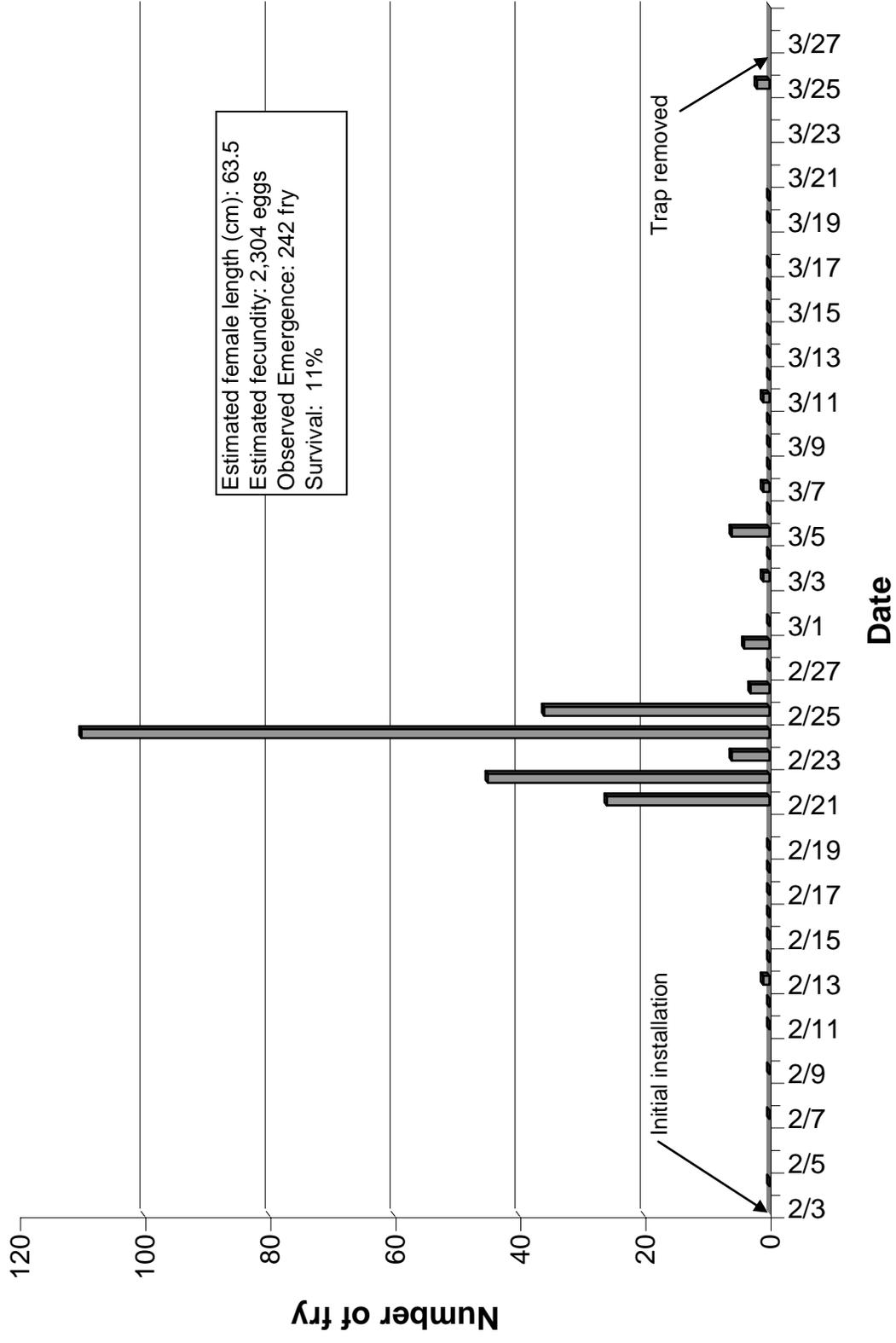


Figure A-27. Daily emergence totals at the Shafter site, Redd #2.

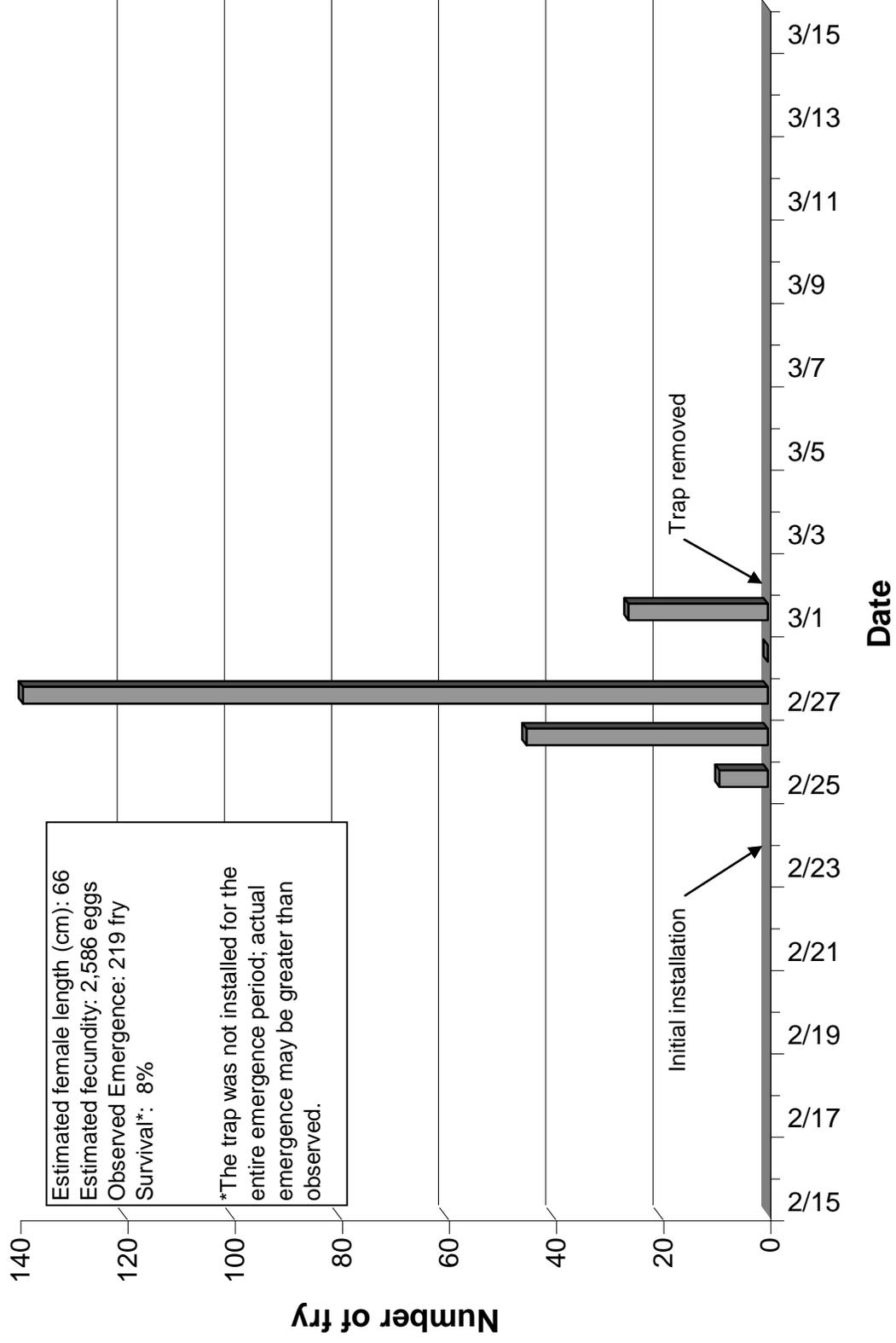


Figure A-28. Daily emergence totals at Site 2.

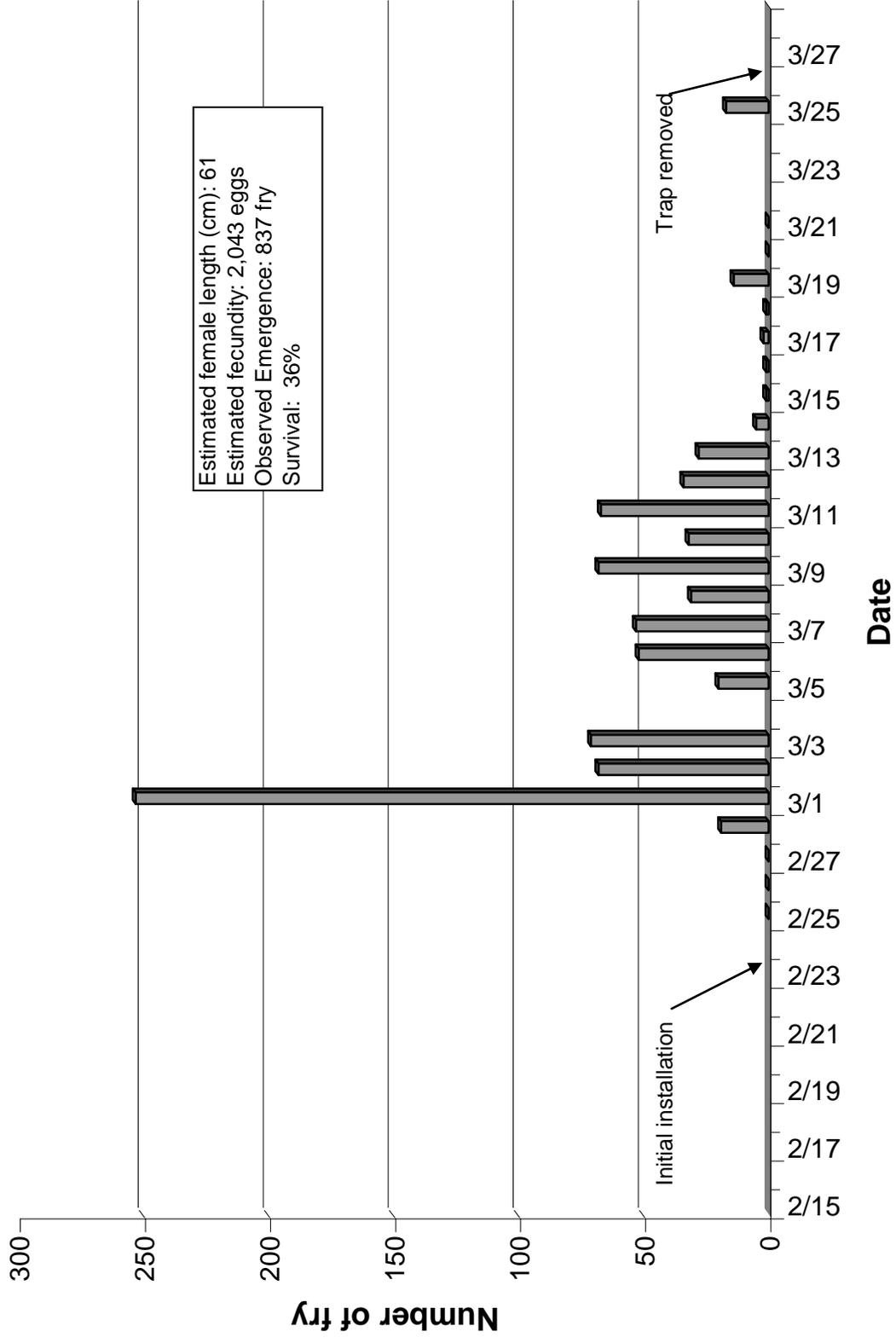


Figure A-29. Daily emergence totals at Site 1.

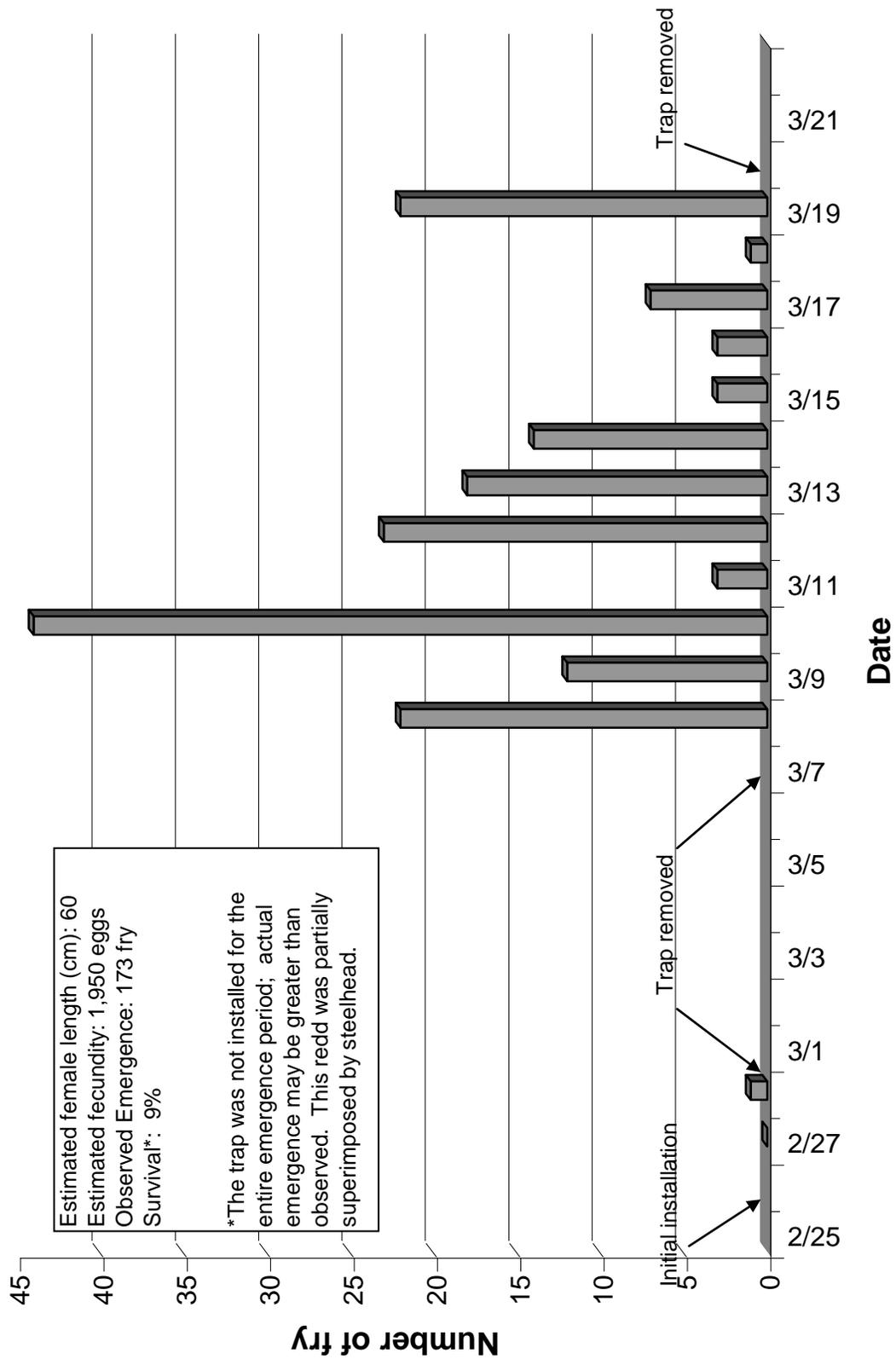


Figure A-30. Daily emergence totals at the Olema site, Redd #2.

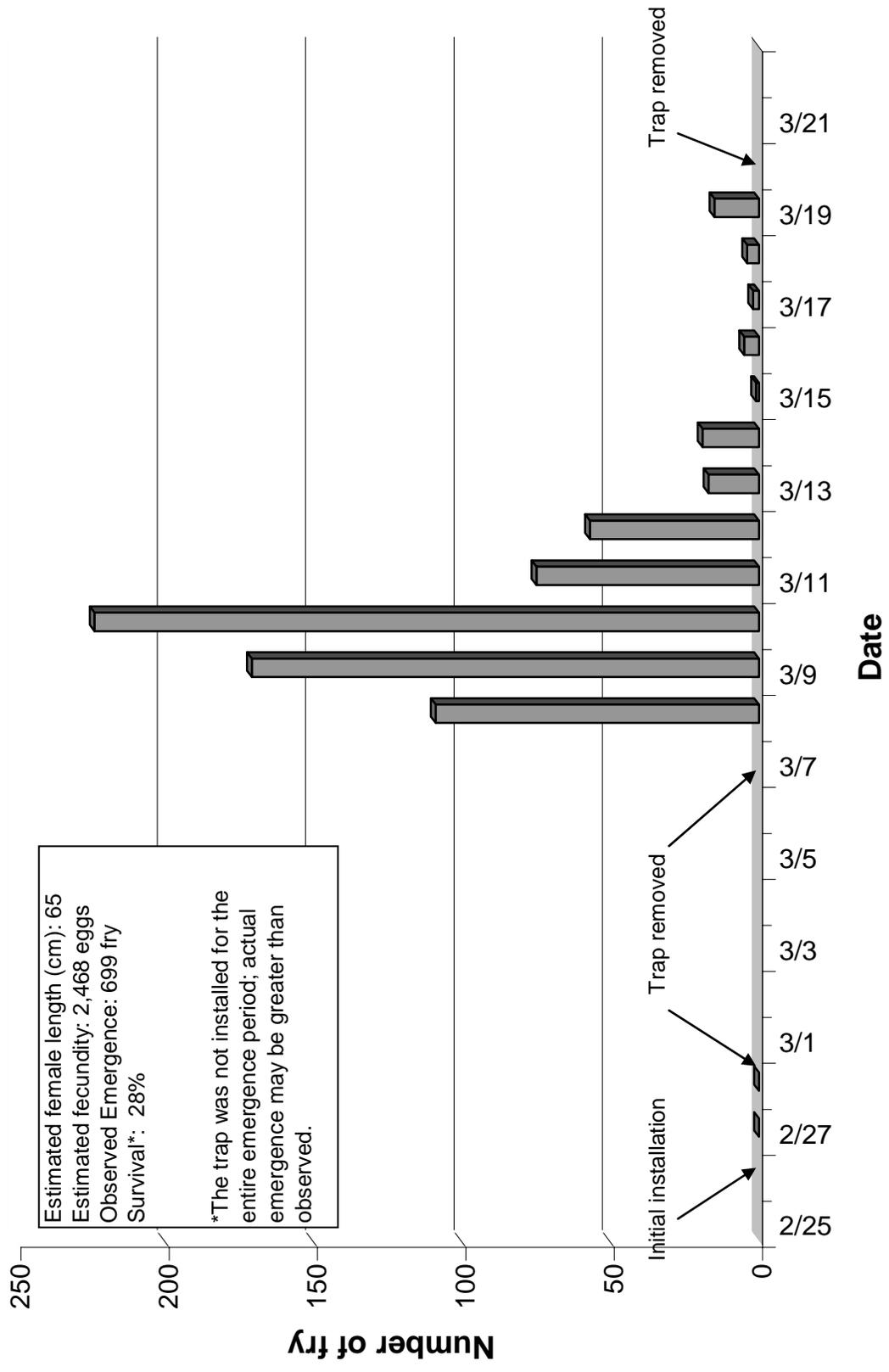


Figure A-31. Daily emergence totals at the Olema site, Redd #3.

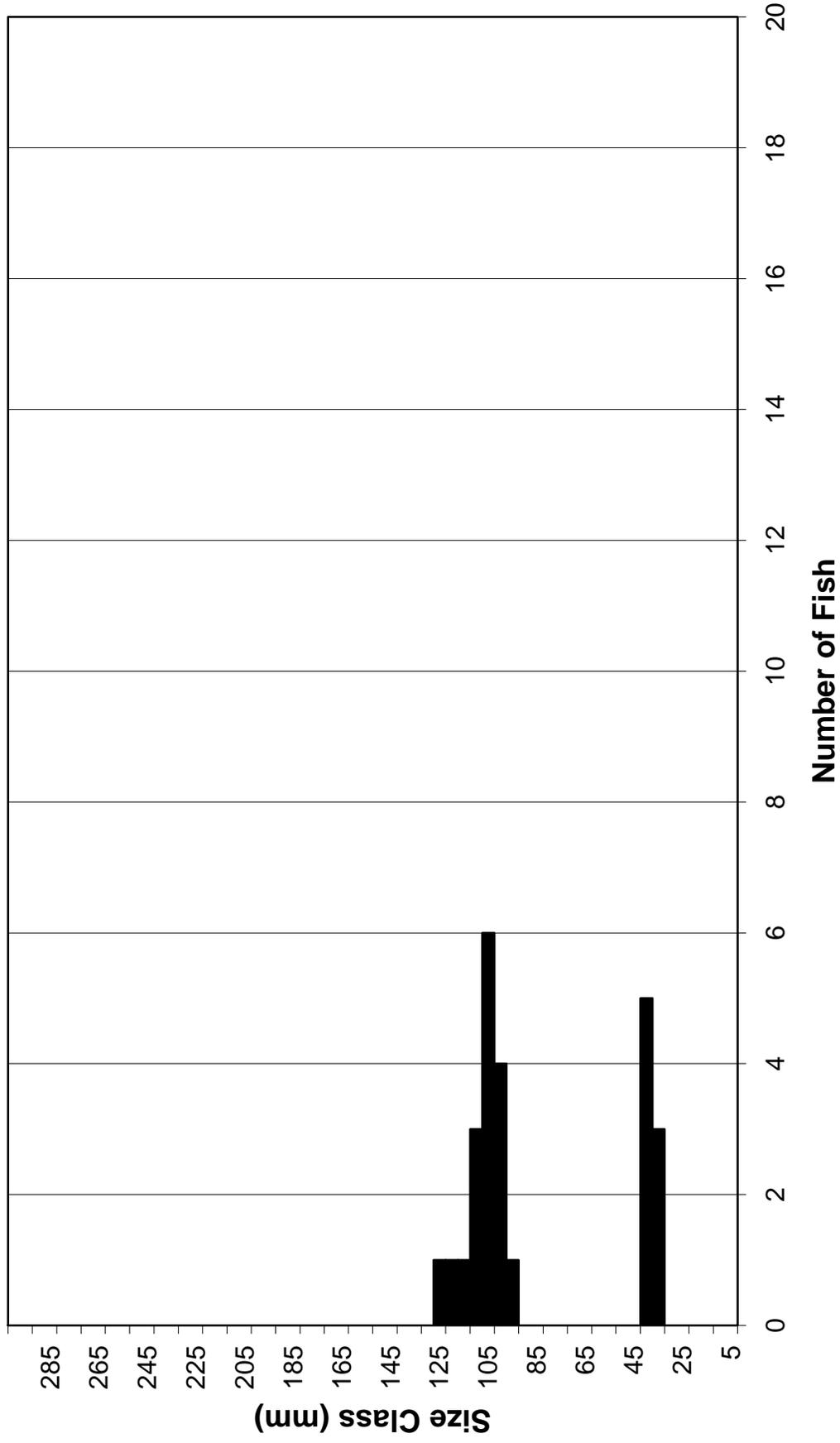


Figure A-32. Length frequency histogram for downstream migrating coho salmon captured at the Upper Lagunitas Trap, March 20-April 2, 2006.

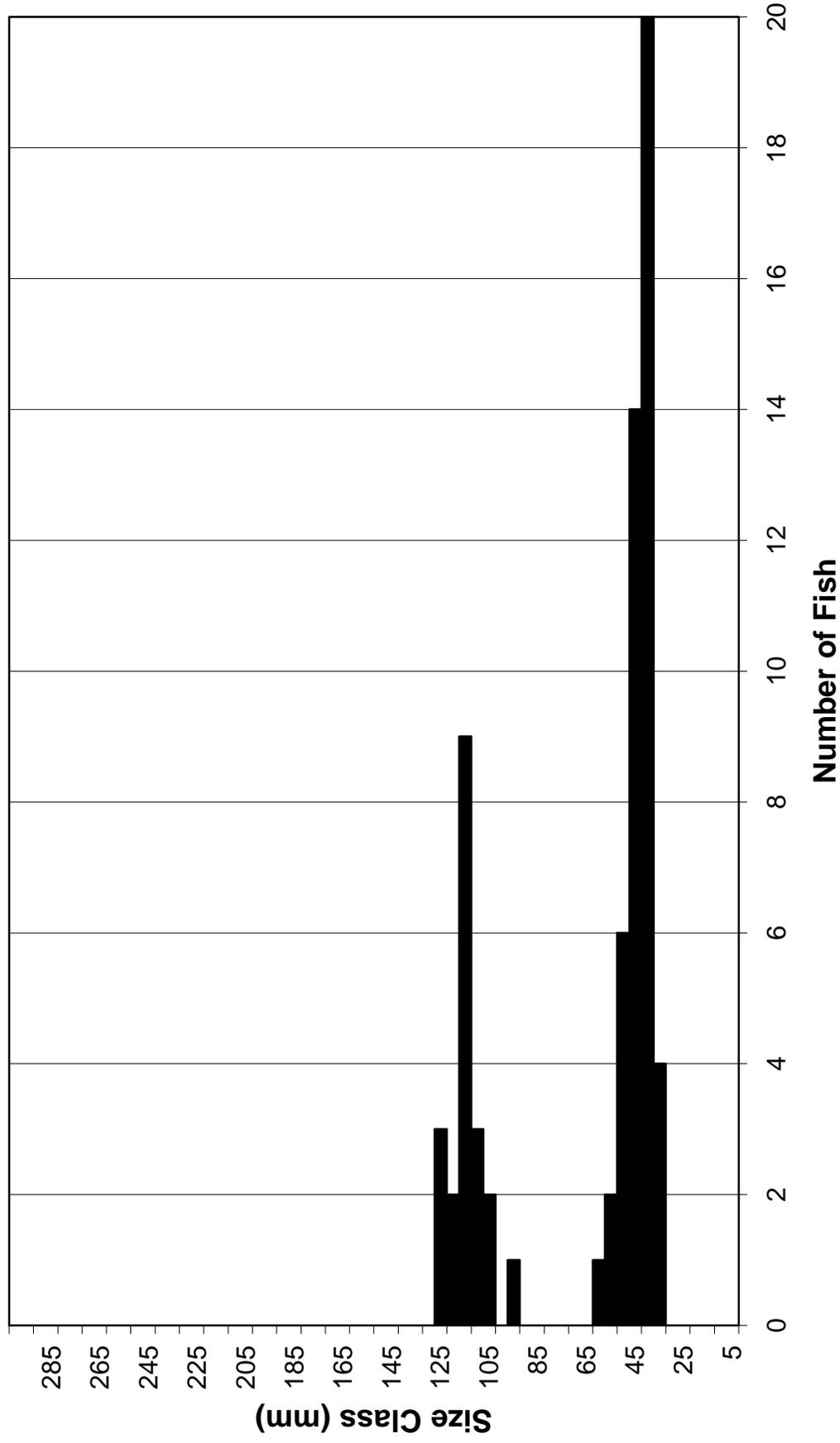


Figure A-33. Length frequency histogram for downstream migrating coho salmon captured at the Upper Lagunitas Trap, April 3-April 16, 2006.

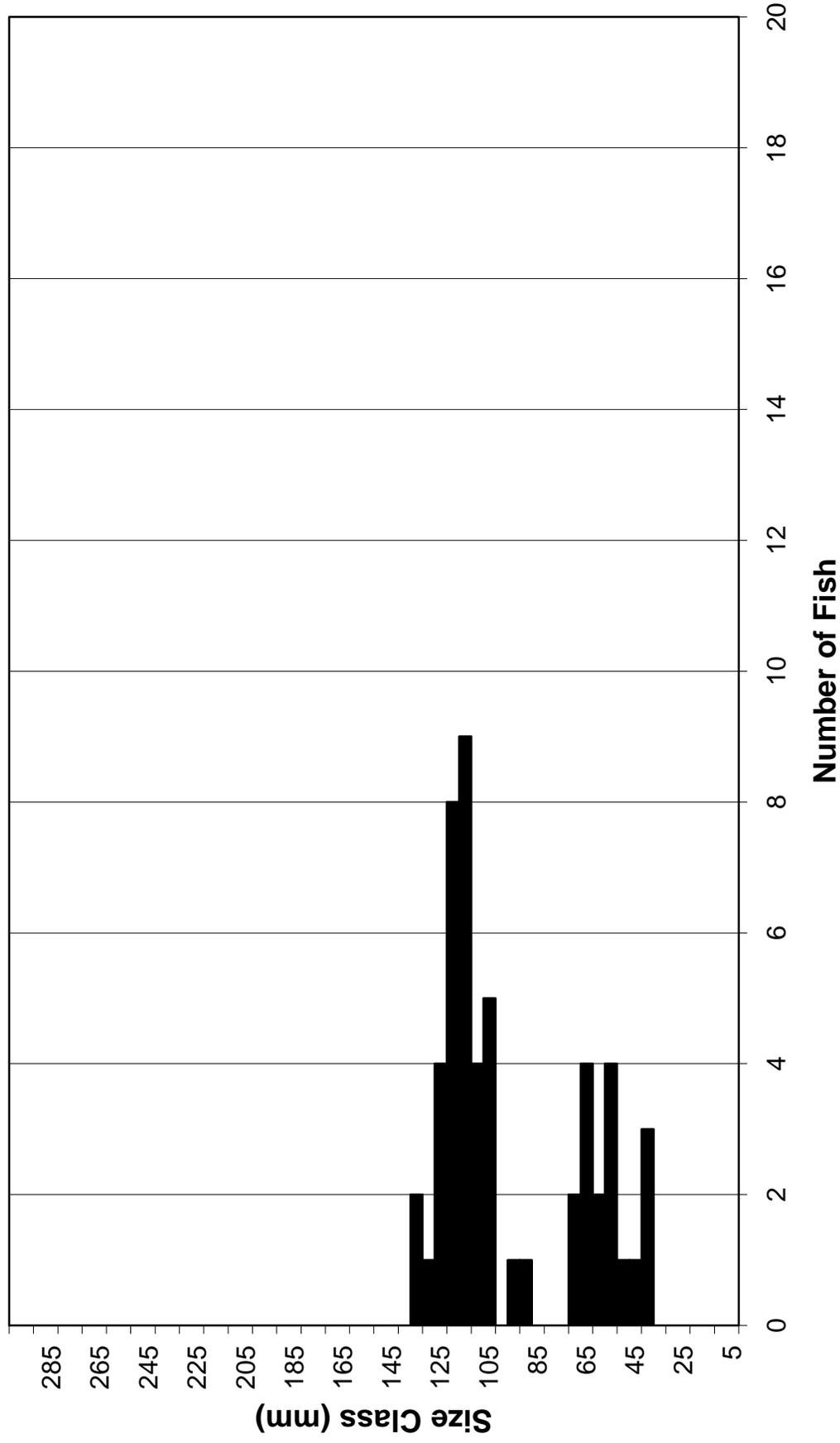


Figure A-34. Length frequency histogram for downstream migrating coho salmon captured at the Upper Lagunitas Trap, April 17-April 30, 2006.

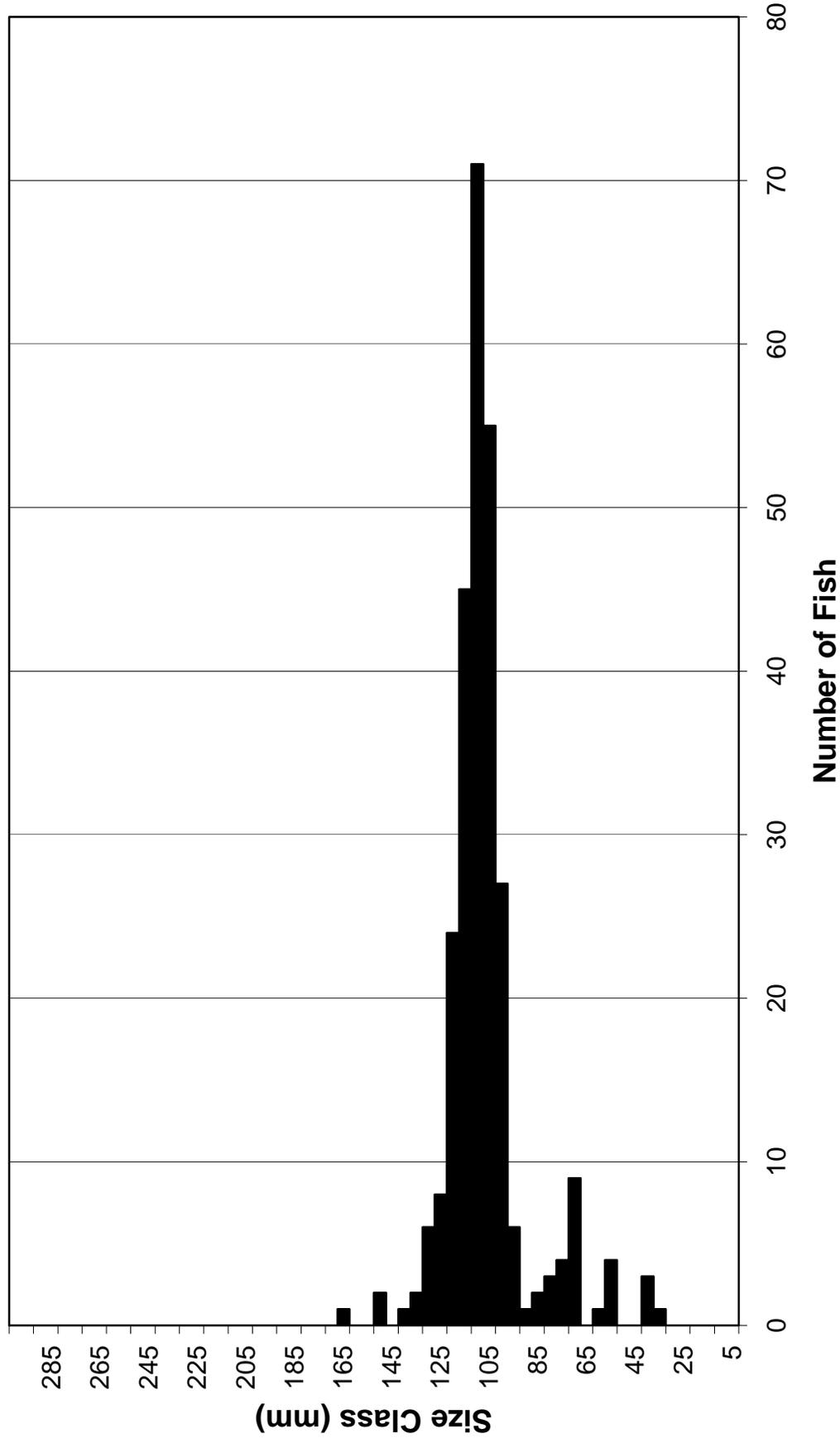


Figure A-35. Length frequency histogram for downstream migrating coho salmon captured at the Upper Lagunitas Trap, May 1-May 14, 2006.

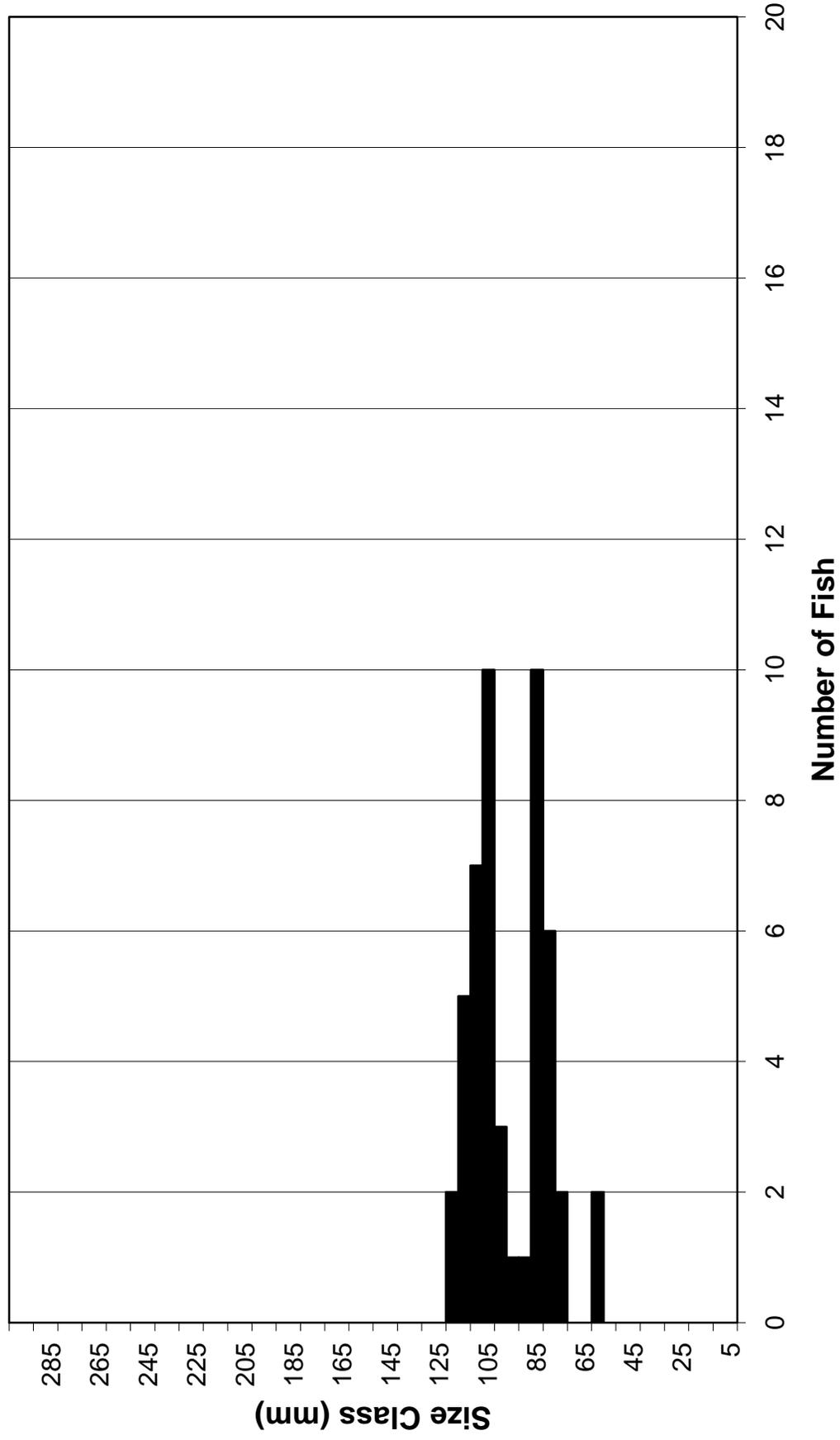


Figure A-36. Length frequency histogram for downstream migrating coho salmon captured at the Upper Lagunitas Trap, May 15-May 28, 2006.

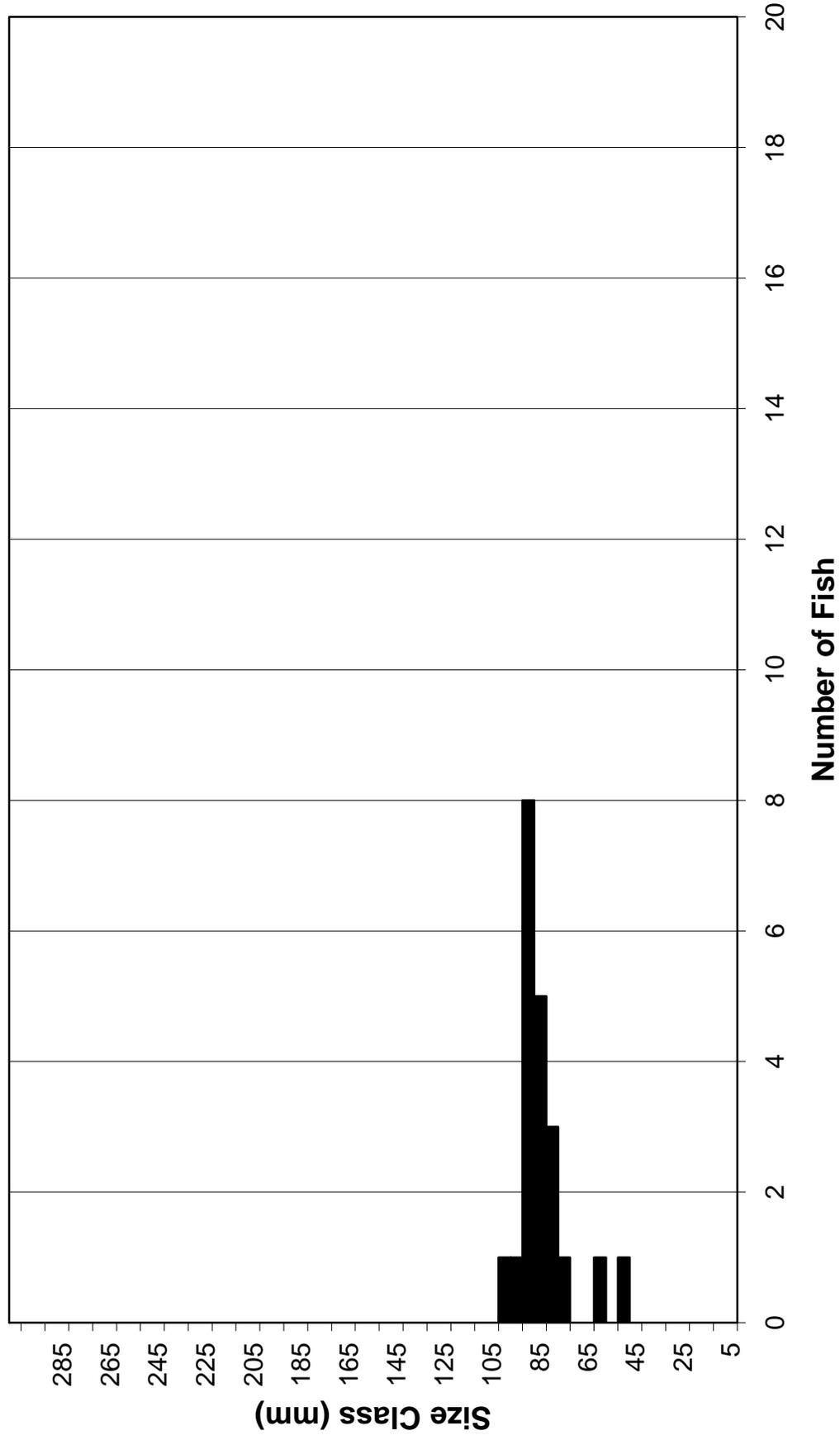


Figure A-37. Length frequency histogram for downstream migrating coho salmon captured at the Upper Lagunitas Trap, May 29-June 8, 2006.

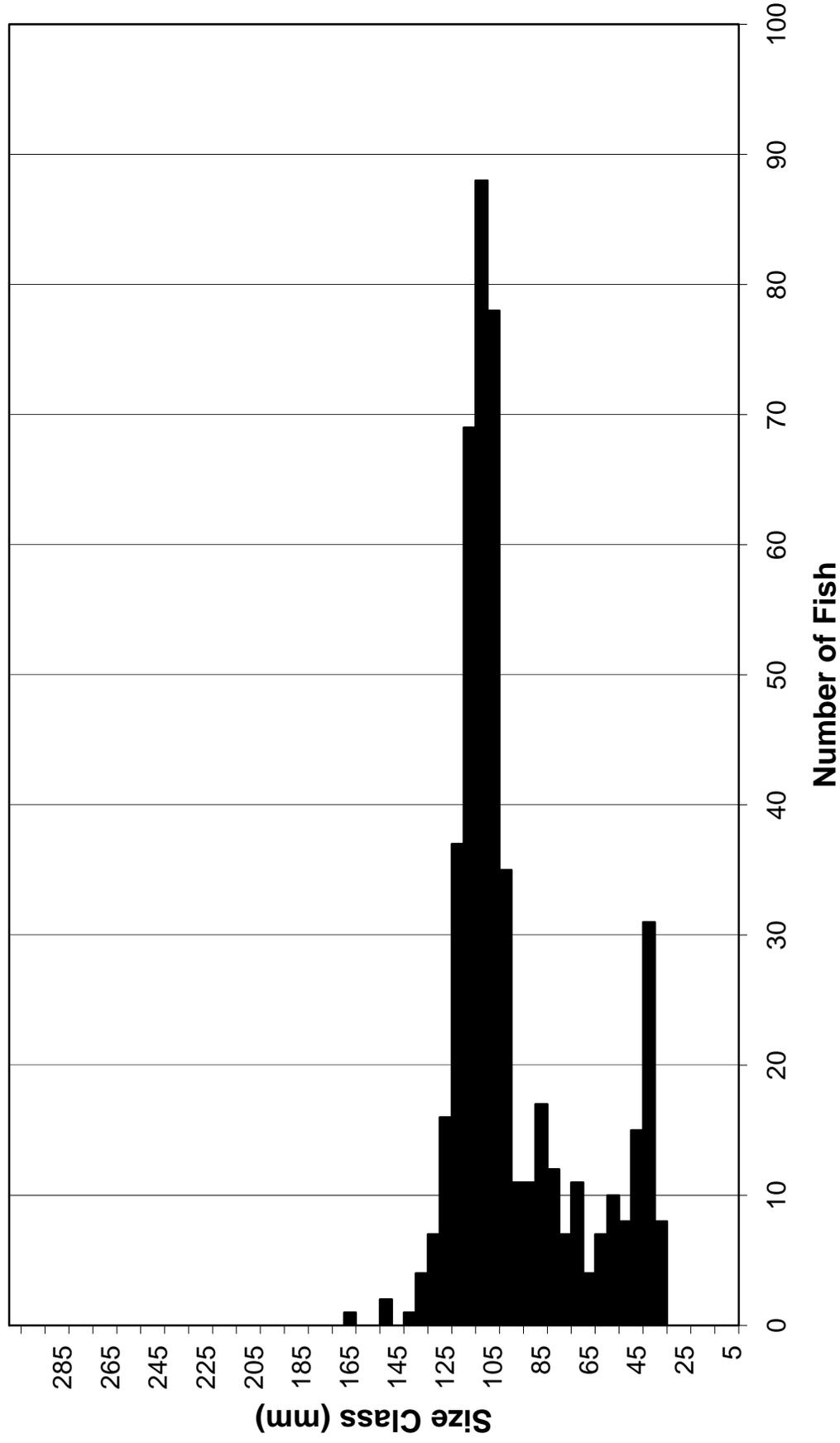


Figure A-38. Length frequency histogram for downstream migrating coho salmon captured at the Upper Lagunitas Trap for all weeks, March 20-June 8, 2006.

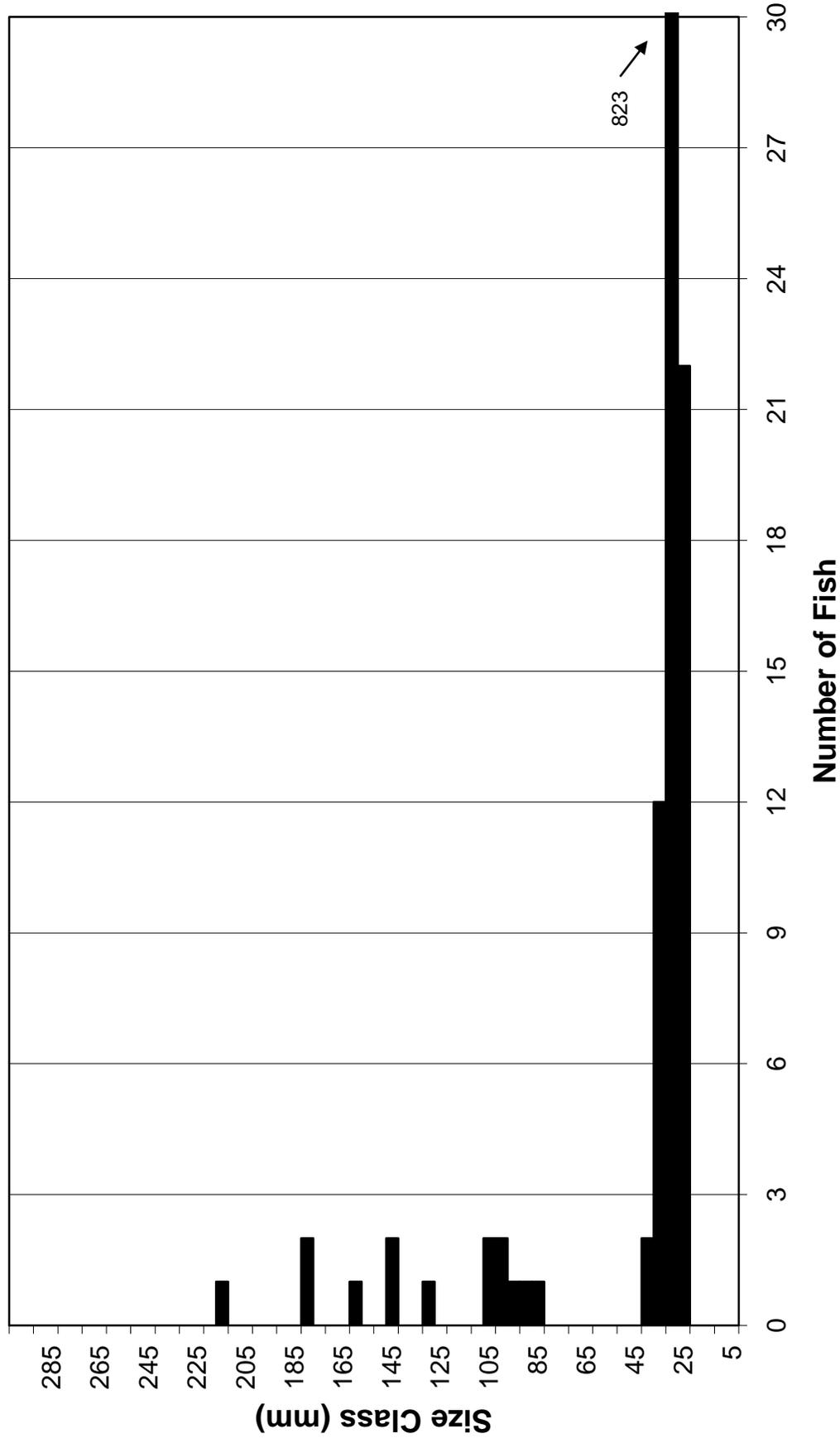


Figure A-39. Length frequency histogram for downstream migrating steelhead captured at the Upper Lagunitas Trap, March 20-April 2, 2006.

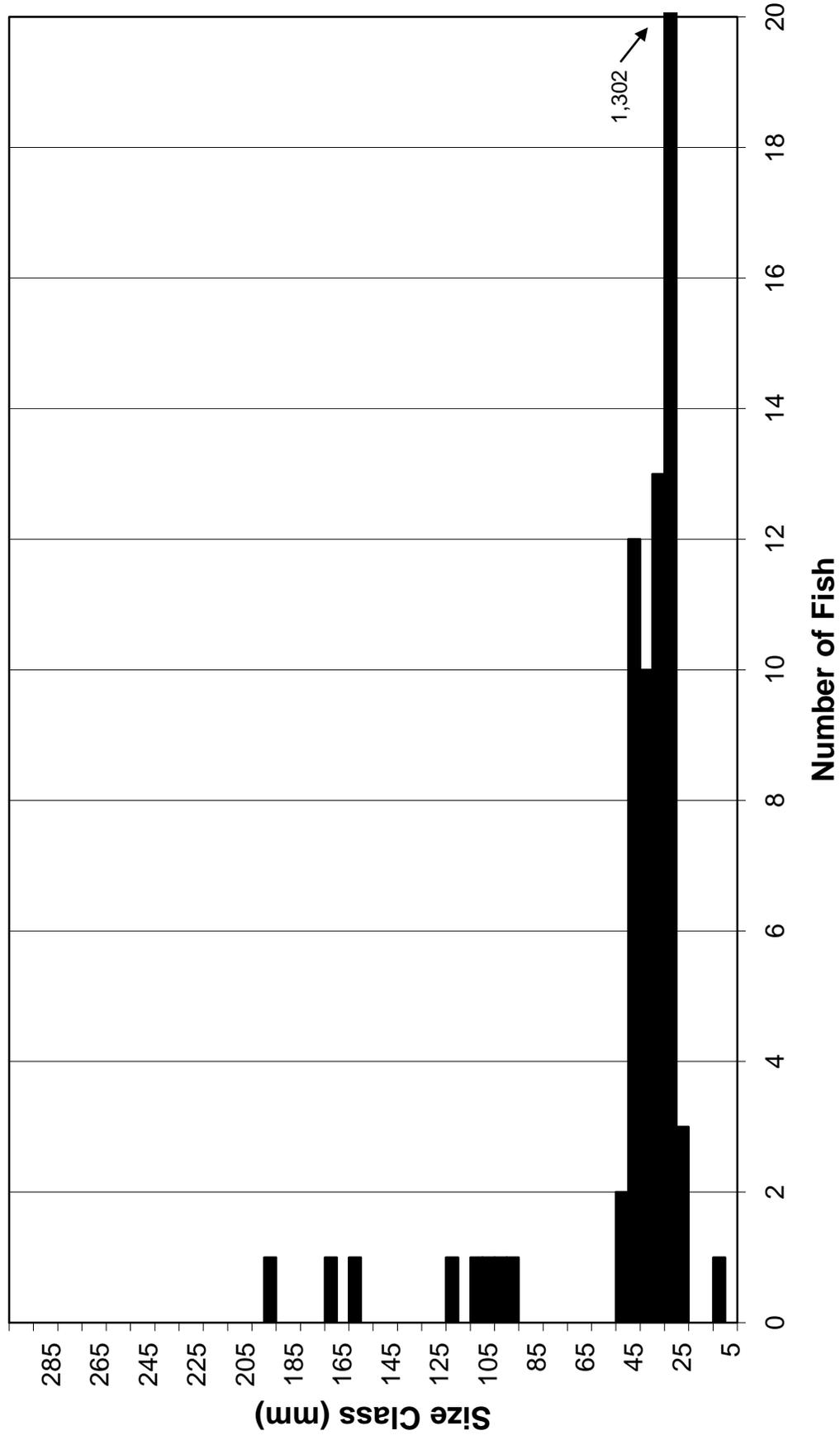


Figure A-40. Length frequency histogram for downstream migrating steelhead captured at the Upper Lagunitas Trap, April 3-April 16, 2006.

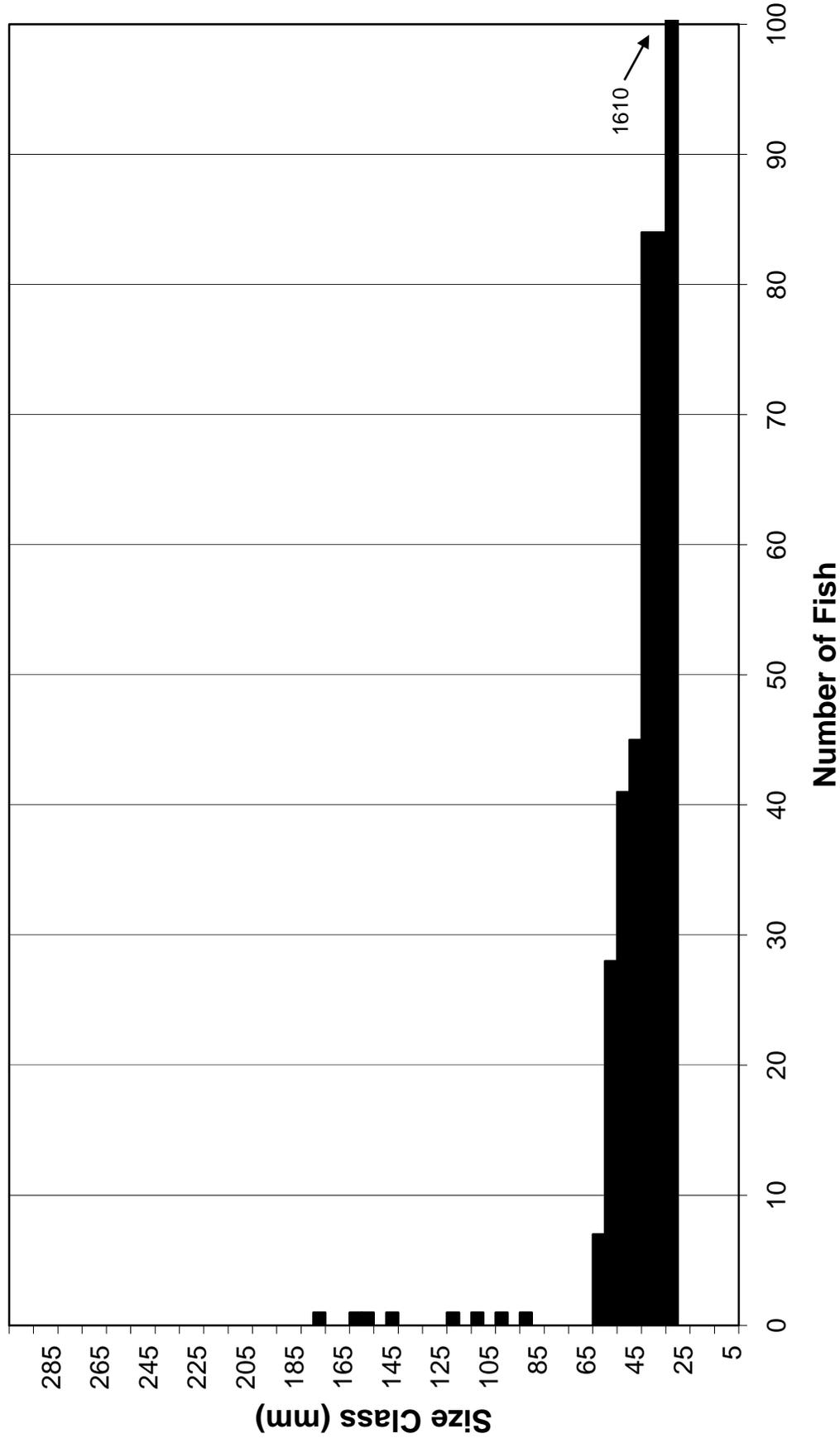


Figure A-41. Length frequency histogram for downstream migrating steelhead captured at the Upper Lagunitas Trap, April 17-April 30, 2006.

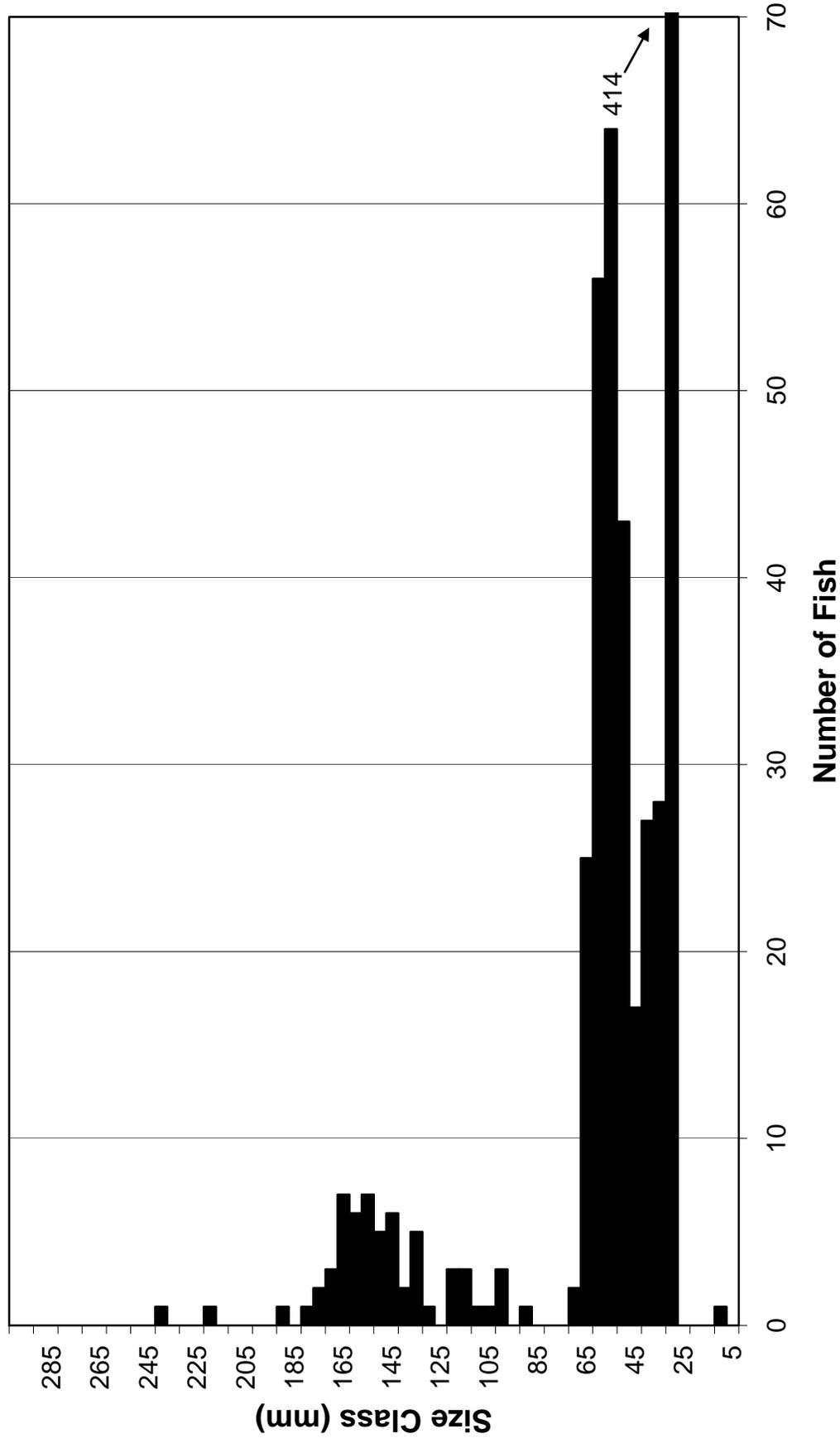


Figure A-42. Length frequency histogram for downstream migrating steelhead captured at the Upper Lagunitas Trap, May 1-May 14, 2006.

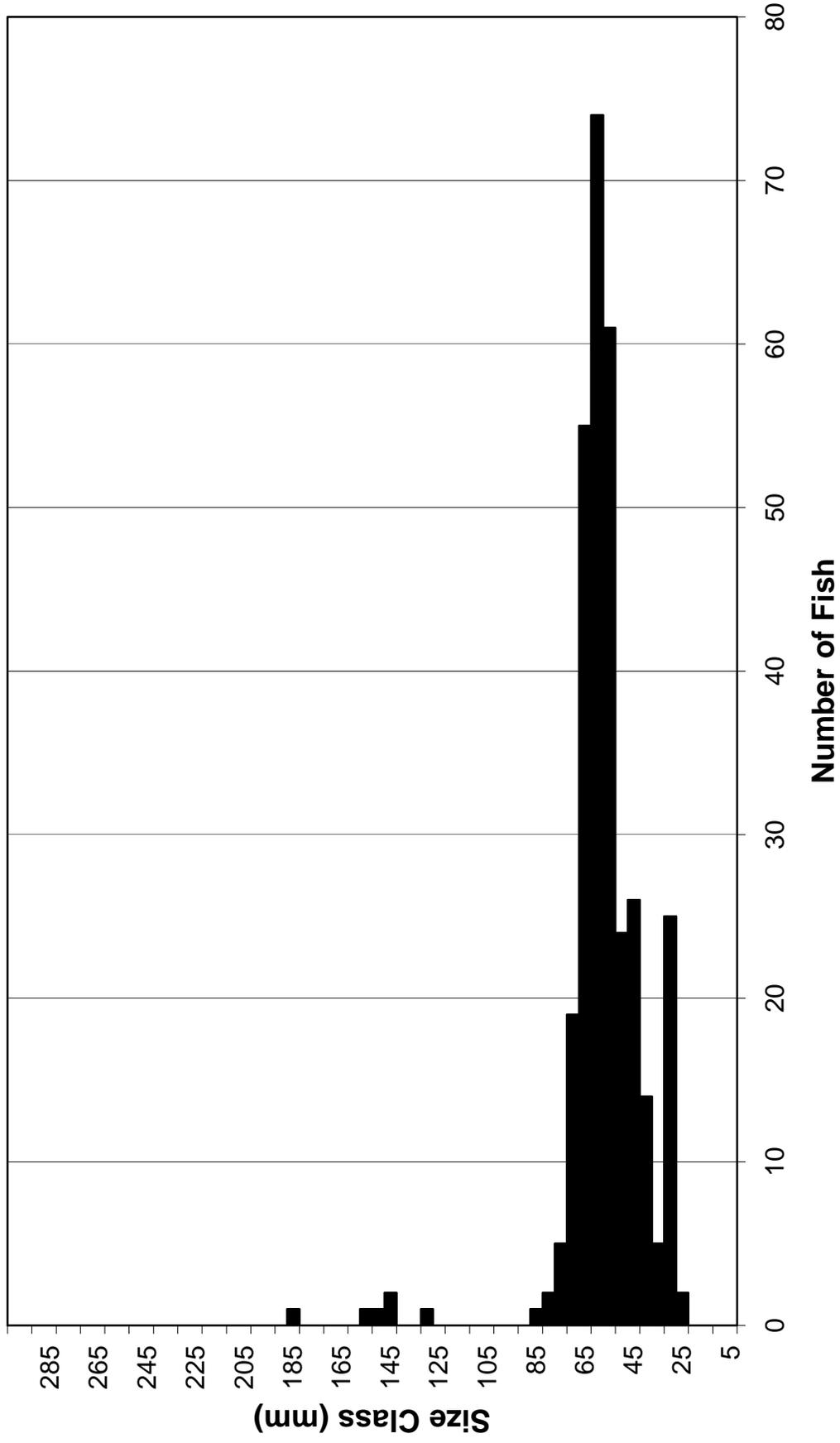


Figure A-43. Length frequency histogram for downstream migrating steelhead captured at the Upper Lagunitas Trap, May 15-May 28, 2006.

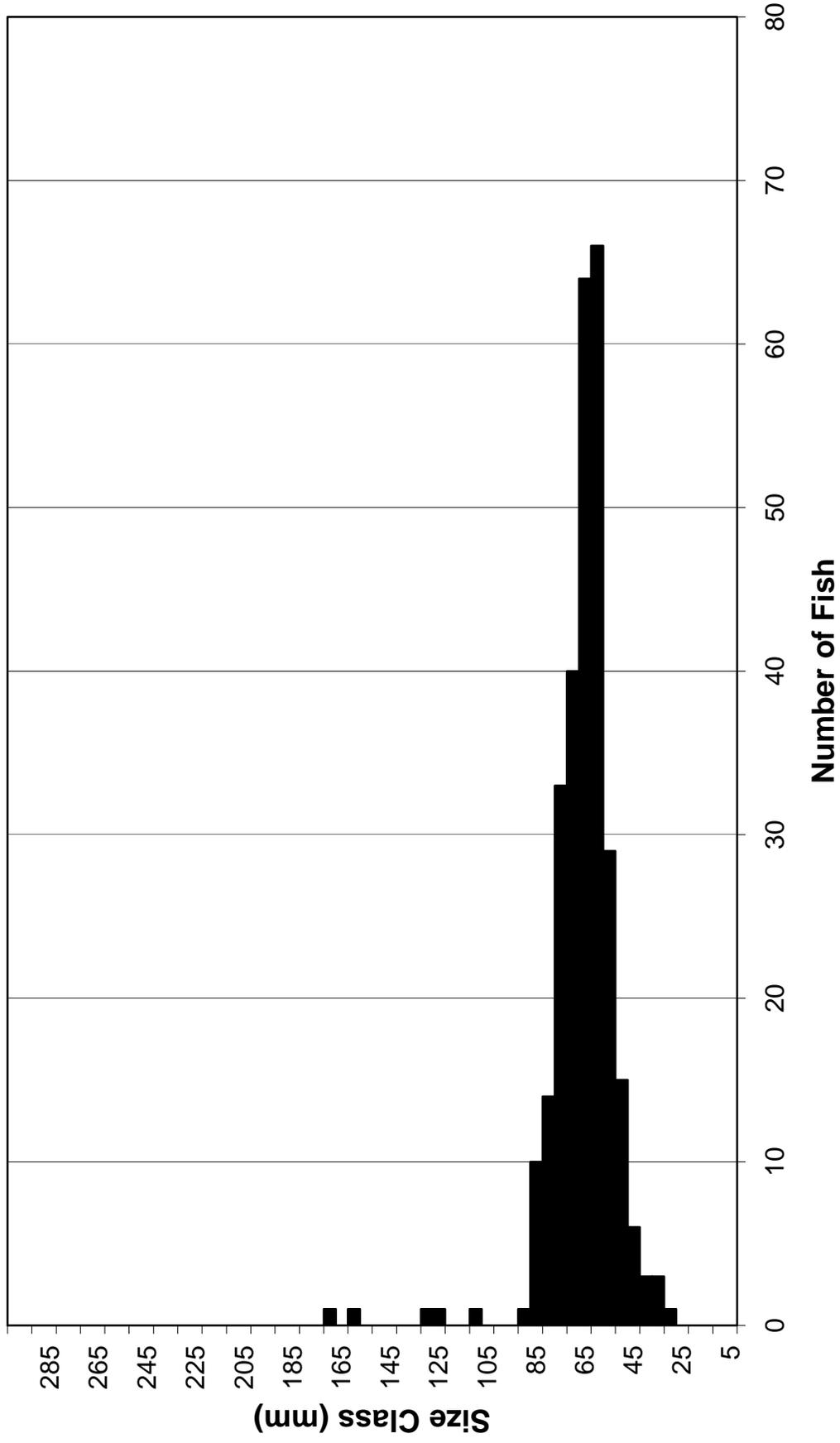


Figure A-44. Length frequency histogram for downstream migrating steelhead captured at the Upper Lagunitas Trap, May 29-June 8, 2006.

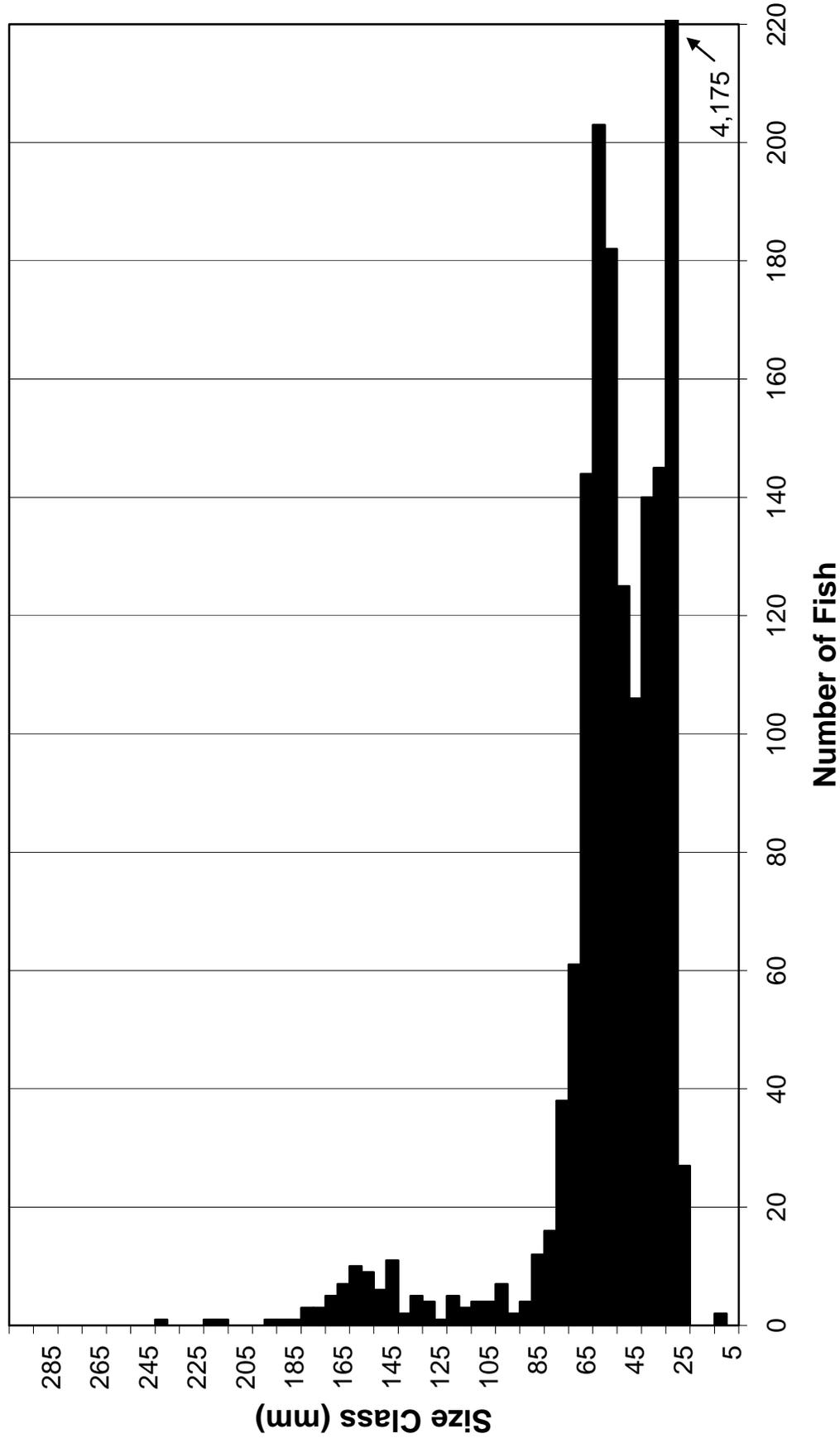


Figure A-45. Length frequency histogram for downstream migrating steelhead captured at the Upper Lagunitas Trap for all weeks, March 20-June 8, 2006.

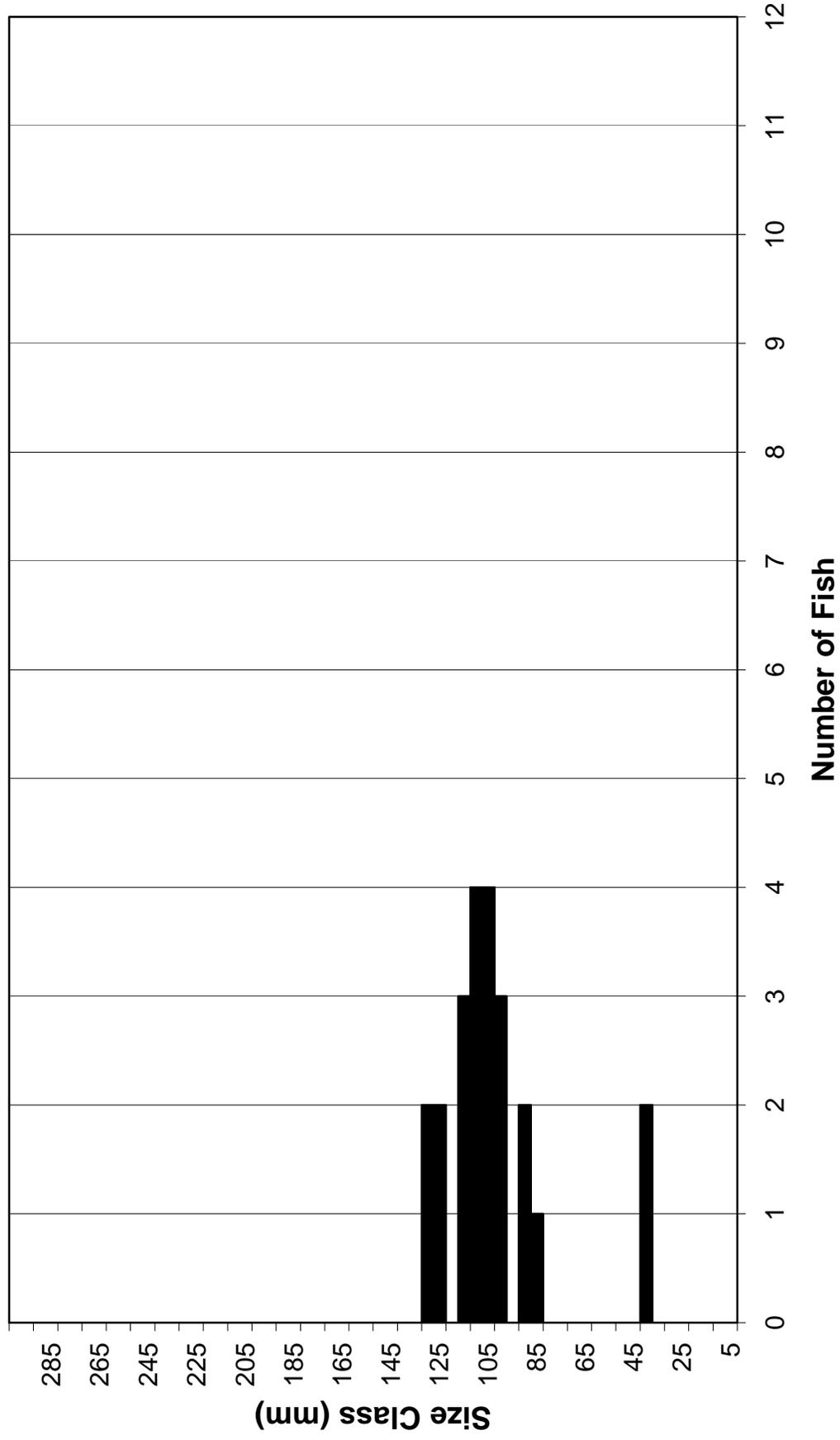


Figure A-46. Length frequency histogram for downstream migrating coho salmon captured at the Lower Lagunitas Trap, March 20-April 2, 2006.

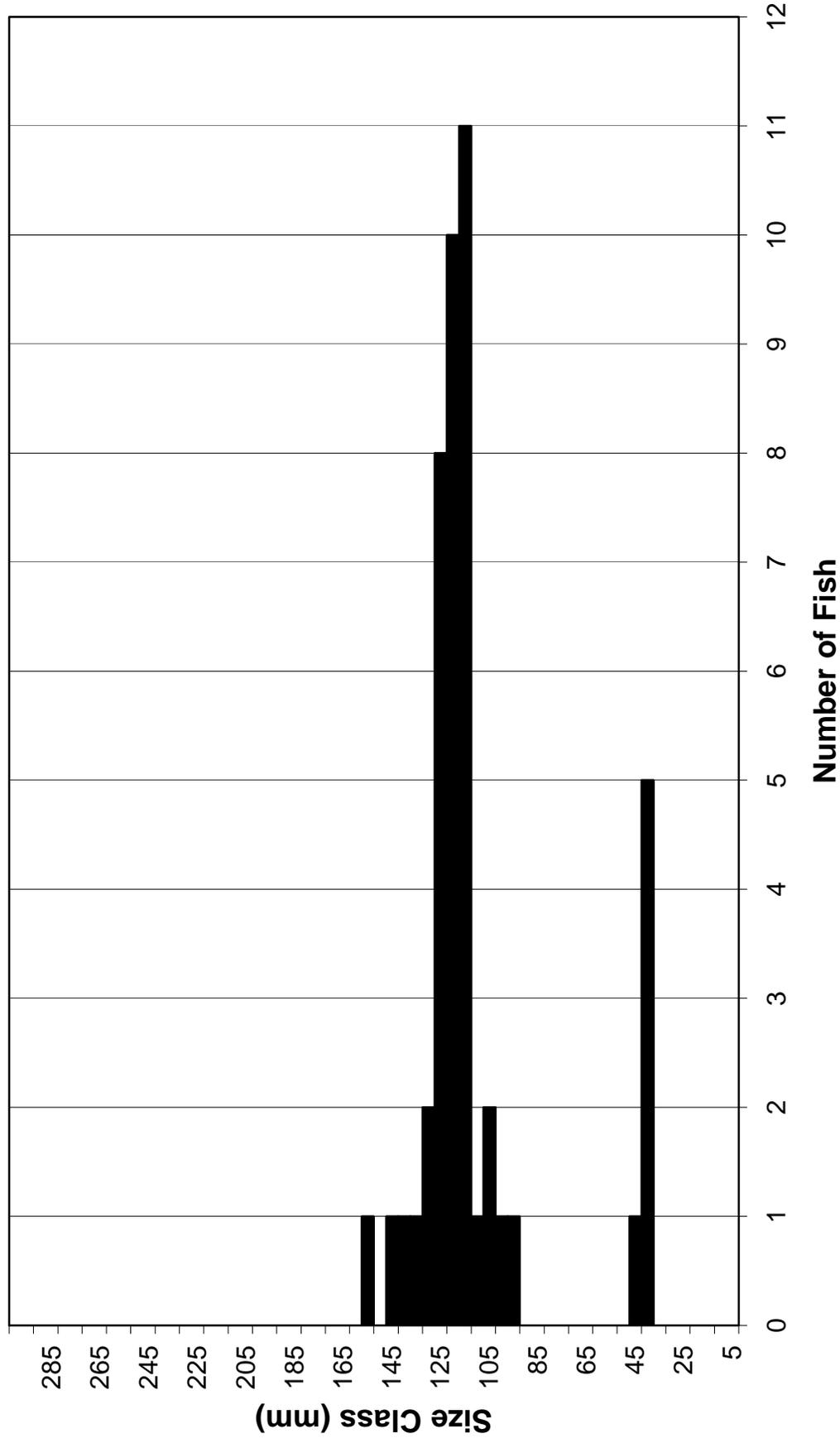


Figure A-47. Length frequency histogram for downstream migrating coho salmon captured at the Lower Lagunitas Trap, April 3-April 16, 2006.

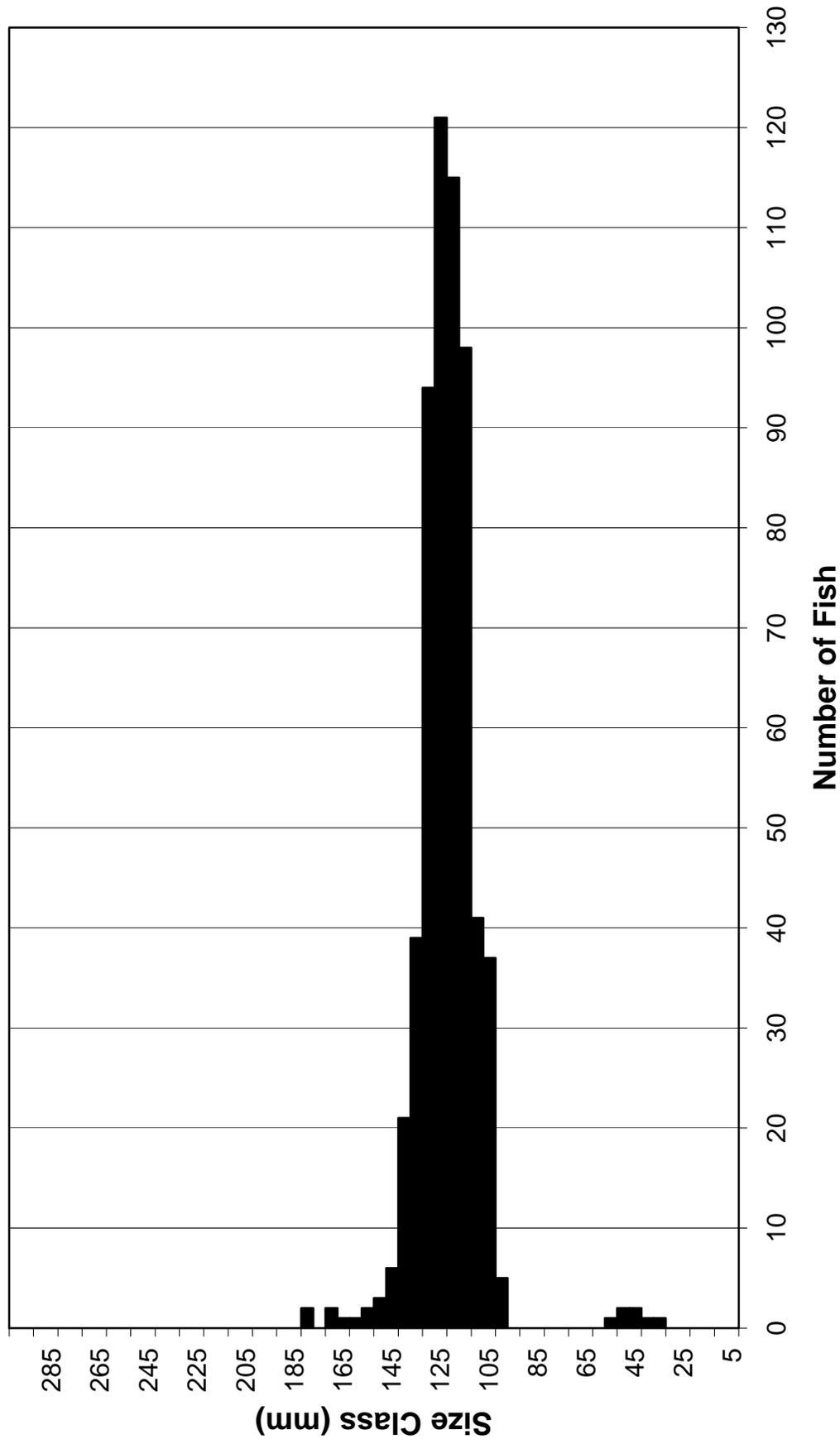


Figure A-48. Length frequency histogram for downstream migrating coho salmon captured at the Lower Lagunitas Trap, April 17-April 30, 2006.

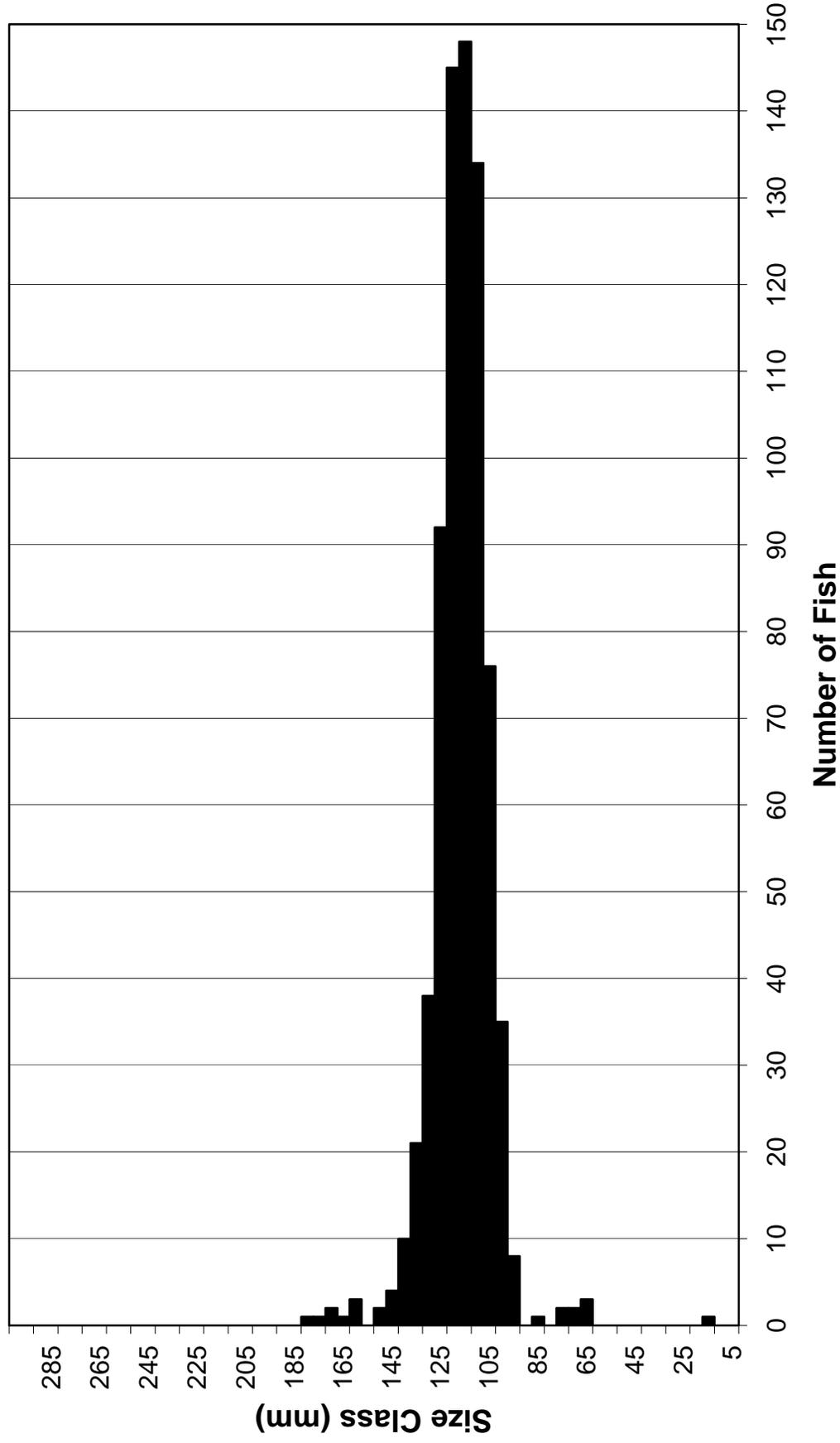


Figure A-49. Length frequency histogram for downstream migrating coho salmon captured at the Lower Lagunitas Trap, May 1-May 14, 2006.

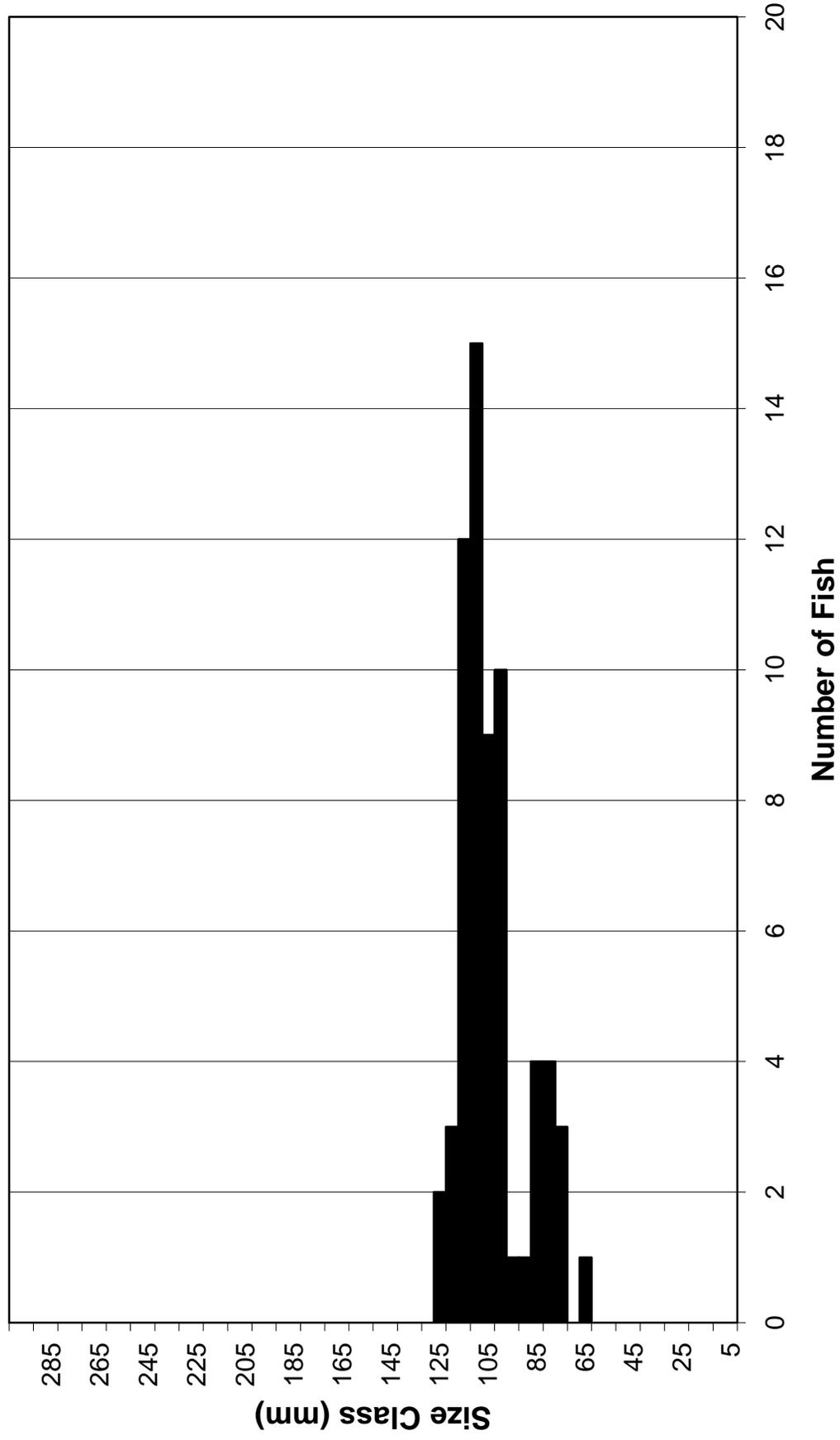


Figure A-50. Length frequency histogram for downstream migrating coho salmon captured at the Lower Lagunitas Trap, May 15-May 28, 2006.

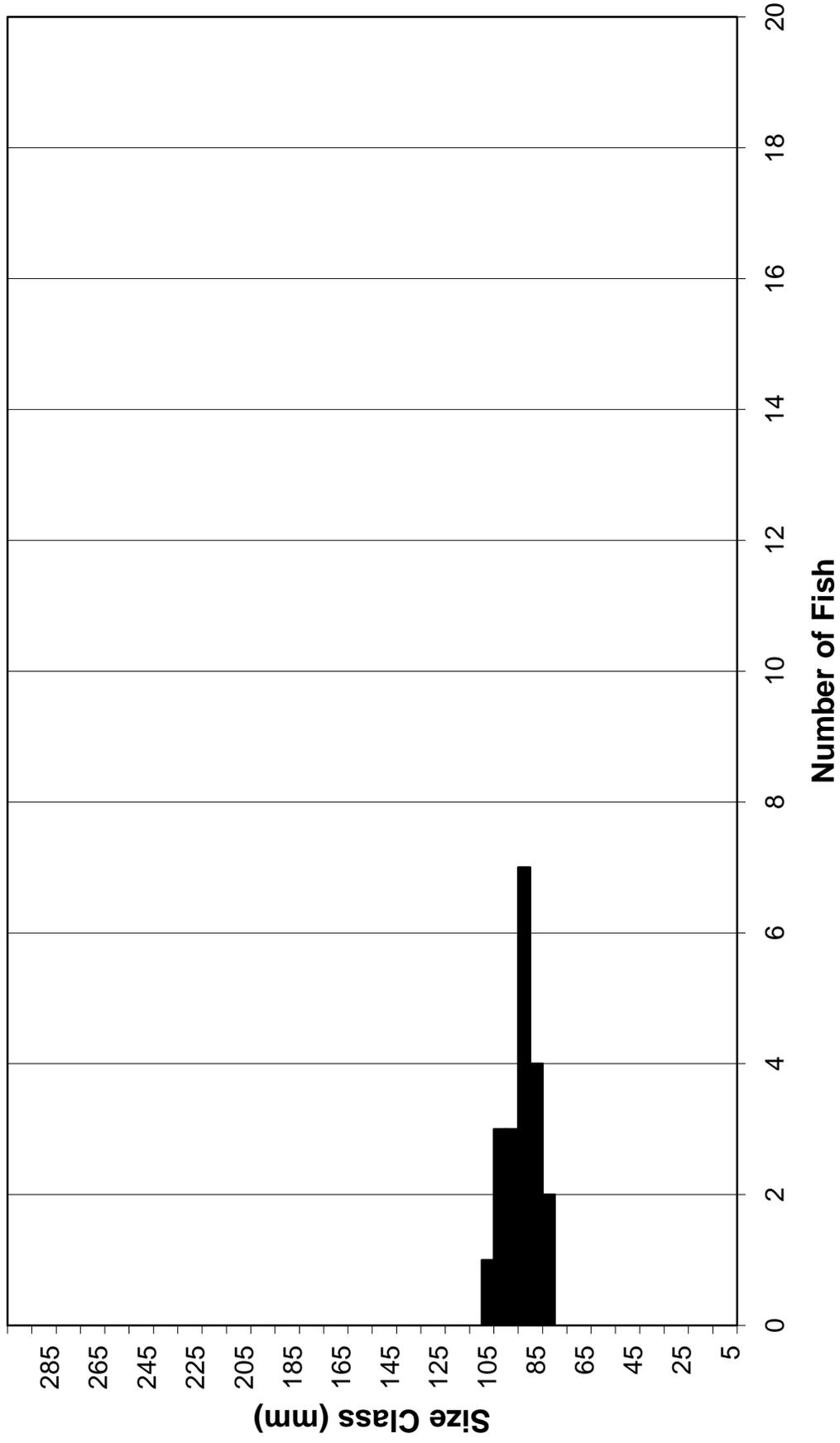


Figure A-51. Length frequency histogram for downstream migrating coho salmon captured at the Lower Lagunitas Trap, May 29-June 8, 2006.

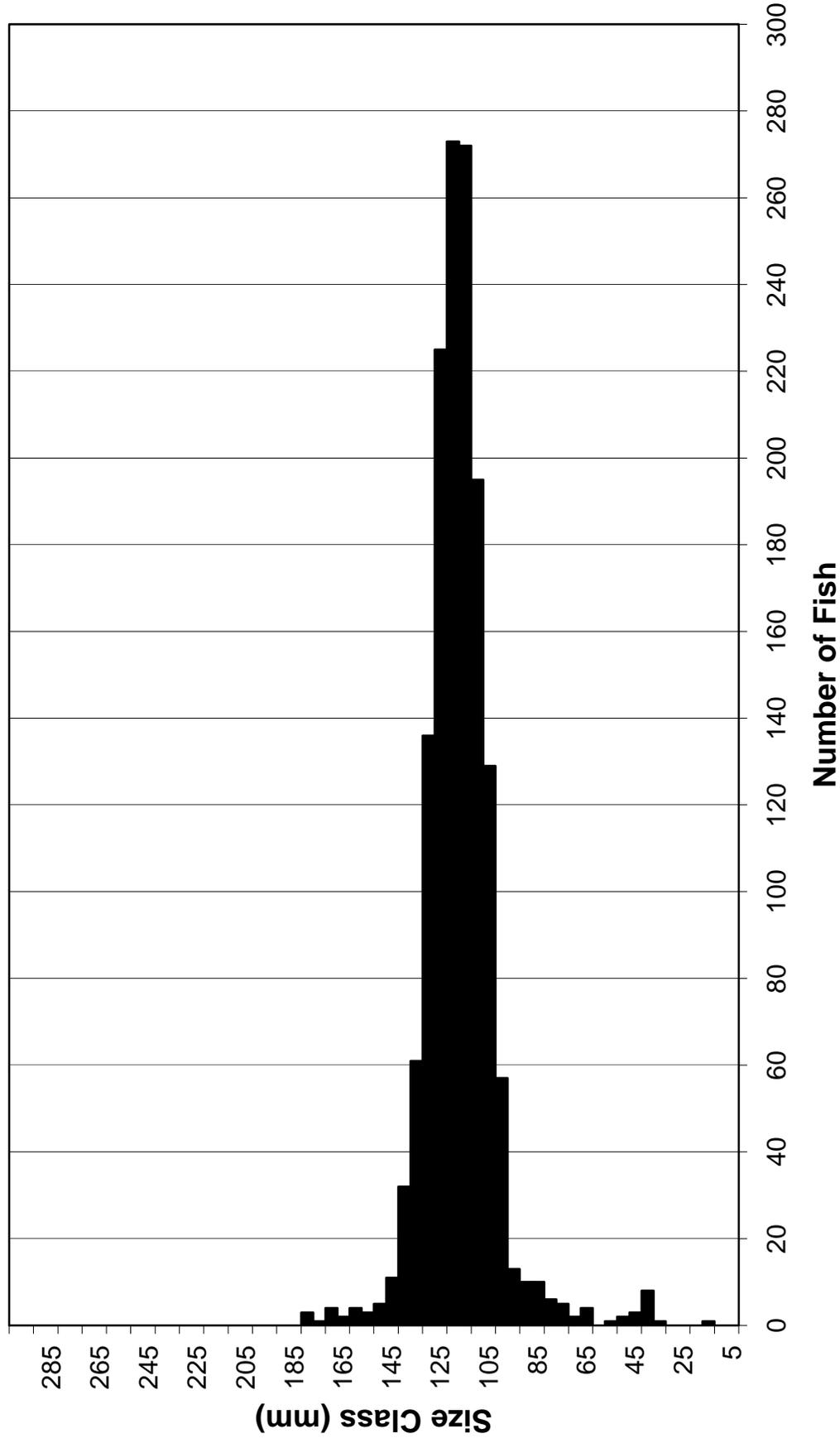


Figure A-52. Length frequency histogram for downstream migrating coho salmon captured at the Lower Lagunitas Trap for all weeks, March 20-June 8, 2006.

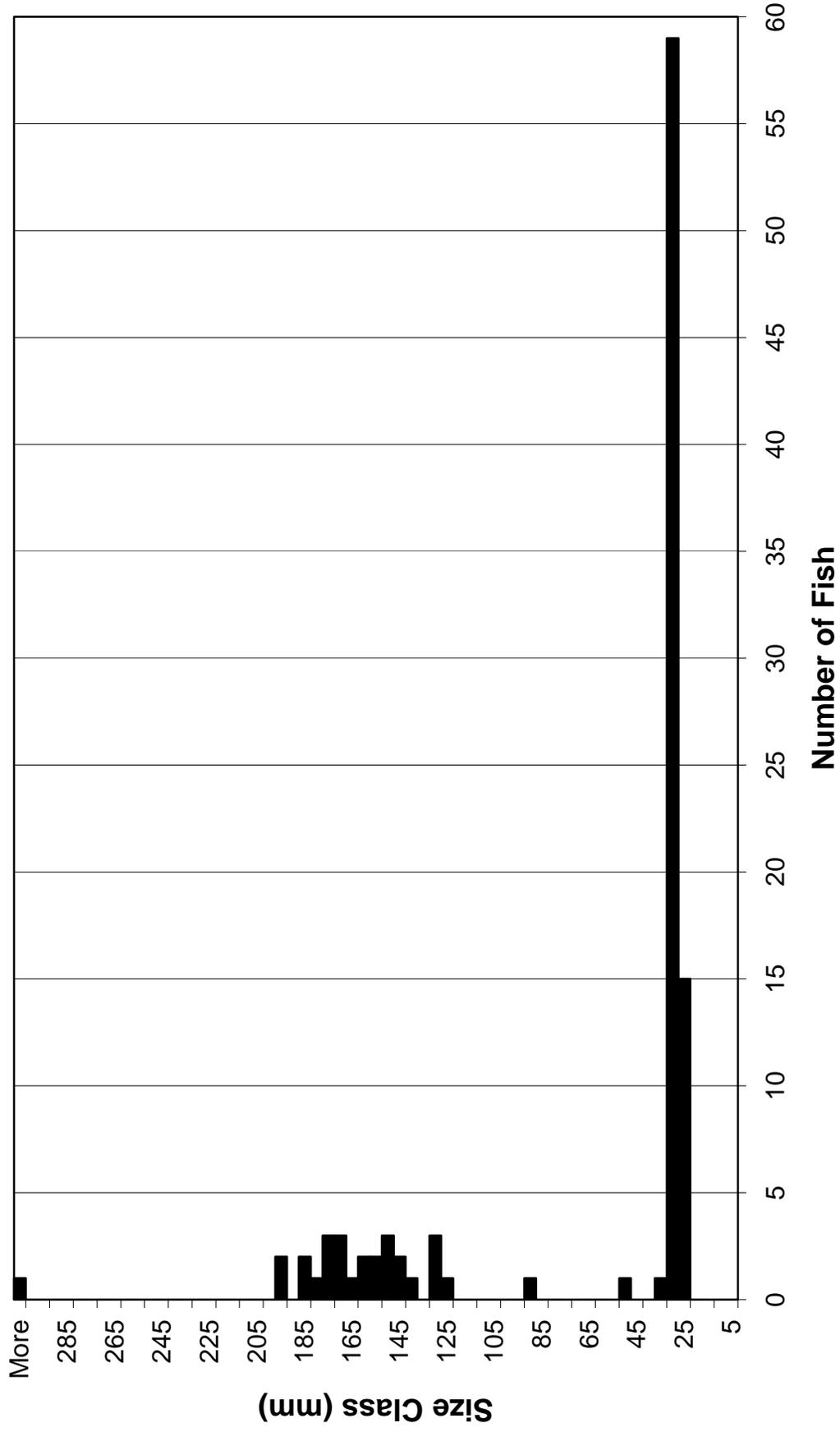


Figure A-53. Length frequency histogram for downstream migrating steelhead captured at the Lower Lagunitas Trap, March 20-April 2, 2006.

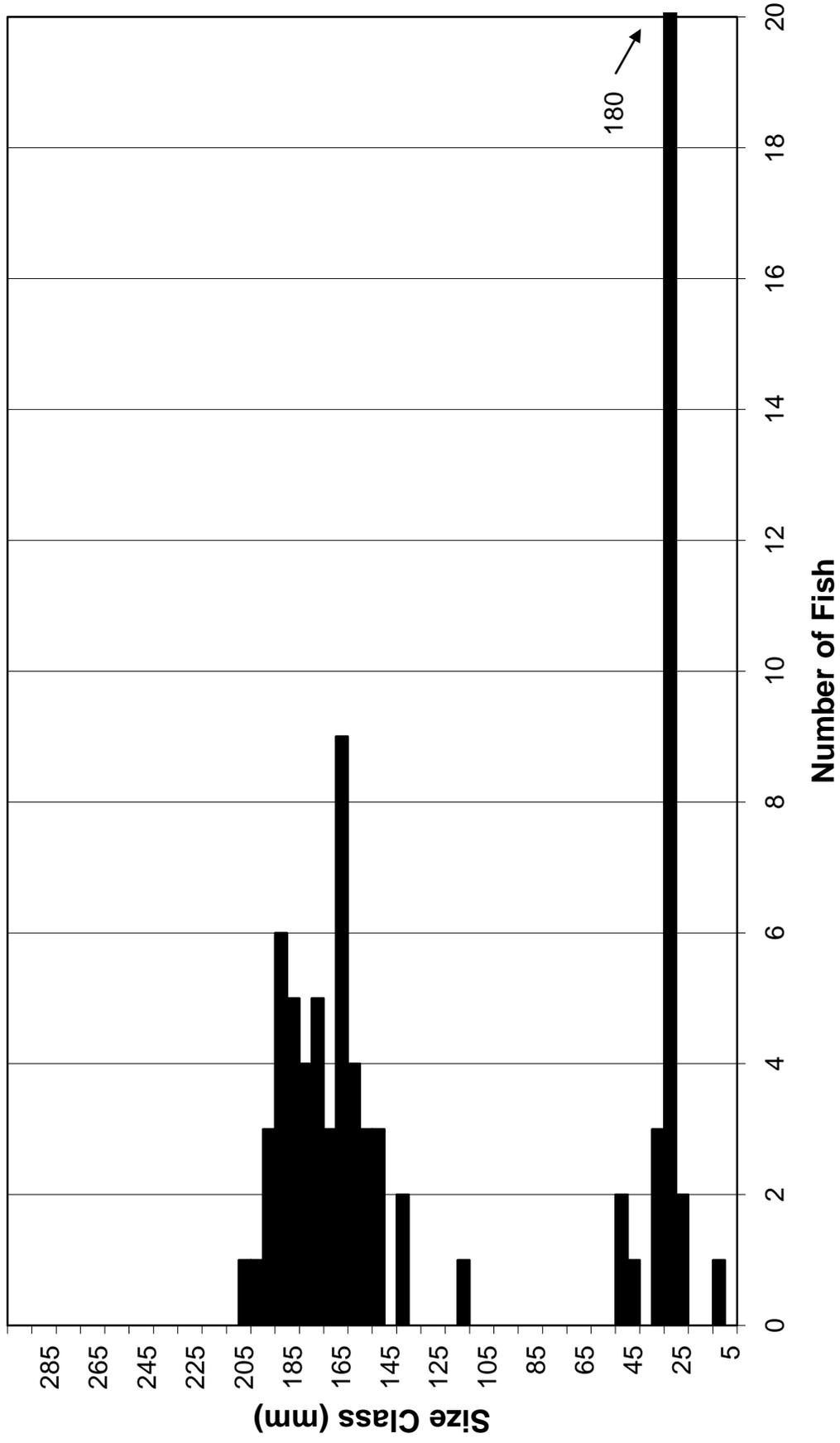


Figure A-54. Length frequency histogram for downstream migrating steelhead captured at the Lower Lagunitas Trap, April 3-April 16, 2006.

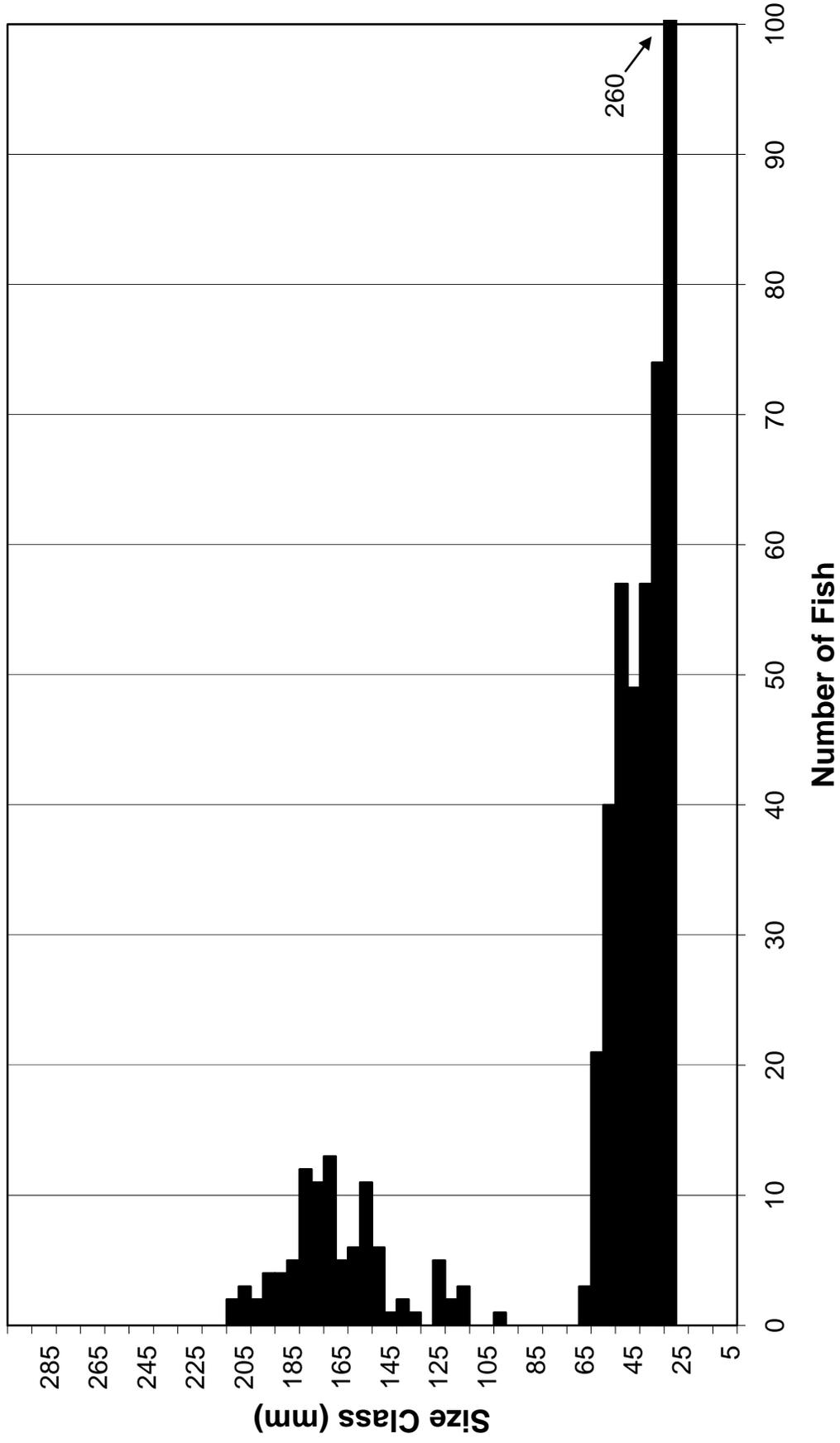


Figure A-55. Length frequency histogram for downstream migrating steelhead captured at the Lower Lagunitas Trap, April 17-April 30, 2006.

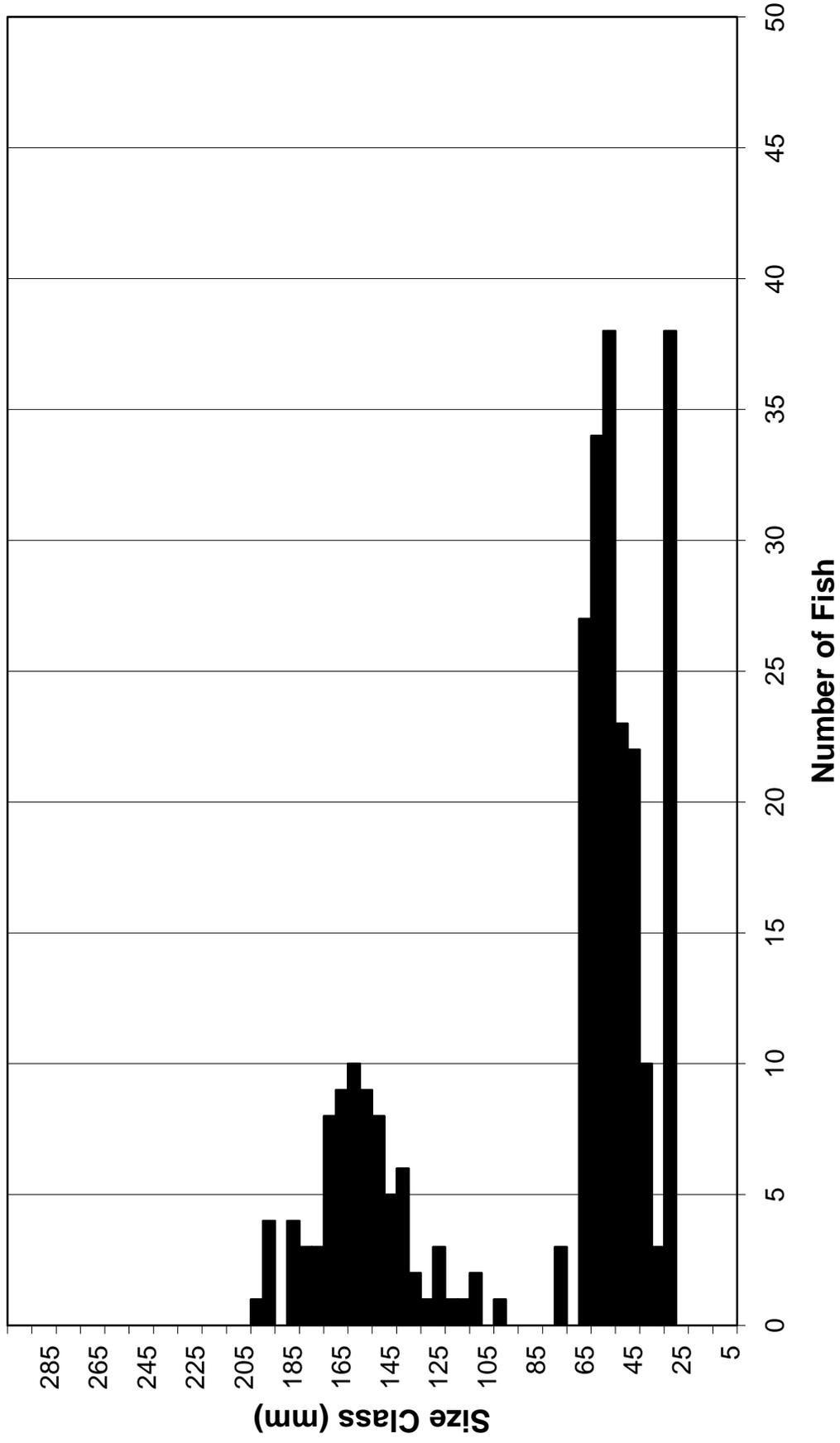


Figure A-56. Length frequency histogram for downstream migrating steelhead captured at the Lower Lagunitas Trap, May 1-May 14, 2006.

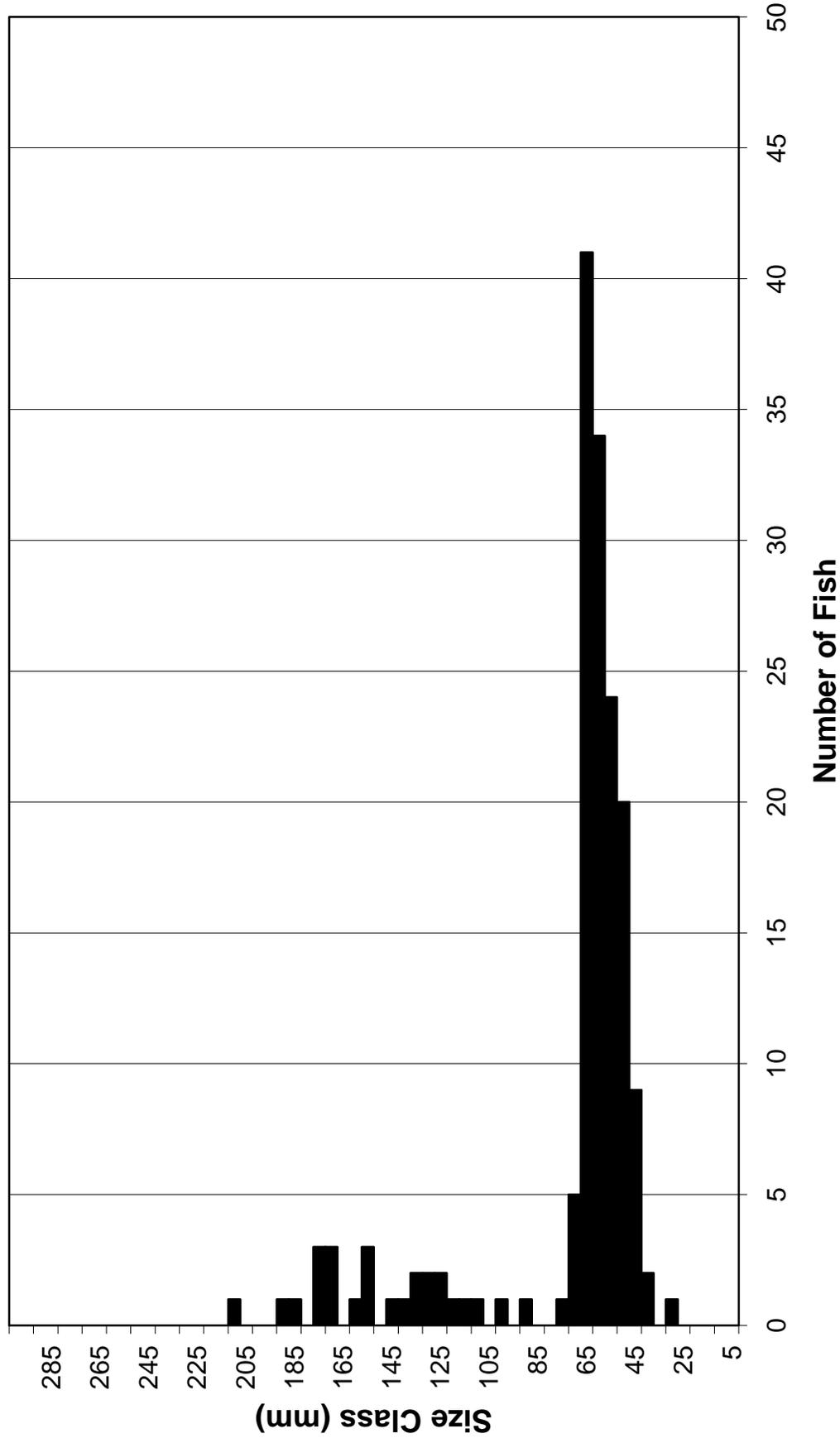


Figure A-57. Length frequency histogram for downstream migrating steelhead captured at the Lower Lagunitas Trap, May 15-May 28, 2006.

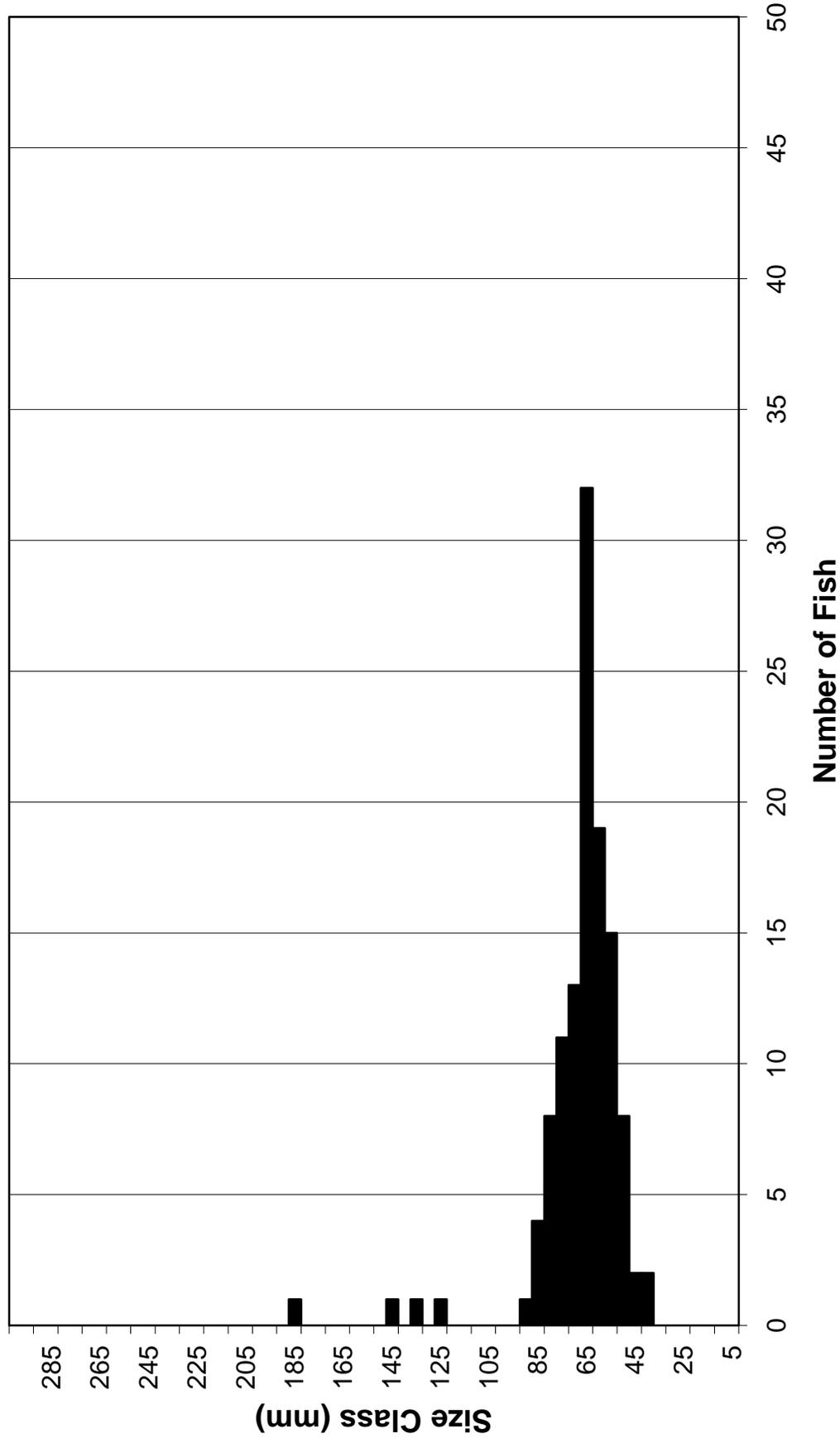


Figure A-58. Length frequency histogram for downstream migrating steelhead captured at the Lower Lagunitas Trap, May 29-June 8, 2006.

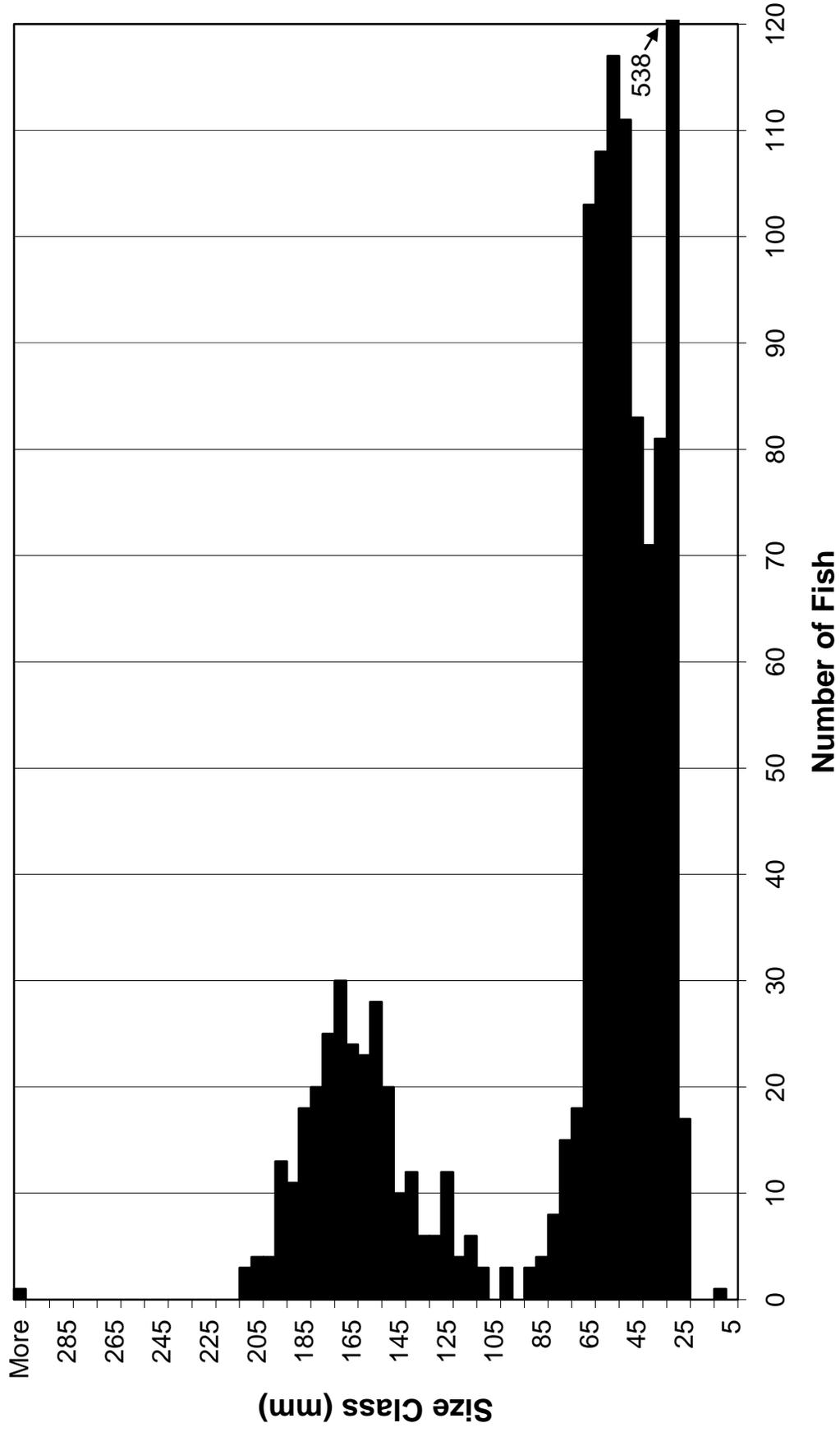


Figure A-59. Length frequency histogram for downstream migrating steelhead captured at the Lower Lagunitas Trap for all weeks, March 20-June 8, 2006.

Appendix B

Report Comments and Responses

Lagunitas Limiting Factors Analysis Draft Report
Comments by Leslie Ferguson, Dale Hopkins and Mike Napolitano (attached)
May 15, 2007

The draft “Lagunitas Limiting Factors Analysis” report provides extremely valuable data and insights into potential mechanisms affecting salmonid population dynamics. This LFA is an excellent Phase I and Phase II analysis that frames the important coho and steelhead population dynamic questions, identifies future research needs, and suggests important restoration activities in the watershed. We are very appreciative of the diligence and commitment to excellence that Stillwater staff have brought to this project. The high quality of the data produced and analyses reflect this effort.

Our comments below focus on the areas of the report that we believe would be improved by either additional presentation of the data, or modification of the conclusions. Several RWQCB staff reviewed this document. In an effort to respond with comments as quickly as possible, we are including two sets of comments, one from Dale Hopkins and Leslie Ferguson, and one from Mike Napolitano specifically addressing the redd scour study.

General Comments:

Report Conclusions

- We think that the overall analysis could benefit from a discussion as to why you are expecting to find one major factor (“smoking gun”), rather than a number of factors that may vary in different year types, but result in an overall population limit.

In our analysis, we did not necessarily expect to find one factor, or “smoking gun”, limiting the populations of interest. Our objective was to integrate the effects of mortality across all freshwater life stages to determine the factor or factors most likely controlling population dynamics of the study species. For the coho salmon, we concluded that there are probably multiple chronic constraints to smolt production (high spring flows and winter habitat availability), the influence of which will vary annually according to seasonal patterns of high flow events. In the report we used the term “smoking gun” strictly in relation to the early life stage investigations because the existing information suggested that if mortality due to redd scour or redd entombment controlled population dynamics, investigations into these factors should produce unequivocal results.

SWS:

- We support many of the conclusions presented in the report that are based on the excellent data that was gathered as part of this study. However, as they are currently presented, we think that some of the conclusions are stated too strongly for the available data and the analyses performed. We think the analyses would be improved by placing the conclusions within the context of their spatial (Lagunitas, San Geronimo, Devils Gulch, Olema, tribes) and temporal variability. The Lagunitas watershed and stream system is very dynamic and subject to major interannual and occasionally large episodic fluctuations. As you know, 2005/2005 was a relatively moderate winter compared to 2005/2006, and the spring flows also varied. Overall, the report does not highlight clearly enough that the different studies were done in very different types of water year.

In the final draft, we attempt to make more clear how hydrologic conditions during our focused studies relate to conditions in other years.

SWS:

- There are instances where the report rules out or includes hypotheses that are not well supported by the analysis of existing data (data that was not collected for this study). This includes the conclusion that summer temperatures do not appear to affect fall coho abundance, and the evaluation of MMWDs coho/steelhead population values. We discuss these instances in detail below.

The possibility of summer temperature limitations and the precision of MMWD population estimates are discussed in detail below.

SWS:

- It would be useful to include a separate recommendations section for future recommended studies. It is difficult to tease out the recommended restoration actions verses the recommended studies.

Data Presentation:

- The appendices need to include most of data that was collected for these studies in table format. Tables should include the data set and data summaries. Currently, most of the data is presented in graphical form. The Marin RCD and RWQCB will also need copies of the data files. For the smolt trapping data, this data should include all species trapped, not just salmonids.

We will provide the data sets requested in electronic form and we suggest making such appendices available in electronic form on request from Marin RCD.

Specific Comments:

I. Evaluating the causal mechanism for low fall abundance of coho during 1998, 1999 and 2000:

1. **Redd scour:** we concur that the study data indicate that during the winter 2004-05, there is no evidence of redd scour that would lead to low fall population numbers. The presentation of the representativeness of the data for this year is well-constructed and convincing. However, we think the conclusion should be modified to discuss streambed variability as noted in Mike Napolitano's redd scour comment # 5 (attached). Additionally, p. 23 states that the magnitude and data of winter flows during the redd scour study were similar to the years 1999 and 2000. A more thorough presentation of these data including hydrographs and spilling of Kent Lake should be included to back up these conclusions.

The suggestions will be incorporated in the final report.

2. **Redd entombment, infiltration and scour:** Page 22 states that these factors were not the "smoking gun" causing expected mortality resulting in low juvenile coho abundance. However, the mean 15% minimum survival (Table 2-2) is considerably lower than the 59% predicted by Kelley and Dettman. Further, we believe a discussion is needed of

how these survival rates in general affect coho population dynamics. Please include references to the literature or data that you have developed in other studies. It is our impression that in dealing with an endangered species with low population levels, decreased survival at any critical life stage is significant (see Mike N. comment #10). In planning future management strategies, it is important to avoid serial bottlenecks. We do not want to eliminate the current “smoking gun” only to have it become the crucial factor in the future.

As stated in the report, we were only able to estimate minimum survival rates for emergence and these rates should not be compared to survival-to-emergence estimates from other studies. As discussed in detail within the report, survival-to-emergence does not appear to affect coho population dynamics in the Lagunitas watershed except perhaps in extreme high flow years (e.g., flows occurring on decadal time scales). An example of how even low survival to emergence is sufficient to fully seed available summer rearing habitat is provided on pages 28 – 29.

- 3. Entrainment of newly emerged fry (April high flows):** The concluding remarks on this hypothesis are confusing: on page 26 it is stated that “**we found no evidence for a decline related to spring flows**” based on data collected in April 2005. However, in the final conclusions on page 54, the report states that the “**existing data suggests that entrainment of fry during spring freshets may explain low juvenile abundance in some years**”. It is not clear what this second conclusion refers to compared to the first, and we suggest this should be further clarified. In our analysis, the 2005 data appear equivocal because there are both relatively high fall numbers in the Tocaloma reaches as well as the upper reaches of Lagunitas. If there had been entrainment in the upper reaches of Lagunitas, then you would expect lower fall numbers in this reach. Ettlenger and Andrew’s¹ have indicated that while numbers in fall of 2005 were relatively high, they were actually lower than expected given the large number of redds in 2004-05. However, it is also true that the majority of the additional redds were found in San Geronimo and Devils Gulch, not in Lagunitas where the spring snorkeling occurred. It may be the case that newly emerged fry were displaced from San Geronimo to Lagunitas.

The statements on page 26 and 54 are apparently contradictory and will be reconciled in the final draft. What was meant was that, despite evidence from 2005 to the contrary, data from the majority of years suggests a pattern between spring freshets and late fall juvenile abundance.

- 4.** In the analysis of the spring snorkeling data, you indicate that there is an apparent longitudinal trend in abundance (Figures 2.3-11 and 2.3-12). However, the observed trend comparing spring snorkeling to historical fall juvenile numbers may not be accurate due to errors introduced by comparing spring to fall sampling times (fish relocate) and significant habitat changes between years in the units measured that may explain the observed decreases between the study spring data and historical data (e.g., large woody debris jam formed in Unit 12 in 2003 and MMWD removal of jam prior to 2004).

The concerns regarding comparison of spring and fall sampling are valid. We conducted the spring sampling to determine if the overall abundance of juvenile coho was low, not necessarily to look at habitat unit-specific abundance. However, after conducting the surveys we noticed that overall abundance was low, except in the case of the lowermost two habitat units surveyed. The results for the spring snorkeling were very similar to the subsequent fall sampling conducted by

¹ Eric Ettlenger and Greg Andrews’ April 2007 comments on the Draft LFA report

MMWD. Results for both spring and fall surveys would have been consistent with the hypothesis that spring flows reduce juvenile coho abundance were it not for higher than average abundance at two of the units sampled. We were not able to perform a formal analysis of the influence of particular habitat units on the overall population estimate. If additional funding became available, such an analysis could be conducted.

Ettlinger and Andrews² present a model that correlates coho population to San Geronimo redd numbers, moderate winter flows and relatively high spring flows. This suggests that there may be a complicated relationship between fall juvenile numbers, redd numbers and location, moderate winter flows and high spring flows, and provides a compelling reason to continue to study this issue. We concur with your conclusions on page 54 related to continued study of the Tocaloma reach, but also feel that additional studies throughout the watershed are necessary.

We agree that the relationship between stream flow, particularly spring flows, and juvenile abundance warrants more research.

- 5. Variability in Existing Summer population data sets:** We think it is appropriate for Stillwater to use the existing data collected by MMWD. However, we think there are several potential sources of error that have not been evaluated and therefore, the report should not make the general conclusion that the fall abundance data accurately represents year to year variability (pg 9). However, while we are not certain that the data can accurately detect some of the smaller population changes observed in many years, as discussed below, we do concur that the data are accurate enough to detect the large decline in abundance observed in 1998-2000. In your report (pg 9), we think your general conclusion regarding the accuracy of the data should be modified to refer only to this time period (1998-2000) of large population differences. Further evaluation of coho habitat use variability in the Tocaloma reach, index unit variability over time, and habitat typing variability is necessary before making broad conclusions about the accuracy of the data.

A full evaluation of existing monitoring protocols used by the various local agencies was not possible in this analysis given the available funding. However, because of the importance of these data for the LFA, for the final draft we have completed an analysis of error associated with MMWD's annual juvenile coho salmon population estimate at our own cost.

Some of our concerns related to the population data are the following:

- **Variability in coho densities in the Tocaloma reach that may not necessarily follow the same trends as SP Taylor State Park mainstem reaches of Lagunitas Creek :** The habitat in the Tocaloma reach is significantly different than the Lagunitas mainstem habitat in the State Park. MMWD population numbers are calculated by averaging electrofishing results including both State Park reach and Tocaloma units, and then the average numbers are multiplied by linear feet of habitat. For example, an average pool density is calculated by electrofishing pools in both reaches and then pooling all of this data to create one average density. Habitat typing surveys categorize and measure pool lengths in both reaches. The total combined pool length is then multiplied times the average pool coho density. Because there is very little similarity between what is considered a pool in the Tocaloma reach and the upper Lagunitas, we hypothesize that

² Eric Ettlinger and Greg Andrews' April 2007 comments on the Draft LFA report

there is a significant potential for differences in coho habitat use. Additionally this habitat may be used differently in different years depending on winter/spring flows. Therefore, this method of calculating population numbers may introduce variability into the population estimates that is an artifact of the calculation method.

Whether or not habitat and fish use differences exist between Tocaloma and other reaches of Lagunitas Creek, because the Tocaloma reach comprises a relatively small percentage of available rearing habitat, errors associated with applying average coho densities to this reach are not likely to significantly affect the overall coho population numbers reported by MMWD. As mentioned in previous correspondence with SWRQCB, a sensitivity analysis could be conducted to quantify the influence of data collected from the Tocaloma reach on the precision of the Lagunitas coho estimate if funding was available.

However, despite this potential, we believe the trend of lower coho numbers in 1998-2000 is real because the estimates would need to be inaccurate by 10,000 – 14,000 coho, and we would hypothesize that Tocaloma would not hold that many fish. Therefore the population estimate is most likely not inaccurate by this amount. In your report, we think your general conclusion regarding the accuracy of the data should be modified to refer only to this time period (1998-2000) of large population differences. Further evaluation of the variability in the Tocoloma reach is necessary before making broad conclusions about the accuracy of the data.

Partly in response to these concerns, we have calculated confidence intervals for MMWD coho population estimates to determine their precision. As is apparent in the revised figures within the report, the precision is sufficient to differentiate the years of large population differences. We make no claims as to the accuracy of MMWD's data, only that there appears to be no reason why the quality of summer abundance data would vary from year to year since consistent field personnel, sampling methods, and analysis techniques have been used.

- **Index unit changes over time:** There have been significant changes in both the location and quality of the index units over time. These changes have included natural and man-made addition of large woody debris jams in two units (of seven), significant shallowing of one complex unit resulting in lower quality habitat, changes of index locations of both lower Tocaloma sites to more representative units, and a change from electrofishing to snorkeling in one Tocaloma site. We are unclear if these changes are significant enough to lead to inconsistent results; however, we believe they should be thoroughly evaluated.

If additional funding were available, an analysis could be conducted to determine the influence of individual sample sites on the overall coho population estimates.

- **Discrepancies in habitat typing data:** there is unexplained variability in the habitat typing data between surveys that is most likely explained by variability in the interpretation of habitat units by field surveyors, rather than variability in the units themselves. Several different consulting companies have done the habitat typing over the years.

If additional funding were available, an analysis could be conducted to determine the influence of changes in habitat composition (e.g., the change in relative abundance of pool, riffle, run habitat types) on the overall coho population estimates.

5. High density-independent mortality during summer:

Pg. 9 indicates that this is not a likely hypothesis because a) evidence of high temperatures limitations is lacking and b) there is no correlation between summer stream flow and density (pg 10). We agree that you have presented sufficient data to suggest that there is no correlation between summer flow and juvenile numbers, but do not think that the temperature issue was adequately addressed. You indicated that SWRCB Order requires a temperature of 14.4 ° c temperature in Lagunitas. While this is correct, there have been significant, and during some years, relatively long duration exceedances of this temperature. MMWD has this data and provides it yearly to the SWRCB. Additionally, this temperature requirement does not affect temperatures in Devils Gulch, Olema or San Geronimo. The KRIS database contains data from the SWAMP program (not yet formally released by the RWQCB) indicating that temperature monitoring sites in San Geronimo, Lagunitas, and Olema exceed an MWAT of 14.8 degrees C. We have not had time to review the data to determine the representativeness of the monitoring locations, but we think the data is sufficient to merit further investigation. Therefore, we would hypothesize that temperatures in those tributaries, and possibly in reaches in Lagunitas, exceed stress thresholds for coho during hot summer days potentially leading to migration or decreased growth. As noted in x below, the coho in San Geronimo, Devils Gulch and Olema are smaller than their juvenile counterparts in Lagunitas. One reason for this may be temperature related growth patterns. Additionally, when you examine the fall pool density patterns in Lagunitas, San Geronimo and Devils Gulch, it appears that the highest variability is found in San Geronimo and Devils Gulch. Therefore, we think that rather than eliminating this hypothesis as has been done on page 9, it should be noted that the reason it wasn't pursued was because it wasn't the highest priority hypothesis to explore as redd scour/entombment and spring entrainment appeared to more likely. Additionally, since we have not yet determined the cause of the low summer juvenile abundances in some years, it would seem prudent to continue to consider potential hypotheses until they have been sufficiently explored.

Juvenile coho are smaller in San Geronimo and Devil's Gulch than in the main stem Lagunitas Creek, which may be a reflection of differences in water temperatures between the streams. No temperature data were available to us during the analysis, so we relied on an alternative indicator of summer habitat availability and quality, stream discharge. The available evidence suggests that there is not likely to be high density-independent mortality over the course of the summer. The fact that juvenile coho densities tend to be higher in San Geronimo and Devil's Gulch than in Lagunitas Creek might indicate that temperature is not a problem in these tributary streams. However, because land use activities can quickly alter stream temperatures, we believe that temperature monitoring should be a component to management of coho in the Lagunitas watershed. Once temperature data are formally released, if additional funding became available, we could re-examine the annual trends of juvenile coho abundance with respect to temperature.

II Juvenile Coho Overwintering Habitat

1. On page 53 it is concluded that "winter habitat currently constrains coho population growth during most years within the last decade." Please be more specific how you came to this conclusion. We do agree that the winter 2005-06 demonstrates that during a year of very high flows, Devil's Gulch and Lagunitas Creek mainstem do not provide good overwintering habitat or smolt production. However, we do not think this data can be extrapolated to "during most years" without further study, due to the extremely high flows. Therefore, we recommend that wherever this conclusion is stated, that it be qualified and put in context. We also agree that during these high flow years, some

currently unidentified attributes of San Geronimo Creek and its tributaries are important for overwinter survival and smolt production. It would be useful to have further recommended studies to determine what attributes of San Geronimo and the tributaries may be contributing to the over- winter survival. We concur with the recommended restoration measures, which are prudent even in the absence of definitive data.

The conclusion on page 53 is based on both the Devil's Gulch field study and our analysis of existing data, which shows a large discrepancy between juvenile abundance and smolt production in the majority of years. Together, these lines of evidence strongly indicate that winter habitat limits the coho population. This will be clarified in the final report.

2. We concur with Ettliger and Andrew's presentation that the available evidence does not suggest that smolt production is limited to 6000 to 7000 fish. We think the conclusions should be modified appropriately. They indicate that the smolt data from the 1980s should not be included because the trapping did not occur during some very high flow events. Additionally, we think this data should not be included because we do not think it is representative of current creek conditions. At the time of the 1980 (Bratovich and Kelley) studies, the summer flows in Lagunitas did not include the mandatory release from Peters Dam. At this time, it was hypothesized that summer carrying capacity may be a limit due to this. Additionally, the dam height had not been raised. It is unclear how the raising of the dam affects winter survival, but most likely it affects it differently in years when the dam spills versus years when it doesn't. Prior to raising the dam, spilling was much more frequent. We also concur with Ettliger and Andrews that the values of smolt/juv survival that exceed one should not be graphed at values greater than 1.

We would like to clarify that estimate that the 6 to 7K fish is an approximation of maximum smolt production under "average expected conditions", but that we expect smolt production to vary somewhat from year to year in relation to winter severity. Despite potential criticisms of the data from Bratovich and Kelley their results are relevant to our analysis. First, Peters Dam was raised in 1982 prior to the study of Bratovich and Kelley. Second, the analysis addresses survival over the winter period and can be treated somewhat independently of summer flow conditions before the mandatory instream flow releases. As addressed in our comments to Ettliger and Andrews, in the few years where smolt:juvenile ratio is greater than 1, smolt production is only slightly higher, well within the error associated with their population estimates, and adjusting the values does not affect our interpretation of the pattern (in fact it improves the fit of a Beverton-Holt curve).

3. We are interested in your thoughts about how the Tocoloma reach is being used for overwintering habitat, and what might contribute to your hypothesized carrying capacity limit. There appears to be a large expanse of off-channel floodplain area that could be accessed during high flow events. Stranding could be an issue here, but we are unclear about high flow habitat limitations. However, we would hypothesize that during non-high flow winter conditions, when the majority of the coho are located within the channel that habitat availability could be limiting in the channel. To our knowledge, this has not been demonstrated. In fact, somewhat conversely, the coho and steelhead in this reach are larger than smolts from other reaches. We think the report would benefit from some answers or hypotheses to the following questions:
 - You have suggested (pg 37) that the larger sizes of coho and steelhead in this reach (as compared to Devils Gulch and San Geronimo) indicates greater "growth opportunities" in this reach? It doesn't appear that the off- channel

habitat is flooded for very long and therefore they are not feeding for long periods on the floodplain. The ratio of riffles/pools is lower in this reach than in other reaches suggesting that invertebrates from this source are not as prevalent in other reaches. Willows are much more prevalent and insect drop could be significant. Can you hypothesize what factors are contributing to the greater growth opportunities in this reach and how you might assess these?

- What are the possible implications for the watershed of these different size trends? Is it more likely that the smolts overwintering in Tocoloma smolts are surviving and returning than San Geronimo smolts? If so, is this something we should evaluate and what studies might we conduct to accomplish this?

Discussion related to these important points is included in the final draft.

STEELHEAD

III. Steelhead Overwintering Habitat

1. We think that the Bratovich and Kelley data is useful for developing hypothesis, but should not be considered representative of current conditions for reasons discussed in II.2. above.
2. Our comment related to overwintering habitat limitations is the same as that for the coho: the conclusion that overwintering habitat is limiting should be modified and put into the context that the winter studied had very high flows. If you suspect that this conclusion is valid for years with other, more moderate flows, then we think this should be hypothesized and further studies recommended. As a comparison between different years of YOY steelhead survival, it was interesting to note that of the 989 steelhead pit-tagged in Devil's Gulch, 213 (21%) were 1+. Was this a representative sample? If so, this would suggest that YOY survival in 2004/05 was significantly better than the 7% survival in 2005/06.

Similar to our argument regarding winter habitat limitations to the coho populations, the conclusions regarding steelhead are based on both the results from the Devil's Gulch study as well as an analysis of the existing population information from MMWD. Given only one year of data, we would feel more confident in the results if additional years of study were possible. With regard to the last comment, the ratio of 0+ to 1+ is not representative of overall population abundance, since we sampled primarily pools, while age 0+ steelhead are known to use runs and riffles. Also, we did not tag steelhead below 60 mm, but there were many steelhead below this size.

3. We do concur that there is enough evidence to merit improving winter conditions to increase survival of YOY and 1+. To improve overwinter survival, you have recommended the adjustment of the configuration of course cobble/boulder. However, the lack of unembedded substrate is most likely due to both a lack of sufficient cobble and boulder, and due to the large amount of embedding sands and small gravel in the system. We do not think that adjusting the bed material without altering the ratio of fine sands and gravels to cobble and boulder will provide the desired unembedded conditions. Therefore, we think an accompanying recommendation should be similar to the following "measures should be taken to reduce the delivery of bed material that contribute to embeddedness (silts, sands, fine gravel)."

The maintenance of unembedded coarse substrate refuge in high sediment yielding watersheds is a subject of ongoing investigation in both laboratory and field settings. We agree that reducing fine sediment input would be beneficial. However, we also have empirical evidence that the kind of habitat we are recommending be created can persist even in watersheds with very high fine (sand and silt) and coarse (small gravel) sediment yields. In these systems, there are many areas where coarse substrate is naturally embedded, but there are also specific areas that would be used by juvenile steelhead, such as the bottoms of pools and pool tailouts, that remain unembedded.

We have observed that the past 2 winters (05/06 and 06/07) have led to the in-filling of many pools and this years storms led to an increased overall embeddedness. We are aware that your 2006 habitat typing data has concluded that there is less embeddedness in the system following the 2005 New Years Eve storm. However, after a qualitative field reconnaissance this spring, we hypothesize that the 2006/2007 storms have resulted in increased embeddedness. We will need the data from Barry Hecht's 2007 embeddedness surveys to confirm this. Further, the Phase II sediment budget from Stillwater should provide assistance in understanding how to appropriately manipulate bed conditions for improved overwintering habitat.

For the reasons described above, general embeddedness is not a good index of winter habitat quality. What matters is whether there are unembedded areas in locations within the stream channel that would be used by steelhead, such as the bottoms of pools and pool tailouts.

Miscellaneous questions:

1. Page 10 equates the second highest fall coho population observed with the summer carrying capacity. Please provide a justification for this. There may be a bottle neck at a different lifestage and the summer habitat capacity may be greater than that observed.

This summer "carrying capacity" was a hypothetical value and was used to illustrate the specific point that the actual survival of egg and early emergent fry during years with relatively high juvenile abundance may be higher than we can calculate because a larger number of fry may have survived initially, but a portion died or were forced to emigrate due to territorial/agonistic behavior. We did not chose the year with the highest abundance because it may have been anomalous due to fish rescue operations that year.

2. Pg 10 Fig. 2.3-2 graphs juvenile Coho verses summer low flows. Did you look at total salmonid population and low flows? It might be useful to look at the total population as the species compete for resources and their densities seem to be inversely related.

Because the purpose of this comparison was to examine potential summer habitat limitations for coho we did not look at relationships between flow and the total salmonid population.

3. Page 29: Smolt/juv survival ratio: Does the literature identify a level of concern ? If not, based on your own experience do you have levels of concern below which you think the population might be threatened?

There are no standards by which to answer these questions. The smolt/juvenile ratio must be judged within the context of the local population dynamics. It is really the absolute number and quality (size) of smolts that matters for population persistence. The critical number of smolts necessary for population maintenance could be determined through a viability analysis to determine the number of adults necessary to seed available rearing habitat.

4. Page 17: please provide reference(s) for agonistic behavior causing downstream dispersal of fry in spring.

The comment is addressed within the final draft.

5. Downstream migrant trap results: what size was used to make the breaks for coho between smolts and YOY and steelhead YOY, 1+, and smolts? Please present size data in tables in appendix

The comment is addressed within the final draft.

6. Pg 52: you state that growth opportunities were greater for fish that “reared” in Tocoloma. Do you mean reared for summer as well as winter and spring, or just winter and spring?

The statement refers to fish that reared in Tocaloma at least during the spring.

Lagunitas Limiting Factors Analysis Draft Report
Comments by Mike Napolitano
May 15, 2007

Redd scour

Although I would concur that redd scour does not appear to have been a significant source of mortality at the sites that you monitored in water year 2005, I think there are some important caveats that need to be presented in discussing your results and conclusions. Also, I have a few remaining questions regarding methods and assumptions. My specific comments are as follows:

1. Were any of the scour chains placed within the area of the streambed that was mounded up (e.g., the mound and/or tailspill), and/or lowered (e.g., the pit) via redd construction? If not, did you establish a convention for the standard distance between the redd perimeter and the location where the chain was installed?

We could not disturb the study redds, so chains were placed immediately adjacent to redds (within approximately 10 cm). Tracer washers were installed in the egg mound and cross sections were measured across each egg mound. Please see methods in the appendix for further detail.

2. Please confirm that the reference datum against which the scour depth was measured, is the elevation of the streambed surface adjacent to the chain following redd construction.

The reference datum for cumulative scour was the elevation of the streambed surface adjacent to the chain following redd construction. Instantaneous scour for any particular flood event was measured against the elevation of the streambed prior to that storm.

3. Please report the estimated recurrence interval, based on annual maximum series, of the 1,800 cubic feet per second peak in Lagunitas Creek at SP Taylor that occurred on December 27, 2004. Was this peak equal or greater to a 1.5-year or greater recurrence interval event? Also, is this an appropriate benchmark for considering recurrence interval/relative magnitude of peak flow in the Shafter Reach, and/or in Olema Creek? For your measurement sites in Olema Creek, do your estimates of maximum stage correspond closely to field indicators of bankfull stage? Some discussion of the dampening effects of Peters Dam on sediment supply and peak flow is needed in discussing redd scour results for the Shafter Reach.

The recurrence interval was between 1.5 and 2 years for the annual maximum series at the San Geronimo Creek Gage and Lagunitas Creek at SP Taylor. This flow level is an appropriate benchmark because it occurs at a biologically significant time scale, and is similar to peak flow values observed during the years 1998 – 2000 with very low juvenile coho abundance. This is discussed in more detail in the report. Observations in Olema Creek and Lagunitas Creek below San Geronimo Creek closely correspond to field indicators of bankfull stage. The Shafter Reach was probably slightly below bankfull because of the dampening effects of Peters Dam on peak flow. Bed mobility might be expected to be lower in this reach because the bed is coarser. However, results from the Shafter site were consistent with results from other sites.

4. On pages 21 and 22, it's not clear what the basis is for your statement that "Bratovich and Kelley overestimated the impact of scour on egg survival since they appear to have not

accounted for redeposition of material after scour events.” Please present and interpret the passage and/or data in their report to support your conclusion. With regard to the discussion on page 21, paragraph 2, please state the location where the 2600 cubic feet per second flow was estimated, and what the recurrence interval is at this site (e.g., based on an annual maximum series). Also, please report the average and range of values for redd scour reported by Bratovich and Kelley in response to the bankfull event in water year 1984. Finally, if I understand correctly, you seem to be suggesting that none of the previously collected redd scour data, if interpreted correctly, support the argument that redd scour is a high source of mortality during a typical (e.g., bankfull) high flow event; even under somewhat finer streambed conditions (e.g., water year 1984). If so, this is an important conclusion that deserves additional attention and support.

The argument that is the basis of the statement in question is presented on page 21 paragraph 2 and will be clarified with summary data from Bratovich and Kelley. All flow levels refer to the SP Taylor gage.

5. Although I would concur that redd scour does not appear to have been a significant source of mortality at the sites that you monitored in water year 2005, it is important to discuss the fact that following a period of higher total and/or fine bed material supply, that the extent of redd scour would be expected to increase by an unknown amount. Furthermore, during the late 1970s through early 1980s the streambed apparently was much finer than it was in water year 2005, therefore it is plausible to hypothesize that redd scour could be a problem following periods of elevated sediment supply.

Yes, one would expect there to be greater potential for redd scour during periods when the streambed was finer, as could happen in the case of elevated sediment supply. Our discussion refers to current conditions of the watershed (1996 to present) for which there is population data. We do provide a comparison of our results to the results of scour studies conducted in the early 1980's (Bratovich and Kelley 1988). The streambed was slightly finer during the previous study, and not surprisingly, for a similar flow, Bratovich and Kelley (1988) documented a slightly higher incidence of scour. However, in the report, we also discuss potential problems with the interpretation of their data.

6. Could redd superimposition have occurred at one or more of the sites where you monitored emergence? Please discuss this issue in the final report.

Superimposition by steelhead of one of the coho study redds monitored for emergence was suspected (as discussed in the report). However, we are very confident that superimposition by coho or steelhead did not occur in any of the other redds monitored for emergence because we closely monitored the redds throughout the study period.

7. Based on the discussion in Appendix A, it appears the three redds you monitored in the Shafter Reach are very close to each other. Therefore, at this site, can you conclude with confidence that the number of emergent fry you counted only represent eggs deposited in redd 2 and 3 (not 1, 2, and 3)?

Yes, the redds were close together but did not overlap. We monitored emergence by individually capping two of three redds. The emergence traps have netting above the streambed that prevents fry from other redds entering the trap area. The traps also have a

skirt that is buried approximately 30 cm below the streambed that prevents alevins migrating from one redd to another within the gravel.

8. Considering the importance of San Geronimo Creek and Devils Gulch for coho salmon, and the fact that these watersheds are the primary source regions in the watershed for fine bed material, wouldn't it useful at a future date to measure scour at potential spawning sites in these tributaries?

Further studies could be conducted to confirm our conclusions and applicability of results to other stream reaches within the watershed, but we would consider these a low priority compared to investigations related to emergent fry displacement and overwinter survival.

9. In the larger discussion of potential explanations for low numbers of juveniles estimated for 1998 through 2000, it is important to consider the issue of proximity of good spawning habitat to good high flow refuge habitat (for early fry). For example, it is possible that the carrying capacity at a given site that provides high flow refuge may not be reached, if survival to emergence is low within the redds within an effective distance of the refuge (e.g., the fry need refuge habitat that is close to the place where they emerge from the streambed, otherwise they get entrained). In such cases, coupling or decoupling of habitats may need to be considered in evaluating population dynamics.

This is a good point and a potentially important issue worth further investigation. If spawning was not located in close proximity to refuge habitat, then fewer emerging coho fry might be expected to survive. A formal analysis could be conducted to quantify spatial variability of coho redd locations across years with differing summer juvenile densities if funding was available.

10. Finally, and most importantly, considering the fact that coho salmon in Lagunitas Creek are a small and geographically isolated population, from a conservation biology standpoint, although redd scour and entombment may not have been the most important limiting factor during the monitoring period, it would still seem essential to address elevated levels of mortality at all life stages in order for the population to be resilient to natural and anthropogenic disturbances, the relative significance and frequency of which would be expected to vary greatly over the longer periods of time that will effect the persistence of the population.

The point is well taken. However, you would need to define "elevated levels of mortality" against some reference or benchmark. Absent of such a reliable benchmark, we have evaluated coho population dynamics in the context of current conditions. What follows from this analysis is that (in brief) the population appears highly resilient to factors affecting survival-to-emergence, and susceptible to factors affecting displacement of newly emerged fry and/or winter habitat quality.

Lagunitas Limiting Factors Analysis (LFA) Draft Report
Comments by Eric Ettlinger & Gregory Andrew, MMWD
April 2007

Let us start by saying that we believe Stillwater Sciences has done an excellent job carrying out the Lagunitas Creek Limiting Factors Analysis. The study was well conceived and well executed, despite difficult field conditions. We also enjoyed reading the draft report, which is well laid out, well written, and easy to read. We particularly like how the hypotheses are clearly laid out, and how the evidence for each hypothesis is weighed in order to reach the report's conclusions. The study has raised some interesting issues that lead to considerations for future management and monitoring studies. That said, we disagree with some of the conclusions reached in the draft report. In particular, we find no evidence for an upper limit on coho smolt production while we do find evidence for coho incubation mortality, which is rejected in the report.

Coho Smolt Production

1. We question the analysis of estimated smolt production shown in Table 2-3 and Figure 2.3-15. We believe that the asymptotic curve showing a density-dependent smolt production limit is a product of some incorrect data and false assumptions. First, the redd counts used to estimate adult coho escapement are watershed totals for some years (1994, 1995, 1997 and 1998), while excluding redd counts in the San Geronimo Creek tributaries in other years. Using correct watershed redd totals greatly increases the number of smolts required, particularly for 2003 (see Figure 1). In that year, 12,400 smolts would be needed to produce the 496 redds observed in 2004/2005, assuming 8% ocean survival.

In response to the implication that incorrect data was used we will include further information on our analysis methods that was not clearly disclosed in the draft report and which may explain some discrepancies between the numbers we used for our analysis and previously reported watershed totals. Although roughly the same reaches of Lagunitas, Devil's Gulch, and San Geronimo creeks have been surveyed over the period of record, the same is not true for tributaries to these streams. Therefore, a comparison of redd totals across years is confounded by the fact that the area surveyed has differed from year to year. For example, the table below shows sampling records for tributary streams for all years surveyed since 1982. The table illustrates the consistent addition of new survey areas over the years and also indicates that in some years a large number of redds are built in tributaries that were not surveyed every year. Consequently, adult returns, as indexed by redd counts, may have been underestimated during the first years of sampling. We therefore standardized the redd counts used in our analysis to include only redds built in reaches that have been surveyed every year (i.e., Lagunitas, Devil's Gulch, and San Geronimo creeks). In most years, this makes little difference; in some years the difference is more dramatic; but, for the sake of hypothesis testing both data sets would yield a similar pattern of juvenile to smolt ratios.

Stream	Coho redd count (winter beginning in year indicated; shaded area indicates stream not surveyed)												
	1982	1983	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Larsen Creek				4	2	0	6	6	4	3	13	7	1
Arroyo Creek				10	12	3	16	12	6	30	39	23	9
Woodacre Creek	11						9	24	7	24	51	15	14
Evans (Bates) Creek								0	1	1	3	3	1
Cheda Creek								3	2	6	6	2	9
NF (Upper) San Geronimo Ck								1	14	7	11	6	1
Montezuma Creek										1	1	0	0
Nicasio Creek													3
Total	11	0	0	14	14	3	31	46	34	72	124	56	38

A second, less significant problem is the inclusion of smolt estimates that exceed the juvenile estimates in some years (particularly in 2000). Reducing these smolt estimates to reflect 100% overwinter survival (which is still unlikely), improves the fit of a linear regression between juvenile and smolt estimates.

For the purpose of our analysis, ocean survival is based on a flat rate across all years (due to the absence of data on actual ocean survival). Because actual ocean survival will vary from year to year, this flat rate may overestimate ocean survival in some years, resulting in smolt estimates slightly above the previous fall's juvenile population estimate (3 of 12 years), and underestimate ocean survival in others. Of course more age 1+ smolts cannot be produced then there were juveniles in the previous fall. However, the overestimates resulting from an eight percent ocean survival rate are very slight (see table 2-3) and well within the error associated with the fall juvenile abundance estimate (see revised figures within the report).

Lastly, the asymptotic curve of Figure 2.3-15 relies heavily on the low smolt production estimates of 1983-1985. Stillwater correctly points out that smolt production was likely underestimated by Bratovich and Kelley in these years due to their smolt trap being located upstream of reaches known to support winter rearing of coho salmon (footnote #6, page 28).

We hypothesized that smolt production was underestimated in 1983 – 1985 due to the trap location but the degree to which it was underestimated is probably slight since the previous fall's juvenile abundance was not much greater than the number of smolts captured. Similar to above, if we assume that maximum smolt production cannot exceed the previous fall's juvenile abundance estimate then adjusting the smolt 1983 – 1985 estimates upwards results in only slight changes to the pattern illustrated in Figure 2.3-15.

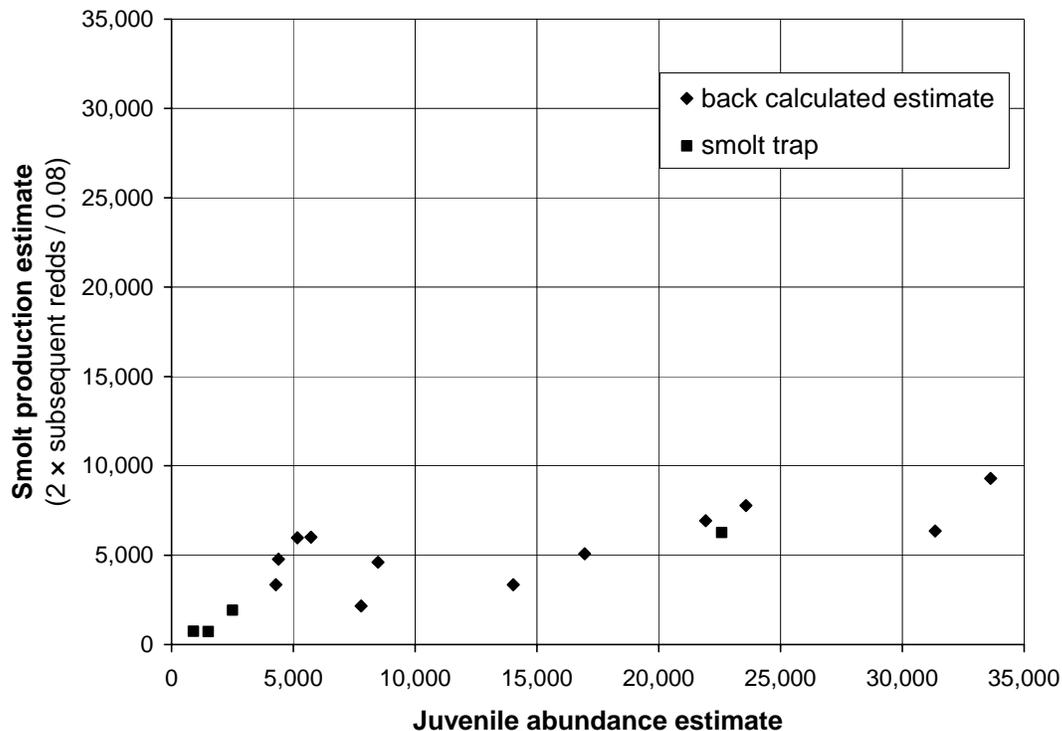
When the redd total numbers and smolt production overestimates are corrected, a linear regression fits the data better than a logarithmic regression (see Figure 1). If the smolt estimates of 1983 through 1985 are eliminated or increased, the evidence for the asymptotic relationship disappears entirely. Finally, no evidence has been presented to support the ocean survival assumptions necessary to produce the smolt estimates. We believe that there is no compelling evidence to suggest a carrying capacity for overwintering coho in Lagunitas Creek.

All other technical details aside, we believe that we are more in agreement with the reviewers about the effects of winter habitat on the coho salmon population than may be apparent. The majority of comments are related to the form of the relationship between juvenile abundance and smolt production, namely whether this relationship is curvilinear and asymptotic or whether it is linear. However, regardless of whether you fit the data with a straight line or a curved one, it is clear from the available data that smolt production is typically much less than the previous fall's juvenile estimate. To help illustrate the discrepancy between juvenile abundance and smolt production, we modified report figure 2.1-15 so that the scales on the x and y axis are equal. If

one were to draw a 1:1 line on the figure, the ratio of juveniles to smolts would fall well below that line when juvenile abundance exceeds about 6,000 to 7,000 fish, indicating that winter survival is well below 100 percent, and is closer to 15 to 20 percent. Therefore, even if winter survival is density independent (i.e., a linear relationship in which the more late-summer juveniles you have, the more smolts will result), you could achieve fairly dramatic increases in smolt production by improving winter survival.

Supporting evidence for our ocean survival assumption is presented on page 29, but information on actual ocean survival rates for the population is unavailable. Eight percent is the ocean survival rate that is most agreeable with the available Lagunitas data and values presented in the literature. We suspect that, on average, ocean survival is not much lower than eight percent, since using lower ocean survival values to back-calculate smolt production results in a higher number of years in which smolt estimates exceed the previous fall's juvenile estimates. If mean ocean survival is higher than eight percent, fewer smolts are necessary to produce the observed number of adults returning, and therefore evidence for winter habitat limitations is even stronger (i.e., decreasing the smolt:juvenile ratio means that winter mortality would have to be higher). That said, we do not mean to suggest that actual ocean survival is constant across all years, only that using a flat survival rate is the most parsimonious approach given a lack of data on ocean survival.

We believe that there is some uncertainty regarding the exact relationship between juvenile abundance and smolt production, but the results of our study suggest that winter mortality may be substantial. These results are consistent with results of other studies demonstrating winter habitat limitations of coho salmon populations in the Pacific Northwest. We would look forward to continuing the discussion of the potential for winter habitat limitations with MMWD.



Coho Incubation Mortality

We also question the conclusion that coho incubation is not a major period of mortality. We agree with the conclusion that redds in Lagunitas Creek appear to have good survival to emergence even at bankfull flows, based on the redd and emergence monitoring conducted in 2005. We agree with Stillwater's conclusion that other redds in Lagunitas Creek are not likely to have significantly lower emergence rates.

Technically, we are arguing that mortality during incubation does not influence population dynamics. We agree that density-independent mortality is probably quite high during this period, but that this mortality does not translate into reduced abundance of summer juveniles. This is because thousands of fry are produced from a relatively low number of redds even at very low survival to emergence (in the report we provide an example using 10-20% survival to emergence on p 24).

However, there's clearly a strong negative correlation between peak winter flows and coho population estimates (see Figure 2). The evidence from the emergence traps indicates that these flows don't impact Lagunitas redds, although extraordinary flows, like in 1998 and 2006, probably scour these redds. We suspect, however, that peak flows cause significant incubation mortality in redds in San Geronimo Creek, and that these redds may produce the majority of coho fry in the watershed. Our evidence is based on correlations and anecdotal observations, and would need to be substantiated in the field. Estimated coho populations in Lagunitas Creek are more strongly correlated with redd totals in San Geronimo Creek than redd totals in Lagunitas Creek (see Figure 2). Instantaneous peak flows are highly correlated with Lagunitas Creek coho populations. These two factors explain nearly 95% of the variability in the Lagunitas Creek coho population. This coho population model is described in more detail in Attachment A.

It is difficult to say much about redd scour or entombment in San Geronimo Creek since redds there have not been closely monitored. We have observed, anecdotally, redds constructed in fine substrates and these redds are no longer visible after moderate to high flows. Such flows could be scouring these redds, burying them, or filling egg pockets with fine sediment. Winter flows should be discussed in the report as an alternative "smoking gun," which could be more important than spring flows. The correlations we have found support the theory and warrant more research. With the data being collected at SPAWN's smolt trap, we'll be able to compare the numbers of downstream-migrating coho fry and late-summer coho estimates in Lagunitas Creek. If there is support for a San Geronimo origin for Lagunitas coho, then monitoring San Geronimo redds may be an important next step.

We agree that sediment dynamics are probably different between San Geronimo Creek and the samples sites in Lagunitas and Olema Creek. A similar study of scour and infiltration could be conducted in San Geronimo Creek to reduce uncertainty about our conclusions. We do have some concerns about the correlations presented by MMWD because data have been adjusted to achieve the best fit. It is common for people to find strong correlations between seemingly related variables when data are adjusted in a trial and error process.

Coho Displacement during Spring Flows

We agree with Stillwater's conclusion that there is evidence for entrainment of newly-emerged coho fry during spring freshets. In fact, we believe the evidence is stronger than presented in the draft report. Spring snorkel counts and late-summer electrofishing surveys in 2005 found more coho fry than would be expected based on the high April flows that year (Figure 2.3-13). But

Stillwater did not account for the unusually large coho run in 2004/2005, which produced 496 coho redds in the watershed. The 2005 coho population estimate fits closely with our model predictions factoring in the high redd count, moderate winter flows and relatively high spring flows (see Attachment A).

We agree that, 2005 results notwithstanding, spring freshets are probably an important factor influencing coho population dynamics in some years. This is an area worthy of additional research.

Steelhead Limiting Factors

The first hypothesis related to the estuary no longer being viable for 1+ steelhead was not tested or substantiated in the report. It seems to be disregarded in favor of the 2nd hypothesis (related to low winter survival of 0+ steelhead) but that alone does not seem a valid reason to disregard the first hypothesis. Of course, the study was not meant to be a survey of the estuary and there is essentially no existing data on this issue. Perhaps Stillwater could suggest some ways to more directly test this hypothesis.

This hypothesis was not thoroughly tested because no data was available on estuarine conditions and we discovered evidence for the alternative hypothesis, that age 0+ winter survival is sufficiently low that springtime downstream migration of age 1+ fish does not occur, through our study of Devil's Gulch.

We agree with the conclusion that the steelhead population bottleneck occurs during the first winter. We would really like to see more detail, however, on the restoration recommendations. Reconfiguring the cobble substrate that naturally exists sounds good, but what does this actually mean? Stillwater has pointed to a lack of large interstitial spaces as a limiting factor, but we still haven't heard how those could be created in a high-sediment-load system. Perhaps another habitat enhancement measure could be creating deep undercuts, which steelhead utilize readily, but we don't know if this has been attempted in other streams.

Please see our response to a similar comment by the RWQCB.

We realize that the LFA is intended to identify the limiting factors, not propose detailed restoration options. But we would like to understand if the major limiting factor for steelhead could be ameliorated on a scale that's effective and practical. If the solutions aren't practical, then we may want to look at increasing survival in the second winter, or in the estuary, or addressing some other secondary limiting factor.

Please see our response to a similar comment by the RWQCB.

Additional editorial comments provided by MMWD were addressed directly within the report.

**US Government
Memorandum**

May 14, 2007

To: Nancy Scolari

From: Brannon Ketcham and Michael Reichmuth

RE: Lagunitas Creek LFA Comments:

The NPS has participated in the Lagunitas Creek Limiting Factors Analysis project from the initial stages. We appreciate the collaborative process managed by the RCD to convene and conduct the LFA. We believe that overall, Stillwater Sciences brought a good deal of energy and expertise to this project, and worked well beyond initial expectations.

Overall, we remain concerned, as voiced at various meetings, that Stillwater relied on, and continues to use the extrapolated salmonid numbers from the MMWD monitoring program for the LFA. We have, and continue to recommend that the LFA should be presented in a manner that indexes the salmonid density results, rather than using extrapolated totals. While the extrapolated numbers likely reflect the reality of the conditions in the system, the use of these non-statistical extrapolated numbers reduce the scientific validity of the statements and determinations made throughout the document.

The MMWD monitoring program, despite potential limitations, presents the best available long term dataset for coho and steelhead populations within the watershed. We think the monitoring efforts within the watershed could be improved (the non-random nature of MMWD's sampling and the relatively low number of habitats sampled may reduce the accuracy of the extrapolated values). However, we recognize the current monitoring program is a compromise between data needs and limited available funding and time. After analyzing the error associated with MMWD's extrapolated population estimate for coho salmon (see revisions in final report), we believe that the precision of the MMWD population estimates is sufficient to detect annual variation in juvenile coho abundance at the level we are interested in, and is sufficient to allow the type of population analysis that we have conducted through the LFA. The alternative of not using the data would make an analysis of population dynamics largely speculative. Furthermore, if we just used the summer density of juvenile fish, the annual trends would parallel the extrapolated values since the extrapolated values simply multiply observed densities by habitat area (accounting for differences in habitat type composition between years). Therefore, we would reach the same conclusions regarding summer abundance of juvenile fish whether we used extrapolated numbers or observed densities. However, without the extrapolated juvenile population estimates we would not be able to compare the overall abundance of different life stages and conduct a population dynamics analysis.

We have also had a variety of peer-review on our monitoring program which has indicated the severe limitations of index reaches for statistical analysis. The only way to develop basinwide estimates (which are readily reported incorrectly in the Stillwater report), is to conduct a population estimate based on a two-phase randomized survey approach (Hankin-Reeves method). The strong dependence on non-statistical data should be explained within the document.

The basinwide estimates are reported annually in MMWD's juvenile population reports. We have not reported them incorrectly (when taken directly from the MMWD reports, the population numbers are identical; where we have reanalyzed MMWD's data in order to compute confidence intervals, the population estimates very closely match those reported by MMWD). With regard to the Hankin-Reeves method of estimating whole-basin fish populations, while the Hankin-Reeves (or more recently the Hankin-Mohr methodology) method may be preferable, and we use the method on a number of our projects, that type of data does not currently exist in the Lagunitas watershed. In the LFA we have relied on the best available data to generate and test hypotheses about factors controlling coho and steelhead populations.

Additional specific comments are included below.

2.1.1

Need to add information on emergent fry habitat requirements.

The comment is addressed in the final report.

2.3.1.1

Need to add hypothesis #4: Quality or abundance of adequate spawning grounds are not available due to migration barriers and gravel augmentation.

This hypothesis was not explored after an initial examination determined that redd counts were relatively consistent across years with widely varying juvenile populations. Also, the LAG indicated that spawning habitat was prevalent in accessible reaches within the watershed. We think that work to remove barriers to migration should be continued so that fish can access headwaters, but the proportion of fish spawning in tributary vs mainstem habitats is not correlated with annual juvenile abundance.

Ettliger et al. 2003 is cited but the data are not presented in a manner that verifies the statement that index reaches are representative of the watershed.

We believe that Ettliger et al. 2003 does a good job of summarizing habitat trends within the watershed and since the point is a relatively minor one within the context of the report, we have not reproduced their data analysis within the LFA. Therefore, it was only our intention to provide a reference for the reader who is interested in further information about the "representativeness" of sample sites.

When estimating fecundity, was there enough data on female carcass length to justify using an average female fecundity of 2,600 eggs?

Fecundity of 2,600 eggs is a mean value for coho salmon in central coastal California derived from Shapovalov and Taft (1954). The estimated fecundity of coho that built study redds ranged from approximately 1,800 to 2,600 eggs (mean = 2,190; Table 2-2). This estimated fecundity is based on the measured female length of coho in Lagunitas (n = 10) and the female length/fecundity relationship reported by Shapovalov and Taft (1954). We did not adjust the fecundity from 2,600 to 2,200 because the low number of Lagunitas females sampled may not be representative of the population and because the analysis is not sensitive to errors in fecundity values (i.e., we would reach the same conclusions regarding coho population dynamics whether we used a fecundity value of 2,200 or 2,600).

How were juvenile estimates determined? Our data suggests that estimates derived from index based monitoring do not adequately represent the watershed in all years when compared with basinwide monitoring. In fact, in only one out of four years of doing both, have the index based estimates been within the confidence limits of the basinwide estimate.

Please see the discussion of MMWD juvenile salmonid estimation methods above.

To reduce entrainment you could also decrease channel confinement.

Where it is feasible, reducing channel confinement could reduce entrainment by improving access to floodplain habitat. However, where the channel is naturally confined by valley walls, such as in Devil's Gulch, this type of management action may not be possible.

2.3.1.2

Redd Scour

How does the redd scour observed in Lagunitas compare to other systems.

The level of scour for a bankfull event appears to be similar to other systems that have been studied.

Entombment of eggs

Can't rule out sediment transport since no redd caps were placed in San Geranimo which is a major sediment source.

We agree that sediment transport dynamics in San Geronimo may behave differently than in Lagunitas Creek.

Observed fry emergence

How is female length derived in table 2-2.?

Please see the comments related to estimating female length and fecundity above.

What are the redd numbers in which total seeding was derived from?

All redd data referenced within the report are from MMWD monitoring reports. Specific references are provided within the report.

Displacement of newly emerged fry

The utility in the spring dives may be limited, since the timing and methods for these surveys were not consistent and due to the high water a majority of the fish could be still moving within the watershed.

Snorkel survey results were consistent with MMWD's fall electrofishing results.

Need to use current data information instead of past habitat info to extrapolate numbers. Past habitat data is not applicable. As we understand, habitat data for most of Lagunitas is collected every 5 years, while habitat likely changes annually.

Any analysis performed in the LFA used the most recent available habitat data for the watershed, which was collected by MMWD in '97, '98, '03, and '06.

2.3.2.1

What trapping method was used?

A combination of fyke and rotary screw traps were used to monitor downstream migrants.

A four year period is not enough time to take into account production shifts such as PDO. % survival should be based on each year's ocean production estimates.

We agree that ocean survival rates based on local information would be preferable to the assumptions we relied upon within the report. However, we are not aware of any available data on local ocean production estimates. We would welcome any pertinent data related to ocean survival of salmonids.

Survival rates can only be a rough estimate unless you run a power analysis on your data to determine your level of detection. If your levels of detection is low then you may not be able to detect change in survival using the current sampling design.

If this statement is referring to ocean survival rates, we relied on relatively simple assumptions of a constant eight percent survival across years. The rationale for this assumption is presented in the final report.

Need to take condition factors into consideration when determining the cause of low survival rates. For instance if the summer condition is low then which leads to reduced overwintering survival then summer growth could also be a problem.

We agree that low condition factors at the onset of winter could reduce overwinter survival and that improving summer growth conditions, if possible, might slightly improve overwinter survival, all other things being equal.

More years of smolt trapping is necessary to prove that back calculations are reliable predictors or you could have tested this using Olema data first since there are is more data available.

We agree that actual data on smolt production would be preferable to our estimates based on annual redd counts and assumptions about ocean survival. Because the analysis requires data on smolt production and subsequent adult returns and the monitoring program in Olema Creek is relatively new, there are not yet data available to calculate ocean survival rates.

2.3.2.2

Devil's Gulch experimental set-up

No tag retention or mortality rates due to tagging were performed? Or reported.

Tag retention and survival was found to be 100 percent of 24 hours. Longer term estimates are not available, but the literature typically indicates a 2 to 5 percent tag loss over longer periods. However, this loss rate is dwarfed by the reduction in population abundance that we observed.

Devil's Gulch Results

Can assumptions on winter habitat availability be made when a 25 year flood even occurred during the sampling period? What would displacement would normally occur during a large flood event?

Conclusions about winter habitat are based on both the focused field studies conducted as part of the LFA and the analysis of existing data. We agree that the magnitude of winter storms during the study period likely had an influence on our results. We have been looking for additional funding to repeat the study in a different water year type in order to determine the influence of flood magnitude on the change in population abundance. We are not aware of any reliable benchmarks to answer the second question. What really matters is the absolute number of fish that survive the winter period and smolt.

April 27, 2007

To: Matt Sloat, Stillwater Sciences
From: Gail Seymour, CA Dept of Fish and Game
Subj: Commnets: DRAFT Lagunitas Limiting Factors Analysis – Limiting Factors for Coho Salmon and Steelhead

On behalf of the Department of Fish and Game, Bay-Delta Region, I wish to thank Stillwater Sciences staff for completing this important analysis in the Lagunitas Creek watershed. The Department recognizes the collaborative effort that initiated and completed this project – thank you to the Marin Resource Conservation District, Tomales Bay Watershed Council, Point Reyes National Seashore, Marin Municipal Water District, SPAWN, Trout Unlimited, and Marin County, the State Water Resources Control Board and SF Regional Water Quality Control Board.

The following are my comments:

Page 4, Fig 2.1-1: water quantity should be added to Factors Affecting Fry Rearing and Factors Affecting Juvenile Rearing (your report states on pg 7, paragraph 3 that, “Therefore, the availability of suitable juvenile rearing habitat (either in the summer or winter) is the factor that usually governs the number of coho salmon smolts produced from a stream.

Water quantity as a potential factor influencing fry rearing and juvenile rearing was meant to be implied in the statement “Availability of suitable stream margin and off-channel habitat for fry rearing.” What matters is not necessarily the absolute amount of water, but the amount of the stream channel providing suitable fry rearing habitat.

Page 7, paragraph 3: poor gravel quality, redd dewatering, fungal infections, redd scour in most cases will not be “selective” and could certainly result in wide-spread egg mortality in a small system such as San Geronimo Creek. I would think that this could have a deleterious effect on coho salmon population dynamics.

We agree that these factors could potentially affect a large number of redds. However, in our conceptual model, we hypothesize that these factors rarely will have an impact on population dynamics (i.e., number of smolts produced) because the fecundity of coho salmon is so high that even a few successful redds are sufficient to seed the available juvenile rearing habitat

Page 8, 2.3.1.1, #2: what historical research brought you to the conclusion that in some years, high density-independent mortality of juvenile coho salmon occurs after summer densities have been established through territorial/agonistic behavior?

This statement was included as a hypothesis that might explain dramatic annual variation in late-summer juvenile abundance, and was not based on historical research.

Page 13 – 14: Inverse pattern of juvenile coho salmon and steelhead abundance is related to differences in the timing of reproduction for the two species. That observation is commonly overlooked. I definitely agree with it.

Page 24: Regarding comparison between four sample sites above the confluence of Devil's Gulch (low #s) and two sites below Devil's Gulch (much higher #s than previous years), isn't the Devil's Gulch flow relatively "flashy"?

Below the confluence, isn't the channel relatively wide with low gradient and more instream habitat complexity than in Devil's?

So although it's stated that, "...we found no evidence for a decline in juvenile coho abundance related to spring flows." it may have significant impact as 0+ fish are removed from relatively good quality summer habitat (Devil's Gulch and San Geronimo tribs).

This is true, and the statement referred to above has been modified to be consistent with the statement quoted below.

Page 27: "Although there appears to be indirect evidence for entrainment of newly emerged fry during late winter and spring freshets, the mechanisms for this mortality remain unclear. Further tests of this hypothesis are proposed in subsequent sections of this report". I agree that more research is needed.

Page 36: "Wigington et al.... coho salmon immigrated from mainstem channels to exploit intermittent steam habitat once flow resume in the fall.... Experienced higher winter survival and attained larger sizes...". This is interesting as DFG is re-evaluating the cost/benefit of removing barriers in these tribs since during the summer, habitat is disconnected due to low or no flow (e.g. San Geronimo tribs). If these tribs are used during the late fall/winter as you indicate in this report, that provides greater justification for removing barriers.

Page 41, paragraph 6: "Steelhead May rear for one month to a year in the estuary..."
We believe that habitat and population assessment in the estuary is a high priority.

Synthesis and Restoration Recommendations, page 53 – 55: As I had stated above, removing barriers (restoring connectivity between the main channel and its low gradient tributaries) and restoration of the estuary are high priorities for the Fisheries Restoration Grant Program for Lagunitas Creek and possibly other coho watersheds.

I had not realized the importance of the low gradient tributaries for winter habitat until I read this report.

Adjusting cobble and boulder substrates for SH is a recommendation that I had not realized; but seems very reasonable

(last paragraph): This is a critical concern, however, increasing winter refugia, especially woody debris accumulations in the channel would also increase summer refugia habitat that would offset the "excess" 1+ habitat bottleneck. We could accomplish that sooner and at lower cost than restoration in the estuary (although NPS is working on that) and could address the bottleneck until the estuary could provide additional habitat.