D. W. KELLEY & Associates aquatic biology

INVESTIGATIONS OF SALMON AND STEELHEAD IN LAGUNITAS CREEK, MARIN COUNTY, CALIFORNIA

VOLUME I.

MIGRATION, SPAWNING, EMBRYO INCUBATION AND EMERGENCE, JUVENILE REARING, EMIGRATION

Prepared for the
Marin Municipal Water District
Corte Madera, California

by

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ACKNOWLEDGMENTS

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Many individuals and organizations contributed to this study. The senior author and Heidi Rooks planned and conducted the field investigations and data analysis. Barry Hecht provided understanding of the geomorphological and hydrological processes unique to Lagunitas Creek, and was instrumental in sampling technique development and data analyses. Expertise and field assistance was supplied by William Cox; and knowledge of local erosion processes and familiarity with the watershed was contributed by Liza Prunuske. Landon Waggoner of Samuel P. Taylor State Park, and the Giacomini and Zanardi families allowed for unrestricted access to much of the creek. Many local residents, particularly Sis and Lefty Arndt, Richard Plant, and Willis Evans, provided valuable insight to the habitat and fishery resources of Lagunitas Creek. Leo Cronin and other members of Trout Unlimited stimulated public interest in the study and organized and conducted stock enhancement and habitat improvement projects. Comments and study suggestions were offered and various projects were undertaken by members of the Lagunitas Creek Citizens Advisory Committee.

Special appreciation is extended to the many individuals who participated in data collection and analyses, including John Brezina, Wayne C. Fields, Jr., William Mitchell, Dana Roxon, Gary Stern, and Jerry Turner.

David Dettman helped edit the final version and incorporated some recent results of Barry Hecht's geomorphology into Chapter VI.

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CHAPTER 1 - SUMMARY

This Volume I report describes our biological investigations on Lagunitas Creek conducted primarily in 1982, 1983, and 1984. These investigations were conducted to determine how streamflow and other environmental factors affect coho salmon and steelhead trout and to recommend instream flows for the fishery resources in Lagunitas Creek. Those recommendations and predictions of their effect are described in Volume II.

The report is organized to correspond to the life stages of salmon and steelhead. A summary of the life history stages and important environmental factors for salmon in Lagunitas Creek is illustrated in Figure 1-1.

UPSTREAM MIGRATION

Adult salmon move into Tomales Bay from the ocean in early fall and congregate in the Lagunitas Creek estuary. As in other coastal streams, salmon migrate upstream to spawn only after autumn or winter storms provide sufficient outflow.

Comparison of daily salmon catch at the California Department of Fish and Game (CF&G) Nicasio fish trap with estimated flows during the 7 years (1963/64 to 1967/70) in which it was operating indicated that a mean daily flow of 28 cfs at the US Geological Survey (USGS) Point Reyes gage was the lowest flow that attracted them. In addition, we conducted attraction flow experiments on four separate occasions during the fall in 1982, 1983, and 1984. Results of these experiments and analysis of Nicasio fish trap data indicate that a mean daily flow of 35 cfs at the Point Reyes gage is needed to attract salmon into Lagunitas Creek.

After fish are attracted into Lagunitas Creek, they must swim upstream and distribute themselves throughout the spawning areas. We assessed the flows necessary to provide passage over five "critical" riffles and concluded that a minimum flow of 35 cfs is desirable. Past lack of flows sufficient for upstream migration have probably had an adverse effect on salmon runs in Lagunitas Creek.

There usually has been sufficient unregulated flow in Lagunitas Creek during winter to provide for upstream migration of the steelhead that migrate later in the winter than do salmon. Even during the severe drought years of 1975/76 and 1976/77, flows higher than 35 cfs occurred on 3 consecutive days in early March 1976, and for 2 consecutive days in early January and 1 day in mid-March 1977.

SPAWNING

Many adult salmon entered Lagunitas Creek and its major tributaries several weeks prior to spawning. During our study approximately half of the

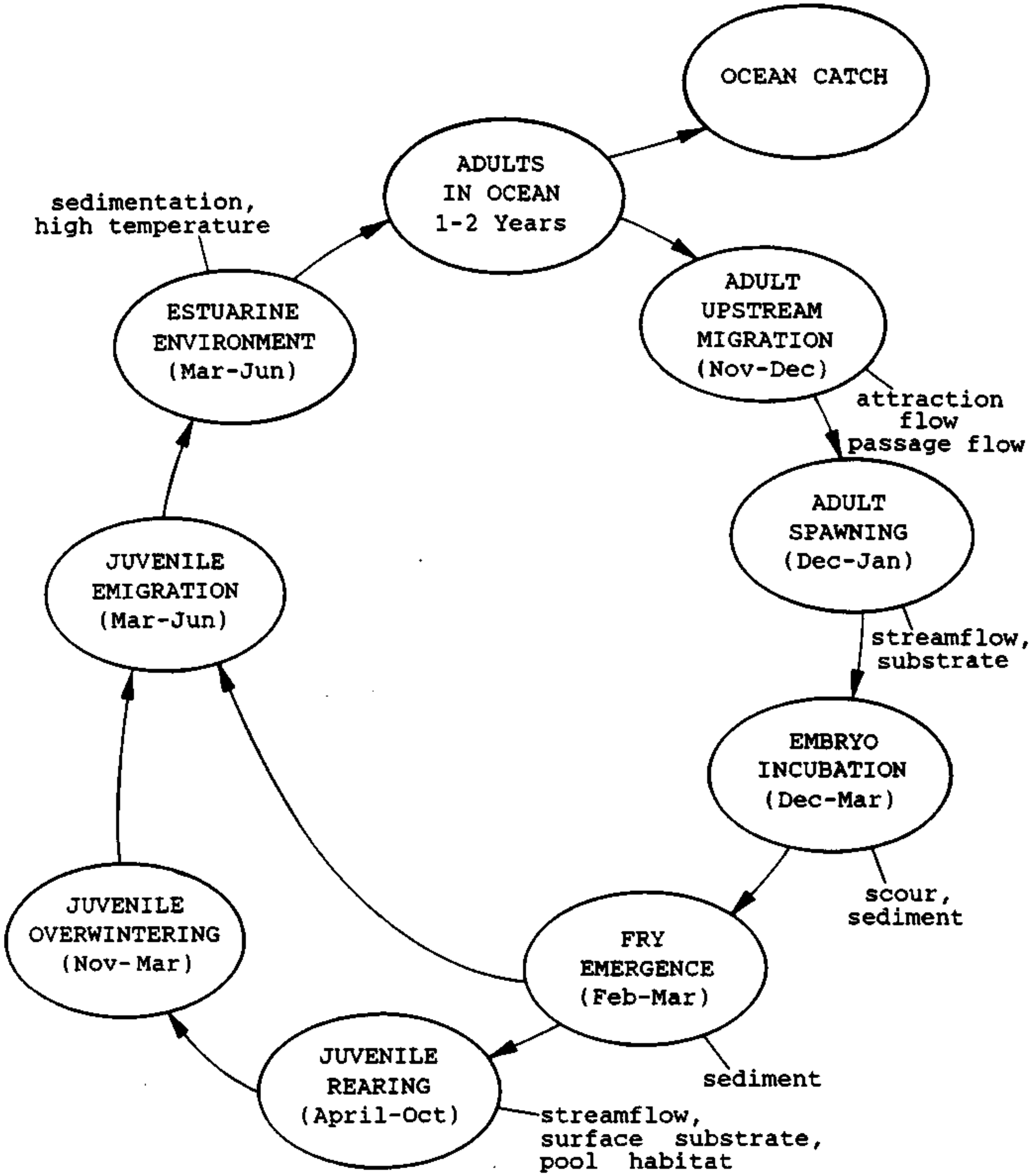


Figure 1-1. Conceptual model of major environmental factors influencing the life stages of coho salmon in Lagunitas Creek, Marin County. Late fall flows constrain adult migration in dry years while high winter flows often scour eggs from the gravel in wet years. Rearing habitat limits juvenile production because of the heavily sedimented streambed and low streamflows. Estuarine habitat has been reduced by combinations of sediment deposition and high water temperatures.

salmon and steelhead spawned in Lagunitas Creek and half in the tributaries. In Lagunitas Creek, most redds (nests) were built in the State Park Reach.

Nearly all redds were located in the center of the low-water channel where potential dewatering was not likely to occur. Redds were built in the tails of glides, immediately upstream from riffles. Fish selected relatively sandy and highly embedded substrate for spawning, and cleaned the streambed surface during redd construction. We believe that spawning habitats were selected for characteristics that result in good intragravel oxygen supply, relative ease in redd construction during low to moderate streamflows, and relative stability during high scouring flows.

The total amount of salmon and steelhead spawning habitat in Lagunitas Creek increased with increases in flow over the range of flows (approximately 12 to 28 cfs at the Samuel P. Taylor State Park [SPTSP] gage) examined. Based on spatial requirements of the redds and assuming reasonable reproductive success, streamflows of about 12 cfs or more provide enough spawning habitat to saturate the juvenile rearing habitat in the creek.

EMBRYO INCUBATION

Salmonid embryos incubate under a mound of gravel in the redds for several weeks during winter and spring. Embryo survival and development rates are related to dissolved oxygen concentrations and temperature of the intragravel water. Exchange of surface and intragravel water is necessary to replenish dissolved oxygen concentrations, maintain water temperatures, and remove waste metabolites produced by the developing embryos.

In the 2 years of our incubation studies in Lagunitas Creek, intragravel dissolved oxygen concentrations and water temperatures that we measured in natural salmon redds and simulated redds were suitable for embryo incubation. With streambed conditions similar to those that existed during 1983/84, flows from 11 to 13 cfs at the SPTSP gage during much of the incubation period provided suitable conditions for incubation.

The only problem that we observed with embryo incubation in Lagunitas Creek was scouring of the streambed. The sandy streambed of Lagunitas Creek becomes mobile and is easily scoured at high streamflows. Lagunitas Creek experienced extremely high streamflows during the winter of 1982/83 and scour occurred to depths of 8 inches or more in several areas of the creek. We believe that most of the salmon redds built in 1982/83 were destroyed due to high, scouring streamflows. We also believe that most salmon redds built the preceding year were destroyed in the January 4, 1982 flood.

The magnitude, duration, and frequency of flows that scour the streambed to depths that adversely affect incubating embryos depend upon streambed conditions. A heavily-sedimented streambed comprised of loosely compacted fine material is more prone to scour than a streambed of larger, or more tightly compacted, material.

FRY EMERGENCE

Salmonid embryos incubate in the gravel of the streambed, hatch, then emerge from the gravel as fry. Sediment accumulates on the mounds of the redds during the incubation period and can adversely affect reproductive success by acting as a physical barrier to fry emergence.

Fry emergence was not a major problem during 1983/84. Based on comparisons between substrate composition of salmon redds and investigations conducted elsewhere, we estimated survival from egg deposition through embryo incubation and fry emergence averaged 59%.

We did not assess emergence survival of steelhead, but do not expect it to be a problem. Steelhead fry are better able to tolerate fine sediment than salmon. At the time of emergence, steelhead fry are smaller and better able to emerge through the restricted gravel interstices.

Substrate composition at the time of fry emergence is influenced by previous streamflows and sediment loading. Estimated survival through fry emergence was comparatively high following the relatively stable flows, generally from about 11 to 13 cfs (measured at the SPTSP gage), that occurred during the 1983/84 incubation period. These streamflows and 1983/84 streambed conditions provided suitable conditions for fry emergence. If permitted, increased sedimentation of the streambed will reduce salmonid survival during both incubation and emergence phases.

JUVENILE REARING

Most emerging fry of both species remain in the stream feeding and growing during their first summer. The quantity and quality of summer rearing habitat for juveniles have been considered by us and by biologists of CF&G to sometimes limit populations of both species in Lagunitas Creek. Both the amount and quality of rearing habitat are functions of water depth, water velocity, substrate, and cover characteristics. Streamflows directly affect water depths and velocities and indirectly affect substrate and cover characteristics.

We measured juvenile steelhead summer rearing habitat increasing with increased flow up to 5 cfs in the State Park Reach and 12 cfs in the Tocaloma Reach in 1978 and 1979 (Kelley and Dettman 1980). CF&G biologist Gary Smith estimated that in 1982 juvenile steelhead habitat increased with streamflow up to approximately 30 cfs (Smith 1986). Summer flows have historically been less than 2 cfs. We did not study the relationship between flow and juvenile salmon habitat in Lagunitas Creek but believe that it is similar to that for steelhead.

Substrate characteristics strongly influence the quality and quantity of juvenile salmonid rearing habitat. Cobble larger than about 45 mm in diameter provides cover for juvenile salmonids but the more that cobble or boulder is embedded in sediment the less cover it provides. We found that relatively small increases in embeddedness were associated with large decreases in juvenile steelhead population densities in Lagunitas Creek. A slight increase in embeddedness could easily negate the benefits of increased summer flows.

SALMONID EMIGRATION

Many salmon and steelhead smolts emigrate from Lagunitas Creek from March through June. Most emigrate during April and May. In 1983, streamflows were high during winter and spring and many smolts did not emigrate until June. Delayed emigration can adversely affect smolts by exposing them to elevated water temperatures in the Lagunitas Creek estuary during late spring.

The general time of smolt emigration and periods of peak emigration were similar between 1984 and 1985. Flows measured at the SPTSP gage in April and May were relatively stable and averaged 12.6 cfs and 10 cfs in 1984 and 17.2 cfs and 11 cfs in 1985. Streamflows of this magnitude during April and May were suitable for salmonid emigration from Lagunitas Creek.

The numbers of salmon smolts captured in our trap continuously increased over the 3-year study period, and the highest number of steelhead smolts was collected in 1985. Although the numbers of smolts produced in the creek have increased, they are still quite low.

Numbers of smolts and the age and size composition of the smolt population were highly variable among the 3 years that we examined. Numbers, age, and size of smolts that emigrate in any given year depend on conditions that occurred earlier that same year and in each of the 2 previous years.

ESTUARINE ENVIRONMENT

Nearly all salmonids were collected in the upper section of the estuary where there is more shade, riparian and instream cover, and where salinity is lower and water temperatures cooler.

Water temperatures through much of the estuary reached high levels considered to be harmful to juvenile salmonids during part of the emigration period. This is a problem that requires further investigation.

Salmonid smolts and their most important food source, <u>Neomysis</u> <u>mercedis</u>, were both associated with cooler water temperature and lower salinity. Water temperatures and salinity concentrations increased farther upstream in the estuary as flows declined during spring.

CHAPTER 2 - LAGUNITAS CREEK AND ITS FISHERIES RESOURCES

INTRODUCTION

Lagunitas Creek drains much of west central Marin County, California (Figure 2-1). It originates on the northern slope of Mt. Tamalpais, flows approximately 8 miles through three small reservoirs, and discharges into Kent Lake. From Kent Lake, Lagunitas Creek flows northwesterly for about 14 miles before emptying into the southern end of Tomales Bay near the community of Point Reyes Station.

Five dams have been constructed in the Lagunitas Creek system. Existing dams on Lagunitas Creek (and year of construction) include Lagunitas Dam (1872), Alpine Dam (1918), Bon Tempe Dam (1948), and Peters Dam (1954). In 1961 Nicasio Creek, a major tributary, was dammed about 1 mile upstream from its confluence with Lagunitas Creek. The impoundment behind Peters Dam, Kent Lake, is presently the largest of the municipal supply reservoirs operated by MMWD (Table 2-1).

The original Peters Dam provided a storage capacity in Kent Lake of 16,700 acre-feet. Construction to raise the spillway crest of the dam 45 feet began in 1979 and was completed in 1983. Enlargement of Peters Dam nearly doubled the storage capacity of Kent Lake—from 16,700 to 32,700 acre-feet.

Prior to 1979, MMWD had no agreement with CF&G to provide instream flow releases downstream from Peters Dam and no releases were required by the State Water Resources Control Board permits. However, about 400 acre-feet of water has usually been released from May through October to satisfy downstream water rights agreements, with approximately 20% from Kent Lake and 80% from Nicasio Reservoir (Anonymous 1978). In an October 1979 agreement with CF&G, MMWD agreed to release minimum flows of 10 cfs from Kent Lake during winter and 3 cfs during summer of normal water years to maintain salmon and steelhead resources in Lagunitas Creek. The State Water Resources Control Board reviewed that agreement and a concomitant water rights application by MMWD. Decision 1582 set an interim regimen of instream flows and required further investigation of instream flow needs and measures to reduce detrimental sedimentation of the streambed.

LAGUNITAS CREEK

For study purposes, we divided Lagunitas Creek downstream from Peters Dam into five distinct reaches. Boundaries of the reaches in Lagunitas Creek, longitudinal profile of the creek, and identifying landmarks are shown in Figure 2-2. Major tributaries that join Lagunitas Creek downstream from Peters Dam include San Geronimo, Devils Gulch, Nicasio, and Olema creeks.

Each study reach in Lagunitas Creek and major tributaries is different. Following is a brief description of the hydraulic, morphologic, streambed sediment, and biologic characteristics of each reach.

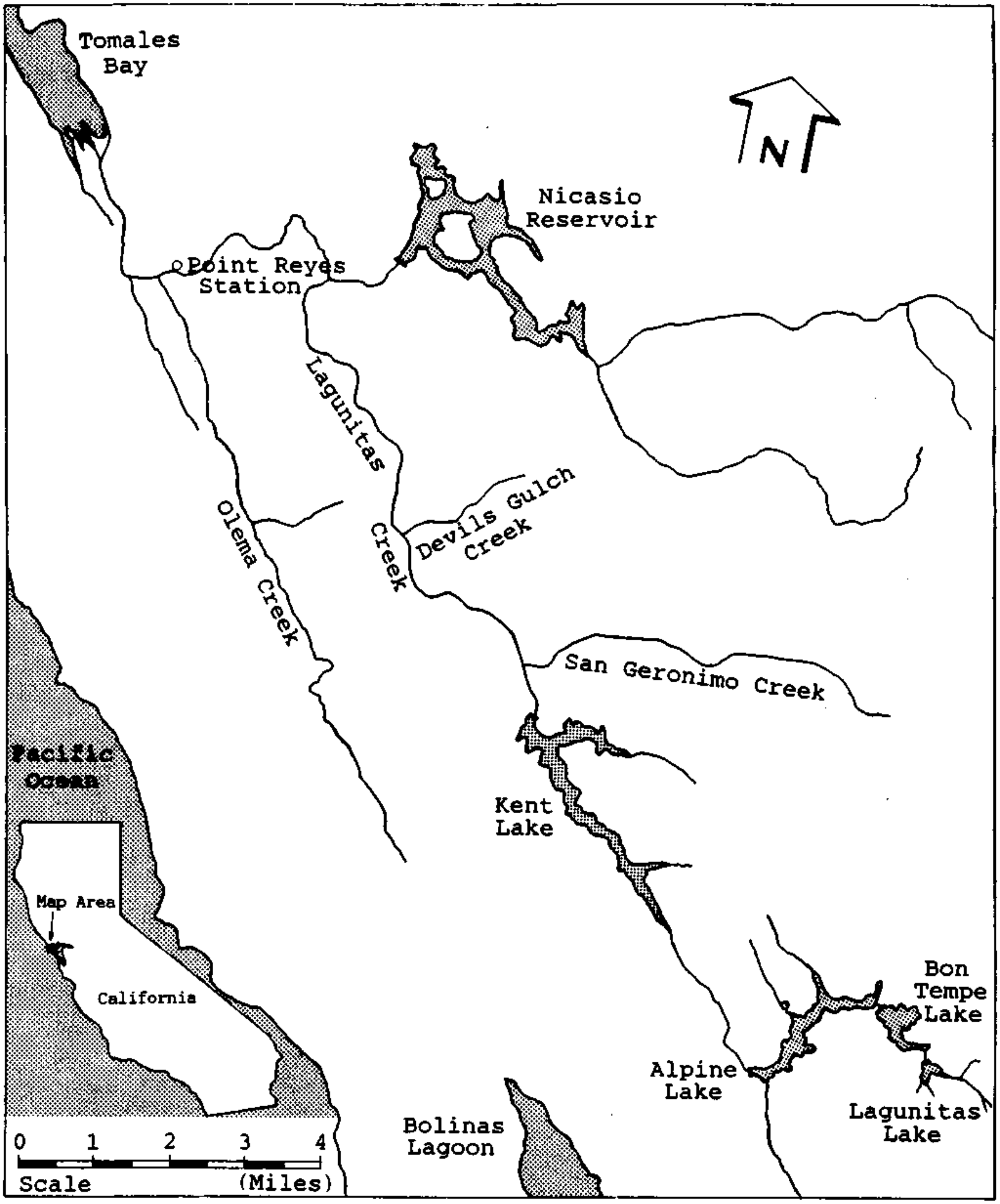


Figure 2-1. Lagunitas Creek and its major tributaries, Marin County, California.

Table 2-1. Reservoirs in the Lagunitas Creek Basin, Marin County, California (from Emig 1985).

	LAGUNITAS	BON TEMPE	ALPINE	KENT	NICASIO
Type	Earth fill	Earth fill	Concrete	Earth fill	Earth fill
Construction Completion Date	1872	1948	1942	1983[1]	1961
Height (ft)	50	94	140	225	115
Capacity (ac-ft)	390	4300	8900	32,700	22,700
Storage Elevation (ft)	784	718	646	400	165
Surface Area (ac)	23	130	219	460	869

[1] Original construction was completed in 1954 with 16,700 acre-feet capacity.

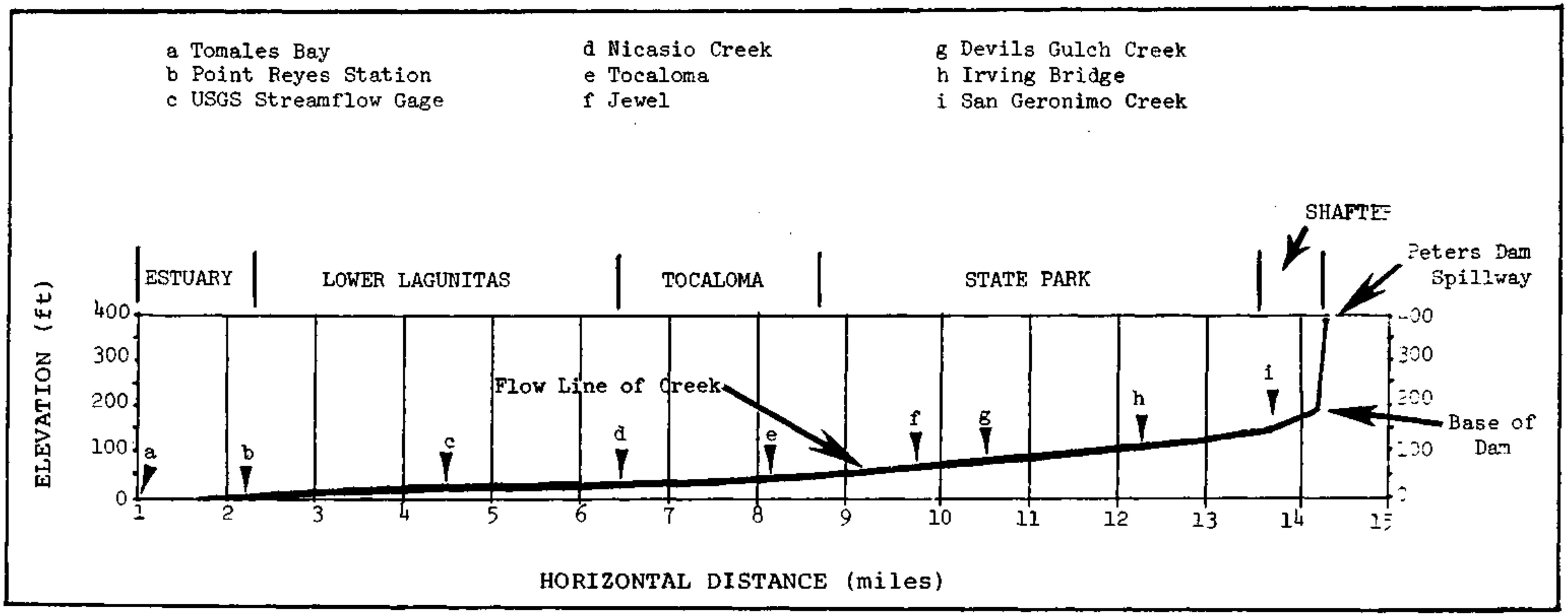


Figure 2-2. Major reaches, longitudinal profile, and landmarks of Lagunitas Creek downstream from Peters Dam.

Shafter Reach. The reach from Peters Dam downstream to Shafter Bridge is steep, with a gradient of about 2%, and has low concentrations of sand and fine material in the streambed.

State Park Reach. In the 4.9-mile reach from Shafter Bridge to a point about one-half mile upstream from the Tocaloma Bridge, the creek flows through a relatively steep and narrow canyon that is part of SPTSP. In this reach, the creek is well shaded by a canopy of coast redwoods and Douglas firs. The State Park Reach contains the premier fish habitat in the system, and receives major recreational use in the form of camping, picnicking, group day-use, hiking, swimming, jogging, and bicycling.

Tocaloma Reach. In the 2.1-mile reach from the lower boundary of the State Park Reach to the confluence of Lagunitas and Nicasio creeks, the creek flows through a broad canyon. The creek is aggraded and the streambed is covered with coarse sand and fine gravel. Multiple channels, logjams, and other woody debris are common. Riparian areas consist of a mixed evergreen/deciduous canopy interspersed with open pastureland.

Lower Lagunitas Creek. Located in a wide valley floor, this reach extends from the mouth of Nicasio Creek downstream to the vicinity of the Highway 1 Bridge in Point Reyes Station. The streambed is almost entirely comprised of sand and silt and becomes fully alluvial near Point Reyes Station. Most of the creek is overgrown with dense riparian vegetation, except for isolated areas grazed by cattle.

Lagunitas Creek Estuary. The Lagunitas Creek Estuary, where saline and fresh water mix, is about 2.8 miles long and extends from the vicinity of the Highway 1 Bridge to the mouth of Lagunitas Creek in the southern end of Tomales Bay. The estuary is a diked slough bounded by pastures, and varies in width from 30 to 200 feet. Juvenile salmonids emigrating from Lagunitas Creek pass through the estuary on their way to the ocean. Most of the estuary is shallow, has a silt and sand substrate, and provides virtually no cover or shade. An extensive alluvial fan, almost completely exposed during low tides, dominates the southern end of Tomales Bay. The area downstream from the Highway 1 Bridge is the only portion of the Lagunitas Creek system that has been open to recreational fishing since 1982.

San Geronimo Creek. A major tributary, San Geronimo Creek joins Lagunitas Creek near Shafter Bridge. The creek flows through several small towns, pastureland, and a golf course. The streambed is covered with sand and fine gravel, and the streambanks are unstable and erodible. San Geronimo Creek is a major source of sediment contribution to Lagunitas Creek.

Devils Gulch Creek. A smaller tributary located primarily within the State Park boundaries, Devils Gulch Creek flows through a narrow canyon with a steep gradient. The creek is well shaded due to a mixed forest canopy, and receives moderate recreational use in the form of picnicking and day-hiking.

HISTORICAL STREAMFLOWS

The USGS has recorded streamflows in Lagunitas Creek near Point Reyes Station since October 1974. Mean monthly streamflows at this gage are shown in Table 2-2. The dry season usually extends from April or May through October or November. Streamflows in Lagunitas Creek during the dry season result from limited natural accretion and water released from Kent Lake and Nicasio Reservoir. The first fall rainstorms usually recharge the watershed without causing increased streamflows. Once the ground is saturated, rainfall results in runoff and streamflows of variable magnitude and duration. After the wet season, streamflows rapidly decline, usually in April or May.

In 1982, MMWD's consultants established a streamflow gaging station on Lagunitas Creek in the State Park. This gaging station was established because:

1) it was located within the area of premier fish habitat, the State Park Reach; and

2) streamflows measured at the SPTSP gaging station are not influenced by water released or spilled from Nicasio Reservoir. The USGS also began recording flow at the SPTSP gage in water year 1983; and, on March 1, 1983, MMWD discontinued its gage.

Mean daily streamflows at the SPTSP gage in water years 1983, 1984, and 1985, are shown in Figures 2-3, 2-4, and 2-5. These hydrographs illustrate that the frequency and magnitude of runoff differed in the 3 years we studied Lagunitas Creek. Water year 1983 (i.e., October 1, 1982 through September 30, 1983) was the wettest year on record for the North Bay area. Water year 1984 began extremely wet, but rainfall was light following December resulting in near normal total runoff. Water year 1985 was relatively dry with only two major isolated rainstorms after November 1984.

FISH RESOURCES

The goal of investigations ordered by the State Water Resources Control Board was to develop flow regimes for the protection of coho salmon and steelhead trout resources in Lagunitas Creek.

Salmon and steelhead share many life history characteristics. Both species spend their adult life in the Pacific Ocean and return to spawn in freshwater. Adult salmon enter Lagunitas Creek in autumn and early winter when rainstorms produce runoff and increased streamflows (Figure 1-1). Adult steelhead enter the creek in winter and early spring. Both species migrate upstream to spawn, usually in the tails of glides or heads of riffles with suitable combinations of water depth, velocity, and substrate. The eggs are laid in a pit in the streambed and covered with gravel where they incubate. After the eggs hatch in winter and spring, fry emerge from the gravel and distribute themselves in the creek. Most of the young fish reside in the stream one full year or more before emigrating as "smolts" to begin the ocean phase of their life cycle. However, some fish leave freshwater the year in

Table 2-2. Mean monthly streamflow (cfs) at the USGS gage near Point Reyes Station.

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ACRE-FEET
1974-1975	3.3	2.8	16.8	13.6	278.0	509.0	55.1	8.2	4.6	3.4	3.4	3.0	53,610
1975-1976	5.2	3.7	2.8	2.4	8.6	11.5	11.0	2.0	1.1	1.8	1.5	2.0	3,220
1976-1977	0.2	1.4	1.5	9.0	3.5	7.4	1.6	0.7	0.5	1.8	1.7	1.1	1,840
1977-1978	0.3	56.7	68.1	369.0	467.0	299.0	116.0	10.5	3.3	2.5	3.0	2.3	82,760
1978-1979	1.5	2.3	2.4	145.0	312.0	126.0	28.7	8.8	2.9	3.3	2.8	2.7	37,320
1979-1980	7.7	27.4	179.0	525.0	620.0	174.0	39.8	11.7	2.4	2.0	2.5	2.2	95,440
1980-1981	2.8	2.1	9.7	140.0	31.5	119.0	13.1	3.5	1.8	2.3	3.1	2.1	20,080
1981-1982	3.5	56.8	329.0	991.0	411.0	415.0	531.0	13.9	7.2	5.0	3.7	3.2	166,800
1982-1983	8.7	177.0	271.0	499.0	937.0	1109.0	146.0	86.4	14.1	8.7	5.9	5.8	194,700
1983-1984	19.2	132.0	542.0	96.4	44.8	49.4	18.3	11.3	8.5	5.3	4.3	4.3	57,050
1984-1985	6.1	165.0	73.2	34.8	183.0	98.3	34.4	12.6	7.8	5.9	4.7	5.3	37,280
1985-1986	5.8	14.1	29.2	137.0	1193.0	482.0	25.4	12.5	7.2	5.7	4.7	5.4	111,100
1986-1987	5.1	5.8	7.8	29.0	170.0	109.0	13.3	9.1	6.4	5.3	5.3	4.6	21,720

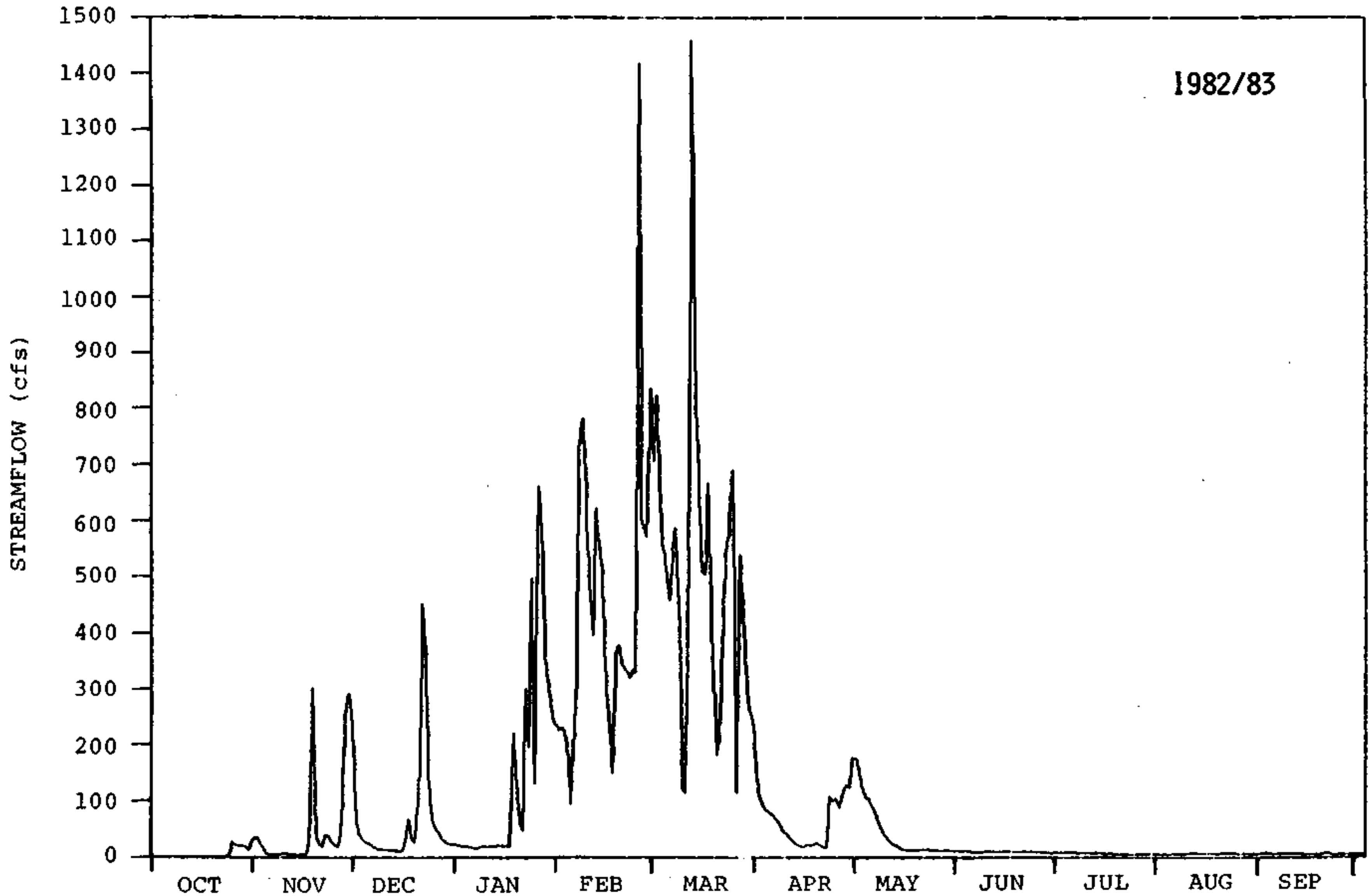


Figure 2-3. Mean daily streamflow measured at the SPTSP gage in Lagunitas Creek from October 1, 1982 through September 30, 1983. Flows prior to March 1, 1983 were measured by consultants to MMWD, and by the US Geological Survey from March 1, 1983 onward.

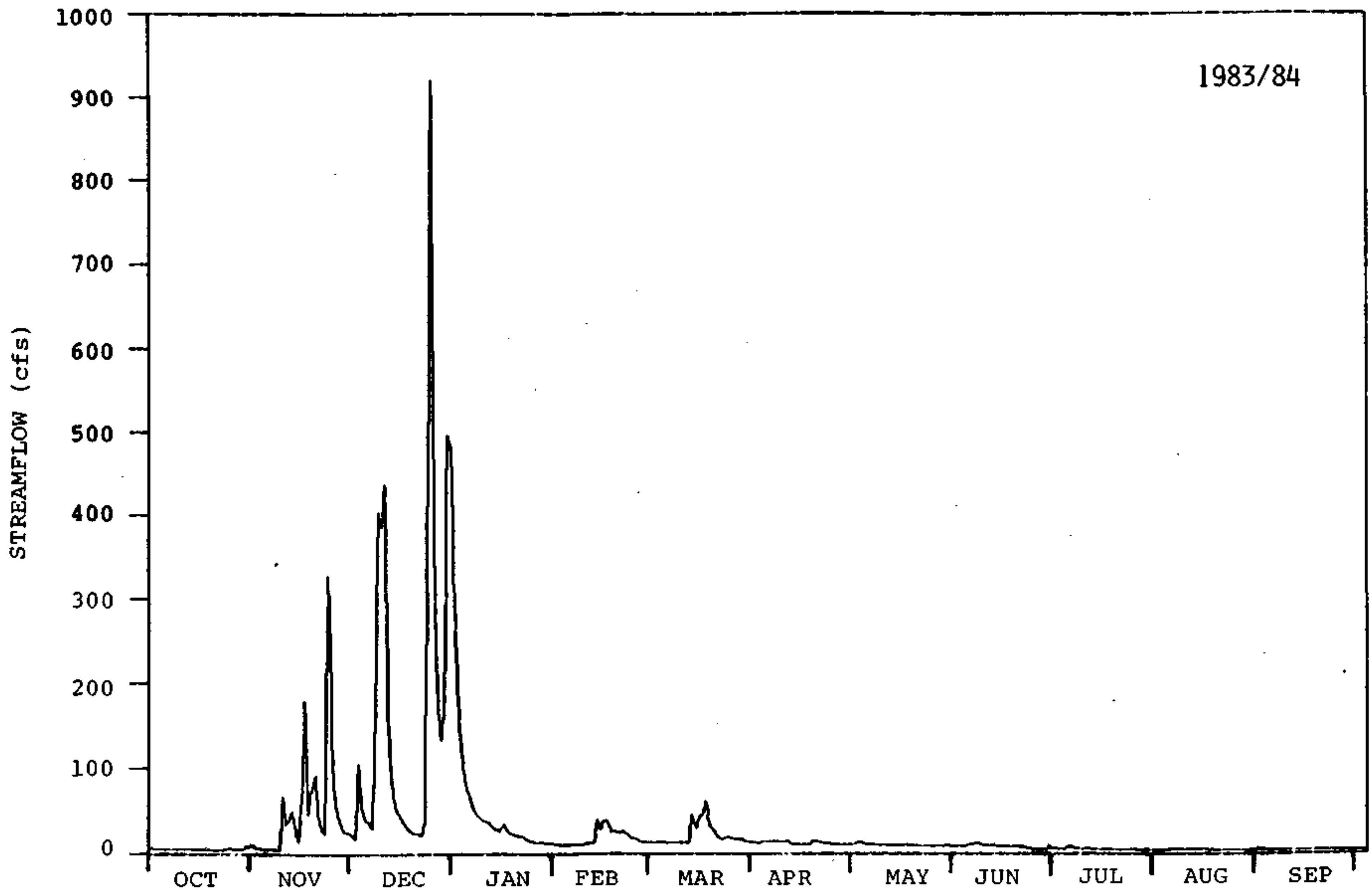


Figure 2-4. Mean daily streamflow measured at the SPTSP gage in Lagunitas Creek from October 1, 1983 through September 30, 1984.

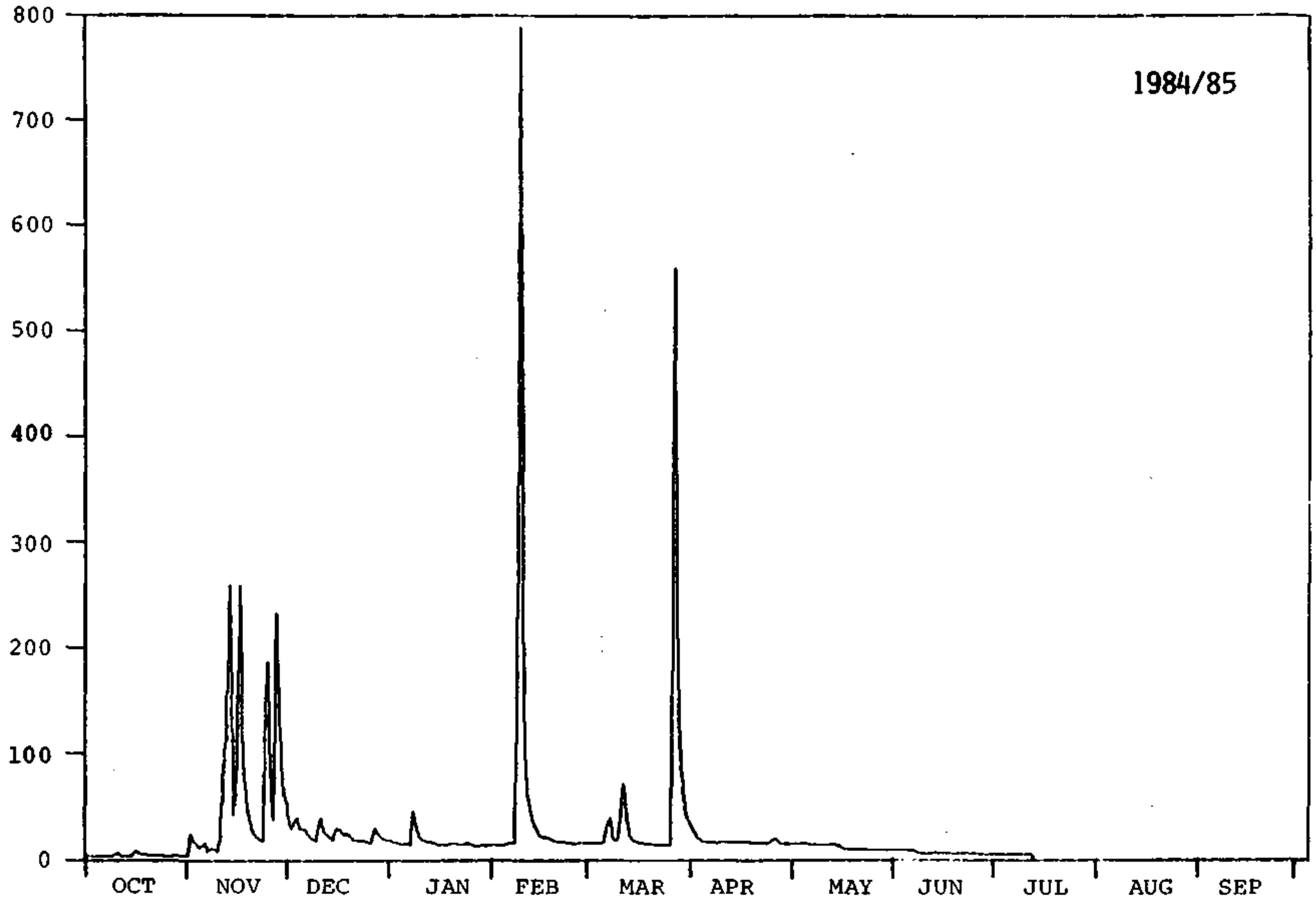


Figure 2-5. Mean daily streamflow measured at the SPTSP gage in Lagunitas Creek from October 1, 1984, through July 10, 1985. Flow records after July 10, 1985 were not yet available from the US Geological Survey.

which they hatch. These age 0+ fish may leave the creek due to the flushing effect of spring freshets, high numbers of fry exceeding available habitat or carrying capacity of the creek, or rapid growth in the spring which may stimulate early smolting.

The life cycle of salmon and steelhead differ in several important ways. Most salmon spend 2 years in the ocean before they return to spawn. Adults spawn once and die soon afterwards. Because of the rigid cycle, poor reproductive success during any given year usually results in poor spawning runs 3 years later. Successive years of poor reproductive success caused by adverse conditions can reduce populations to low levels for several generations.

Not all adult steelhead die after spawning. Some return to the ocean and spawn as many as 3 or 4 different times, at ages varying from 2 to 6 years. Due to their relatively wide range in age at first spawning, their ability to spawn repeatedly, and their later spawning success, steelhead populations are generally more resilient to adverse environmental conditions than salmon populations.

This report examines the influence of streamflow and other environmental factors on the life history stages of salmon and steelhead in Lagunitas Creek.

Other biota of Lagunitas Creek were described in the EIR and its Appendix on the proposed raising of Kent Lake (Anonymous 1978). An additional report on the freshwater shrimp Syncaris pacifica in Lagunitas Creek was issued in 1981 (Li 1981).

CHAPTER 3 - UPSTREAM MIGRATION

Adult coho salmon move into Tomales Bay from the ocean in early full and congregate in the estuary of Lagunitas Creek prior to any increase in freshwater outflow above base summer levels. As in other coastal streams, salmon migrate upstream to spawn when autumn storms provide sufficient outflow.

Records of the first sightings of salmon upstream in Lagunitas Creek date back to 1949. Observations were made by Game Warden Al Giddings, CF&G employees operating the Nicasio fish trap, or by biologists from D. W. Kelley & Associates (Table 3-1). The earliest sighting of salmon was on November 6, 1983. Nearly half of the first sightings occurred during the month of November.

ATTRACTION FLOWS

Historical Information

Information on the daily upstream migration of salmon is available from Nicasio fish trap catch records for a 7-year period from 1963/64 to 1969/70. A comparison of daily salmon captures and estimated flows during the 7-year period indicates that fish migrated upstream in response to storm flows (Figure 3-1). A mean daily flow of 28 cfs in November 1967 is the lowest storm flow that attracted salmon to the trap over the 7 years of catch information (Table 3-2).

The 1979 Fish and Game Agreement recognized the association between storm flows and the upstream migration of salmon. This agreement called for triggering flow releases for upstream migration when the first November mean daily flow at the USGS gage near Point Reyes Station reached 25 cfs. The day following this "triggering" flow, MMWD was to begin release of enough water from Kent Reservoir to maintain a minimum of 35 cfs for 3 consecutive days, measured at the SPTSP gage.

We planned to test this 25 cfs "trigger" and the 35 cfs upstream migration flow and tried to test these flows on four occasions.

Attraction Flow Experiment 1982

A test of the 25 cfs "trigger" and 3-day 35 cfs migration flow on November 1, 1982 did not attract adult salmon into Lagunitas Creek. We believe that no salmon were congregated in the estuary at that time.

A second test, in mid-November 1982, attracted fish into the creek. However, during the test a rainstorm produced one mean daily flow of 302 cfs. We do not know if fish would have been attracted into the stream without that one day of high flows.

Table 3-1. Date of first sighting of coho salmon in Lagunitas Creek.

WATER YEAR	DATE	SOURCE	WATER YEAR	DATE	SOURCE
1949	Dec 6	Game Warden	1964	Nov 7	Nicasio Trap
1951	Dec 4	"	1965	Nov 10	"
1952	Dec 2	"	1966	Nov 25	"
1954	Dec 19	"	1967	Nov 20	"
1955	Dec 5	"	1968	Nov 16	"
1956	Dec 7	"	1969	Nov 17	"
1958	Dec 21	"	1970	Dec 13	"
1959	Jan 5	"	1971	Dec 1	"
1960	Jan 7	"			
1961	Nov 27	"	1983	Nov 19	Kelley & Assoc.
1962	Dec 16	"	1984	Nov 6	Kelley & Assoc.

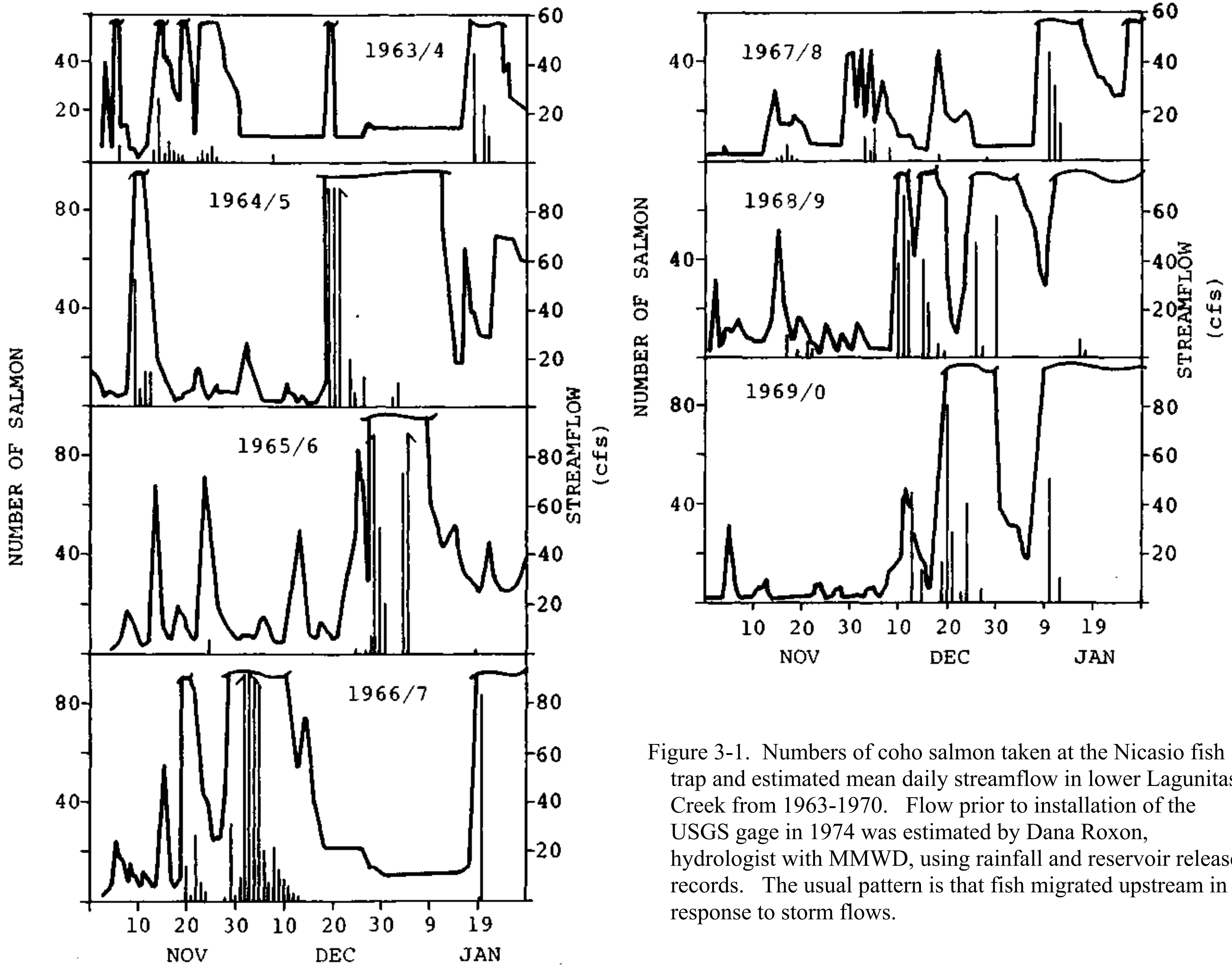


Figure 3-1. Numbers of coho salmon taken at the Nicasio fish trap and estimated mean daily streamflow in lower Lagunitas Creek from 1963-1970. Flow prior to installation of the USGS gage in 1974 was estimated by Dana Roxon, hydrologist with MMWD, using rainfall and reservoir release records. The usual pattern is that fish migrated upstream in response to storm flows.

Table 3-2. First coho salmon captured in the Nicasio fish trap and estimated mean daily streamflows in lower Lagunitas Creek, 1963 to 1969.

Date of Capture		High Flow Preceding Capture (cfs)	Flow at Time of Capture (cfs)
1963	Nov 7	95	15
1964	Nov 10	71	166
1965	Nov 25	72	42
1966	Nov 20	1	261
1967	Nov 16	28	14
1968	Nov 17	22	12
1969	Dec 13	45	35

Attraction Flow Experiment 1983

We again tested the proposed attraction flow in the fall of 1983. Adult salmon were present in the White House Pool area of Lagunitas Creek estuary by early November 1983. From November 3-8, a few salmon were reportedly being caught by sport fishermen each day, and fish were observed rolling on the surface of the water.

The water level in Nicasio Reservoir had remained relatively high throughout the summer of 1983. To postpone the time when Nicasio Reservoir spilled and increase our opportunity to test the proposed attraction flows, Nicasio Reservoir was drawn down by releasing 27.5 cfs from October 20 through November 1, 1983. Following that drawdown, MMWD released about 5 cfs from Nicasio Reservoir through November 4, at which time flow was reduced to about 0.5 cfs.

On November 9, 1983, we established an observation station in Lagunitas Creek at the Tocaloma pipeline crossing about 500 ft upstream from the confluence with Nicasio Creek. A riprap barrier dam was built across the entire width of the creek. In the center of the dam we constructed a 6-foot-wide x 12-foot-long chute, with a 6 foot x 8 foot bright yellow plywood board anchored to the creek bottom. To migrate upstream, fish had to swim up the chute and over the board.

The Marin Municipal Water District began releasing enough water from Kent Lake to maintain 35 cfs, at 0900 hrs on November 10, 1983, measured at the SPTSP gage. We began our observations at 0800 hrs that same day, recording the time and number of fish passing the observation station. Night observations were made by shining spotlights across the chute, gently illuminating the bright yellow board.

Within a few hours a storm struck the area, producing heavy rain and increasing streamflow above the 35 cfs experimental flow (Figure 3-2). The first two fish were observed migrating upstream at about 1530 hrs, when streamflow at the SPTSP gage first reached 70 cfs and flows at our observation stations had first reached 35 cfs. By 1615 hrs visibility was markedly reduced, and at 1900 hrs observations were suspended for the remainder of the night. Streamflow rapidly declined to about 30 cfs by 0800 hrs on November 11, observations were resumed and conducted until 1230 hrs, November 13, 1983. Mean daily flows were 68, 35, 39, and 51 cfs on November 10, 11, 12, and 13, 1983, respectively.

Near mid-day November 11, when streamflow was less than or equal to 35 cfs, 20 fish (61% of the total number) were observed migrating upstream. Although the first two fish and the majority of all fish were observed migrating upstream at flows at or below 35 cfs, we are uncertain they would have been attracted into the creek without the pulse in streamflow. During this 4-day experiment a total of 33 fish were observed migrating upstream. Twenty-six fish (79%) were observed migrating upstream during daytime hours and 7 (21%) during nighttime hours. This pattern is similar to results of studies conducted in California on Waddell and Scott creeks

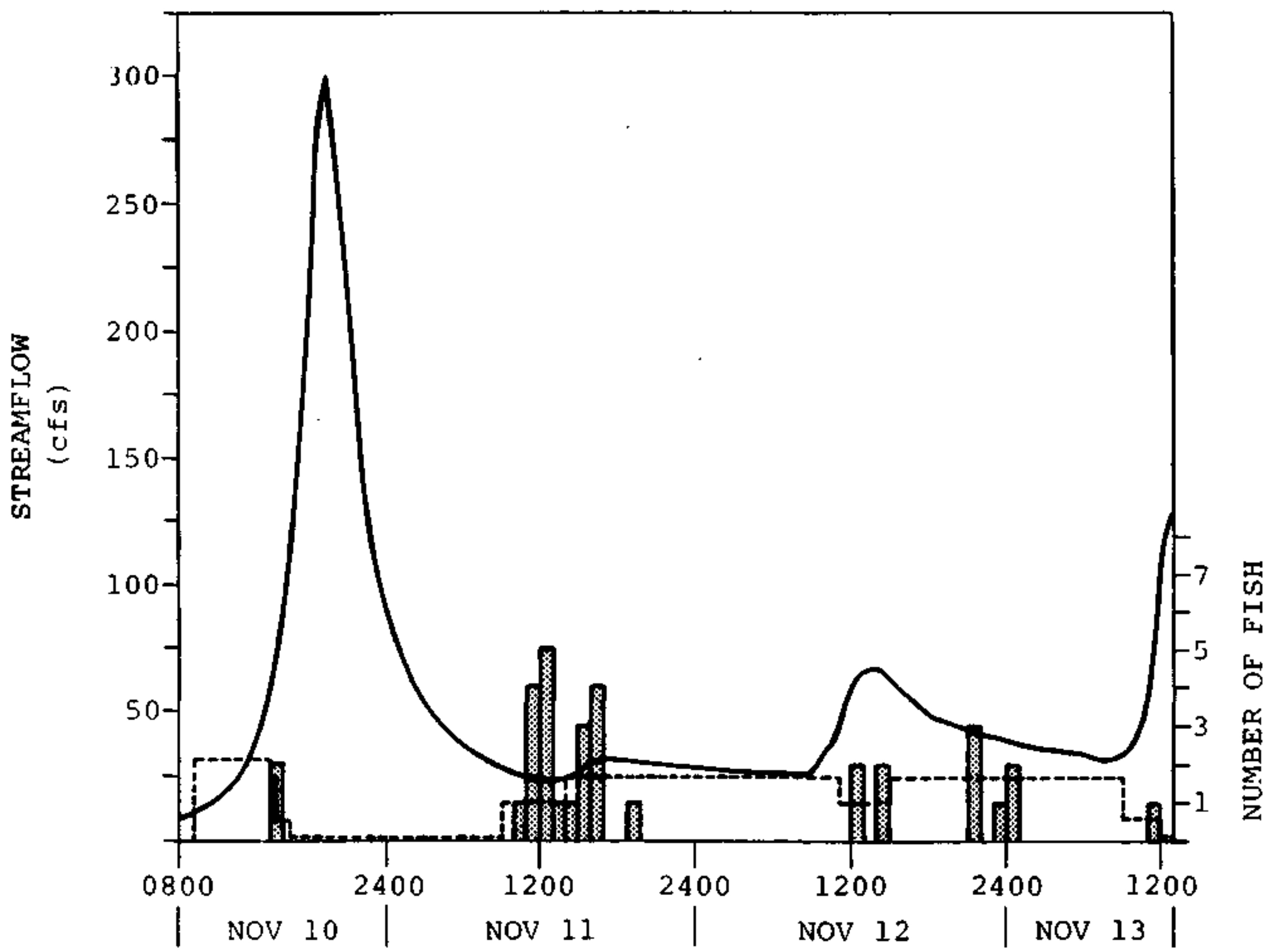


Figure 3-2. Hourly streamflow measured at the SPTSP gage (solid line), number of coho salmon observed migrating upstream (histograms), and release from Kent Lake (dashed line) in Lagunitas Creek, November 10-13, 1983. Fish observations were continuous except between 1900 hrs on November 10 through 0800 hrs November 11 due to high streamflow and turbidity.

(Shapovalov and Taft 1954) and in British Columbia on the Cowichan River (Neave 1943) which indicate salmon migrate upstream mainly during daylight hours.

In other studies, salmon and steelhead have been reported to migrate upstream in conjunction with the ascending or descending flows around peak streamflows. After a 9-year study of Waddell Creek, California, Shapovalov and Taft (1954) stated that salmon and steelhead migrated upstream during both rising and falling stream levels but did not move during peak flows. Huntsman (1945) reported that Atlantic salmon migrated upstream primarily as high water, resulting from an artificial freshet, was declining. The only period of nearly stable flows during our experiment was from 1900 hrs November 11 to 0900 hrs November 12. Streamflow during this time period would have been declining under natural conditions, but instead was maintained between approximately 25 cfs and 32 cfs by release from Kent Reservoir. Only one fish was observed migrating upstream during this period of stable flows.

Attraction Flow Experiment 1984

Based on the results of the 1983 experiment, we tested a slightly different flow regime in 1984. Rather than maintain a constant flow of 35 cfs for 3 consecutive days, we suggested releasing enough water to maintain 35 cfs at the SPTSP gage for 1 day (24 hours), returning to base summer flow of 5 cfs for 1 day, then repeating the pattern (35 cfs 1 day, 5 cfs the next) two more times. This release regime would result in the same total amount of water being released as in the originally proposed attraction flow release schedule. The difference is that the new regime would produce short pulses of 35 cfs every other day during a 6-day period, rather than a continuous flow of 35 cfs for 3 days. We believed this regime more closely resembled naturally occurring freshets and had a better chance of successfully attracting fish into the creek.

Releases began on November 2, 1984 and observations were conducted between about 1 hour before sunrise to 1 hour after sunset, from November 2-6, 1984. Only two fish were observed entering Lagunitas Creek. We believe that the test was not successful because fish were not congregated in the estuary at that time. All indications were that very few salmon returned to Lagunitas Creek at all during the 1984/85 season.

Conclusion - Attraction Flows

Results of four experiments and analysis of Nicasio fish trap data indicate that a mean daily flow of 35 cfs is probably needed to attract salmon into Lagunitas Creek. Absence of fish in the Lagunitas Creek estuary and naturally occurring freshets resulting from storms prevented additional testing of proposed attraction flows for salmon.

Minimum flows necessary to attract adult steelhead into Lagunitas Creek are unknown. During the 3-year study period, there was no opportunity to conduct tests similar to those made for salmon. In 1981/82, our field work was postponed for 1 year following the catastrophic flood on January 4, 1982.

The 1982/83 season was extraordinarily wet, and the continued recurrence of storm-induced runoff precluded testing minimum attraction flows for steelhead. In the winter of 1983/84 there was no indication that sufficient numbers of adult steelhead were present in lower Lagunitas Creek during low-flow periods between storms. Sport fishermen reported that adult steelhead congregated in the Lagunitas Creek estuary during the first week of February 1985, after a low-flow period. We arranged with MMWD to begin an attraction flow experiment on Monday, February 11, 1985. A storm struck the area and produced heavy runoff in Lagunitas Creek on February 7-10, 1985, preventing the attraction flow test. Attraction flows for steelhead have not been determined and we assume that the 35 cfs flow necessary to attract salmon into Lagunitas Creek also is sufficient for steelhead.

PASSAGE FLOWS

Critical Riffles

After fish are attracted into the creek, they must pass upstream and distribute themselves throughout the spawning areas. On November 11 and 12, 1982, biologists S. Li and J. Turner walked upstream in Lagunitas Creek from the Tocaloma pipe crossing to the mouth of San Geronimo Creek. They located five shallow riffles that were potential obstacles and "critical" to upstream migration of adult salmon and steelhead (Figure 3-3).

Flow Assessment

Flows necessary to provide passage over critical riffles were assessed by three methods—a modified Thompson (1972) method, the Thompson method itself, and direct observation. A permanent transect was established across the shallowest portion of each critical riffle, and at different streamflows the depth of the water was measured at 3-ft intervals along each transect. The width of each transect with depths greater than or equal to 0.6 ft was plotted against streamflow in Lagunitas Creek measured at Irving Bridge (Figure 3-4). With this data we then calculated the flow needed to provide water 0.6 ft deep or deeper over 5 contiguous feet of the transect, which we assumed was adequate for salmon passage. Fan Riffle requires 39 cfs to provide a 5-foot passage width for salmon, and all other critical riffles require flows less than 32 cfs (Table 3-3).

This method is a modification of the Thompson (1972) method which is commonly used by fisheries agencies. Thompson defined the flow needed for salmonid passage in Oregon streams as the minimum flow that provides water 0.6 ft deep or deeper across 25% of the stream width over the shallowest course from bank to bank.

According to the Thompson (1972) method, the Dog Hollar Riffle, where a flow of 61 cfs would be required, was the most difficult riffle for salmon passage. All of the other critical riffles required a flow of 40 cfs or less. The Dog Hollar Riffle presents a special problem caused by a large deposit of small gravel and sand extending diagonally across the stream. This makes the shallowest course from bank to bank greater than the stream width.

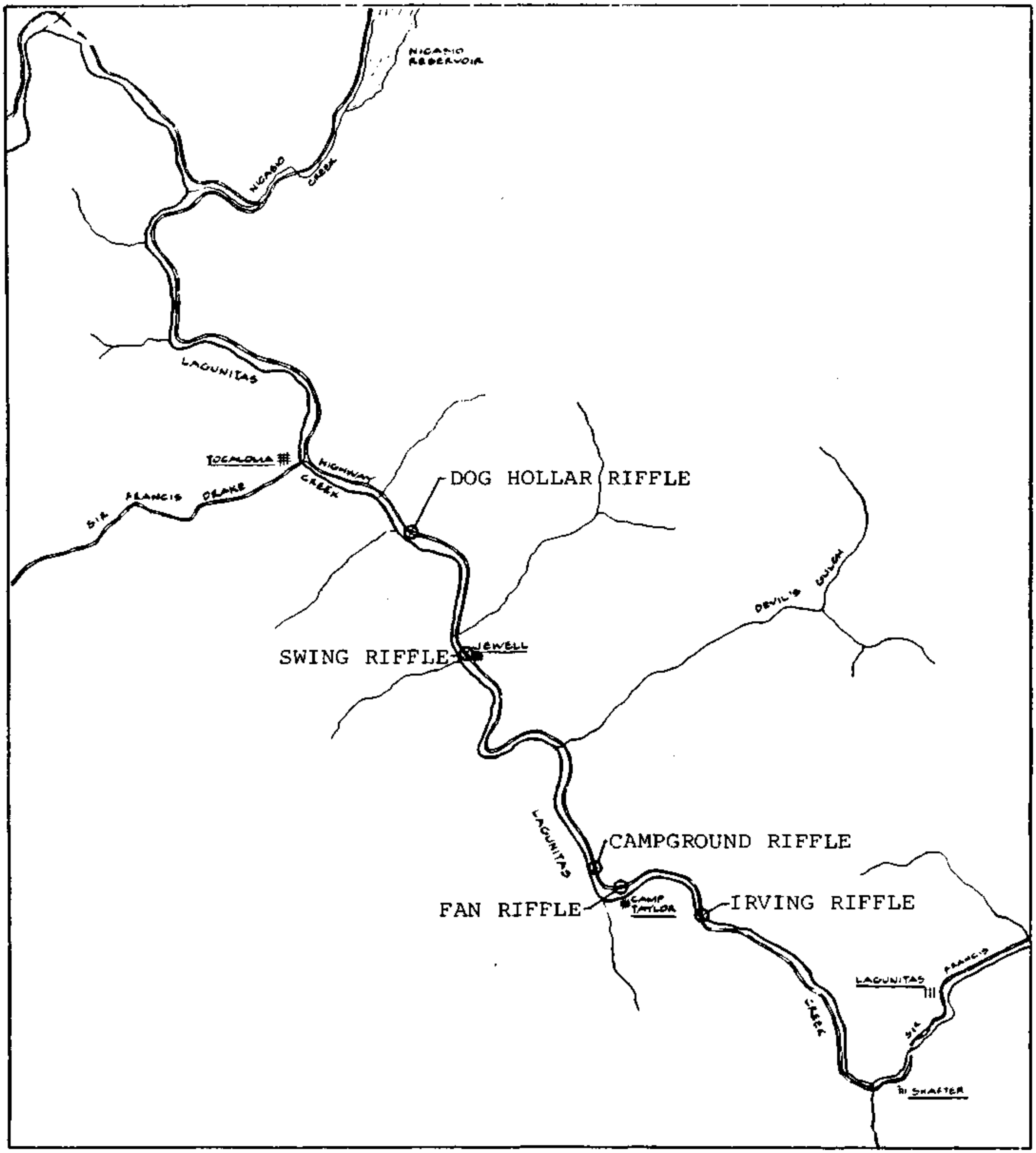


Figure 3-3. Location of five shallow riffles that are potential obstacles and "critical" to upstream migration of adult salmon and steelhead.

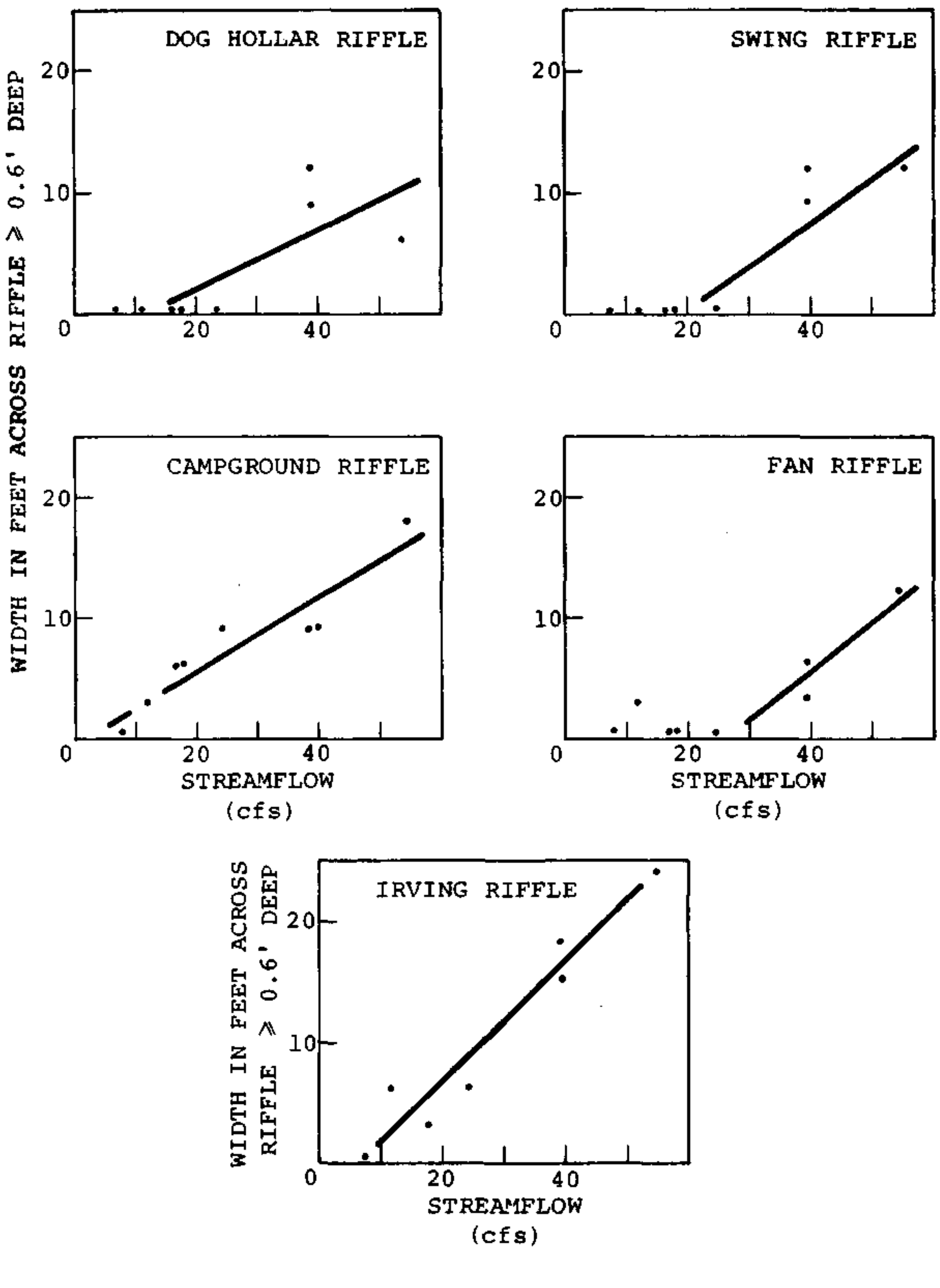


Figure 3-4. Relationship between streamflow at Irving Bridge and water deep enough for salmon migration in critical riffles.

Table 3-3. Equations relating adult coho salmon passage at critical riffles to streamflow in Lagunitas Creek measured at Irving Bridge.

RIFFLE LOCATION	EQUATION		Flow Required to Provide 0.6 ft Depth Over 5 ft Width
Dog Hollar	width = - .96 + .19(Q)		31.4
Swing	width = - 7.45 + .39(Q)		31.9
Campground	width = - .52 + .30(Q)		18.4
Fan	width = - 10.48 + .40(Q)		38.7
Irving	width = - 3.49 + .49(Q)		17.3
		MEAN	27.5

RIFFLE LOCATION	EQUATION		Flow Required to Provide 0.6 ft Depth Over 25% Stream Width (Thompson Method)
Dog Hollar	% = - 16.43 + .68(Q)		61.2
Swing	% = - 46.05 + 1.76(Q)		40.3
Campground	% = - 2.67 + .70(Q)		39.5
Fan	% = - 14.96 + 1.02(Q)		39.2
Irving	% = 1.79 + 1.07(Q)		21.7
		MEAN	40.3

With increasing flows the shallowest course widens—the percentage of width greater than 0.6 ft deep does not increase very rapidly. The Thompson (1972) method is not appropriate under such conditions.

The third method of evaluating flows needed over critical riffles was to watch salmon moving through the riffles and compare the ease of their passage with flows measured at the Irving Bridge stream gage. We recorded 68 attempts by adult upstream migrating salmon to pass these riffles at flows ranging from 29 to 80 cfs (Table 3-4). Fish easily succeeded in passing upstream in most cases. We observed only three unsuccessful passage attempts, one each at 39, 60, and 80 cfs. These unsuccessful attempts did not appear to be related to flow.

Conclusion - Passage Flows

We conclude from these various approaches that a minimum flow of 35 cfs is desirable for the passage of adult salmon through critical riffles, given 1982/83 streambed and channel conditions. Our observations were that while salmon could pass some critical riffles at lower flows, they were not often stimulated to move until flows reached about 30 cfs. Lack of flows sufficient for passage may have contributed to the decline of the salmon runs in Lagunitas Creek. The USGS gage near Point Reyes Station was established in 1974. Upstream migration and subsequent spawning of salmon would have been adversely affected by lack of flow in 4 of the past 11 years. Streamflows greater than 35 cfs for 3 consecutive days first occurred during the month of January in 3 of the years and not at all 1 year (1975/76).

There usually has been sufficient unregulated flow in Lagunitas Creek during winter to provide for upstream migration of steelhead. Based on upstream migration flows required by salmon, lack of flow over the past 11 years would probably have impaired upstream migration of steelhead only during the severe drought years of 1975/76 and 1976/77.

Table 3-4. Observations of adult coho salmon passage at critical riffles during upstream migration in Lagunitas Creek 1982/83.

RIFFLE LOCATION	DATE	STREAMFLOW (cfs)	HOURS OBSERVED		PASSAGE	
			DAY	NIGHT	SUCCESSFUL	UNSUCCESSFUL
Dog Hollar	12/20/82	29	0.5		1	0
	12/27/82	35	4.0		0	0
	11/19/82	39	2.5		10	1
	11/19/82	39		0.8	12	0
Swing	12/17/82	44	1.0		3	0
	12/17/82	98		1.5	0	0
Campground	12/18/82	32	1.9		2	0
	1/21/83	35	5.0		6	0
	11/23/82	39		0.3	1	0
	12/17/82	44	8.5		17	0
	1/20/83	50	4.5		0	0
	1/20/83	60		3.5	0	0
	1/20/83	60	2.0		3	1
	1/19/83	80	2.1		1	1
Fan	11/23/82	39	0.3		1	0
	11/23/82	39	0.5		1	0
	12/17/82	44	3.5		4	0
Irving	1/21/83	35	3.0		1	0
	12/17/82	44		2.0	0	0
	1/20/83	50	5.5		2	0
	1/20/83	80		3.5	0	0
TOTAL			44.8	11.6	65	3

CHAPTER 4 - SPAWNING AND SPAWNING SITE SELECTION

After migrating into Lagunitas Creek female salmon and steelhead select a suitable site to construct a redd and defend this site against intruders, particularly other females. The female turns on her side, places her tail against the streambed surface and lifts her body upward with a powerful muscular contraction. This lifts and loosens gravel and finer materials which are then carried downstream by the water current. Repeated contractions eventually produce a well-defined pit. Once the pit is constructed, the female and male simultaneously release their eggs and milt into the bottom. Immediately the female moves a short distance upstream and continues digging. Loosened gravel rolls downstream and buries the fertilized eggs under what usually appears as a mound of gravel.

Individual pairs of salmon generally exhibit breeding activity from 2 days to a week or longer. The male abandons the female soon after spawning. The female continues to defend the redd and the immediate surrounding territory up to 2 additional weeks (Briggs 1953). After spawning all individuals of both sexes undergo rapid physical degeneration, weaken, and die.

Unlike coho salmon, adult steelhead do not necessarily die after spawning. Some return to sea soon after spawning, and others return several months after spawning. Steelhead return to fresh water to spawn in as many as 3 or 4 different years.

To determine the time and location of spawning, we searched for salmon and steelhead redds in Lagunitas, San Geronimo, and Devils Gulch creeks periodically through the fall and winter of 1982/83 and 1983/84. Observed redds were located on a map, and numbered markers were tied to streambank vegetation to aid in relocating the redds and to avoid duplicate redd counts during subsequent searches.

DISTRIBUTION OF SALMON REDDS IN LAGUNITAS CREEK AND ITS MAJOR TRIBUTARIES

Only 139 and 44 redds were located during 1982/83 and 1983/84, respectively (Table 4-1). During both years about half of the redds were built in Lagunitas Creek and half were built in the tributaries.

In Lagunitas Creek, redds were scattered throughout a 6.9-mile section extending from below the sediment retention pond below Peters Dam to 0.7 mile above the confluence of Nicasio Creek (Figure 4-1.) Most redds were located in the upper State Park Reach of Lagunitas Creek (Table 4-1).

SALMON SPAWNING SEASON

The salmon spawning season lasted more than a month during late fall and early winter in both years. We found newly constructed redds in Lagunitas Creek and its tributaries from December 7 through January 12, 1982/83 and from

Table 4-1. Coho salmon redds located in Lagunitas Creek and its major tributaries during 1982/83 and 1983/84.

Location	Coho Salmon Redds			
	1982/83		1983/84	
	Number	Percent	Number	Percent
Lagunitas Creek	65	46.8	26	59.1
Tocaloma Reach	8	5.8	2	4.55
State Park Reach	52	37.4	24	54.55
Shafter Reach	5	3.6	0	0
San Geronimo Creek	51	36.7	7	15.9
Devils Gulch	23	16.5	11	25
TOTAL	139		44	

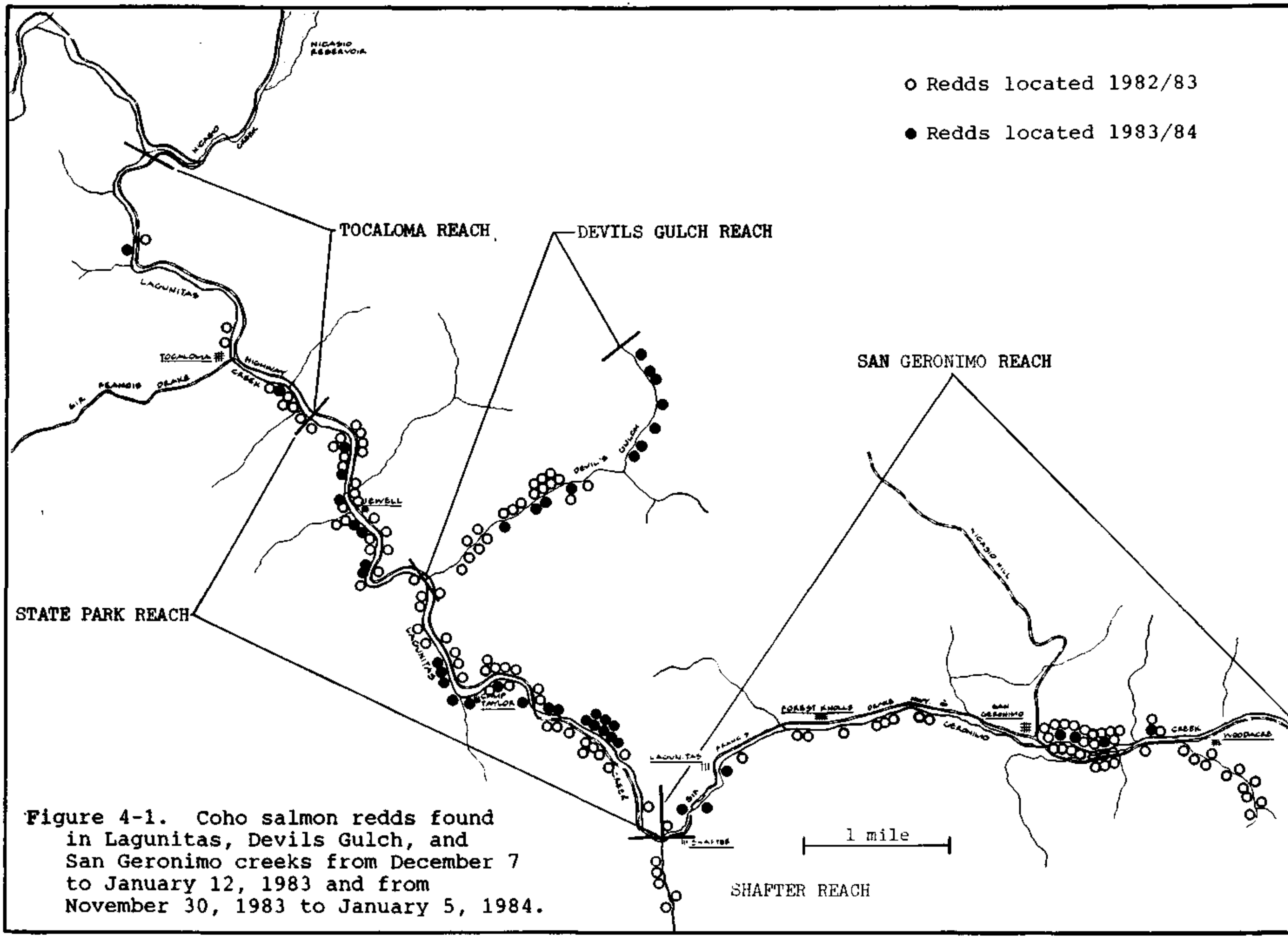


Figure 4-1. Coho salmon redds found in Lagunitas, Devils Gulch, and San Geronimo creeks from December 7 to January 12, 1983 and from November 30, 1983 to January 5, 1984.

November 30 through January 5, 19813/84. New redds were most often observed after increased flows that resulted from storms.

Lagunitas Creek

1982/83 In Lagunitas Creek no redds were observed prior to the storm of late November 1982. Turbid water precluded additional observations until December 6. Between December 6 and 10, nearly a third (20) of all new redds located in Lagunitas Creek during 1982/83 were observed (Figure 4-2). A series of storms increased flows and turbidities from January 18 through March 1983, precluding additional searches for redds.

1983/84 Storm runoff temporarily increased streamflows on several occasions between late November and late December 1983. New redds were found immediately after these storms (Figure 4-3). Although searches were periodically conducted through March, no new redds were found after January 5, 1984.

San Geronimo and Devils Gulch Creeks

Most spawning activity occurred during late December and early January in both San Geronimo and Devils Gulch creeks (Figures 4-2, 4-3).

TIME BETWEEN UPSTREAM MIGRATION AND SALMON SPAWNING

Many adult salmon entered Lagunitas Creek and its major tributaries several weeks prior to spawning. Most spawning occurred from 3 weeks to a month after adult fish had entered the creeks.

Lagunitas Creek

Twenty-two adult salmon were observed migrating upstream in Lagunitas Creek on November 19, 1982. Searches were made, but the first redds were not located until December 9, 1982. Likewise, 33 fish were observed migrating upstream in Lagunitas Creek from November 10-13, 1983. Searches were conducted but no redds were observed prior to November 30, 1983.

Low streamflow was not the reason for the delay between salmon entering Lagunitas Creek and actually spawning. Between November 19 and December 9, 1982, when fish were in the creek, streamflow was temporarily increased twice, up to mean daily flows of 39 and 292 cfs (Figure 2-3). Streamflow fluctuated repeatedly between migration and spawning during the fall of 1983. Runoff from storms increased mean daily streamflows ranging from 94 to 438 cfs on five distinct occasions between November 13 and December 15, 1983 (Figure 2-4). We believe that the Lagunitas Creek fish simply were not ready to spawn for 2 weeks to a month after entering the creek.

San Geronimo Creek

CF&G Game Warden Zumsteg observed adult salmon migrating past the Inkwells at the mouth of San Geronimo Creek on November 20 and 22, 1982.

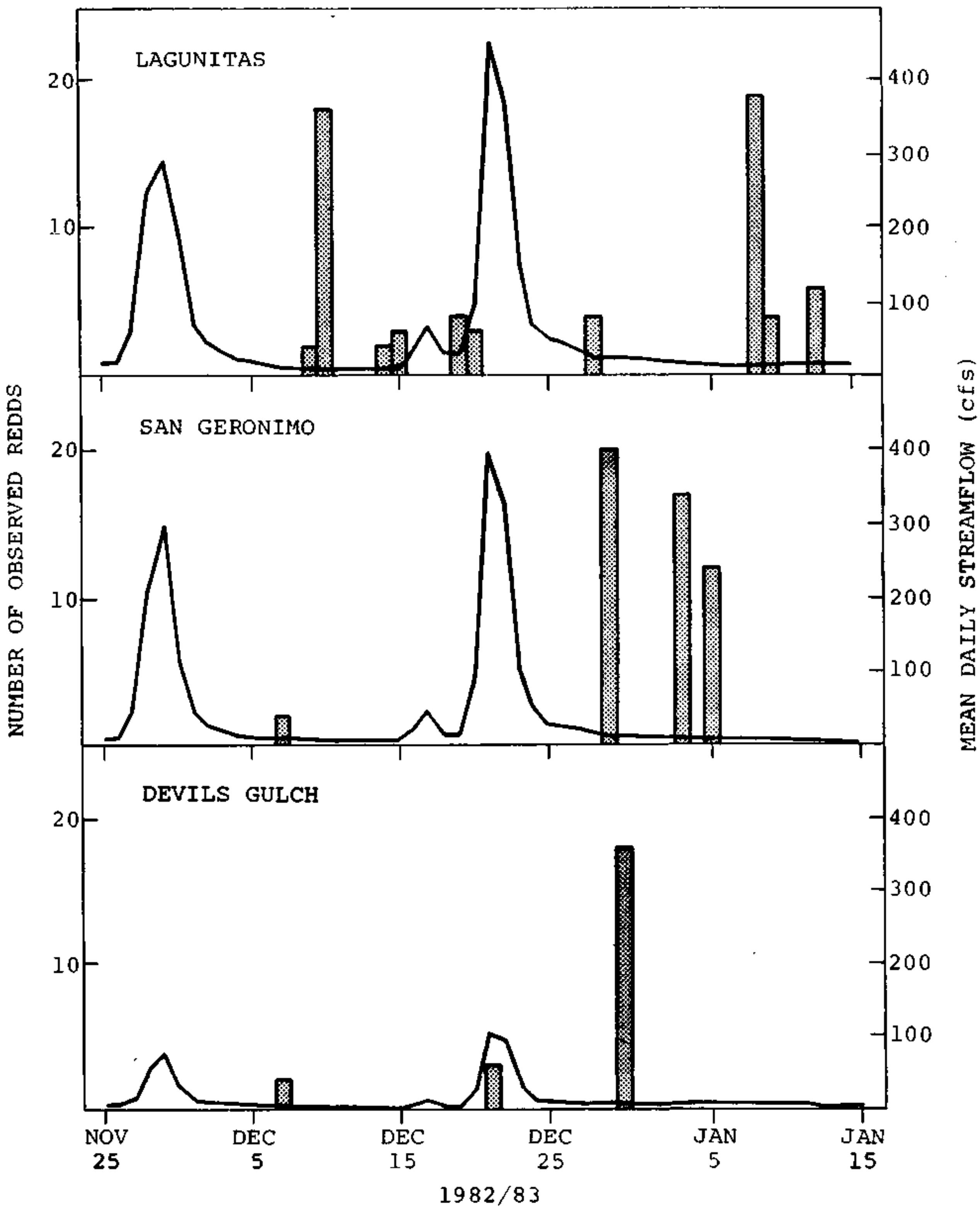


Figure 4-2. Number of new coho salmon redds (bars) and mean daily streamflows (solid line) observed in Lagunitas, San Geronimo, and Devils Gulch creeks from November 25, 1982 through January 15, 1983. Mean daily streamflows calculated from measurements at SPTSP Bridge gage (Lagunitas Creek) and Lagunitas Road Bridge gage (San Geronimo Creek). Streamflow in Devils Gulch Creek was estimated using the relationship developed by Hecht (1983): Devils Gulch Q = 0.59 (San Geronimo Q)$^{0.86}$.

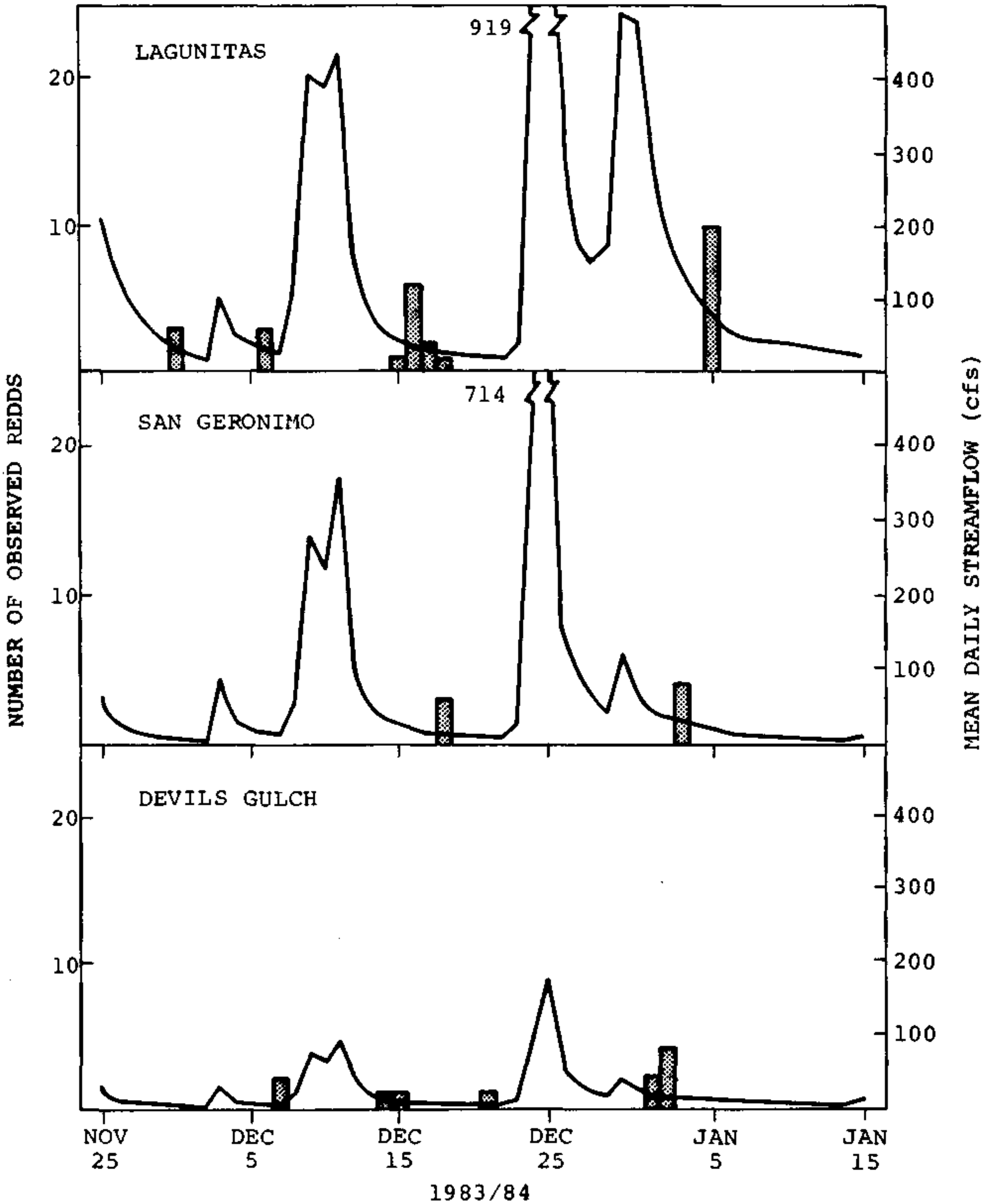


Figure 4-3. Number of new coho salmon redds (bars) and mean daily streamflows (solid line) observed in Lagunitas, San Geronimo, and Devils Gulch creeks from November 25, 1983 through January 15, 1984. Mean daily streamflows calculated from measurements at SPTSP Bridge gage (Lagunitas Creek) and Lagunitas Road Bridge gage (San Geronimo Creek). Streamflow in Devils Gulch Creek was estimated using the relationship developed by Hecht (1983): Devils Gulch Q = 0.59 (San Geronimo Q)$^{0.86}$.

Between December 6 and 15, 1982, when mean daily streamflows ranged from 3 to 14 cfs, we counted 33 adult salmon holding in several deep pools. Although adult salmon were present and searches were conducted, only two redds had been located throughout the entire length of the creek by December 16, 1982. After the storm and high streamflows that occurred during late December 1982, 49 additional redds were located. Either conditions in San Geronimo Creek were not suitable for spawning during the period of low streamflows, the fish were not ready to spawn, or both. As in Lagunitas Creek itself, the fish entering San Geronimo Creek waited nearly a month before spawning.

STREAMFLOW AT THE TIME OF SALMON SPAWNING

Adult salmon find places to spawn in Lagunitas Creek over a wide range of streamflows. Salmon were observed constructing redds or spawning in Lagunitas Creek at 17 different sites during 1982/83 and 20 sites during 1983/84. Most of the spawning was observed after flows receded to low levels following storms (Figures 4-2 and 4-3). It is possible that spawning also occurred at higher flows but was not observed due to high turbidities.

SALMON SPAWNING SITE SELECTION

Low-Water Channel

All but one of the salmon redds we observed were located in the center of the low-water channel where potential dewatering was not likely to occur. This behavior has been noted by other investigators, e.g., Shapovalov and Taft (1954; page 57), who stated: "[Coho] salmon ... so choose their redds that they are rarely exposed by naturally falling stream levels, in either Waddell Creek or other California streams." Because of this behavior, we do not expect that flow reductions, subsequent to spawning, will expose salmon redds in Lagunitas Creek.

Glide/Riffle Habitat

Redds were almost always located in the tails of glides immediately upstream from riffles. Redds were typically built near the glide/riffle boundary where the smooth surface water becomes disturbed and "breaks" into the riffle. This same phenomenon has been reported to occur in other California coastal streams (Briggs 1953; Shapovalov and Taft 1954) and probably results from natural selection. Hydraulic characteristics of the streambed in areas used for spawning may maximize reproductive success. Burner (1951) stated that spawning salmon apparently require water percolation through subsurface gravel, and this factor strongly influences spawning site selection. Shapovalov and Taft (1954) reported that spawning sites (glide/riffle habitat) selected by salmon ensure a good supply of oxygen to the incubating embryos, because a considerable amount of water flows beneath the streambed surface through a swift riffle.

High potential for stream and intragravel water exchange is an important characteristic of areas chosen by salmon for spawning. Vaux (1968) found that intragravel water flow patterns were related to the longitudinal surface profile of the streambed. He found that downwelling occurs in longitudinally convex stream sections, and upwelling occurs in longitudinally concave sections. For example, water would downwell into the streambed where incubating embryos are located and upwell back into the stream at a downstream location.

Salmon may select glide/riffle habitats for two more reasons. First, substrate in these habitats may be easier to move at low to moderate flows. Geomorphologist Barry Hecht and we observed that nearly all salmon built redds in locations where the main flow became narrower and shallower than in the glide immediately upstream. Hecht noted that additional shear is exerted on the streambed at such locations, so that gravel may be more readily moved by the water current once it is dislodged by the female salmon. Second, salmon may choose glide/riffle habitats because these locations are relatively stable during high, scouring flows. Yee (1984) studied gravel movement in spawning riffles in Prairie Creek, a small northern California coastal stream similar to Lagunitas Creek. He found that the upstream part of riffles (called the riffle's "head") experienced minimal net gravel movement, while the downstream portion of the riffles (called the riffle's "tail") was considerably scoured. His explanation was that water increases in velocity as it flows over a riffle, then produces a turbulent "rotor eddy" in the downstream pool which scours the tail of the riffle (Figure 4-4). For this reason Yee suggested that heads of riffles are more favorable locations for spawning.

In Lagunitas Creek, not all glide/riffle habitats are used for spawning. Salmon spawn in them only if combinations of water depth, velocity, and substrate composition are suitable.

Water Depth

Salmon spawning depth, estimated by measuring water depth adjacent to redds with fish present, was greatest in Lagunitas Creek and shallowest in Devils Gulch Creek (Table 4-2). However, spawning depth was not significantly different between Lagunitas, San Geronimo, or Devils Gulch creeks in either 1982/83 (Kruskal-Wallis $H' = 3.68$, $df = 2$, $P > 0.10$)[1] or 1983/84 ($H' = 1.47$, $df = 2$, $P > 0.10$). In Lagunitas Creek, depth of spawning was not significantly different between years (Wilcoxon Rank Sum $T = 94.5$, $P > 0.05$)[2].

The depth of water used for spawning in Lagunitas Creek and its tributaries was similar to depths reported elsewhere. Depths reported elsewhere average 0.6 ft in Washington (Burner 1951), 0.5 ft in California

[1] The Kruskal-Wallis test is the nonparametric analogue of the one-way analysis of variance. Test of location for K (K > 2) independent samples.

[2] The Wilcoxon Rank Sum procedure is a nonparametric test of location for two independent samples.

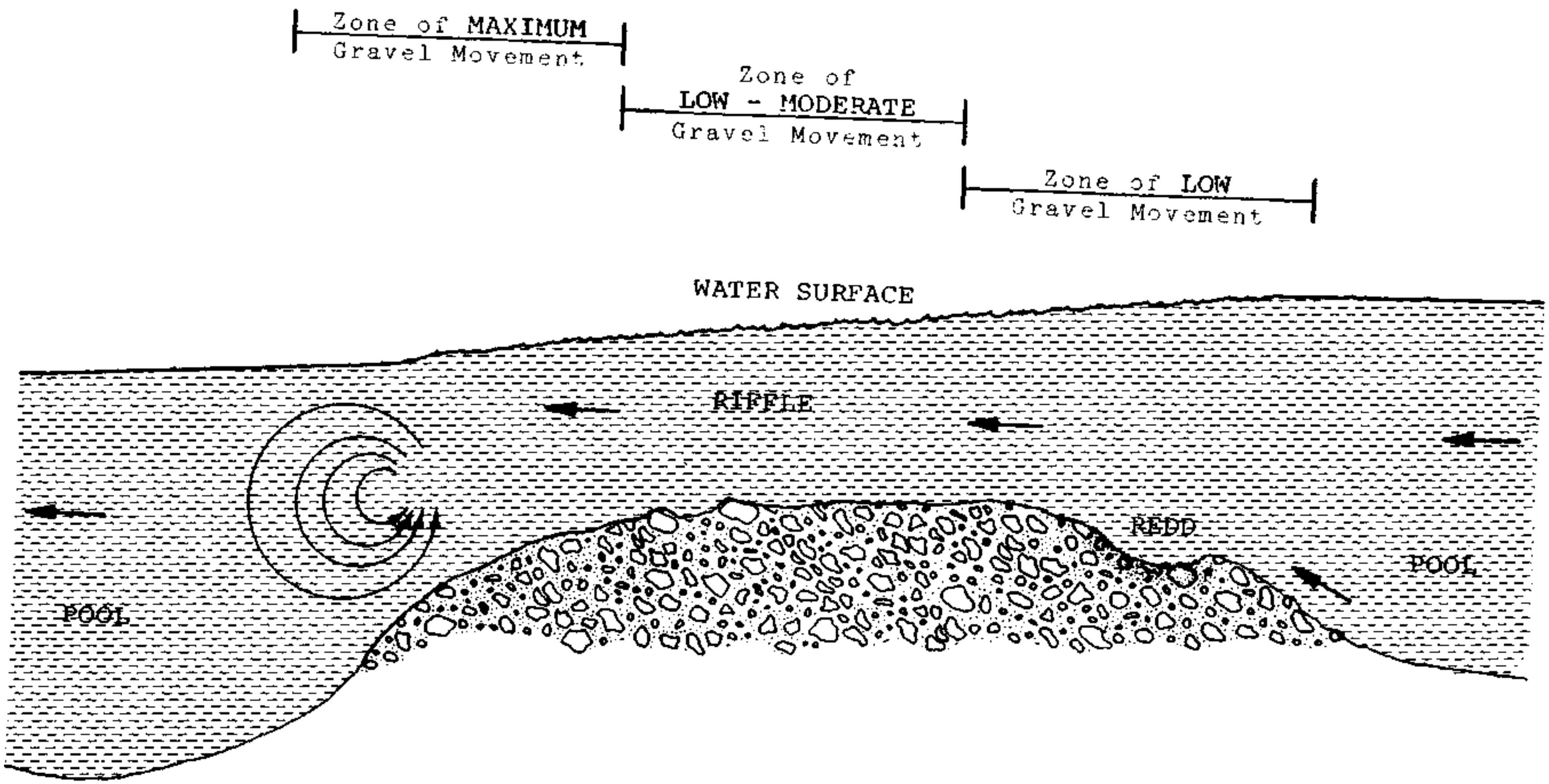


Figure 4-4. Zones of gravel stability for a typical riffle (from Yee 1984). For redd building, coho salmon almost always selected the upstream portion of the riffle, where the risk of scour is lowest.

Table 4-2. Mean water depth and velocity measured in undisturbed gravel adjacent to coho salmon redds with fish present in Lagunitas, Sa n Geronimo, and Devils Gulch creeks, 1982/83 and 1983/84.

			Depth (ft)			Velocity (ft/s)		
Location	Year	n	Mean	SD	Range	Mean	SD	Range
Lagunitas Creek	1982/83	8	0.70	0.26	0.3 - 1.0	1.96	0.44	1.22 - 2.60
	1983/84	18	0.80	0.30	0.3 - 1.6	1.54	0.49	0.72 - 2.27
San Geronimo Creek	1982/83	7	0.68	0.35	0.4 - 1.4	1.21	0.34	0.74 - 1.66
	1983/84	3	0.70	0.10	0.6 - 0.8	1.43	0.16	1.32 - 1.61
Devils Gulch Creek	1982/83	3	0.42	0.08	0.35 - 0.5	0.69	0.35	0.48 - 1.10
	1983/84	7	0.66	0.14	0.5 - 0.8	1.38	0.39	0.99 -1.96

(Briggs 1953), and 0.81 ft and 0.73 ft in Oregon streams (Sams and Pearson 1963; Smith 1973).

We measured water depth over the mounds of redds where fish were present. Water depth averaged 33% (0.26 ft) shallower over the mounds than over nearby undisturbed areas for 23 redds included in the comparison. By forming a hump in the streambed surface, water is forced into the mound of the redd where the eggs are buried. Salmon thereby improve their habitat, as long as subsequent flows do not decline to the point at which the redds become dewatered.

Water Velocity

Mean water velocities measured adjacent to redds with fish present and at 0.6 of the depth from the surface were significantly different ($H = 11.496$, $df = 2$, $P < 0.005$) between Lagunitas, San Geronimo, and Devils Gulch creeks in 1982/83 (Table 4-2).

Velocities measured in 1983/84 were highest in Lagunitas Creek and lowest in Devils Gulch Creek, but were not significantly different ($H' = 0.52$, $df = 2$, $P > 0.10$) between creeks. In Lagunitas Creek, spawning velocities were not significantly different ($T = 143.5$, $P > 0.05$) between years.

With the exception of Devils Gulch Creek during 1982/83, salmon spawned in velocities similar to those reported elsewhere. Sams and Pearson (1963) reported an average mean water column velocity of 1.56 fps for salmon spawning in Oregon. Smith (1973), also in Oregon, reported an average spawning velocity of 1.45 fps measured 0.4 ft above the streambed.

Water velocities averaged 27% (0.37 fps) higher over the mounds than over nearby undisturbed areas for 22 redds included in the comparison. Salmon improved their nest by increasing water flow over the mound of gravel and incubating eggs.

Substrate

1982/83 Substrate utilized by salmon for spawning was assessed by determining the composition of streambed surface materials and the degree to which these materials were embedded in sand and finer particles.

During the 1982/83 spawning season, the proportion of the areas at the side of the redds comprised of each size class of streambed materials was visually estimated. Particles less than 8 mm median diameter were classified as fines. Embeddedness was estimated by randomly removing a few larger stones and measuring the proportion of their height that was buried in sand and finer particles. Visually estimated embeddedness of substrate adjacent to salmon was highly variable (Figure 4-5). Spawning substrate was particularly embedded in San Geronimo Creek (Table 4-3).

Composition of streambed surface materials adjacent to salmon redds varied between the three creeks. A high average proportion of fine sediment

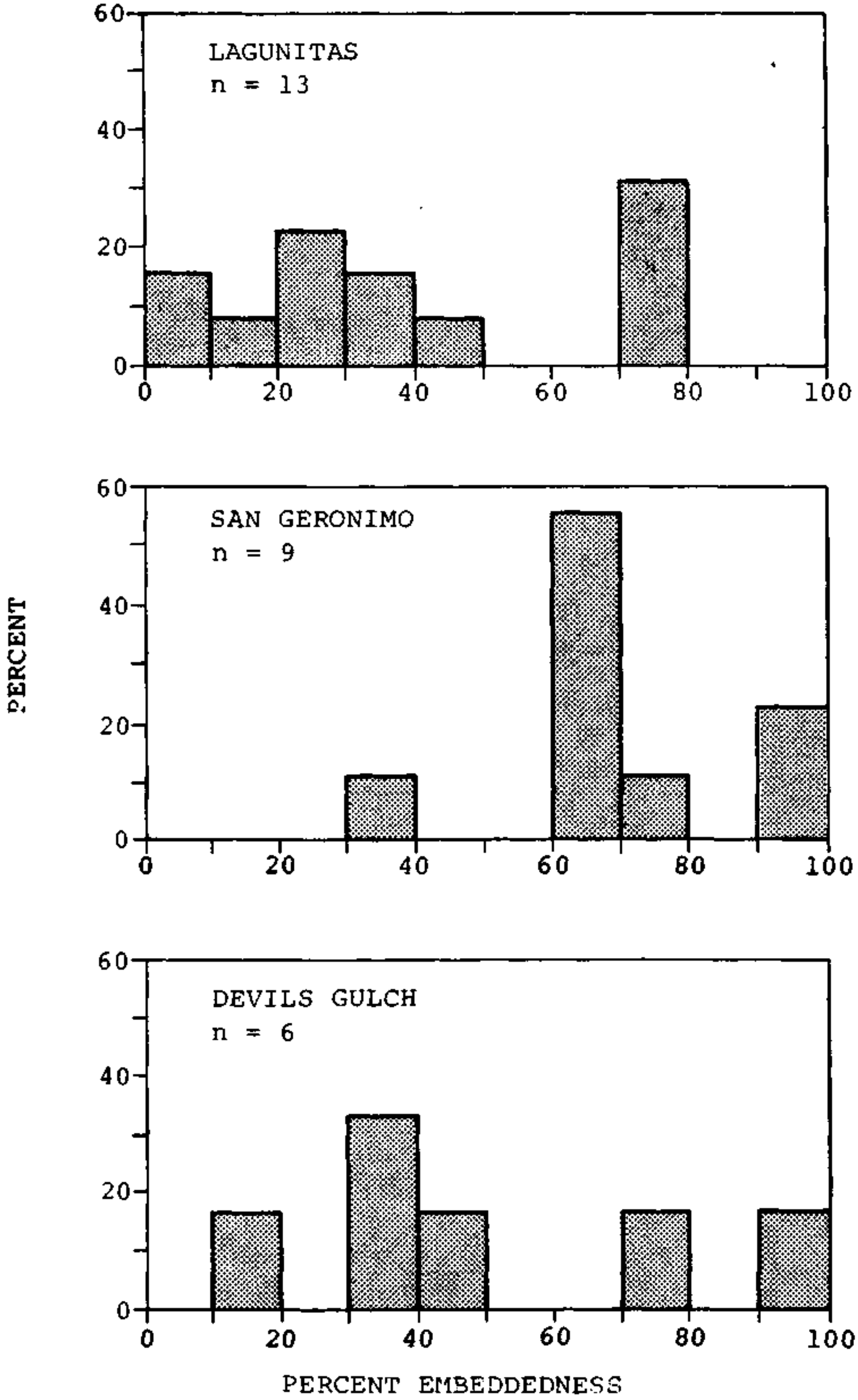


Figure 4-5. Percentage of coho nests built in gravel with different embeddedness levels in Lagunitas, San Geronimo, and Devils Gulch creeks, 1982/83. Embedding material consisted of sediment less than 8 mm median diameter. The number of redds included in the analysis is indicated (n).

Table 4-3. Embeddedness of gravel chosen by coho salmon for spawning in Lagunitas, San Geronimo, and Devils Gulch creeks.

Year	Location	Number of Redds	Average and Standard Deviation of Percent Embeddedness
1982/83	Lagunitas Cr.	13	42 (28)
	San Geronimo Cr.	9	74 (18)
	Devils Gulch Cr.	6	55 (29)
1983/84	Lagunitas Cr.	18	41 (6)
	San Geronimo Cr.	3	45 (7)
	Devils Gulch Cr.	7	43 (8)

was seen at undisturbed areas adjacent to salmon redds in Devils Gulch Creek (Figure 4-6).

1983/84 Information gained during our 1982/83 investigations, along with results of geomorphological studies of Lagunitas Creek conducted by Hecht (1983), led us to revise our surface substrate sampling methods. During the 1983/84 spawning season, we measured streambed composition of undisturbed areas immediately upstream of the redds by placing a rectangular lucite sheet directly on the streambed surface and anchoring it down with small steel rods through holes located at each of the four corners of the sheet. The 51 by 84 centimeter (20 by 33 inch) sheet was etched at 64 mm (2.5 inch) intervals per side to provide a grid comprised of 104 points. Streambed surface particles located at these points were measured using a transparent ruler. Fewer than 104 particles were measured if points overlapped an individual rock or were obstructed by leaves or other debris. At least 60 particles were measured per sample, according to recommended alluvial gravel sampling procedures (Wolman 1954). Particles less than 2 mm median diameter were classified as fines and particles larger than or equal to 2 mm in diameter were classified with a modified Wentworth scale. Embeddedness was estimated by randomly selecting at least 15 of the larger stones located within the boundary of the grid and measuring the proportion of their height that was buried in sand and finer particles.

During the 1983/84 spawning season, salmon again spawned in well embedded substrate in Lagunitas Creek and its major tributaries (Table 4-3). Mean embeddedness of gravel selected for spawning was not significantly different ($H' = 1.29$, $df = 2$, $P > 0.10$) between creeks.

In Lagunitas Creek, embeddedness of substrate used by salmon for spawning fell within a relatively narrow range of values (Figure 4-7), in contrast to the previous year (Figure 4-5). We believe the narrow range of embeddedness values observed during the 1983/84 season best represents what was actually used by salmon for spawning, and reflects the greater precision of the revised substrate sampling procedure.

The surface substrate in Lagunitas Creek and its tributaries is comprised of many specific size classes of streambed materials. Data from our grid sampling procedure were used to calculate the average proportion of each size class of undisturbed gravel located immediately upstream of new salmon redds in Lagunitas, San Geronimo, and Devils Gulch creeks. Distribution of the average percent composition of particle size classes was similar among creeks (Figure 4-8). Spawning gravels were characterized by moderate amounts of each size class of materials less than 8 mm in diameter and relatively large amounts of about 8 to 32 mm diameter gravel.

The objective of our substrate analyses was not only to describe and quantify spawning habitat, but also to help:

1) predict streambed conditions in spawning areas;

2) determine the effect of scouring flows on

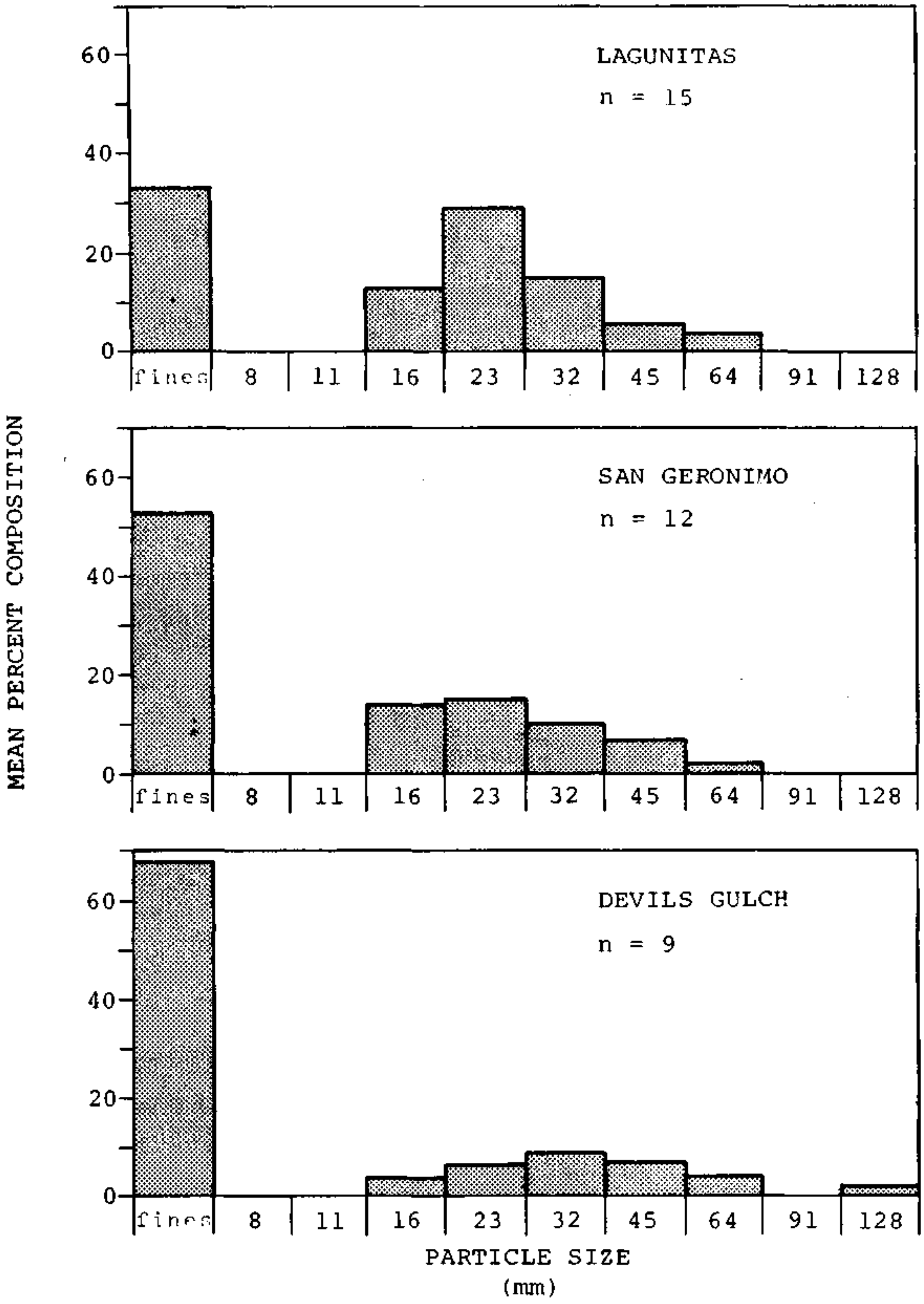


Figure 4-6. Estimated average size class composition of streambed surface materials adjacent to recently constructed coho salmon redds in Lagunitas, San Geronimo, and Devils Gulch creeks, 1982/83. All materials less than 8 mm median diameter were classified as fines. The number of redds included in the analysis is indicated (n).

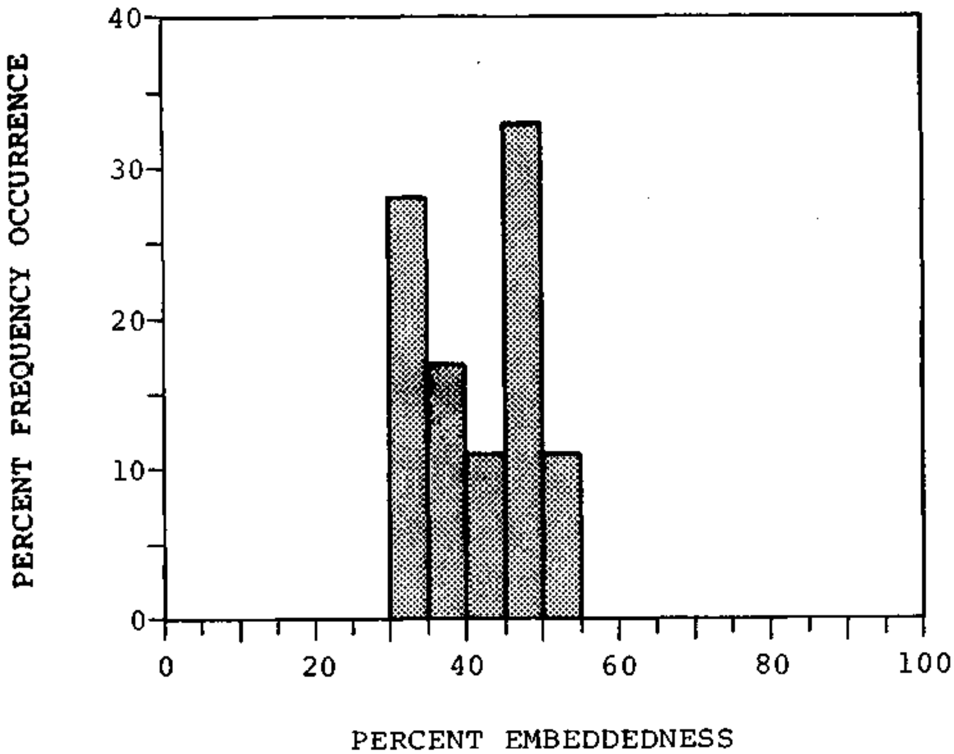


Figure 4-7. Percentage of 18 coho nests built in gravel with different embeddedness levels in Lagunitas Creek during the 1983/84 spawning season.

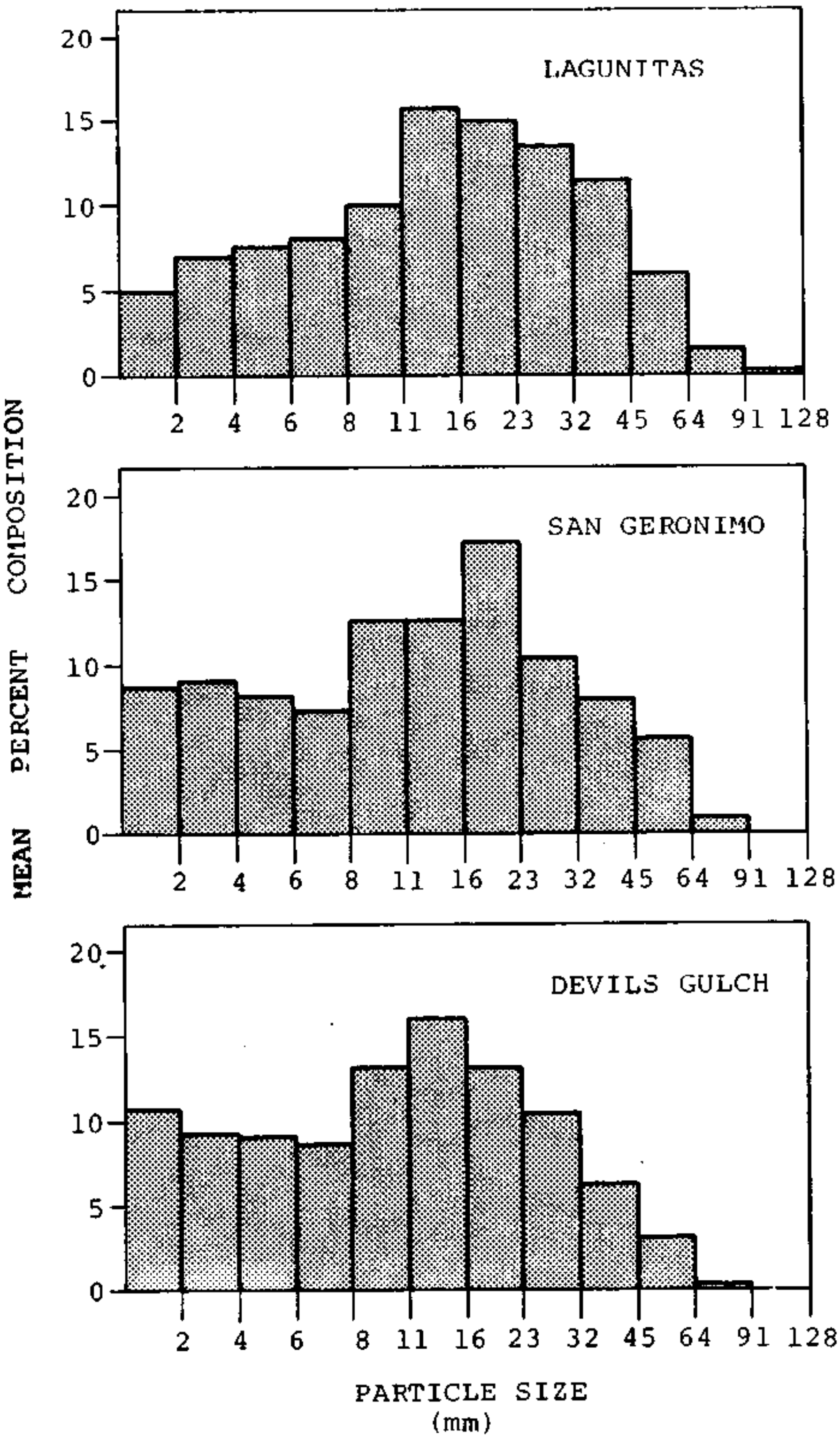


Figure 4-8. Average size class composition of streambed surface materials located immediately upstream of 18 coho salmon redds in Lagunitas Creek, 3 redds in San Geronimo Creek, and 7 redds in Devils Gulch Creek, 1983/84.

salmonid reproductive success;

3) develop a sediment management plan to protect spawning habitat.

To accomplish these tasks, we adopted the approach of the project geomorphologist for describing substrate composition. Geomorphologist Hecht (1983) described the distribution of streambed materials and calculated "key particle size descriptors". These "D" sizes correspond to size of material for which a specified percentage is finer. For example, a D_{50} of 23 mm means that 50% of the material is finer than 23 mm. Key particle size descriptors included in the analyses were D_{50}, D_{16}, and D_{84}, which correspond to the median size of material, and minus and plus one standard deviation, respectively.

Salmon selected consistent combinations of substrate sizes for spawning. The median size (D_{50}) of undisturbed gravel immediately upstream of 18 salmon redds in Lagunitas Creek averaged 15.3 mm and ranged from 9.5 to 19.0 mm (Figure 4-9). The D_{16} averaged 5.3 mm and ranged from only 2.9 to 7.3 mm, whereas the D_{84} averaged 34.2 mm and nearly all observations were within 7 mm of the 32 mm size classification.

We compared substrate used by salmon for spawning with substrate available in glides, using our data and streambed data collected by Hecht (1983). Of the 4 years (1979-1982) of available streambed data, 1981 data were used for the comparison because streambed conditions during the summer of 1981 closely resembled streambed conditions during the 1983/84 spawning season, and are thought by Hecht to represent long-term streambed conditions.

Salmon selected substrate that was smaller than that generally available in glides in Lagunitas Creek (Figure 4-10). They may be unable to dislodge and move the coarser material that is available in potential spawning areas. Salmon in Lagunitas Creek are small, usually weighing from about 2 to 4 pounds. For these small fish, the large gravels may be difficult to dislodge because they are angular in shape (Hecht 1983) and considerably embedded.

We measured surface substrate in the mounds of the redds as well as undisturbed nearby areas. A comparison of these measurements indicates that female salmon cleaned sand and fine gravel from the streambed during redd construction. For 18 salmon redds observed in Lagunitas Creek during 1983/84, average composition of larger material from 16 to 64 mm in diameter was higher in the mounds than in undisturbed areas (Figure 4-11).

To further describe substrate alteration resulting from spawning, we compared the particle size distributions of undisturbed areas with the mounds of the redds (Figure 4-12). Three important results were evident from the comparison. First, female salmon coarsen the redd for about the lower 95% of the distribution of undisturbed streambed surface materials. Second, 85% to 90% of the mound surface was formed out of the coarsest one-half of the streambed material. Third, redd mounds showed an appreciable selective

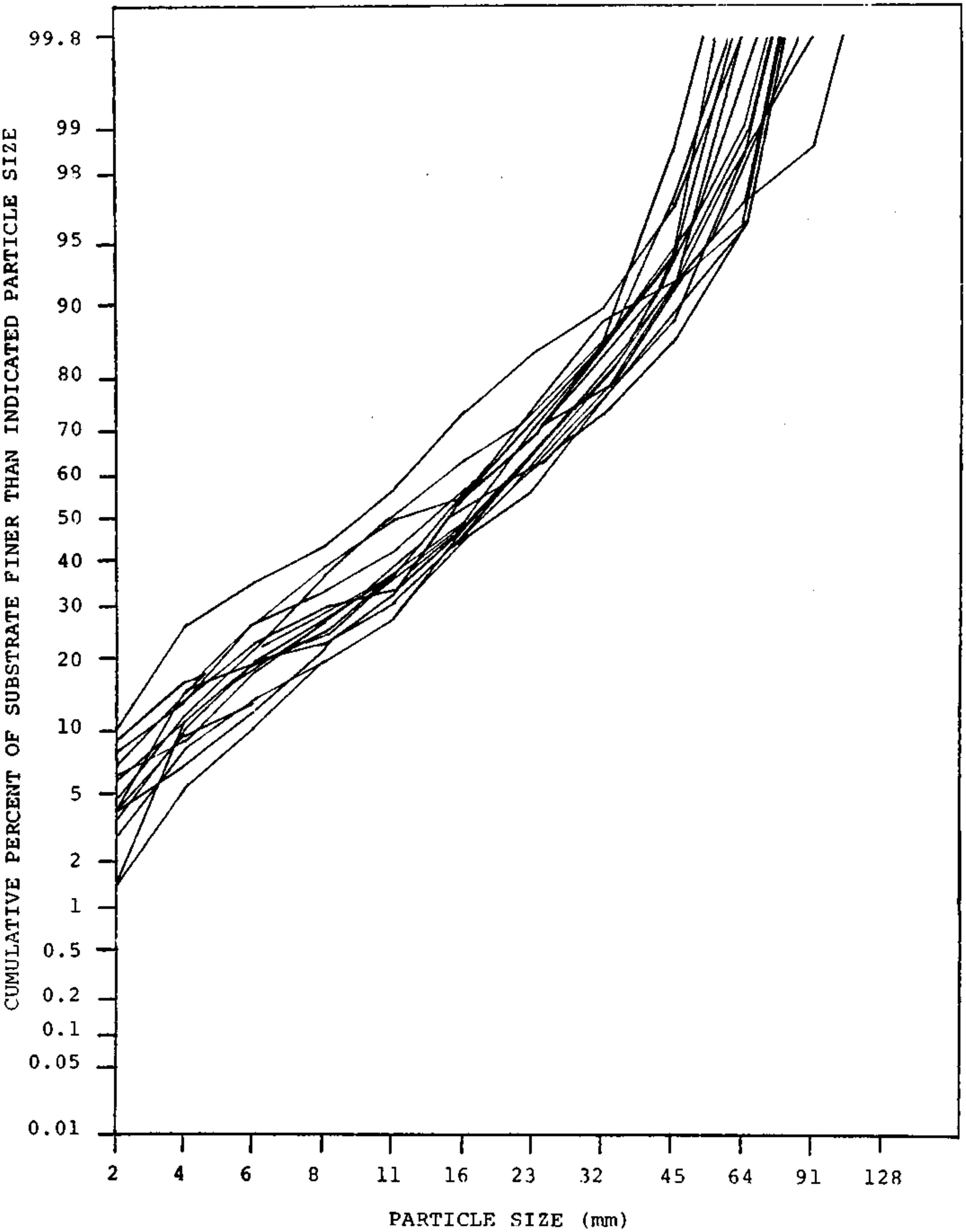


Figure 4-9. Surface substrate particle size distributions measured in undisturbed gravel located immediately upstream of 18 coho redds in Lagunitas Creek, 1983/84.

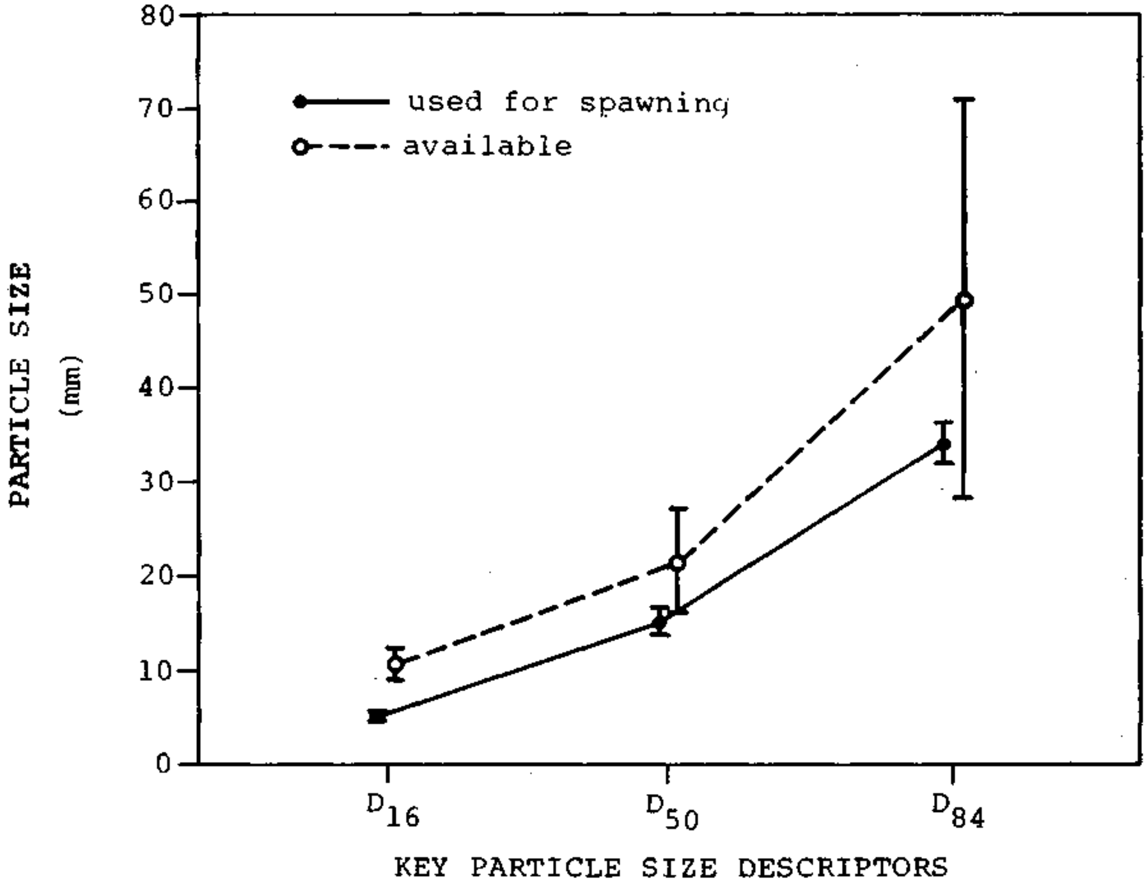


Figure 4-10. Comparison between average key particle size descriptors of streambed surface materials used by coho salmon for spawning and materials available in glides in Lagunitas Creek. Substrate availability data from Hecht (1983). Vertical lines represent 95% confidence intervals.

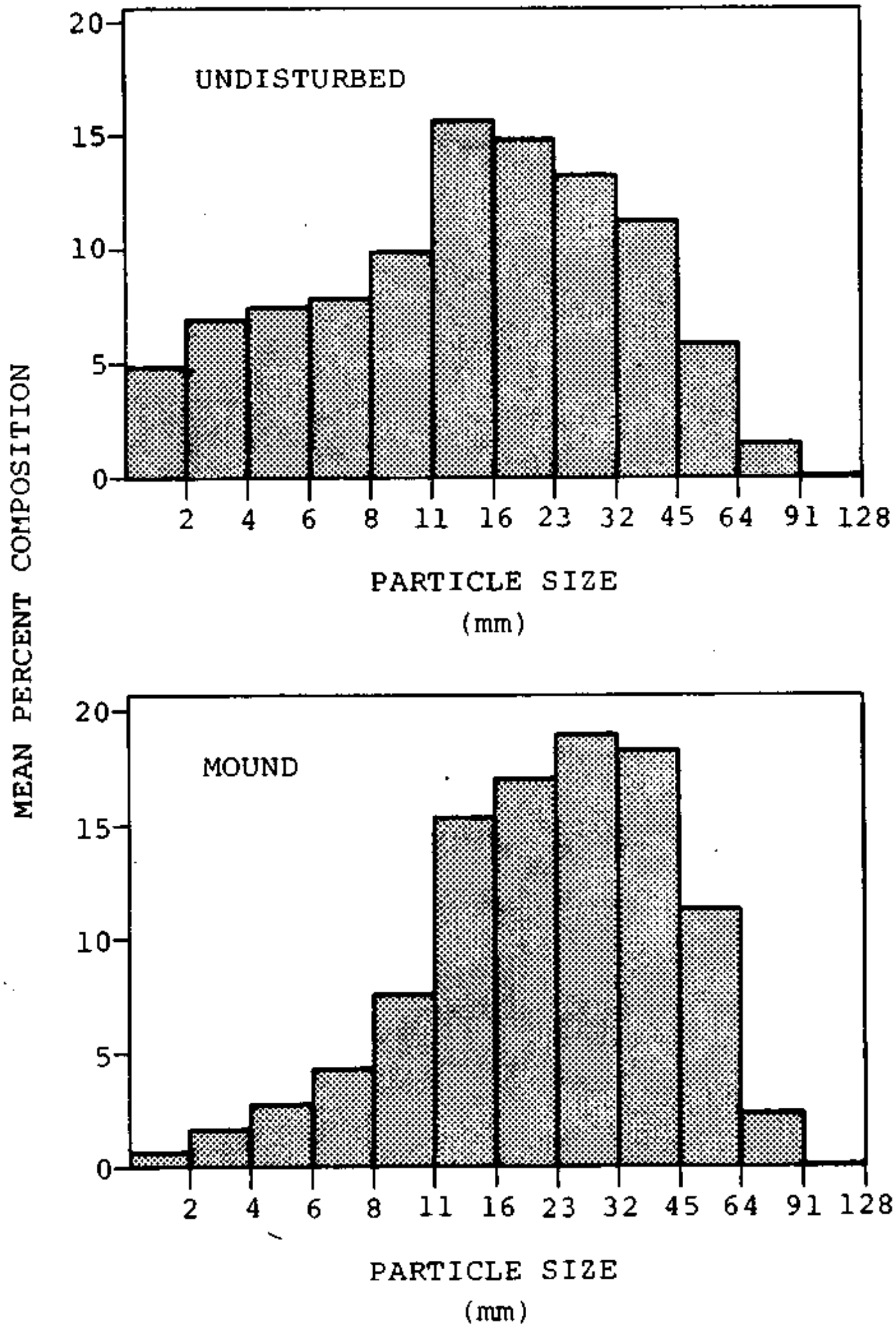


Figure 4-11. Comparison of average percent composition of individual size classes of surface materials measured in undisturbed gravel located immediately upstream and in the mound of 18 coho salmon redds in Lagunitas Creek, 1983/84.

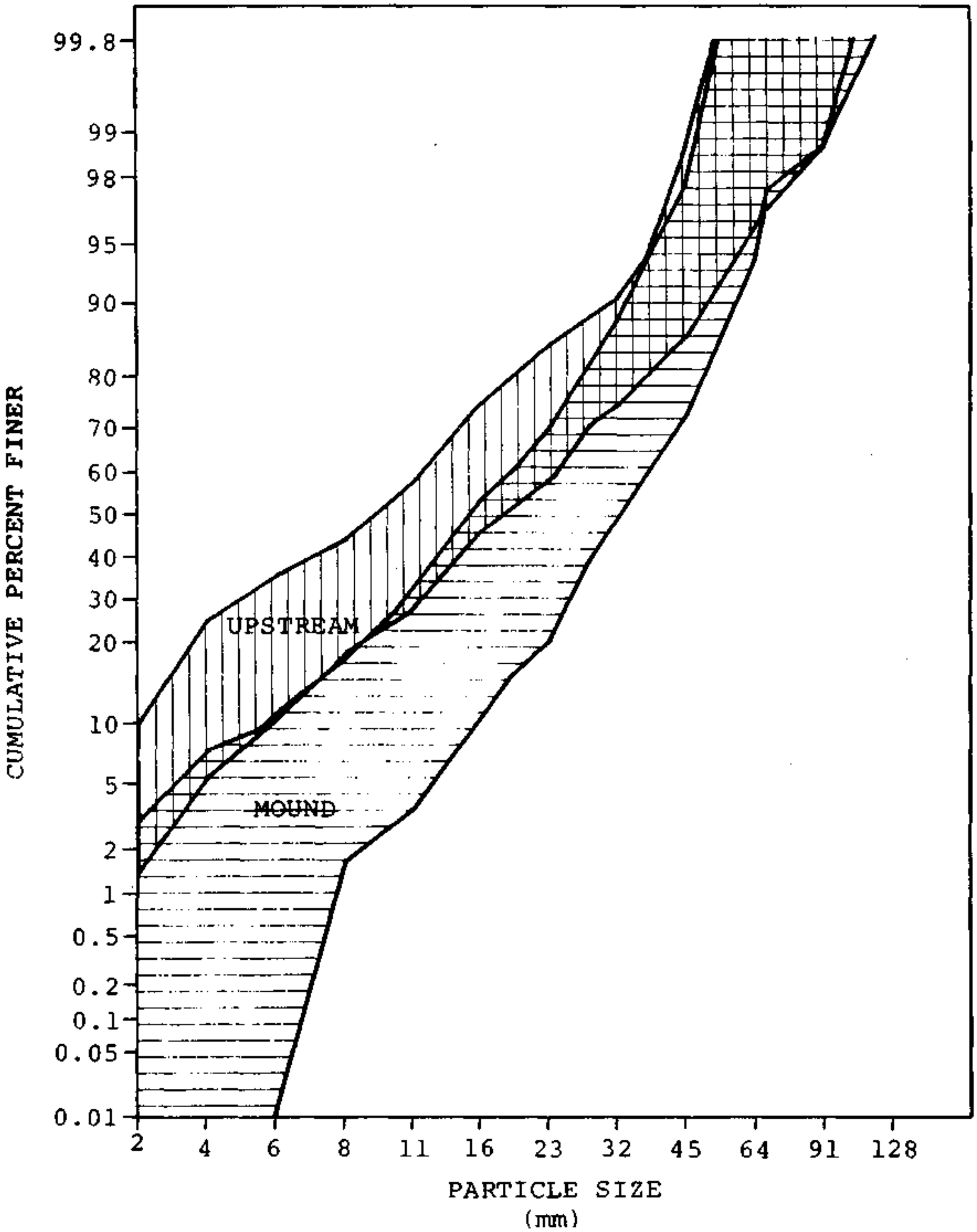


Figure 4-12. Comparison between envelopes of surface substrate particle size distributions measured in undisturbed gravel located immediately upstream and in the mound of 18 coho salmon redds in Lagunitas Creek, 1983/84.

removal of much of the material less than 32 mm in diameter.

THE EFFECT OF FLOW ON OBSERVED SALMON SPAWNING DEPTHS AND VELOCITIES

Water depth and velocity are important factors that influence spawning site selection. We conducted regression analyses to examine the possible relationships between streamflows and water depths and velocities chosen by salmon for spawning in Lagunitas Creek. Water depth and velocity data from the 26 salmon redds that we used to develop spawning criteria were included in the analyses. Streamflows included in the analyses were mean daily flows, ranging from 18.8 to 77 cfs, measured at the SPTSP gage in Lagunitas Creek on the same day redd measurements were taken.

Depths and velocities chosen by salmon for spawning were not affected by change in flow in Lagunitas Creek. Over the range of flows examined, streamflows accounted for only 11% of the variation in depth and none of the variation in velocity measured at the time and location of spawning.

Lack of relationships between streamflow and spawning depths and velocities further indicates that salmon spawn only within specific ranges of depths and velocities.

SALMON SPAWNING CRITERIA

Salmon spawning criteria are needed to estimate the amount of spawning habitat at various streamflows. Most criteria commonly used to measure spawning habitat include combinations of water depth, velocity, and substrate. We developed salmon spawning criteria for Lagunitas Creek using measurements taken only at redds located in Lagunitas Creek itself. These criteria are summarized in Table 4-4 and individual criterion are discussed below.

Glide/Riffle Habitat

During the 1982/83 spawning season we observed that salmon redds were typically built in the tails of glides immediately upstream from the heads of riffles. We quantified this during the 1983/84 spawning season by measuring the distance from the upstream edge of the pit of the redd to the glide/riffle boundary. Only the 18 redds observed at the time of construction were included in the analysis.

Sixteen (89%) of the 18 salmon redds were located in glides within 25 feet upstream of the glide/riffle break. Two redds were located in the head of the riffle within 4 feet of the break. For all 18 salmon redds included in the analysis, the average location was 11.9 (SD 7.7) feet upstream of the glide/riffle break.

We excluded areas not located within 25 feet upstream of the glide/riffle break from our definition of potential spawning habitat. Use of this criterion does not necessarily imply that other areas would not be used

Table 4-4. Summary of spawning criteria for coho salmon in Lagunitas Creek. Criteria developed from measurements taken in Lagunitas Creek during 1982/83 and 1983/84.

Characteristic	Value
Habitat	≤25 ft upstream of glide/riffle break
Water Depth	≥0.5 ft
Water Velocity	0.7 - 2.6 fps
Substrate	D_{16} = 2 - 23 mm
	D_{50} = 8 - 45 mm
	D_{84} = 23 - 64 mm
Redd Area	128 ft^2

in the event of competition for habitat or severely limited spawning habitat availability.

Water Depth

Water must be deep enough for adult salmon to swim into an area, build redds, and spawn. We developed a frequency distribution of spawning depths from measurements taken over undisturbed areas near redds with fish present in Lagunitas Creek (Figure 4-13). We eliminated the lowest observed depth value (0.3 ft) and established depth criterion as water 0.5 feet deep or deeper. Twenty-four (92%) of the 26 redds were built in water at least 0.5 feet deep.

Water Velocity

Water velocities for salmon spawning must be high enough to transport fine particles downstream, allow larger gravels to deposit and build the mound of the redd. Velocities also must be low enough to enable adults to maintain their position over the redd.

We used mean water column velocities measured over undisturbed areas near salmon redds with fish present, to develop a frequency distribution of spawning velocities in Lagunitas Creek (Figure 4-14). We eliminated two values from both the low and high extremes of the range of velocities and established mean water velocity criterion between 0.7 fps and 2.6 fps.

Substrate

Substrate used by salmon for spawning must be small enough and loosely compacted enough to be dislodged during redd construction. However, spawning substrate must contain enough larger gravel that can be carried downstream only far enough to cover the eggs. In this report we use key particle size descriptors to define spawning substrate and establish spawning substrate criteria.

To develop spawning substrate criteria in Lagunitas Creek we used cumulative size class frequencies of key particle sizes in undisturbed areas upstream of redds and in mounds of the redds (Figure 4-12). By including key particle size descriptors of the redd mounds, substrate criteria were not restricted to undisturbed areas with accumulations of sand but included the "cleaner" substrate composition of the redd mounds. We believe the fish will use cleaner substrate if it is available. Low and high values of the key particle size descriptors were rounded to the nearest values corresponding to the Wentworth classification scale. Substrate criteria thus established were D_{16} from 2 to 23 mm, D_{50} from 8 to 45 mm, and D_{84} from 23 to 64 mm in diameter (Table 4-4).

Redd Area

Lengths and widths of redds were measured for the 18 salmon redds located in Lagunitas Creek during 1983/84 that were included in the analyses

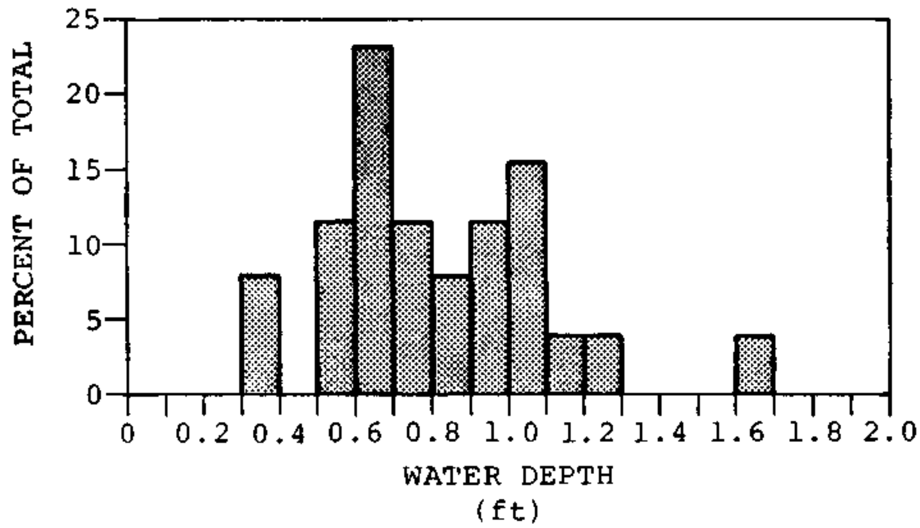


Figure 4-13. Frequency distribution of water depth measured over undisturbed areas near 26 coho salmon redds in Lagunitas Creek during 1982/83 and 1983/84. Only redds with fish present were included in the distribution.

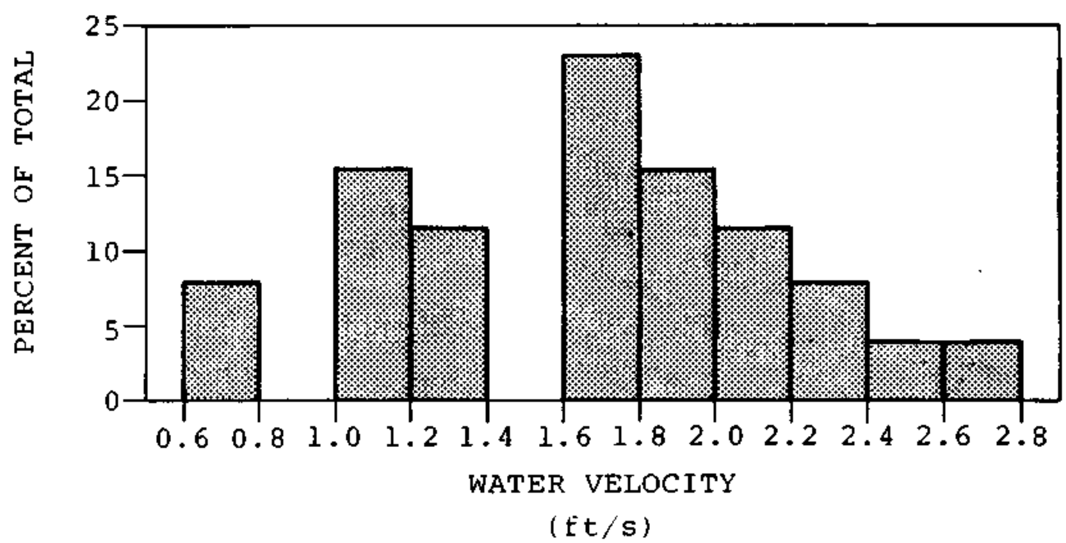
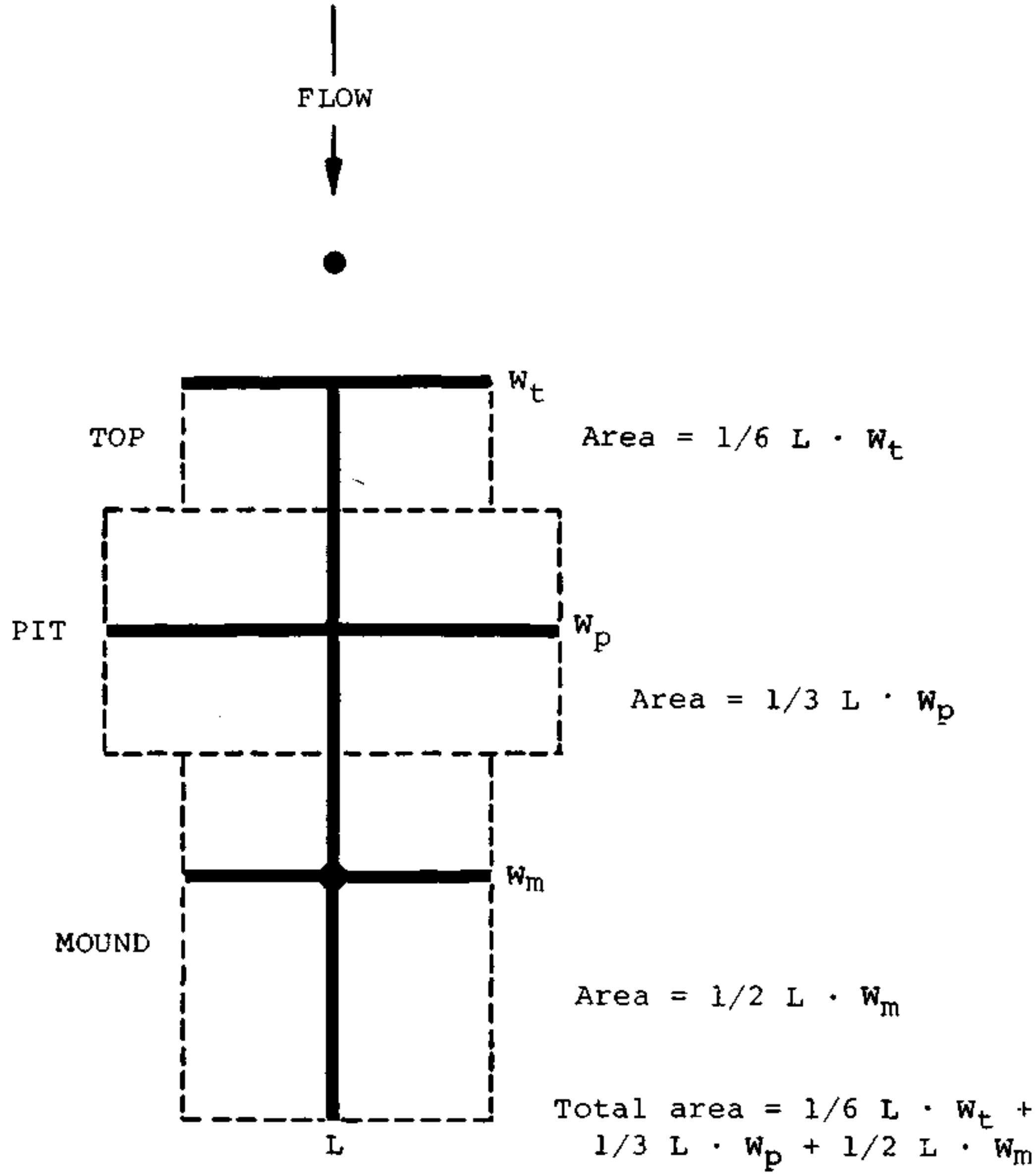


Figure 4-14. Frequency distribution of water velocity measured over undisturbed areas near 26 coho salmon redds in Lagunitas Creek during 1982/83 and 1983/84. Only redds with fish present wore included in the distribution.



L = total length
W_t = width across top
W_p = width across pit
W_m = width across mound
● = Location of redd measurements (depth, velocity, surface substrate composition; also, intragravel D.O. and temperature measured in the mound).
▬ = Distances measured in the field.
- - - = Area estimated from different parts of the redd.

Figure 4-15. Location of redd measurements and calculation of redd area. (Calculations and diagram modified from Reiser and White 1981).

those selected by salmon. Nearly all observed steelhead redds were located in the low-water channel and in the tails of glides immediately upstream from riffles. This habitat was probably selected because of its favorable combination of depth, velocity, and streambed conditions as previously described for salmon.

STEELHEAD SPAWNING CRITERIA

We used the same methods and materials to measure water depth, velocity, and substrate at steelhead redds as we did at the salmon redds. Although we searched for steelhead redds on an approximate weekly schedule from January through March 1984, only three steelhead were observed constructing nests in Lagunitas Creek. Steelhead apparently spawned quickly and left the redd soon after spawning.

To develop steelhead spawning criteria, we measured water depths and velocities at 16 steelhead redds in Lagunitas Creek (Table 4-5). Only new redds were measured. With the exception of the two lowest values, depths that we measured were similar to steelhead spawning depths reported elsewhere (Sams and Pearson 1963; Reiser and White 1981). We eliminated the two lowest depths and established the depth criteria as 0.6 ft deep or deeper (Table 4-6). Velocities that we measured were somewhat lower than reported steelhead spawning velocities. However, at the observed depths corresponding velocities did not exceed 2 fps. Based on measurements taken in Lagunitas Creek, we considered water velocities from 0.7 to 2 fps to be suitable for steelhead spawning (Table 4-6).

The 16 steelhead redds used to establish depth and velocity criteria were also used to develop criteria for spawning substrate and redd areas. To develop spawning substrate criteria for steelhead, we used both the key particle size descriptors of the undisturbed upstream areas and of the mounds of the redds. As with salmon, by including key particle size descriptors of the redd mounds, substrate criteria were not restricted to undisturbed areas with accumulations of sand but included the "cleaner" substrate composition of the redd mounds. Substrate criteria thus established were D_{16} from 2 to 23 mm, D_{50} from 8 to 45 mm, and D_{84} from 23 to 90 mm in diameter (Table 4-6).

Streambed areas encompassed by the 16 steelhead redds ranged from 32.9 to 118.7 ft^2 and averaged 60.3 ft^2. To account for territorial defense of nests, we multiplied the average redd area by 4 and established the criterion of 241 ft^2 required for each steelhead redd in Lagunitas Creek (Table 4-6).

Table 4-5. Water depths and velocities measured over undisturbed areas located immediately upstream of 16 recently constructed steelhead redds in Lagunitas Creek, 1984.

Water Depth (ft)	Water Velocity (ft/s)
0.9	1.45
1.6	1.03
1.3	1.95
0.8	1.35
0.6	1.16
0.6	0.71
0.3	1.43
1.0	0.88
0.9	1.12
0.4	1.23
0.9	1.86
0.8	1.26
1.1	0.99
0.6	1.33
1.3	1.25
0.8	1.21

Table 4-6. Summary of spawning criteria for steelhead trout in Lagunitas Creek. Criteria developed from measurements taken in Lagunitas Creek during spring 1984.

Characteristic	Value
Habitat	≤25 ft upstream of glide/riffle break
Water Depth	≥0.6 ft
Water Velocity	0.7 - 2.0 fps
Substrate	D_{16} = 2 - 23 mm
	D_{50} = 8 - 45 mm
	D_{84} = 23 - 64 mm
Redd Area	241 ft^2

CHAPTER 5 - SPAWNING HABITAT AVAILABILITY

Coho salmon and steelhead trout spawn in areas characterized by suitable combinations of depth, velocity, and substrate conditions. The number and extent of such areas limits the number of fish that can successfully spawn. The suitability of a specific area and the total amount of spawning habitat available in Lagunitas Creek are functions of streamflow, channel size and shape, and streambed composition.

To determine the amount of spawning habitat available at various streamflows, we surveyed all potential spawning areas in Lagunitas Creek upstream from its confluence with Nicasio Creek. All glide/riffle transition areas were considered potential spawning areas. Areas were excluded if the substrate was comprised mainly of boulders, bedrock, or silt and very fine sand.

A total of 184 glide/riffle transition areas were located—116 were judged to be potential spawning areas. A 1-in-5 systematic sample was drawn from these areas, resulting in 23 intensively sampled sites. Each of the 23 sampled sites was evaluated by establishing 3 transects across the stream at approximately 4.2, 12.5, and 20.8 feet above the head of the glide/riffle break. Water depth and velocity were measured and surface substrate composition was visually estimated at 3-foot intervals along each transect. These measurements were taken at each of the 23 sites at 3 different flows that averaged 12, 20, and 28 cfs. Substrate composition, water depth, and mean water column velocity for each 8.3 x 3 ft rectangular segment were compared to the spawning habitat criteria described in Chapter 4. Based on these criteria, each segment was rejected or accepted as spawning habitat at each of the 3 flows examined. Regression equations were developed to describe the relationships between spawning habitat availability and streamflow at each of the 23 sampled sites. To estimate the total amount of spawning habitat available at flows of 12, 20, and 28 cfs, predictions of the amount of spawning habitat available at 23 sites were averaged and the averages were multiplied by 116.

COHO SALMON

The relationships between the amount of salmon spawning habitat available and streamflow measured at each of the 23 sampled sites are illustrated in Figure 5-1. Spawning habitat increased with flow at all sites but the rate of increase varied as we would expect. In 1984, the total amount of salmon spawning habitat in Lagunitas Creek increased in a direct linear manner with increase in flow, from 27,737 ft^2 at 12 cfs to 59,846 ft^2 at 28 cfs (Figure 5-2).

Using our previous estimate that 128 ft^2 of spawning habitat is required per redd, we estimated there is enough spawning habitat in Lagunitas Creek for a minimum of 217 salmon redds at a flow of 12 cfs and 468 redds at 28 cfs (Table 5-1). In Lagunitas Creek, only 65 redds were built in 1982/83 and 26 redds in 1983/84. A flow of 12 cfs provides enough habitat for several times as many redds as were built in recent years. Also, approximately

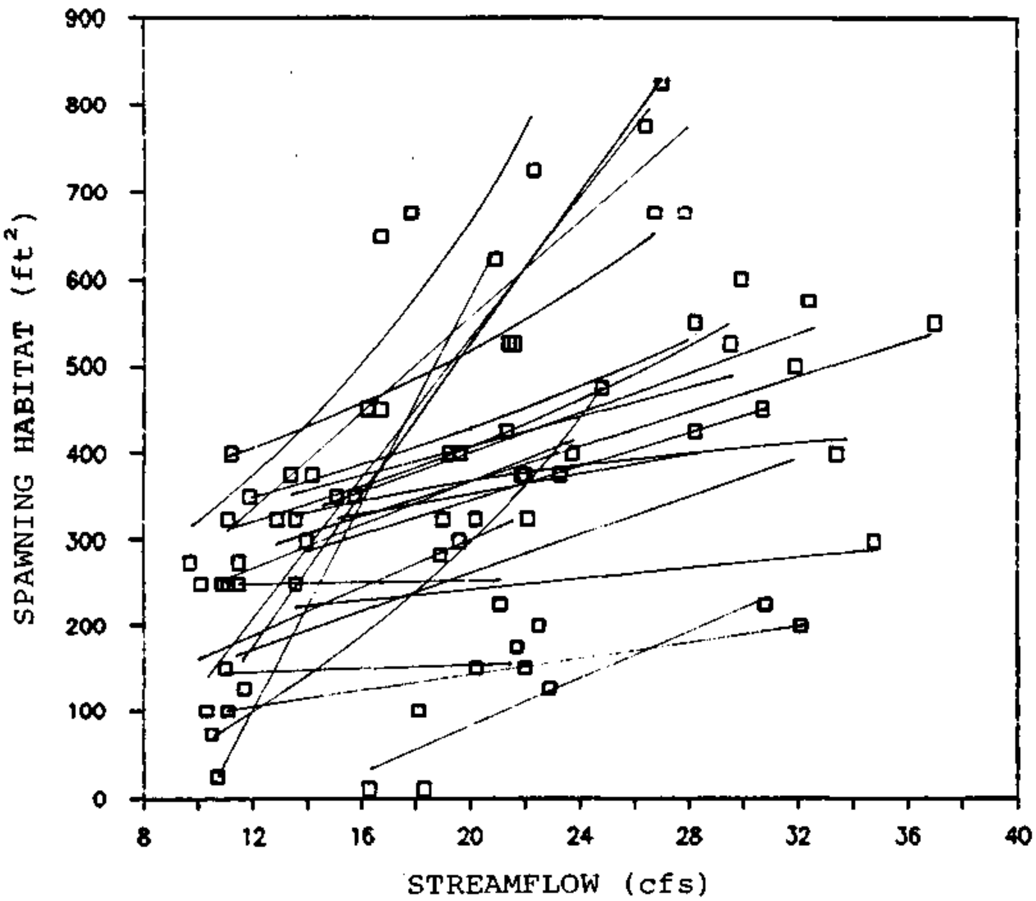


Figure 5-1. Relationships between the amount of coho spawning habitat available and streamflow measured at each of the 23 sampled sites in Lagunitas Creek.

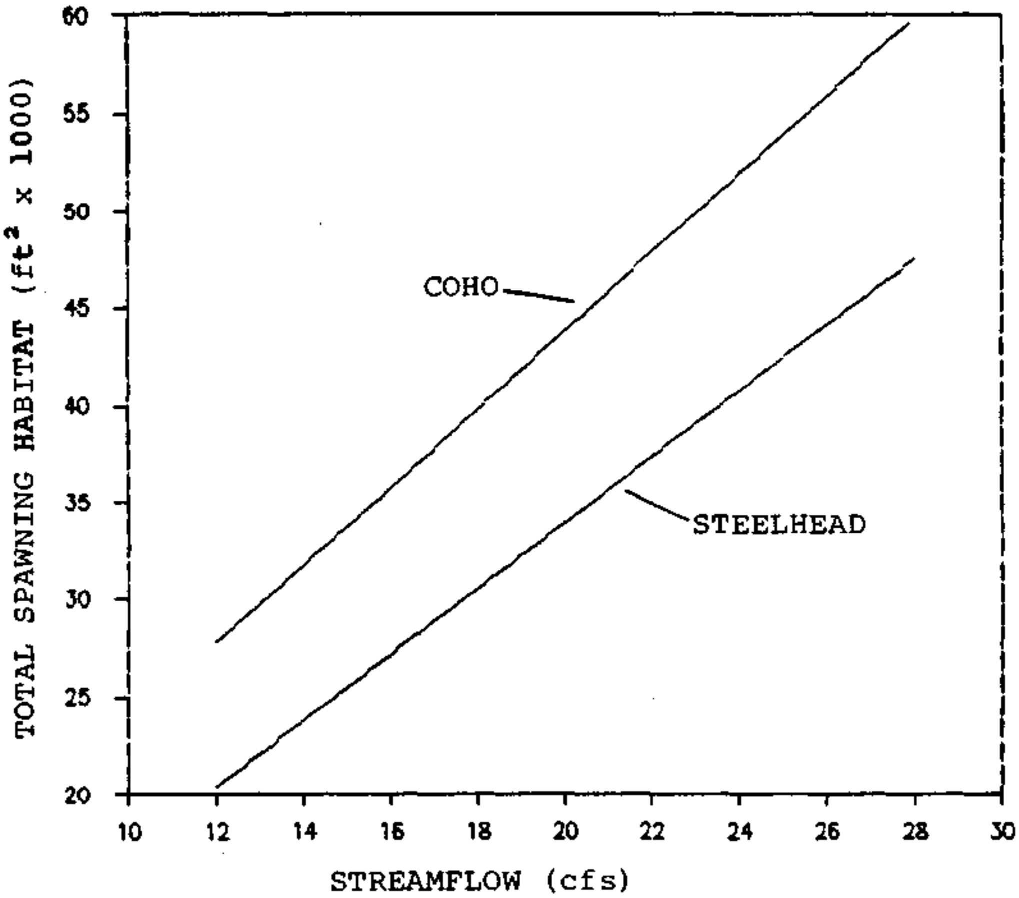


Figure 5-2. Relationship between the total amount of coho and steelhead spawning habitat and streamflow in Lagunitas Creek.

Table 5-1. Estimated number of coho salmon redds that can be built in Lagunitas Creek at flows ranging from 12 cfs to 28 cfs. These are conservative estimates based on four times the actual redd area[1] to account for territorial defense between redds[2].

FLOW (cfs)	NUMBER OF REDDS
12	217
14	248
16	279
18	311
20	342
22	373
24	405
26	436
28	468

[1] The average area of coho salmon redds measured in Lagunitas Creek was 31.9 ft^2.

[2] The criterion of 128 ft^2 required per redd was used to estimate the potential number of redds.

one-half of the salmon spawn in the tributaries (Chapter 4). These estimates do not include the amount of spawning habitat available or the number of redds possible in the tributaries of Lagunitas Creek.

STEELHEAD TROUT

The relationships between the amount of steelhead spawning habitat available and streamflow measured at each of the 23 sampled sites are illustrated in Figure 5-3. The total amount of steelhead spawning habitat in Lagunitas Creek increased with flow over the range of flows examined (Figure 5-2). Less steelhead spawning habitat was available than salmon spawning habitat at any given flow. The estimated total amount of steelhead spawning habitat ranged from 20,392 ft^2 at 12 cfs to 47,498 ft^2 at 28 cfs.

Under 1984 streambed conditions, at least 85 steelhead redds could be built in Lagunitas Creek at a flow of 12 cfs (Table 5-2). This is a very conservative estimate. As with salmon, we estimated the number of redds possible by dividing available spawning habitat by four times the average area of an individual redd to account for territory around the redd that is defended by the female. Because steelhead redd areas averaged nearly twice those of salmon, we estimated that nearly twice as much area was required per redd. If many fish were spawning in the creek, we would expect the territorial area to be reduced and the creek could support more redds. Only 39 steelhead redds were built in Lagunitas Creek during winter 1984. A flow of 12 cfs provides enough habitat for more than twice that number of redds. As with salmon, many of the steelhead spawn in the tributaries.

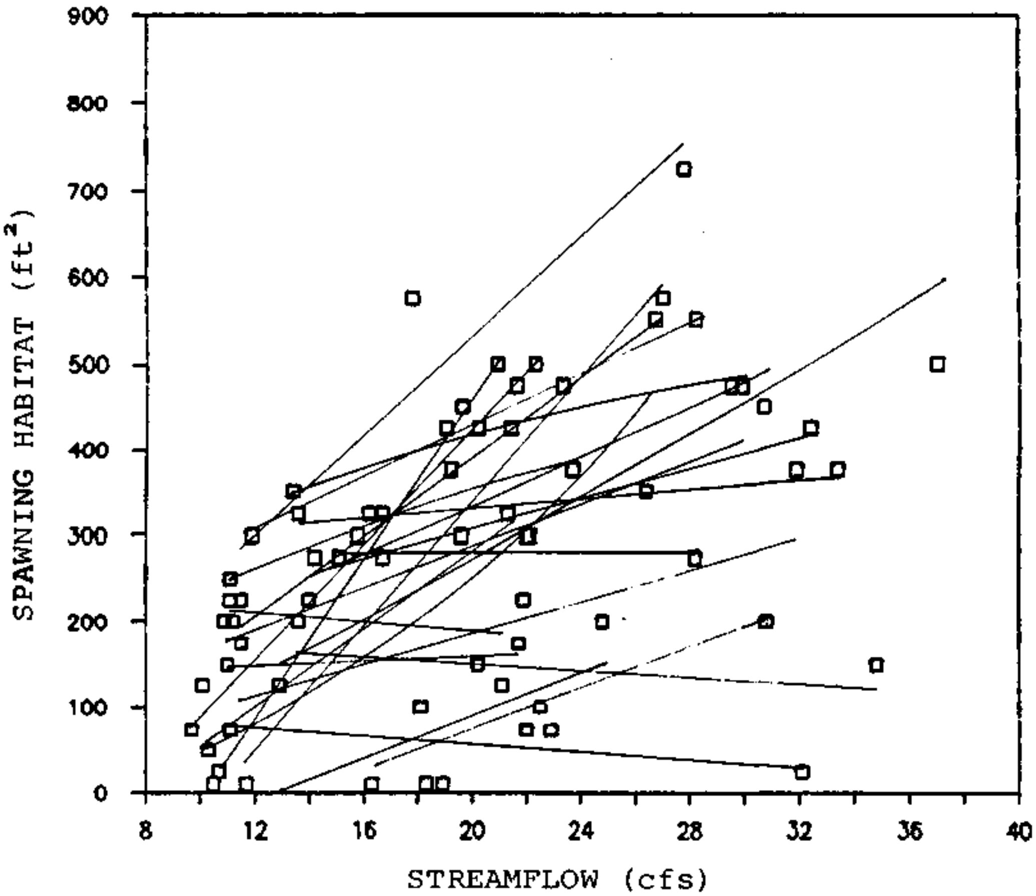


Figure 5-3. Relationships between the amount of steelhead spawning habitat available and streamflow measured at each of the 23 sampled sites in Lagunitas Creek.

Table 5-2. Estimated number of steelhead trout redds that can be built in Lagunitas Creek at flows ranging from 12 cfs to 28 cfs. These are conservative estimates based on four times the actual redd area to account for territorial defense between redds[2].

FLOW (cfs)	NUMBER OF REDDS
12	85
14	99
16	113
18	126
20	141
22	155
24	169
26	183
28	197

[1] The average area of steelhead trout redds measured in Lagunitas Creek was 60.3 ft^2.

[2] The criterion of 241 ft^2 required per redd was used to estimate the number of redds possible at a given flow.

CHAPTER 6 - EMBRYO INCUBATION

Developing coho salmon eggs (embryos) incubate within the mound from 5 to 7 weeks or more depending upon water temperatures (Scott and Crossman 1973). Salmon embryo survival and development rates are related to dissolved oxygen concentrations (Shumway et al. 1964; McNeil 1966) and temperatures (Becker et al. 1982) of the intragravel water. Exchange of intragravel and surface water is necessary to replenish dissolved oxygen concentrations of the intragravel water and to remove waste metabolites which are produced by developing salmon embryos (McNeil 1966; Vaux 1968).

Sediment deposited on top of or within the redd may interfere with the water exchange or, if it contains organic matter, may subject embryos to low concentrations of dissolved oxygen. Either of these conditions leads to poor embryo survival.

SAMPLING METHODS AND PROCEDURES

To assess the effects of streamflow and sediment on incubation of salmon embryos, we measured intragravel and stream conditions at natural and simulated redds in Lagunitas Creek and its major tributaries (Figure 6-1). In 1982/83 we monitored conditions at 28 salmon redds that were located during spawning surveys—17 in Lagunitas Creek, 6 in San Geronimo Creek, and 5 in Devils Gulch Creek. In addition, 36 simulated redds were established throughout the Lagunitas Creek system and monitored. In 1983/84 we monitored conditions in 19 natural salmon redds in Lagunitas Creek, 3 redds in San Geronimo Creek, and 5 redds in Devils Gulch Creek.

Natural and simulated redds were monitored weekly or as soon thereafter as streamflows permitted in 1982/83. In 1983/84, initial measurements were taken immediately following redd construction and spawning and biweekly thereafter. At each monitored natural redd, intragravel dissolved oxygen concentration and water temperature was measured. Intragravel water samples were obtained by driving a 1-inch diameter pipe approximately 10 inches below the substrate surface at the mound of the redd. The pipe had a closed and armored point and was perforated from 2 to 4 inches from the bottom end. We inserted plastic tubing into the pipe and withdrew and discarded a small amount of water, then withdrew approximately 100 ml of intragravel water into a collection bottle without entraining air. We measured dissolved oxygen concentrations and water temperatures in the sample bottle with a Yellow Springs Instrument Model 57 oxygen meter.

In the creek, dissolved oxygen concentrations and water temperatures were also measured at approximately one-half the depth of the water column above the mound of the redds. Water depth also was measured at an undisturbed area near the redds. Water velocity was measured with a Gurley Pigmy current meter at 0.6 of the depth from the surface at both the mound of the redd and at an undisturbed nearby area.

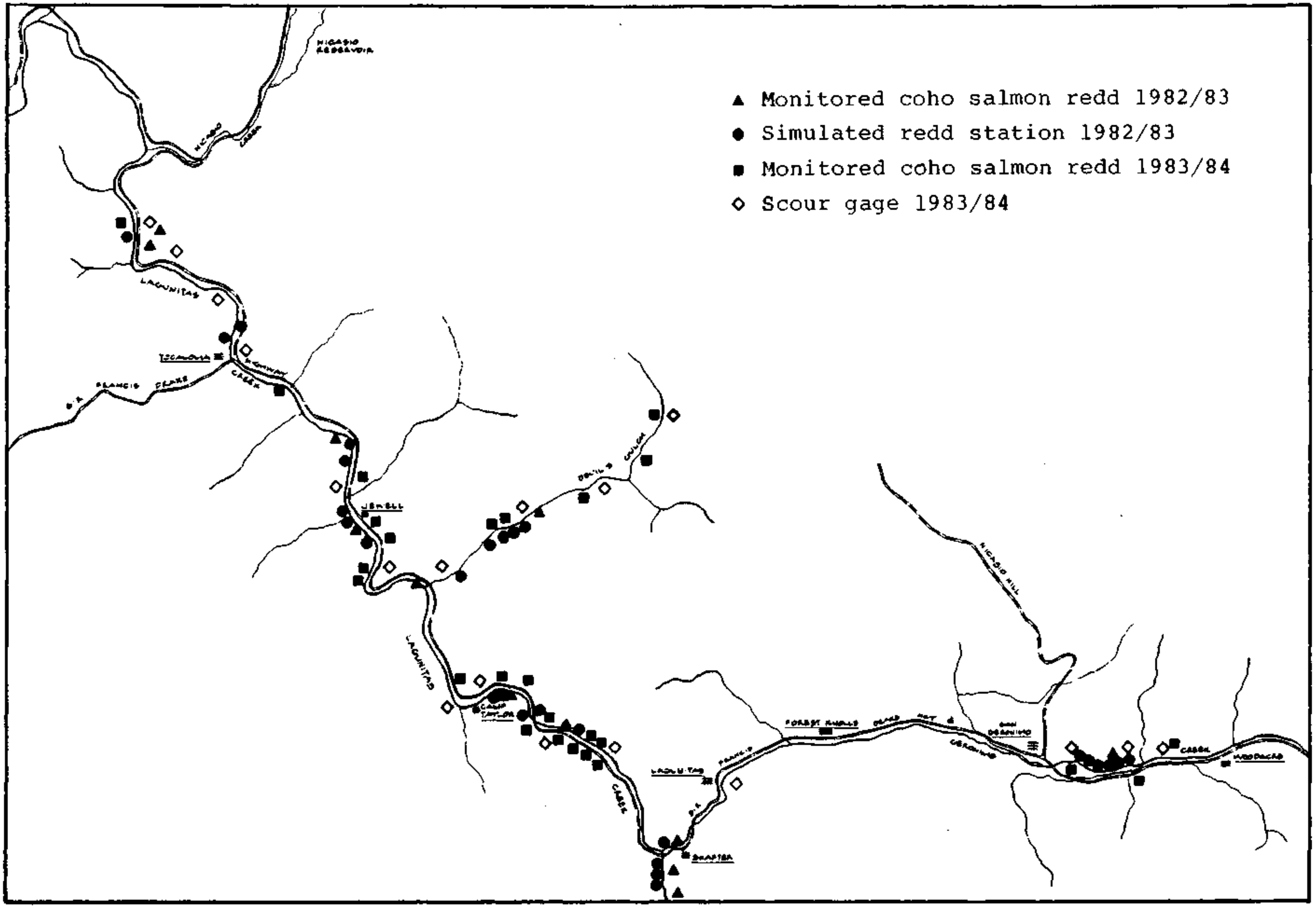


Figure 6-1. Locations of monitored coho salmon redds, simulated redd stations, and scour gages in Lagunitas, San Geronimo, and Devils Gulch creeks.

Intragravel dissolved oxygen concentrations and water temperatures were measured at simulated redds by drawing water from a perforated copper tube encompassed by a small concrete "Dixie cup" anchored in the redd. This apparatus was buried so that the perforations were located 8-10 inches below the streambed surface when the redd was built. A 2-ft length of plastic tubing was attached to the upper end of the copper tube and laid upon the streambed surface. Water samples were withdrawn from within the substrate through the plastic tubing. This technique allowed for measurement of intragravel dissolved oxygen and water temperature without any disruption of streambed materials.

Incubation Period

The salmon spawning season extends from early December through mid-January in Lagunitas Creek (Chapter 4). Salmon embryos have been reported to hatch in approximately 7 weeks when incubated at 8.9°C in Waddell Creek, California (Shapovalov and Taft 1954), similar to the average temperatures of 9.2°C and 10.1°C that we measured in salmon redds from early December through mid-March in Lagunitas Creek in 1982/83 and 1983/84. Hatched salmon embryos (alevins) remain in the gravel an additional 2 to 3 weeks, absorbing the yolk prior to emergence into the creek (Scott and Crossman 1973). Consequently, we estimated that the salmon embryo incubation period, when developing embryos and alevins are in the gravel, extends from the first week in December through mid-March in Lagunitas Creek.

Dissolved Oxygen, Water Temperature, Water Velocity

Intragravel dissolved oxygen concentrations that we measured were generally suitable for salmon embryo incubation. Dissolved oxygen concentrations measured within both natural and simulated salmon redds were usually above 8 mg/l throughout the incubation period in Lagunitas Creek and its major tributaries (Figures 6-2, 6-3). No definite minimum level of intragravel dissolved oxygen concentration has been established for salmon incubation, although Ringler and Hall (1975) selected 6 mg/l as a minimum level. The US Environmental Protection Agency proposed minimum intragravel dissolved oxygen concentrations of 5 mg/l in salmonid spawning areas (American Fisheries Society 1979), and Bell (1980) suggested that dissolved oxygen concentrations in salmon and trout spawning areas should not decline below 7 mg/l. Other studies have indicated that dissolved oxygen concentrations of 7 mg/l or less adversely affect salmonid embryo incubation (Alderice et al. 1958; Coble 1961).

We measured intragravel dissolved oxygen concentrations below 7 mg/l on only a few occasions during the incubation period. Within simulated redds in 1982/83, low dissolved oxygen concentrations of 3.8 and 3.9 mg/l were measured during the sixth week of incubation in San Geronimo Creek, and 2.9 and 4.0 mg/l during the ninth week in Lagunitas Creek. One natural salmon redd exhibited a low dissolved oxygen concentration of 2.8 mg/l during the tenth week of incubation in Lagunitas Creek during 1983/84. Low dissolved oxygen concentrations of 3.5 and 6.0 mg/l were measured during the seventh and ninth week of incubation in 1983/84, in the only dewatered redd that we

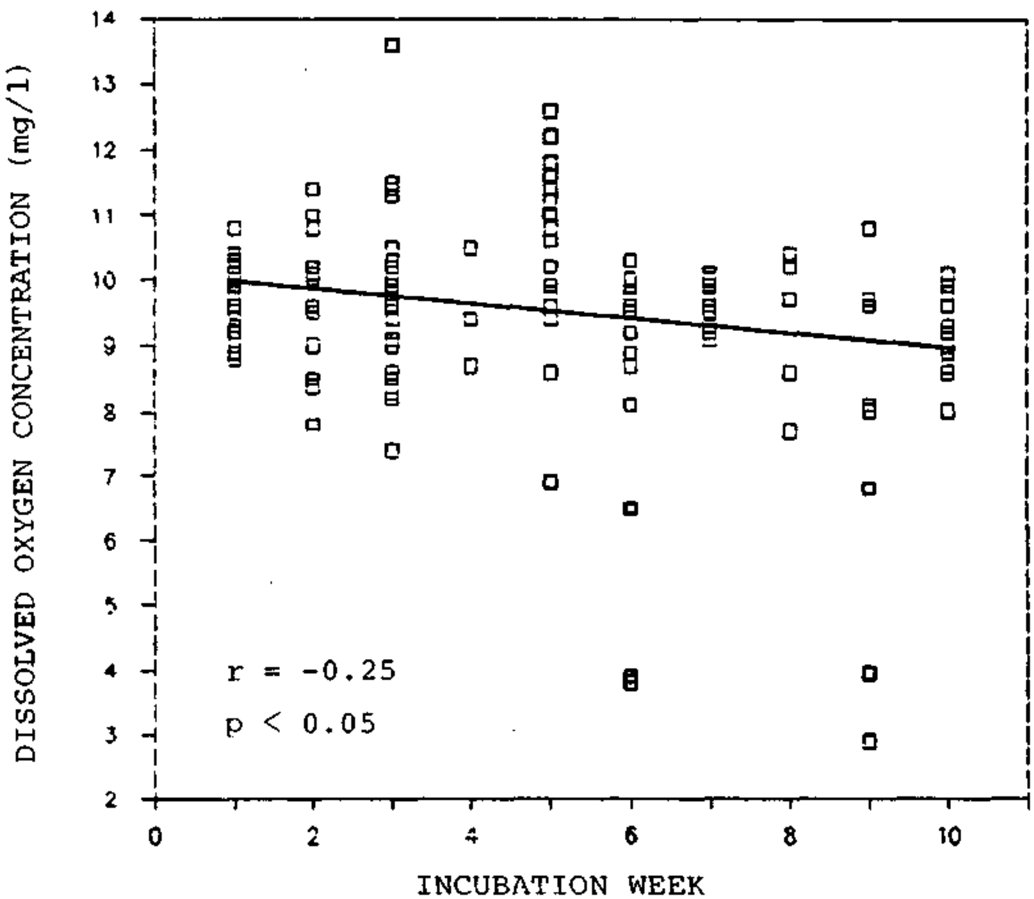


Figure 6-2. Intragravel dissolved oxygen concentration measured within the mounds of representative coho salmon redds and simulated redds in Lagunitas Creek and its major tributaries, 1982/83. Dissolved oxygen concentration gradually decreased but generally remained suitable for salmonid embryos during the incubation period.

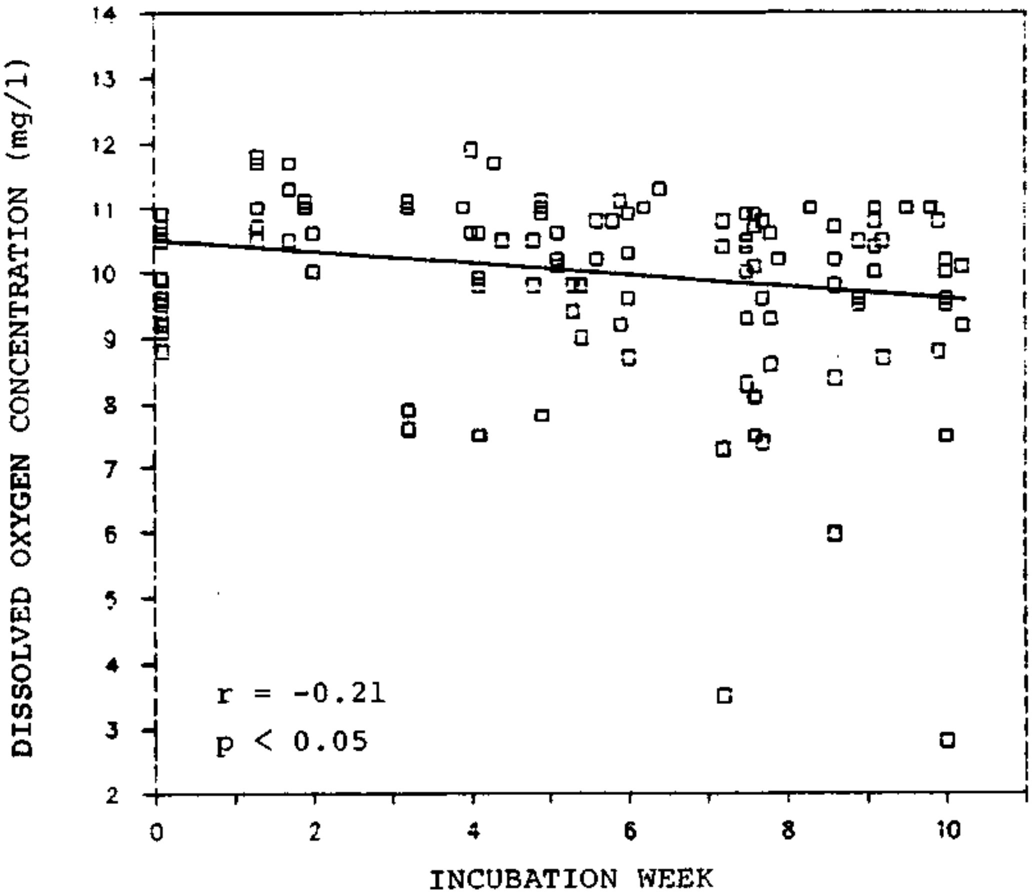


Figure 6-3. Intragravel dissolved oxygen concentrations measured within the mounds of representative coho salmon redds in Lagunitas Creek and its major tributaries 1983/84. Dissolved oxygen concentrations gradually decreased but generally remained suitable for salmonid embryos during the incubation period.

observed in Lagunitas Creek during this study.

Estimated Survival Between Spawning and Hatching

Dissolved oxygen concentration of intragravel water was related to incubation success, or survival to hatching, of salmon in Needle Branch Creek on the Alsea River system, Oregon, by Phillips and Campbell (1961). They buried 24 perforated boxes containing 100 salmon embryos each at a depth of 10 inches below the streambed surface, next to an implanted standpipe that extended above the surface of the water. Intragravel dissolved oxygen concentrations were measured by means of the standpipe at approximately 5-day intervals until incubation to hatching was nearly completed, at which time the boxes containing the embryos were retrieved and survival determined. They found a relationship between survival and mean dissolved oxygen concentration measured throughout the incubation period (Figure 6-4).

Using the relationship presented by Phillips and Campbell, we estimated the survival to hatching of salmon embryos in the 19 natural redds that we monitored in Lagunitas Creek during 1983/84. At high (> 9.4 mg/l) dissolved oxygen concentrations we limited maximum survival to 87%, the highest observed by Phillips and Campbell. We thereby estimated that survival to hatching of salmon embryos ranged from 13% to 87% and averaged 76% in Lagunitas Creek.

Water temperatures from 4° to 14°C are generally considered suitable for salmonid embryo incubation (Reiser and Bjornn 1979). Bovee (1978) proposed water temperatures from 7.8° to 13.3°C as a salmon incubation criterion. Intragravel water temperatures increased throughout the 1982/83 incubation period (Figure 6-5), but remained within levels considered to be suitable for embryonic development of salmonids. During the 1983/84 incubation period, intragravel water temperatures exhibited no distinct trend over time and remained within favorable limits (Figure 6-6).

Given suitable temperatures, embryonic development and survival is dependent upon dissolved oxygen. As suggested by Reiser and White (1981), diminished intragravel dissolved oxygen concentrations may result from flow reductions (McNeil 1962) because of the positive effect of surface velocity on water downwelling into the streambed (Vaux 1968). We measured a wide range of mean water column velocities above the mounds of natural salmon redds and simulated redds and found no significant relationship between water velocity and intragravel dissolved oxygen concentrations (Figures 6-7, 6-8). Water velocities measured in the creek were not useful as predictors of intragravel conditions.

RELATIONSHIPS BETWEEN VARIABLES AFFECTING INCUBATION SUCCESS

Streamflows in Lagunitas Creek were high and variable during the 1982/83 incubation period, and relatively low and stable during the 1983/84 period. We believe that 1983/84 streamflows most closely resemble incubation conditions that would occur in a normal or dry year. We therefore used our 1983/84 data to examine possible relationships between variables that we

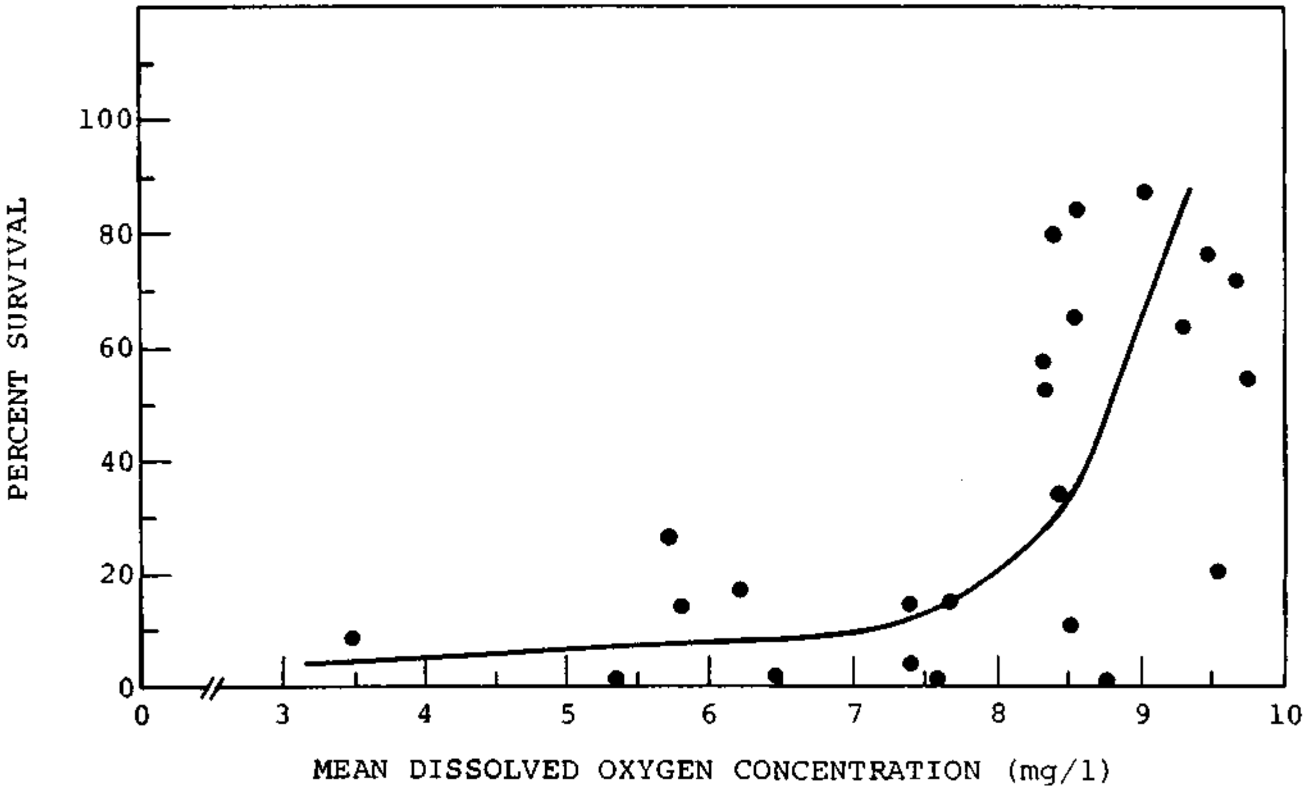


Figure 6-4. Relationship between mean intragravel dissolved oxygen concentration and survival to hatching of coho salmon embryos in Needle Branch Creek, Oregon (from Phillips and Campbell 1961).

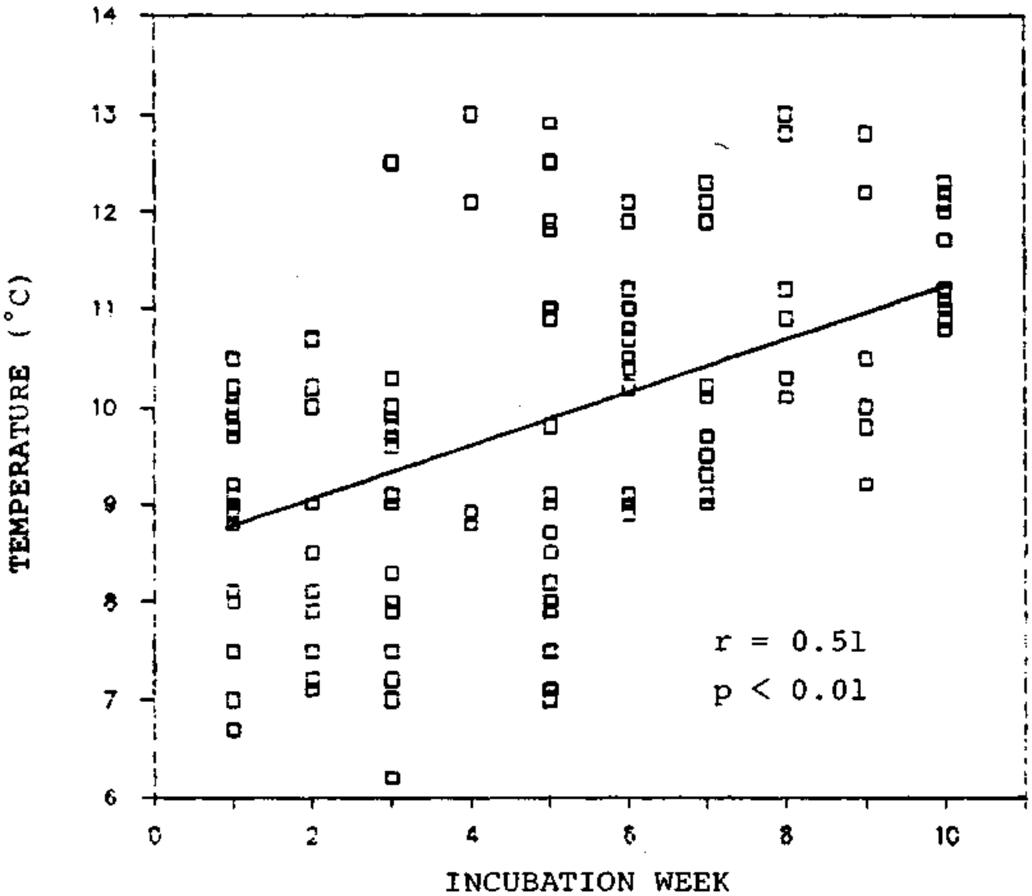


Figure 6-5. Intragravel water temperatures measured within the mounds of representative coho salmon redds and simulated redds in Lagunitas Creek and its major tributaries, 1982/83. Temperatures generally increased throughout the incubation period but remained within levels suitable for embryonic development of salmonids.

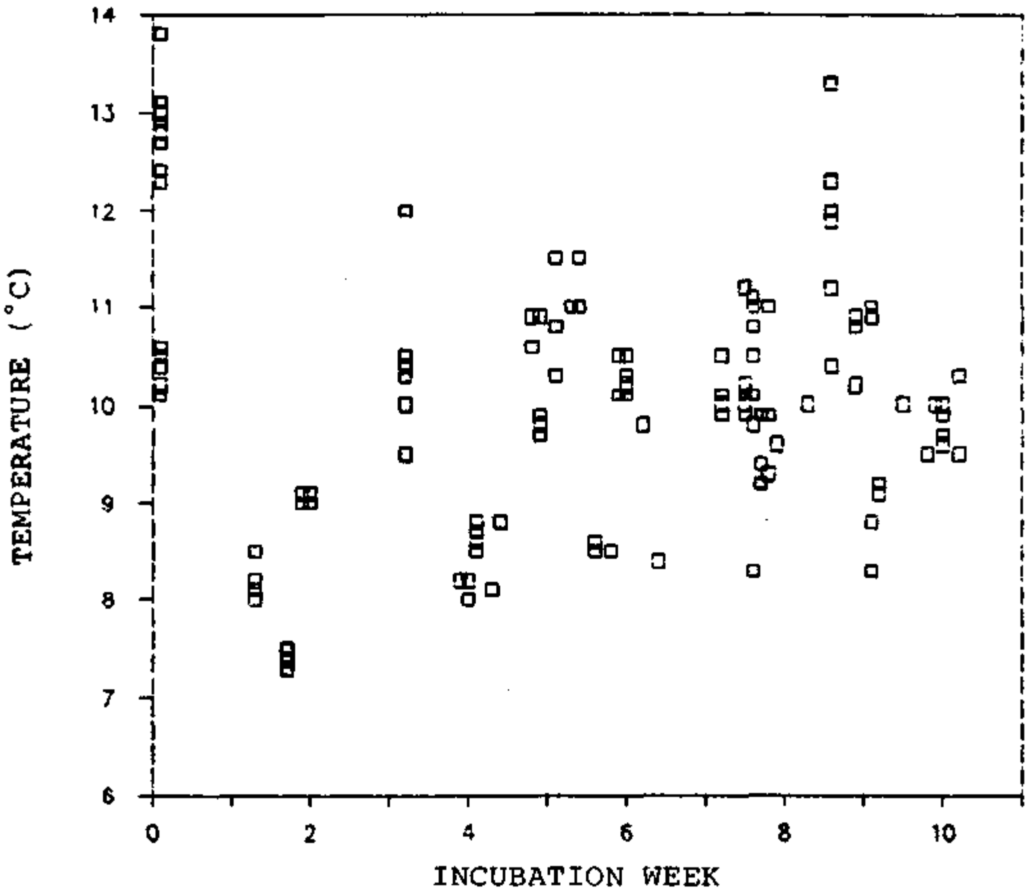


Figure 6-6. Intragravel water temperatures measured within the mounds of representative coho salmon redds in Lagunitas Creek and its major tributaries, 1983/84. Temperatures were suitable for embryonic development and were not significantly correlated to week of incubation.

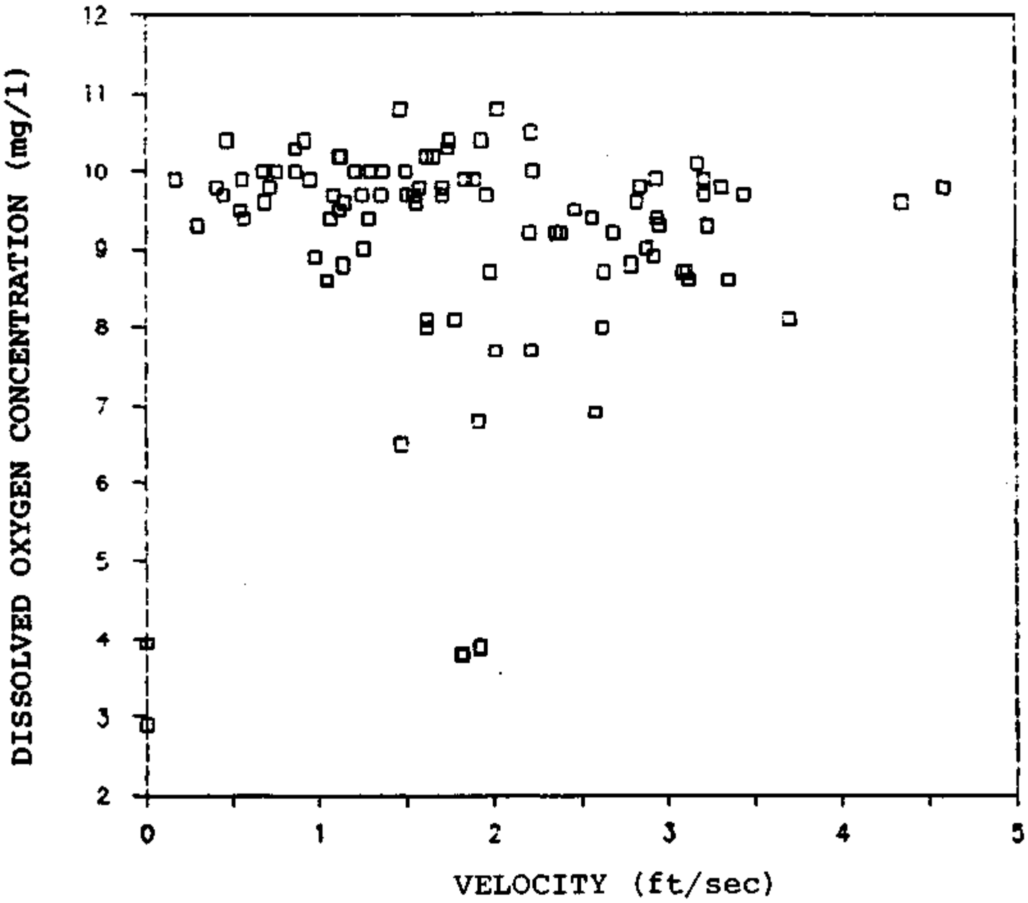


Figure 6-7. Comparison between intragravel dissolved oxygen concentration and mean column water velocity measured over the mound of representative coho salmon redds and simulated redds in Lagunitas Creek and its major tributaries during the 1982/83 incubation period. The correlation was insignificant.

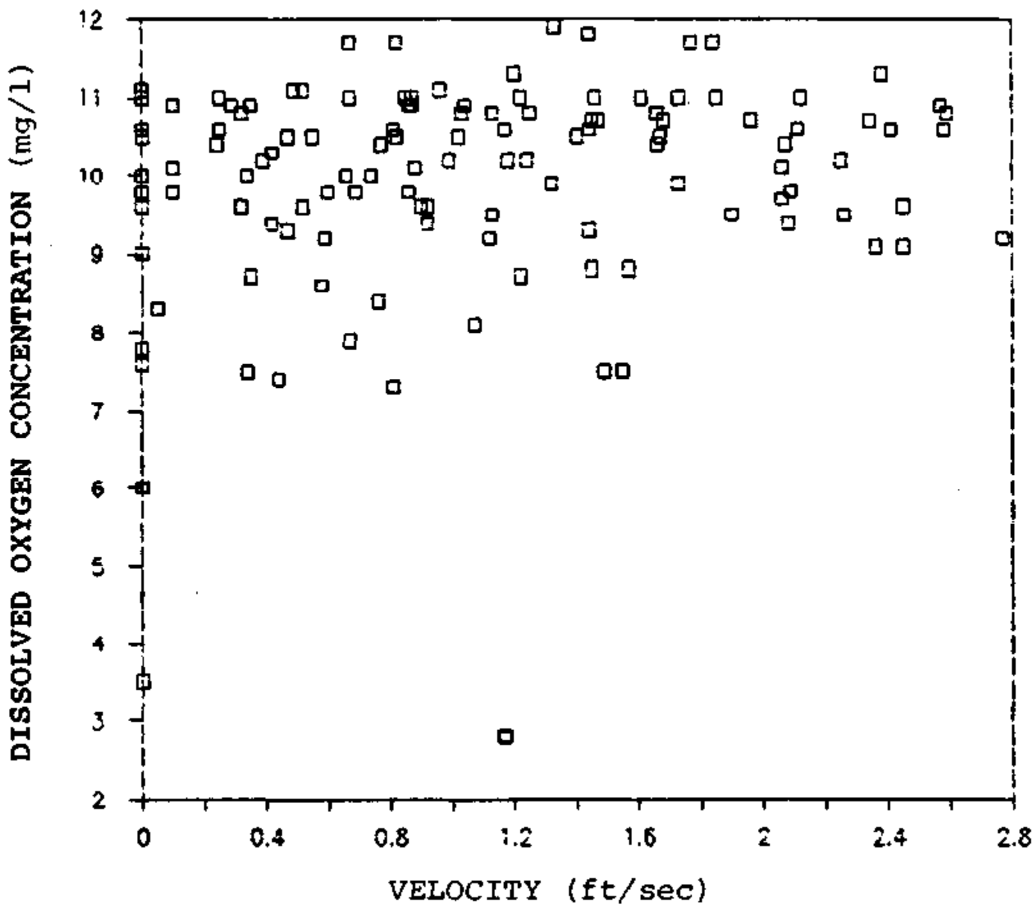


Figure 6-8. Comparison between intragravel dissolved oxygen concentration and mean column water velocity measured over the mound of representative coho salmon redds in Lagunitas Creek and its major tributaries during the 1983/84 incubation period. The relationship was weak (r = 0.17) and not significant ($P > 0.05$).

believed to be important to embryo incubation, using simple linear correlation analysis.

Intragravel dissolved oxygen concentration in the mounds of salmon redds was positively but weakly associated with water depth measured adjacent to the redds, and negatively associated with intragravel temperature (Table 6-1). Considered individually, no single variable included in the analysis accounted for more than 6% of the variation in intragravel dissolved oxygen.

Water temperatures in the creek were usually slightly colder than temperatures within the redds. More than 97% of the creek temperatures were within 10% of the corresponding intragravel temperatures.

Substrate

We reassessed the surface substrate composition of the 17 salmon redds at the end of the 1983/84 incubation season with the same methods used to assess substrate at the time of spawning (Chapter 4). Surface substrate of salmon redds contained higher amounts of fine particles 2 mm in diameter or less at the end of the incubation period than at the time of spawning (Figure 6-9). Fine materials reportedly interfere with water exchange between the surface and underlying substrate and may result in reduced dissolved oxygen concentrations in the mounds of the redds.

We examined the possible relationships between surface substrate composition of the mounds and intragravel dissolved oxygen concentrations with simple linear correlations. We compared the average intragravel dissolved oxygen concentration of each redd measured throughout the incubation period with the average of the cumulative particle size distributions, measured at the time of spawning and end of the incubation period, for each size class of materials.

Intragravel dissolved oxygen concentrations were not significantly correlated with the average percentage composition of fine materials on the redd mounds (Table 6-2). Materials on the surface of the mounds were apparently coarse and/or loosely compacted enough to allow for intragravel dissolved oxygen concentrations that were generally suitable for salmonid embryo incubation.

SCOURING STREAMFLOWS

Lagunitas Creek and its major tributaries experienced many high scouring streamflows during the 1982/83 salmon incubation period. Major scouring storms occurred in late December, late January, and throughout February and March (Figure 2-3).

The sandy streambed of Lagunitas Creek becomes mobile and is easily scoured at high streamflows (Hecht et al. 1980; Hecht 1981). Prior to the 1982/83 incubation period, the streambed of Lagunitas Creek was in an nonequilibrium state characterized by "soft" beds that are prone to scour to depths affecting salmonid embryo incubation (Barry Hecht, personal

Table 6-1. Correlations between variables measured at representative coho salmon redds in Lagunitas Creek and its major tributaries throughout the incubation period, 1983/84. Analysis included 122 measurements of each variable. Significance at the $P < 0.05$ level is indicated (*).

	Incubation Week	Intragravel Dissolved Oxygen	Stream Dissolved Oxygen	Intragravel Temperature	Stream Temperature	Mound Velocity	Adjacent Velocity	Mound Depth	Adjacent Depth
Incubation Week	- - -								
Intragravel Dissolved Oxygen	-0.21*	- - -							
Stream Dissolved Oxygen	0.18*	0.31*	- - -						
Intragravel Temperature	-0.10	-0.35*	-0.59*	- - -					
Stream Temperature	-0.12	-0.26*	-0.60*	0.96*	- - -				
Mound Velocity	-0.34*	0.17	-0.12	0.04	0.10	- - -			
Adjacent Velocity	-0.36*	0.06	-0.11	0.08	0.13.	0.80*	- - -		
Mound Depth	-0.17	0.28*	0.17	-0.18*	-0.10	0.71*	0.59*	- - -	
Adjacent Depth	-0.25*	0.35*	0.02	-0.07	0.01	0.51*	0.33*	0.70*	- - -

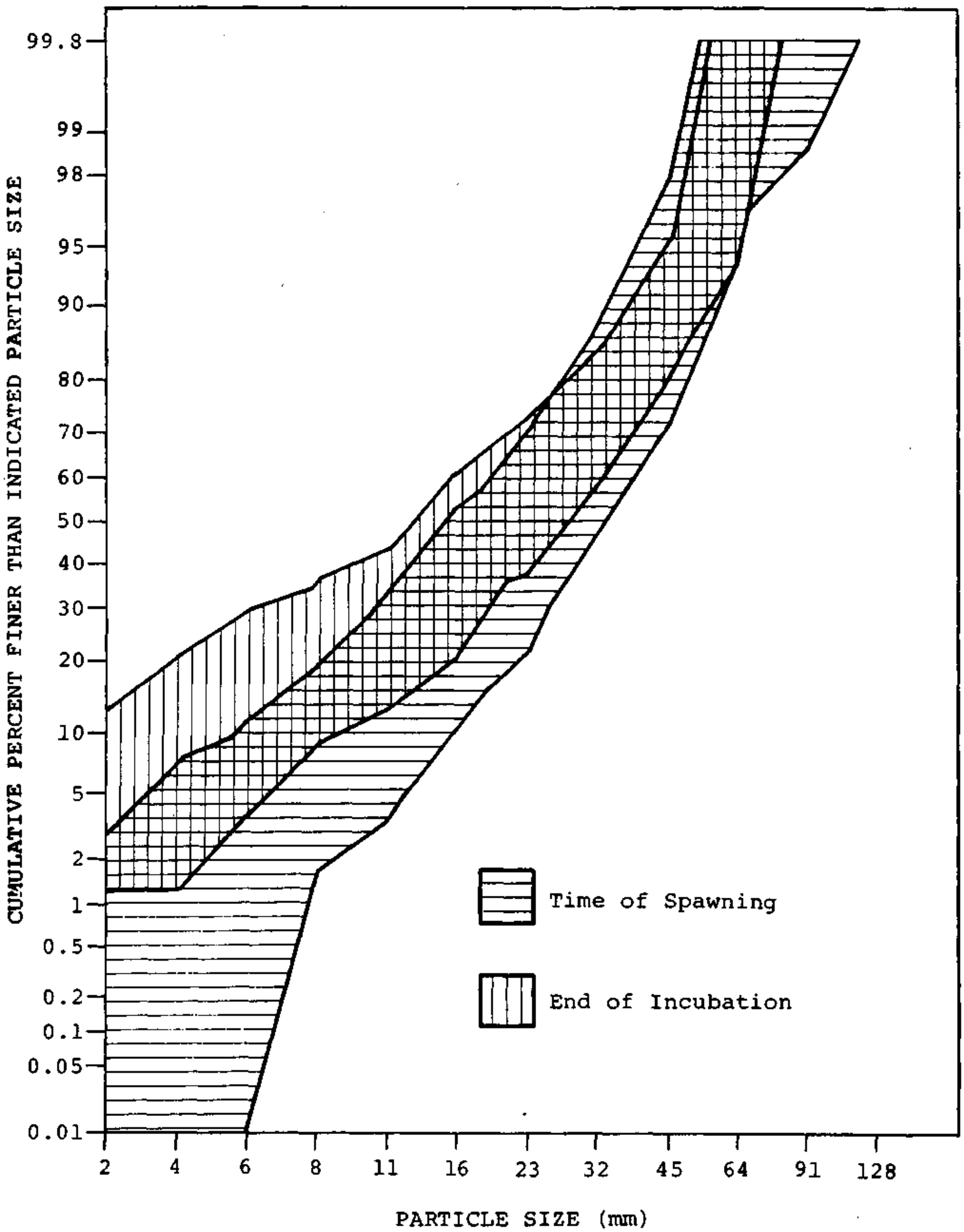


Figure 6-9. Comparison between envelopes of surface substrate particle size distribution at the time of spawning and end of the incubation period for the mounds of 17 coho salmon redds in Lagunitas Creek, 1983/84.

Table 6-2. Relationships between mean intragravel dissolved oxygen concentrations measured throughout the incubation period and means[1] of individual particle size classes measured on the surface of the mounds of 17 coho salmon redds in Lagunitas Creek, 1983/84. Significance at the P < 0.10 level is indicated (*).

Mean Intragravel Dissolved Oxygen (mg/l)	Percentage ≤ Given Particle Size (mm)									
	2	4	6	8	11	16	23	32	45	64
10.7	6.3	9.5	12.2	18.2	26.8	41.1	53.0	68.7	83.3	96.6
9.2	4.2	12.1	15.0	21.7	32.0	48.8	58.9	75.6	37.7	96.5
10.9	5.7	11.4	15.2	20.9	29.9	44.1	61.0	79.5	92.3	98.0
9.7	4.1	11.2	18.4	27.0	32.0	45.1	57.4	70.7	89.1	97.9
10.4	3.1	9.0	15.0	19.5	29.8	45.8	56.6	70.1	85.8	99.4
9.9	3.8	8.2	9.5	13.5	20.1	34.4	52.6	70.6	90.4	99.4
7.5	5.8	10.4	15.0	23.7	34.4	49.1	63.8	78.6	94.2	99.4
8.6	3.1	6.9	10.8	14.0	23.1	48.4	69.0	85.2	96.2	98.7
10.5	1.3	3.3	6.9	9.1	15.9	30.2	51.7	72.3	89.2	98.6
10.1	5.9	10.6	14.3	19.8	26.7	40.1	56.5	72.8	87.4	98.0
10.1	6.3	10.9	18.2	24.3	33.2	48.4	58.9	71.1	84.2	97.4
9.1	1.3	1.9	3.8	8.9	18.6	31.6	50.3	72.9	92.2	97.4
7.8	0.6	0.6	2.6	5.8	9.9	16.5	37.9	56.9	80.7	96.6
10.8	3.2	5.7	9.7	14.4	19.7	30.8	42.1	60.6	81.3	95.4
10.8	3.9	6.6	10.4	13.0	18.1	26.3	39.1	61.5	79.5	98.1
10.8	2.5	3.8	7.1	9.6	12.3	20.6	30.4	52.1	75.6	93.5
10.9	1.3	3.1	4.5	8.2	16.7	30.2	44.5	65.2	86.1	96.0
Correlation Coefficient (r) Between D.O. & Particle Size Class	0.11	0.07	0.07	-0.04	-0.11	-0.15	-0.32	-0.31	-0.43*	-0.32

[1] Calculated as the average of the cumulative particle size distributions, measured at the time of spawning and end of the incubation period, for each size class of materials'.

communication).

1982/83

Two methods were utilized to measure the extent of scour or fill of streambed materials during the 1982/83 incubation period.

To obtain estimates of maximum instantaneous scour, we installed scour gages at each of the simulated redd stations. Scour gages consisted of five "Ping-Pong" balls threaded on a monofilament line strung between an anchor buried 8 inches deep in the streambed and a small float on the streambed surface. As scour occurred, balls were released from the gravel to float up on the line.

Severe scouring occurred at most locations. Prior to December 29, 1982, scour occurred to depths of 2 inches at the lower State Park simulated redd station, 2 inches at the Irving Bridge station, and 3 inches at the station located upstream from Shafter Bridge. The gages located slightly downstream from San Geronimo and Devils Gulch creeks were completely washed away. By March 10, 1983, scour had occurred to depths of 3 inches in Devils Gulch Creek, 8 inches or more in San Geronimo Creek, and 8 inches or more in Lagunitas Creek upstream from Shafter Bridge. Due to high streamflows, monitoring was not again possible until April 18, 1983, by which time the scour gages, as well as most of the concrete anchors of the intragravel water samplers, were completely scoured away at all simulated redd monitoring stations.

To measure net scour or fill, steel concrete-reinforcing rods were driven into the streambed near each monitored salmon redd and simulated redd. The height of rod extending above the streambed, at the time of each monitoring, was measured to obtain a relative estimate of net scour or fill at this point.

High streamflows prevented us from measuring net scour between mid-January and mid-April 1983 at monitoring sites located in Lagunitas Creek downstream from Shafter Bridge. By mid-April 1983, sediment had filled the stream channel up to about 0.6 ft at monitoring stations located below the lower State Park boundary, 0.88 ft upstream of Shafter Bridge, and 0.5 ft in San Geronimo Creek. The fill above Shafter Bridge was composed partly of rock escaping from the gabions formed by the MMWD sediment retention pond. The sediment in San Geronimo Creek probably resulted from bank erosion. The streambed was scoured at two stations—approximately 0.4 ft in the State Park Reach in Lagunitas Creek and approximately 0.5 ft in Devils Gulch Creek.

We believe that most of the salmon redds were destroyed during the 1982/83 incubation period due to high, scouring streamflows. Results from our 1982/83 investigations, along with studies conducted by Hecht (1983), indicated that as streamflows increased and reached peak levels the streambed was scoured, and as flows declined the sediment was redeposited on the streambed. The amount of scour and redeposition of sediment varied depending upon the creek, substrate composition of the streambed, longitudinal location in the creek, and location in the creek channel. 1983/84

In 1983-84 we revised our methods to better define the effect of scouring streamflows on incubating salmon embryos. In early winter of 1983 we established a total of 18 scour gages in Lagunitas Creek and its major tributaries.

Scour gages were buried in simulated redds adjacent to actual salmon redds. We constructed 12-inch-deep simulated redds by lifting a shovel to simulate the digging action of a female salmon. A scour gage was then placed in the pit, the digging was repeated upstream and the gage was buried under a mound of gravel. Ten gages were installed in Lagunitas Creek, and four each in San Geronimo and Devils Gulch creeks (Figure 6-1).

In 1984, net scour at 10 simulated redds in Lagunitas Creek ranged from 2 to 8.3 inches and averaged about 6 inches (Table 6-3). Previous studies have shown that salmon cover their eggs with about 8 inches of gravel. This means that at six of the simulated redds scour was severe enough to have resulted in high mortality rates for incubating eggs. Scour was most severe during two storms in late December and early January that increased mean daily flows from 25 to 925 cfs and from 130 to 500 cfs (see Figure 2-4). During these storms scour ranged from 2.25 inches to 6.5 inches and averaged about 4 inches, or two-thirds of the total average net scour during the season. Two smaller storms in mid-February and mid-March, resulting in mean daily flows not exceeding about 75 cfs, scoured from 0.0 to 5.5 inches of gravel and on average caused about one-third of the total average net scour. Our measurements of scour indicate that with 1984 streambed conditions salmon redds can tolerate one or two moderate sized storms without suffering from the effects of scour, but more than two storms, or one of great magnitude, places most of the redds at risk and increases egg mortality to unacceptable levels.

The deposition of sediment on redds or intrusion of it into redds can cause high egg mortality by reducing oxygen concentrations, if the sediment is fine enough or it is intruded into the nest. The deposition of sediment at simulated redds in Lagunitas Creek ranged from 0.0 to 5 inches and averaged 1.8 inches (Table 6-3). Our measurements of intragravel dissolved oxygen in these simulated redds indicated that oxygen concentration was generally acceptable. It is important to note that this probably would not have been the case had the sediment been composed of fine sand, silt, or clay,

CONCLUSIONS - EMBRYO INCUBATION

In the two years of our incubation studies, flows during the 1983/84 incubation period were lower, more stable, and best for salmonid embryo incubation in Lagunitas Creek. Mean daily flows measured at the SPTSP gage continuously declined from over 100 cfs in early January to 13 cfs on January 26, 1984. From then until February 12 flows were between 13 and 11 cfs. A minor freshet resulted in a mean flow of 40 cfs on February 13, after which time flows again declined to 13 cfs on February 27 and remained at 13 cfs

Table 6-3. Scour and deposition of gravel and sand at 18 simulated redds in the Lagunitas Creek Basin during 1983/84.

		[1] Lagunitas Creek Simulated Redd Number										Devils Gulch Creek				San Geronimo Creek			
Date	**Measurement**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
23-Dec-83	Inflection	17.00	16.00	19.00	19.00	20.00	17.00	18.00	17.00	16.00	17.00								
01-Jan-84	Inflection											18.00	18.00	17.00	18.00				
	Deposition																		
	Scour																		
04-Jan-84	Inflection															15.00	14.00	16.00	12.00
	Deposition																		
	Scour																		
05-Jan-84 [2]	Inflection	23.50	20.50	21.75	22.75	24.00	19.50			18.25	22.00								
	Deposition	0.00	0.00	0.00	2.75	0.00	2.50			3.00	2.00								
	Scour	-6.50	-4.50	-2.75	-3.75	-4.00	-2.50			-2.25	-5.00								
09-Jan-84	Inflection			New gages at #7 & #8				11.00	17.00										
	Deposition																		
	Scour																		
24-Feb-84	Inflection	24.25	20.50	22.25	26.50	24.00	19.50	13.50	22.50	18.50	24.25								
	Deposition	0.75	0.00	0.25	0.50	0.00	0.25	0.00	0.00	1.50	2.75								
	Scour	-0.75	0.00	-0.50	-3.75	0.00	0.00	-2.50	-5.50	-4.50	-2.25								
25-Feb-84	Inflection											18.25	18.00	16.50	18.00	15.00	15.25	21.00	14.00
	Deposition											0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Scour											-0.25	0.00	0.50	0.00	0.00	-1.25	-5.00	-2.00
Subtotal Deposition		0.75	0.00	0.25	3.25	0.00	2.75	0.00	0.00	4.50	4.75	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subtotal Net Scour		-7.25	-4.50	-3.25	-7.50	-4.00	-2.50	-2.50	-5.50	-6.75	-7.25	-0.25	0.00	0.50	0.00	0.00	-1.25	-5.00	-2.00

Table 6-3 (continued). Scour and deposition of gravel and sand at 18 simulated redds in the Lagunitas Creek Basin during 1983/84.

		[1] Lagunitas Creek Simulated Redd Number										Devils Gulch Creek				San Geronimo Creek			
Date	Measurement	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Subtotal Deposition		0.75	0.00	0.25	3.25	0.00	2.75	0.00	0.00	4.50	4.75	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subtotal Net Scour		-7.25	-4.50	-3.25	-7.50	-4.00	-2.50	-2.50	-5.50	-6.75	-7.25	-0.25	0.00	0.50	0.00	0.00	-1.25	-5.00	-2.00
05-Apr-84	Inflection	25.00	20.50	22.25	26.75	24.25	19.00	17.00	24.00	20.00	24.75	19.00	18.50	16.50	18.25	16.00	17.00	23.75	15.25
	Deposition	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.50	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25
	Scour	-0.75	0	0	-0.25	-0.25	0.5	-3.5	-1.5	-1.5	-0.5	-0.75	-0.5	0	-0.25	-1	-1.75	-2.75	-1.25
Total Deposition		0.75	0.00	0.25	3.50	0.00	2.75	0.00	0.50	5.00	4.75	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.25
Net Scour		-8.00	-4.50	-3.25	-7.75	-4.25	-2.00	-6.00	-7.00	-8.25	-7.75	-1.00	-0.50	0.50	-0.25	-1.00	-3.00	-7.75	-3.25
Average Deposition		1.75										0.06				0.06			
Average Net Scour		-5.87										-0.31				-3.75			

[1] A scour gage was buried at each simulated redd. The gage consisted of a buried 2-lb cast iron ball attached to a 36-inch length of 1/4 diameter nylon cord that extended vertically to the streambed surface. The cord was marked at 1/4-inch increments along its length. At time of subsequent monitoring, the distance from the end of the cord to the point of inflection, where the cord bends over a downstream direction, was measured to the nearest 1/4 inch. If deposition had occurred since the last measurement, the position of the fill was noted and the overlying sediment was gently swept away until the new point of inflection was located and the distance from the end of the cord to that point was measured. The amount of deposition was estimated by measuring the distance from the point of inflection to the streambed surface.

[2] Gage reinstalled at #9, set at depth of 14 inches.

through March 12, 1984.

The streamflows, intragravel dissolved oxygen concentrations, and water temperatures we measured in 1984 were generally suitable for incubation. Based on mean intragravel dissolved oxygen concentrations in natural salmon redds, we estimate an average survival to hatching was 76%. With streambed conditions similar to those that existed during the 1983/84 incubation period, we believe that flows as low as 11 to 13 cfs, measured at the SPTSP gage, provide adequate conditions for the incubation of salmon embryos in Lagunitas Creek.

We further conclude that high, scour-inducing, unregulated streamflows resulting from storm runoff adversely affect incubating salmon embryos in Lagunitas Creek.

CHAPTER 7 - FRY EMERGENCE

Coho salmon eggs hatch in the gravel after incubating 5 to 7 weeks in Lagunitas Creek. After the eggs hatch, the embryos retain a large yolk sac that protrudes from their abdomen. At this stage the young fish are referred to as "alevins".

Alevins remain in the gravel an additional 2 to 3 weeks after hatching while they absorb their yolk. They move about in the interstices of the gravel in both lateral and vertical directions (Dill and Northcote 1970). Alevins eventually absorb their yolk, move in an upward direction and emerge from the gravel as "fry". The size of the substrate and the amount of the fine sediment in the nest play an important role in the survival and ability of alevins to emerge from the streambed into the stream.

SEDIMENT ACCUMULATION

Female salmon cleanse the redd at the time of spawning, but sediment accumulates on the redds during the incubation period (Chapter 6, Figure 6-9). Sediment accumulation in the redd can adversely affect reproductive success by acting as a physical barrier to fry emergence.

Because the streambed of Lagunitas Creek appeared to contain large amounts of sand and fine sediment, we assessed the effects of streambed substrate conditions on fry emergence.

Substrate Composition

Our approach was to measure the substrate composition in natural salmon redds in Lagunitas Creek and compare those measurements to laboratory and field studies that quantified the effects of fine sediment on the survival of alevins and emergence of fry.

Substrate Sampling

We sampled the substrate in 17 of the 18 salmon redds that we had monitored throughout the 1983/84 incubation period in Lagunitas Creek. Samples were taken in late March and early April 1984, shortly after the time of emergence of salmon fry.

We collected substrate samples using the same procedure that Hecht has used to monitor streambed conditions in Lagunitas Creek since 1979. A thin-walled cylindrical sampler[1] was gently rotated into the mound of the redd, generally from 5 to 8 inches deep. The samples were removed by gently digging around the sampler by hand, inserting a metal plate under the open bottom of the sampler and pulling the sampler and the plate from the redd mound. Water within the samples was carefully decanted in the field at the time of sampling. Samples were sealed in plastic containers, transported to the J. H. Kleinfelder & Associates laboratory, oven-dried, and sieved.

This sampling procedure results in the loss of some fine materials, mostly silts and clays, from the sample. Particle-size distributions based on this sampling procedure underestimate the percentage of very fine material. Hecht (1983) estimated the loss was usually less than about 0.5%, and probably never more than 2%. Considering there is a relatively small amount of very fine material in the streambed of Lagunitas Creek, we believe the sampling procedure was appropriate.

Most of the redd substrate contained relatively small amounts of fine sediment, primarily coarse sand (Table 7-1).

<u>Analysis</u>

There have been many contrasting definitions by fisheries biologists of what size of material actually is detrimental to survival and emergence of fry. Salmon embryo survival through emergence has been related to the amount of fine sediment smaller than 0.85 mm (Cedarholm et al. 1981), 0.83 mm and 3.3 mm (Koski 1972), and the amount of material between 1 and 3 mm in diameter (Hall and Lantz 1969; Phillips et al. 1975). Salmonid embryo survival also has been compared to alternative measures of substrate that are not dependent upon "percent fines" but include more comprehensive measures of substrate composition (Platts et al. 1979; Shirazi et al. 1981). We compared the amount of fine sediment and substrate composition in redds in Lagunitas Creek to the results and relationships presented in these reports.

In the Clearwater River, Washington, Cedarholm et al. (1981) compared salmon survival from egg deposition through emergence with the amount of fine sediment less than 0.85 mm diameter. Estimated survival from natural redds ranged from approximately 1% to 77%, and averaged 29.9% for the 2-year study period (Figure 7-1). They also conducted a controlled experiment in

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[1] After trying a variety of 6-inch samplers, geomorphologist Hecht (1983) recommended the use of a 2-pound coffee can to collect substrate core samples. With practice, a metal plate can be inserted under the can so that an air-tight seal is formed, and the sampler can be extracted and inverted prior to decanting. Tests on Lagunitas Creek material showed no loss of sand-sized material during careful decanting; other dewatering procedures might be necessary in streams containing substantial amounts of coarse silt or fine sand in their streambeds.

Table 7-1. Substrate composition in 17 mounds of coho salmon redds in Lagunitas Creek at the end of the 1983/84 incubation period. Values presented were used to assess fry emergence survival.

Location in Downstream Order (Nearest Road Marker on Sir Francis Drake Blvd.)		Percent Fines Less Than 0.85 mm	Percent Fines Less Than 3.33 mm	Particle-Size Descriptors		
				D_{16}	D_{50}	D_{84}
Shafter Bridge	15.68	9.1	18.9	1.05	13.35	26.0
	15.89	2.7	9.6	4.33	33.68	53.71
	15.91	3.8	16.0	1.51	15.2	35.16
	15.91	3.5	9.9	4.2	28.76	53.90
	15.98	0.7	1.6	14.48	34.67	41.59
	16.42	12.8	25.2	0.66	8.72	25.37
	16.48	0	0.5	10.28	18.11	35.36
Irving Bridge	16.81	0.1	3.7	5.73	15.26	28.08
	17.20	1.7	9.4	4.55	18.71	41.9
	17.44	0.1	0.5	6.76	18.51	33.42
	18.74	0.6	3.5	10.37	32.0	45.63
	18.74	4.8	13.9	4.18	21.35	44.24
	18.85	0.3	7.6	6.82	26.84	62.09
	18.91	0	0.4	11.63	24.98	43.27
	19.25	4.9	13.4	4.42	17.46	28.43
	19.46	1.3	4.4	9.16	19.36	38.85
Tocaloma Bridge	20.81	2.0	10.0	3.88	17.29	41.85
AVERAGE		2.8	8.7	6.12	21.43	39.93

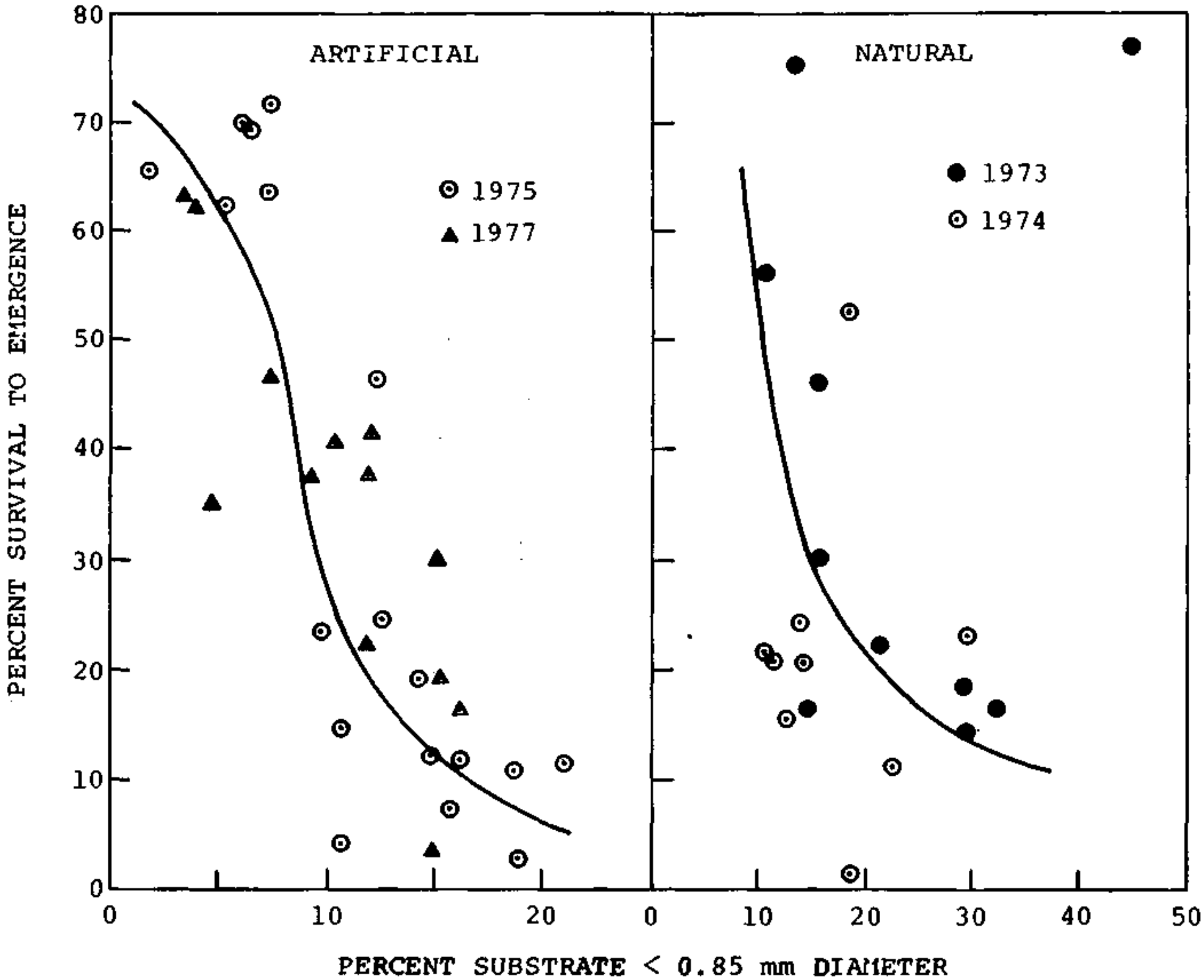

Figure 7-1. Relationship between coho salmon survival from egg deposition to emergence under artificial stream conditions and natural conditions in the Clearwater River, Washington (adapted from Cedarholm et al. 1981).

artificial troughs and found that survival ranged from about 3% to 95%, and averaged 33% and 35.1% each year of the study (Figure 7-1). A significant ($P < 0.01$) inverse relationship was found between survival to emergence and the amount (about 3% to 21%) of fine materials.

Small amounts of fine materials less than 0.85 mm diameter were present in natural salmon redds in Lagunitas Creek (Table 7-1). The amounts of these fine materials ranged from 0% to 12.8% and averaged 2.8% for all 17 redds. By applying Cedarholm et al.'s relationship developed under experimental conditions, we estimate that salmon survival from egg deposition to fry emergence would average about 65% in Lagunitas Creek.

Salmon emergence survival in three coastal Oregon streams has been monitored for several years, and results from the period 1964-1967 were summarized by Koski (1972). He found that emergence survival was negatively correlated ($r = -0.73$) with the amount of fine sediment less than 3.327 mm in diameter. Average survival estimates ranged from about 12% to 54%, with the low survivals associated with large amounts (about 31% to 44%) of fine material (Figure 7-2).

In salmon redds in Lagunitas Creek, the amount of fine materials less than 3.3 mm diameter ranged from only 0.4% to 25.2% (Table 7-1). Even the redd that had the <u>most</u> fine sediment in Lagunitas Creek contained <u>less</u> fine material than the amounts presented by Koski. Using Koski's relationship, estimated salmon survival from egg deposition to fry emergence in Lagunitas Creek would exceed 50%.

There is general agreement among fisheries biologists that excess fines are harmful to embryo incubation and fry emergence, although definition of "fines" varies among researchers. As an alternative measure of spawning substrate, Platts et al. (1979) suggested the use of the geometric mean diameter (Dg) of the substrate. The Dg is calculated as the square root of the product of D_{16} and D_{84}, the particle sizes below which 16% and 84% of the particle size distribution is finer. Geometric mean diameter was proposed for use as an appropriate spawning substrate characterization principally because (1) Dg is a conventional measure used in other disciplines to characterize substrate composition; (2) statistical comparisons among spawning areas and studies are convenient using Dg as a standard; and (3) Dg is a more complete description of total substrate composition than "percent fines".

A positive relationship between embryo survival of salmonids and geometric mean diameter of substrate within the redd was presented by Shirazi et al. (1981). Using data obtained from several other studies, they found an empirical relationship between survival during different embryo to alevin and fry emergence stages with geometric mean diameter of the spawning substrate (Figure 7-3). Their relationship showed that salmonid embryo survival increased to over 90% when geometric mean exceeded 18 mm.

In Lagunitas Creek, substrate composition of salmon redds was characterized by geometric mean diameters that ranged from 4.09 to 24.54 mm and averaged 14.89 mm. Using the relationship presented by Shirazi et al.

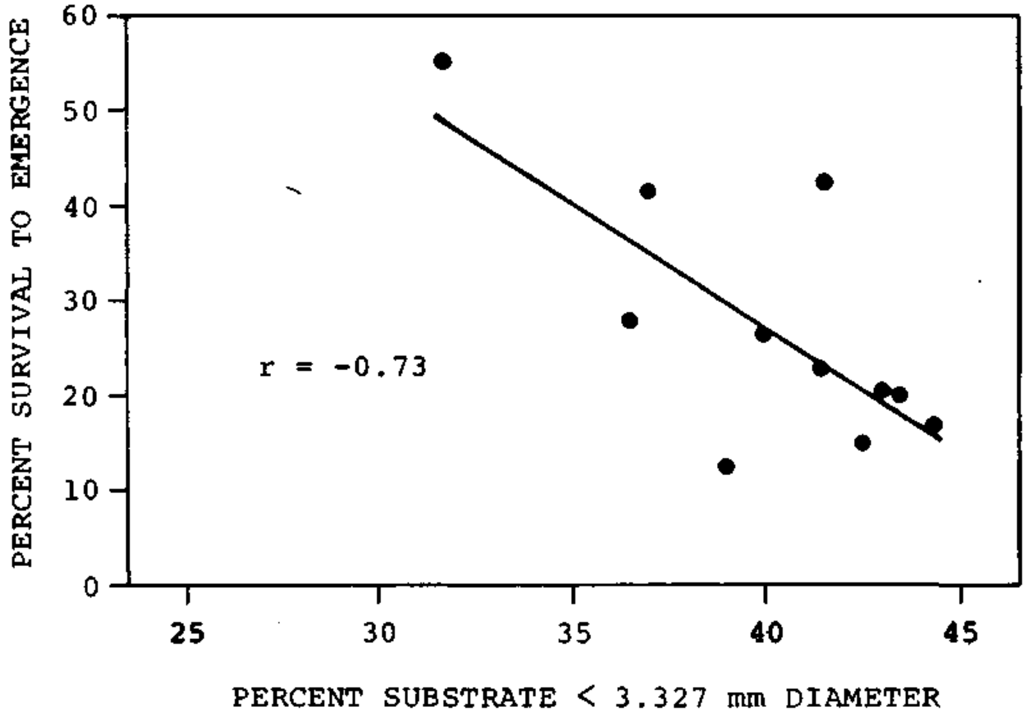

Figure 7-2. Relationship between substrate composition and the average survival from egg deposition to fry emergence of coho salmon from Deer, Flynn, and Needle Branch creeks, Oregon, each year from 1964-1967 (modified from Koski 1972).

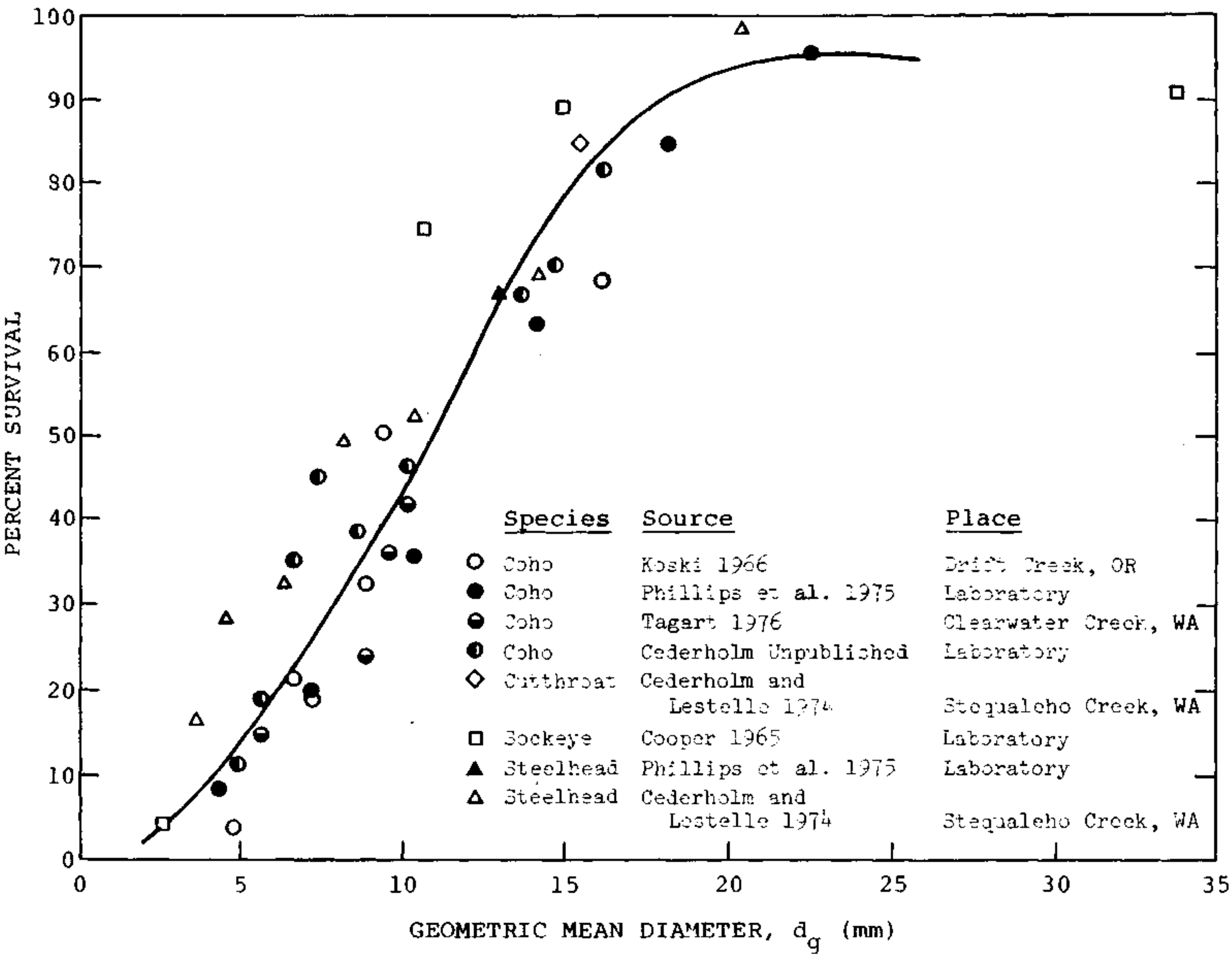

Figure 7-3. Relationship between percent embryo survival and geometric mean diameter of the spawning substrate (from Shirazi et al. 1981) .

(1981), we calculated that survival of salmon embryos in Lagunitas Creek averaged 70% and ranged from 10% to 96% in the 17 redds measured.

The previously discussed studies related percent fine materials to salmon survival from egg deposition through emergence and geometric mean diameter to survival during various embryo to fry emergence stages. They necessarily included the effects of other intragravel conditions such as intragravel water flow and dissolved oxygen concentration, as well as physical entrapment of alevins.

Emergence survival of salmon and steelhead, based on only the physical entrapment of alevins, was studied by Hall and Lantz (1969) and expanded upon by Phillips et al. (1975). In experimental troughs, they buried alevins of both species in eight gravel mixtures that contained from 0% to 70% 1-3 mm diameter sand in 10% increments. They found an inverse relationship between the amount of fines and emergence survival. Mean emergent survival for salmon ranged from 96% in no sand to 8% survival in 70% sand. Steelhead survival was higher than salmon and ranged from 99% to 18% (Figure 7-4).

We compared the amount of fine materials in natural salmon redds in Lagunitas Creek with the relationship presented by Phillips et al. (1975). To obtain a more realistic estimate of emergence survival, we included all materials in the redds less than 3 mm. Using Phillips et al.'s relationship, we estimated that emergence survival of salmon in Lagunitas Creek ranged from 46% to 96% and averaged 78%.

To obtain overall survival estimates from egg deposition through fry emergence, we combined our incubation survival estimates (Chapter 6) and our estimates of emergence survival based on the relationship developed by Phillips et al. Seventeen salmon redds that were monitored throughout the incubation period and sampled for substrate at the end of the emergence period were used to obtain the estimates. For each redd, overall survival was estimated by the product of incubation and emergence survival estimates. Survival estimates thus obtained were conservative in nature. From egg deposition through fry emergence, estimated survival of salmon ranged from 6% to 84% and averaged 59% in Lagunitas Creek. This is relatively high success.

We did not assess emergence survival of steelhead although we do not expect it is a problem because, compared to salmon, steelhead are better able to tolerate fine sediment. Tappel and Bjornn (1983) observed that small particle size classes of materials were less harmful to embryonic steelhead than chinook salmon, and steelhead fry are reported to emerge from sandy substrate more easily than the larger chinook salmon fry (Bjornn 1969). Likewise, emergence survival was higher for steelhead fry than salmon fry in identical mixtures of sand and gravel (Hall and Lantz 1969). At the time of emergence the steelhead were smaller than the salmon fry (Phillips et al. 1975) and better able to emerge through the restricted gravel interstices.

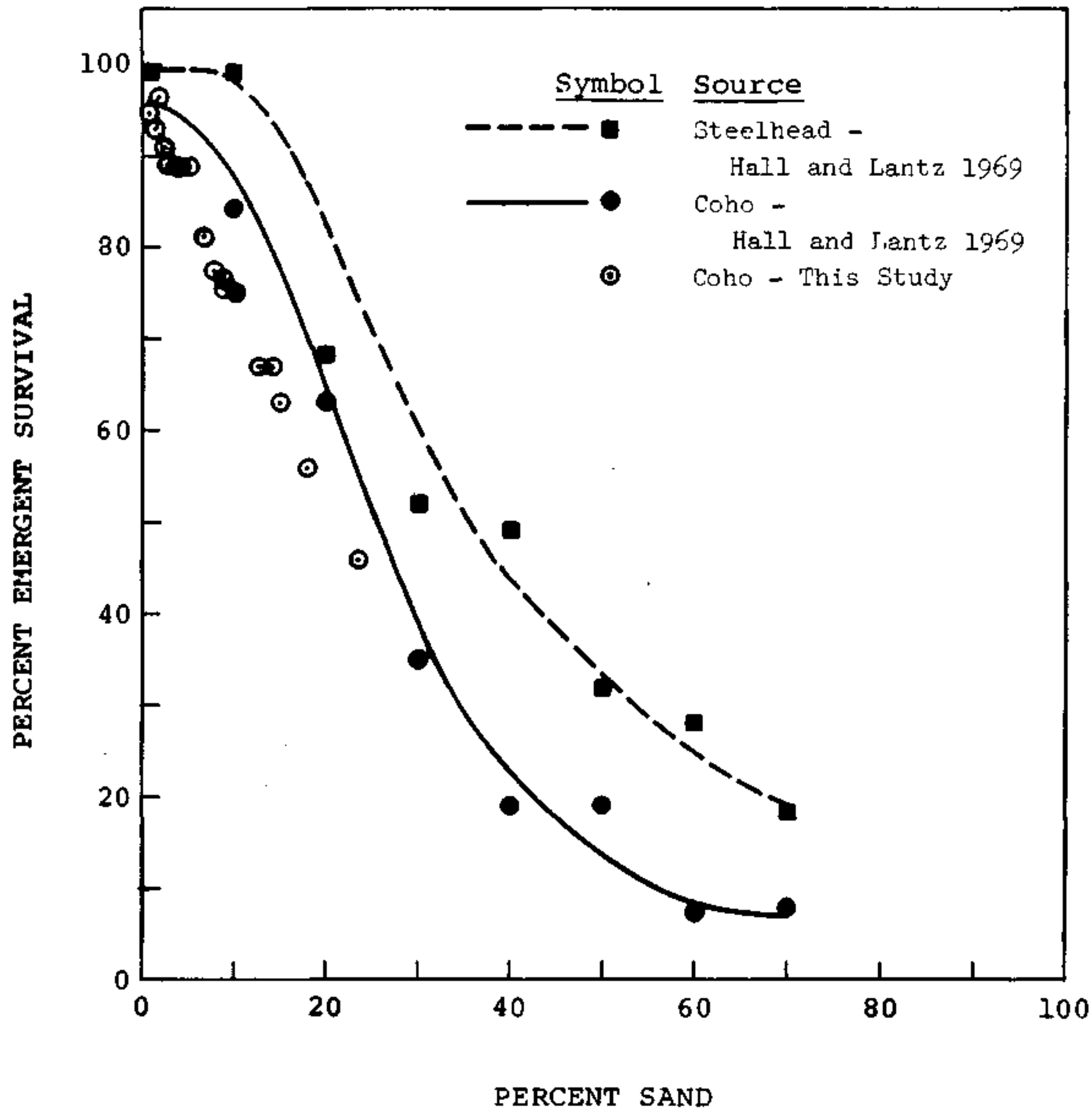

Figure 7-4. Relationship between average percent fry emergence survival and percentage of 1-3 mm sand (adapted from Hall and Lantz 1969). Values for this study were estimated from the relationship developed by Phillips et al. (1975) and were based upon the percentage of all materials less than 3 mm diameter in the mounds of 17 coho salmon redds in Lagunitas Creek, 1983/84.

Conclusions - Substrate Composition and Fry Emergence

Given substrate conditions that existed during 1983/84 and investigations conducted elsewhere, salmon embryo survival from egg deposition through fry emergence ranged from 6% to 84% and averaged 59% in Lagunitas Creek.

Substrate composition at the time of fry emergence is influenced by previous streamflows and sediment loading in the creek. A relatively low steady flow that does not erode banks or transport sand along the bed of the stream is probably best. Estimated survival through fry emergence was comparatively high following the relatively stable flows, generally from about 11 to 13 cfs (measured at the SPTSP gage), that occurred during the 1983/84 incubation period following the last storm in early January (Figure 2-4). These streamflows provided suitable conditions for fry emergence.

While 1983/84 streambed conditions were suitable for fry emergence, increased sedimentation of the streambed will reduce emergence success in Lagunitas Creek. Implementation of the sediment management plan is necessary and will benefit not only fry emergence but other life stages as well.

CHAPTER 8 - JUVENILE REARING

Coho salmon and steelhead trout fry begin residence in Lagunitas Creek after they emerge from the gravel. These newly emerged fry grow rapidly if water temperatures are favorable and food is abundant. They remain and grow in the creek for periods from a few months to 2 years before emigrating to the ocean. Salmonid emigration from Lagunitas Creek is described in Chapter 9 of this report. In this chapter we describe the important aspects of spring and summer rearing of juvenile salmonids in Lagunitas Creek.

SPRING REARING OF SALMONID FRY

Most of our observations on the spring rearing of salmonid fry in Lagunitas Creek were made during 1984. In contrast to 1983 and 1985, relatively large numbers of fry were observed in the creek during the spring of 1984 because of successful spawning, incubation, and emergence the preceding fall and winter. Also, stream conditions were conducive to observing the fish during the spring of 1984. Water was clear and flows were relatively stable. From April 1 through June 30, 1984 mean daily flows, measured at the SPTSP gage, ranged from 5.0 to 16 cfs. Mean monthly flows were 12.6 cfs in April, 10 in May, and 8.3 in June.

Fry Behavior and Habitat Use

Salmon fry emerge from the gravel and begin rearing in Lagunitas Creek from about mid-February to mid-March, depending upon the time of spawning. Steelhead fry emerge and begin rearing from early March to mid-May. Our observations of the behavior and habitat use of recently emerged salmon and steelhead fry in Lagunitas Creek are generally consistent with other published accounts (Shapovalov and Taft 1954; Chapman and Bjornn 1969; Mundie 1969; Bustard and Narver 1975; Tschaplinski and Hartman 1982).

Young fry of both species occupied habitat on the margins of the creek in the early spring. Fry were observed in habitat characterized by shallow depths (≤0.5 ft) and low water velocity. We observed numerous fry in shallow, quiet side channels with little or no flow of water. Fry were also found in slack water areas created by objects such as boulders and woody debris in the main channel of the creek.

Increasing numbers of small fry were observed in relatively quiet, shallow glides in the main channel of Lagunitas Creek as spring progressed. Larger fry were often observed near the streambed surface in less quiet glides. Fry in these habitats appeared to take advantage of reduced water velocities provided by large cobble, woody debris, and occasionally by depressions in the streambed surface resulting from old salmonid redds and lamprey nests. In all habitats the young fry were observed actively feeding. They darted about rapidly and frequently rose to small objects that drifted by or fell onto the water surface. Food appeared to be abundant and the fish appeared to grow rapidly and be in good condition.

Size of Salmon and Steelhead Fry

We measured the length and weight of fish captured biweekly from mid-April through June 1984 to assess the change in size and condition of salmonid fry during their first spring in Lagunitas Creek. Fish were collected with a 15 x 4 ft seine with 1/4 inch stretched mesh in two deep pools and adjacent glides within the State Park Reach of Lagunitas Creek. One sampling area was located near Irving Bridge and the other area was located near the downstream boundary of SPTSP.

Salmon and steelhead fry grew rapidly during the spring of 1984. Average length of salmon fry increased from about 58 mm on April 17 to 77 mm on June 25, 1984 (Figure 8-1). Size of steelhead fry also rapidly increased but, because of later emergence, their average length was lower than that of salmon fry at all times throughout the spring sampling period. Growth rate of salmon fry decreased as spring progressed. No such decrease was observed in the growth of steelhead fry probably because newly emerged steelhead were recruited into the sample population throughout the spring sampling period (Figure 8-2). Steelhead fry as small as 30 mm to 35 mm were sampled on June 25, 1984. Introduction of recently emerged small fry reduced the average length of fish that would otherwise have been observed during late spring.

Condition of Salmon and Steelhead Fry

To determine the general well-being of the fry that were collected in Lagunitas Creek during the spring of 1984, we calculated condition factors. Condition factor (K) is a measure of the general physical condition, or relative plumpness, of fish. It relates the weight (g) of a fish to its length (mm), and is calculated by the following equation:

$$K = \frac{\text{Weight} \times 10^5}{\text{Length3}}$$

The more a fish weighs at a given length the better physical "condition" it is in. A condition factor equal to 1 is an indication that fish are in relatively good condition.

Salmon fry were in good condition throughout the spring of 1984 (Figure 8-3). Average condition factors of salmon fry were quite stable, ranging only from 1.08 to 1.21 during the entire sampling period, and were higher than those of steelhead fry for all but the last sampling date.

Steelhead fry exhibited relatively low average condition factors during mid-April and early May (Figure 8-3) when mostly small fry were in the creek (Figures 8-1, 8-2). Average condition factor values were good (1.03) by mid-May and increased to a high value of 1.22 by late June.

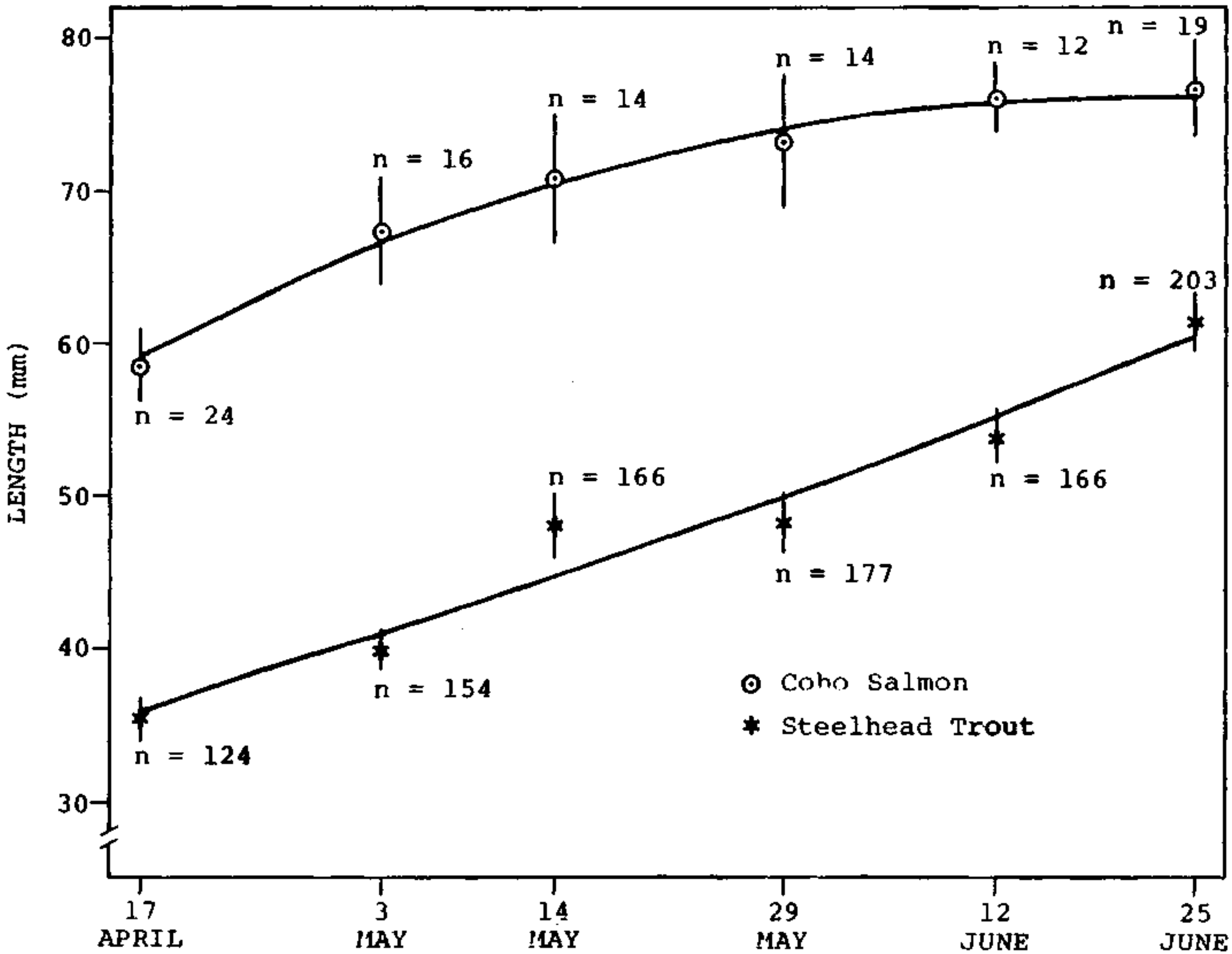

Figure 8-1. Average length for coho salmon (r^2 = 0.99) and steelhead trout (r^2 = 0.96) fry in Lagunitas Creek. Fry were collected by seining in the State Park Reach biweekly from April 17 through June 25, 1984. Vertical lines represent 95% confidence intervals. Number of individuals (n) included in the analysis are indicated.

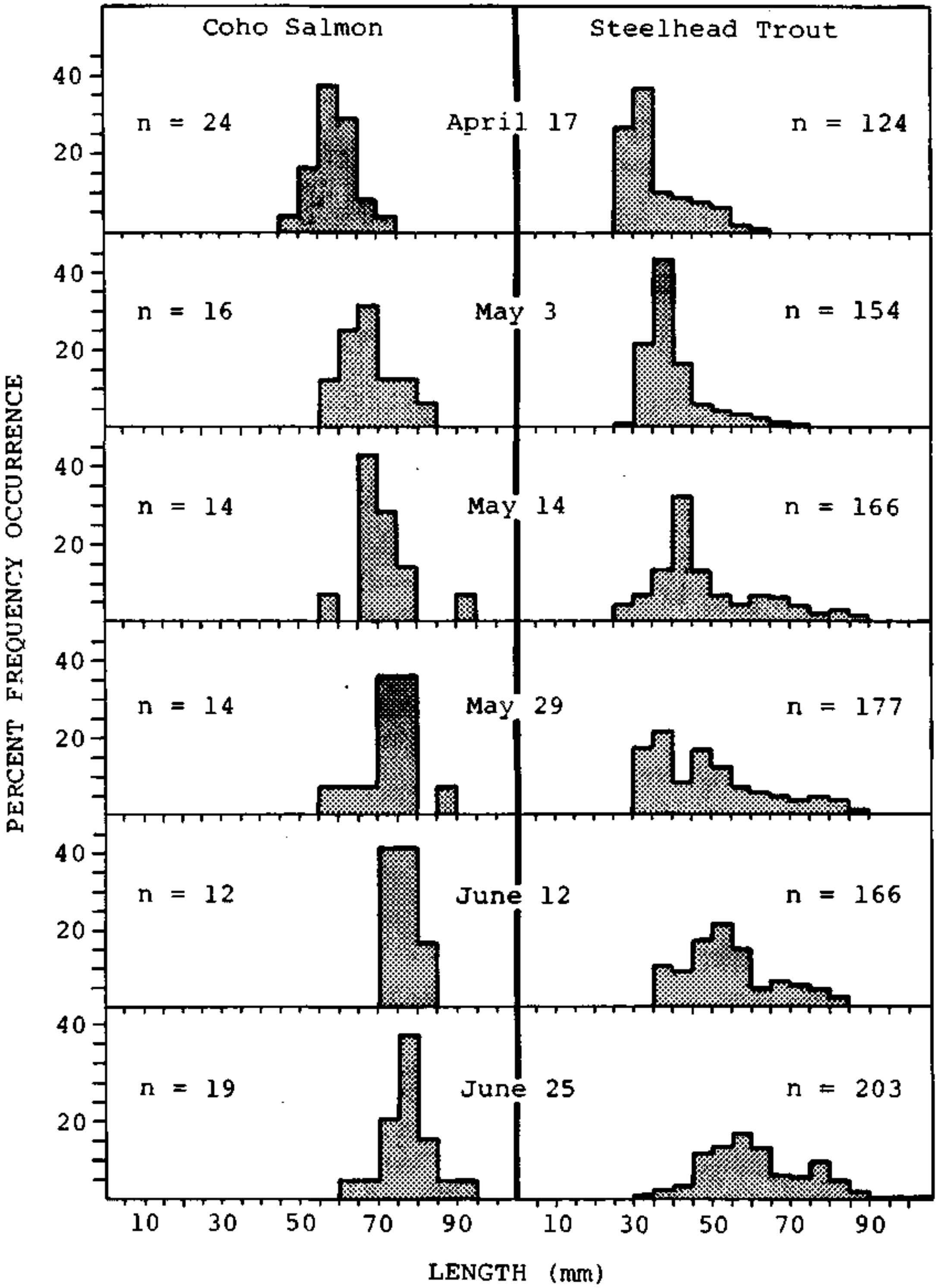

Figure 8-2. Length-frequency distribution of young-of-year coho salmon and steelhead trout collected by seining in the State Park Reach of Lagunitas Creek biweekly from April 17 to June 25, 1984."

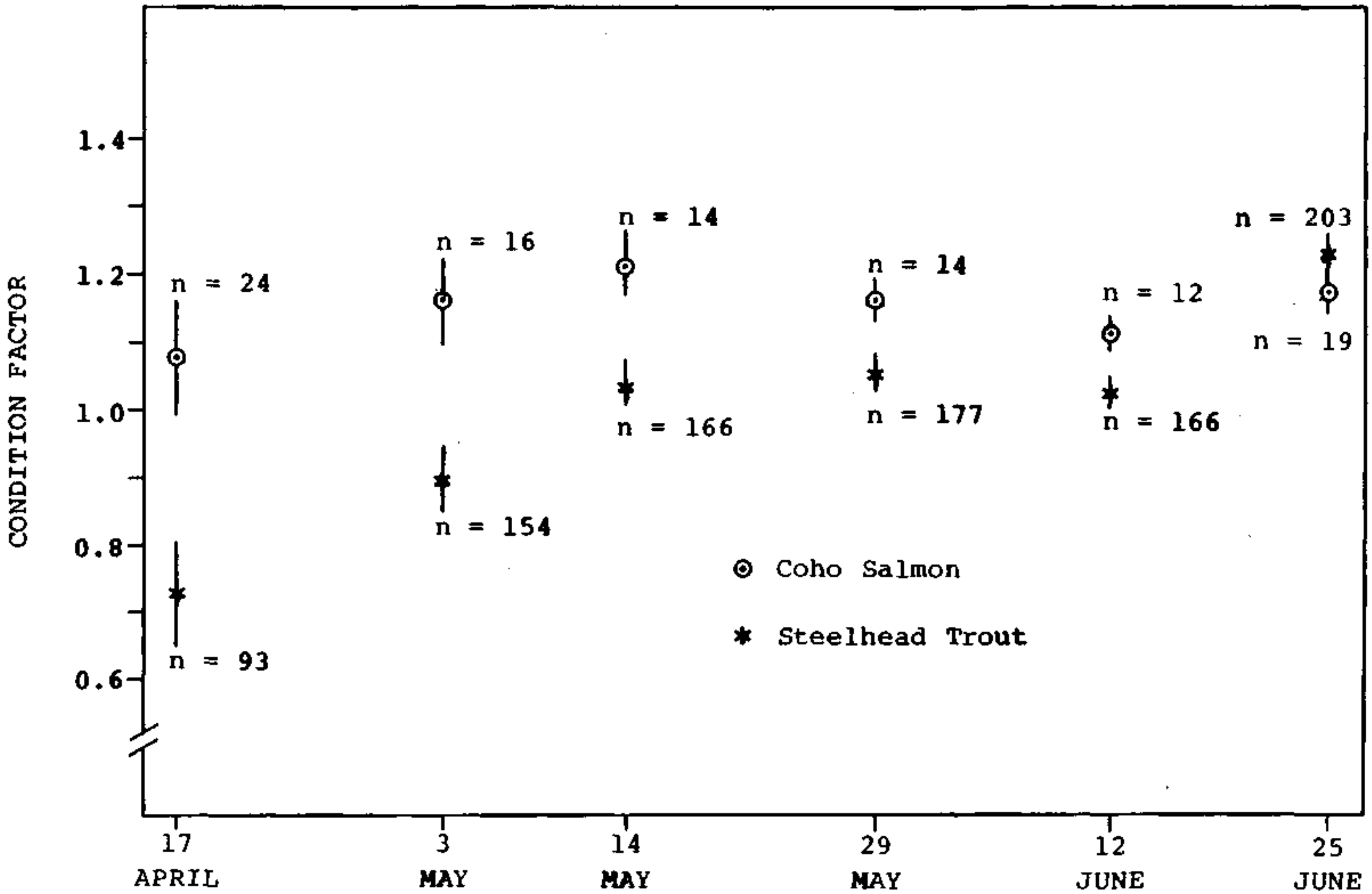

Figure 8-3. Average condition factors for coho salmon and steelhead trout fry in Lagunitas Creek. Fry were collected by seining in the State Park Reach biweekly from April 17 through June 25, 1984. Vertical lines represent 95% confidence intervals. Number of individuals (n) included in the analysis are indicated.

Water Temperature

Streamflows during the spring of 1984 provided water temperatures in Lagunitas Creek that were favorable for rearing salmonid fry. Water temperatures measured at the time and location of the biweekly growth surveys ranged from 53° to 60°F, near the preferred range (53.6° to 57.2°F) reported for salmon fry (Brett 1952).

Conclusions - Spring Rearing of Salmonid Fry

The combination of suitable streamflows and water temperatures during the spring of 1984 allowed for effective habitat use, rapid growth, good condition, and the relatively large size of salmonid fry at the end of the spring rearing season. In this year the relatively stable streamflows from 8.3 to 12.6 cfs (measured at the SPTSP gage) during April, May, and June provided conditions desirable for the spring rearing of salmon and steelhead fry in Lagunitas Creek.

SUMMER REARING OF JUVENILE SALMONIDS

The quantity and quality of summer rearing habitat for juvenile salmonids have been identified as important factors limiting salmonid populations in Lagunitas Creek (Kelley 1978; Kelley and Dettman 1980; personal communication, W. Cox, CF&G Unit Biologist). The amount and quality of rearing habitat are functions of water depth, water velocity, substrate, and cover characteristics. Streamflows directly affect water depths and velocities and indirectly affect substrate and cover characteristics.

Summer rearing habitat was assessed during 1978 and 1979 by biologists D. W. Kelley and D. H. Dettman. The three major objectives of their study were:

1) to determine the relationship between streamflow and the amount of juvenile salmonid rearing habitat;

2) to validate rearing habitat assessments in terms of actual fish populations; and

3) to evaluate the effect of sediment deposition on juvenile salmonid populations in Lagunitas Creek.

Only the most important aspects of Kelley and Dettman's study are presented in this report. For a more detailed description of methods and results see Kelley and Dettman (1980).

Rearing Index

Rearing indexes were developed to describe the relationship between streamflow and the amount of juvenile steelhead rearing habitat in Lagunitas Creek. To develop rearing indexes, the areas of glide, riffle, and pool habitat were measured and their quality was rated based on water depth, velocity, substrate, and cover characteristics. These indexes were developed at various flows for the State Park and the Tocaloma reaches in Lagunitas Creek.

Streamflow and Rearing Index

Juvenile steelhead rearing habitat, represented by rearing indexes, increased in a direct linear manner as streamflows increased from 0.5 cfs to about 5 cfs in the State Park Reach and 12 cfs in the Tocaloma Reach (Figure 8-4). Higher flows were not assessed. Over the range of flows examined, rearing indexes were lower at any given flow and the rate of increase in habitat with increase in flow was lower in the Tocaloma Reach than the State Park Reach. These differences are observed because the Tocaloma Reach generally has poorer quality habitat—a lower gradient, a more broad and meandering channel, and a more sandy streambed—than the State Park Reach.

Biologist Gary Smith (1986) of the CF&G Environmental Services Division used the IFIM method to calculate that juvenile steelhead habitat in Lagunitas Creek increased with flow up to levels higher than Kelley and Dettman measured. He estimated that the maximum amount of habitat was produced at about 35 cfs.

Population Density and Rearing Index

To test the validity of rearing indexes they were compared to steelhead population densities measured in 11 riffles, 10 glides, and 4 pools in Lagunitas Creek during summer and fall, 1979. Strong positive relationships were found between juvenile steelhead population densities and rearing indexes in glides and riffles in Lagunitas Creek (Figure 8-5). Not enough fish were captured in pools to develop a relationship. Rearing indexes appeared to be valid assessments of rearing habitat in terms of juvenile steelhead population densities.

Cobble Embeddedness and Population Density

Substrate characteristics strongly influence the quality and quantity of juvenile salmonid rearing habitat at any flow. Cobble larger than about 45 mm in diameter provide cover for juvenile salmonids. The more a cobble or boulder is buried in sediment the less cover it provides. Embeddedness is a measurement of the proportion of the height of a cobble or boulder that is buried in finer material.

Kelley and Dettman (1980) found strong inverse exponential relationships between cobble embeddedness and juvenile steelhead population densities in glides and riffles in Lagunitas Creek. Relatively small increases in embeddedness were associated with large decreases in juvenile steelhead population densities (Figure 8-6). They concluded that a slight increase in embeddedness could negate the benefits of increased summer flows.

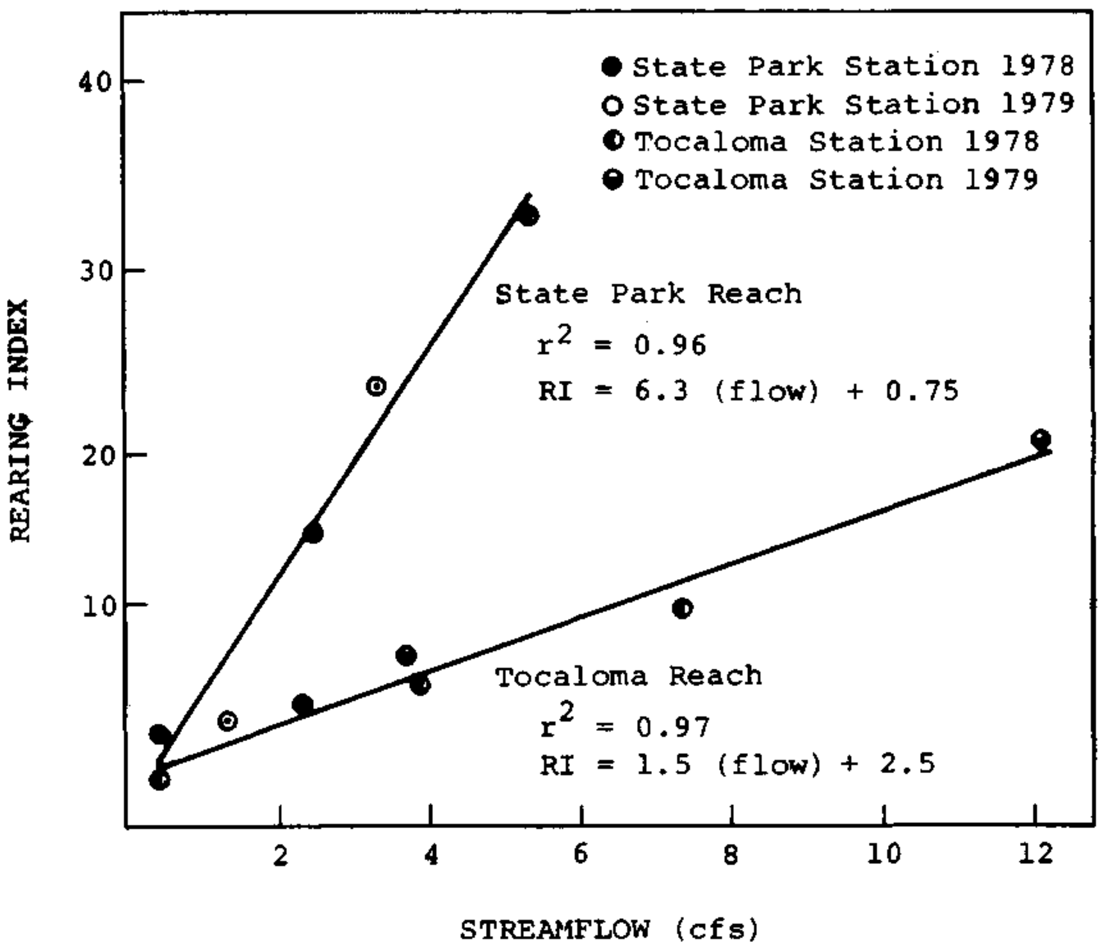

Figure 8-4. Relationship between rearing index, a measure of juvenile salmonid rearing habitat, and streamflow in the State Park and Tocaloma reaches of Lagunitas Creek (from Kelley and Dettman 1980).

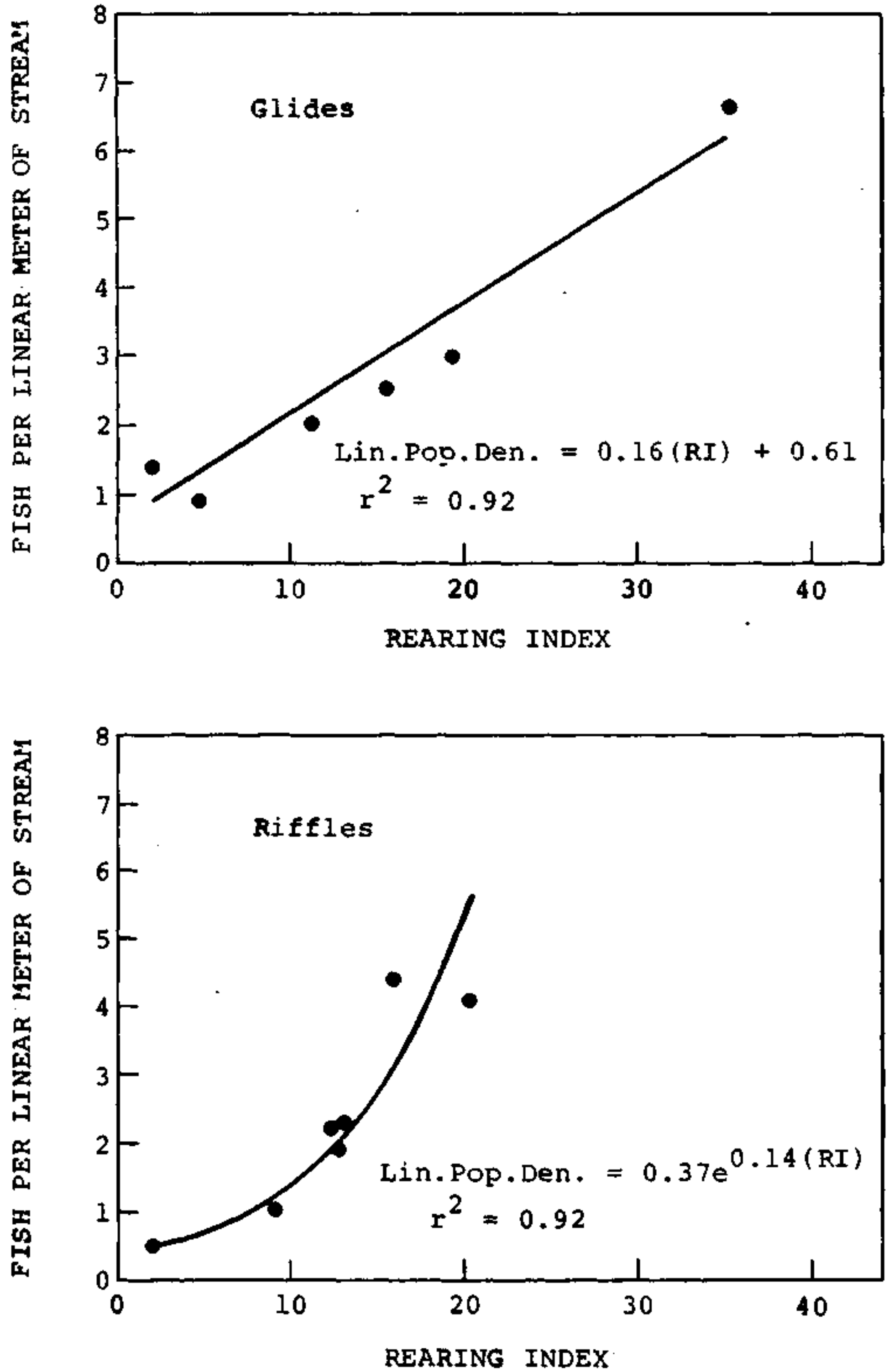

Figure 8-5. Relationship between juvenile steelhead trout population density and indexes of rearing habitat in glides (top) and riffles (bottom) in Lagunitas Creek (adapted from Kelley and Dettman 1980).

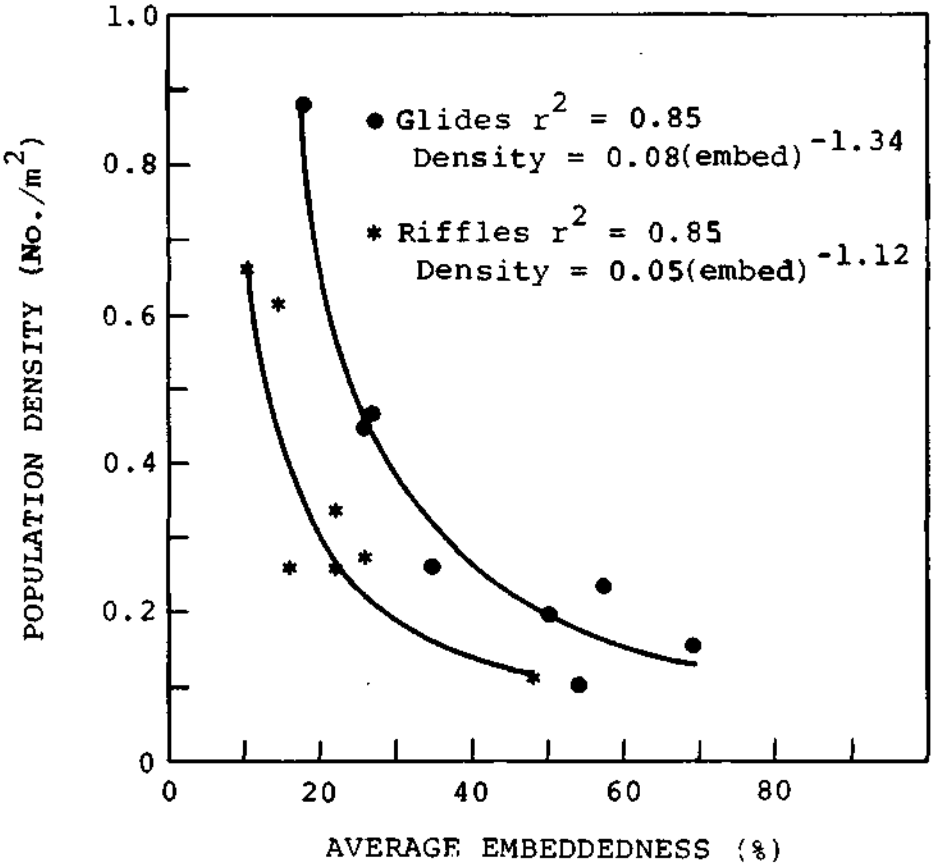

Figure 8-6. Relationships between population density of juvenile steelhead trout and average proportion to which cobble larger than 45 mm in diameter was embedded in sand in glides and riffles in Lagunitas Creek (from Kelley and Dettman 1980) .

Rearing Capacity of Lagunitas Creek

The total rearing capacity of Lagunitas Creek from Shafter Bridge to Nicasio Creek can be estimated for juvenile steelhead. Kelley and Dettman (1980) developed separate equations for glide and riffle habitats in each of the two study reaches, to estimate the number of juvenile steelhead that could be reared per linear foot of stream. They applied these equations to estimates of the total amount of glide and riffle habitat in Lagunitas Creek to estimate the numbers of juvenile steelhead that could be reared at various flows. Although the predictive relationship is valid only for the channel morphology and substrate conditions that occurred during 1979, it is the best available means of assessing steelhead rearing capacity in Lagunitas Creek at summer flows from 0.5 to 5 cfs. No data is available to estimate rearing capacity at flows in excess of 5 cfs.

Assuming 1979 streambed conditions, the estimated total number of juvenile steelhead that can be reared in Lagunitas Creek increases rapidly with increase in streamflow over the range of flows examined (Figure 8-7). For example, doubling the flow from 2.5 to 5 cfs results in an estimated 3.5-fold increase in the number of juvenile steelhead (from about 18,000 to 63,000 fish) that could be reared in Lagunitas Creek.

Other Rearing Habitat Considerations

The relationships between streamflow, habitat, and fish population densities were developed only for juvenile steelhead in Lagunitas Creek. Because numbers of yearling or Age 2+ steelhead or salmon of any age have been so low, no information specific to those fish was obtained. Smith (1986) estimated that juvenile salmon habitat increased with flow up to 30 cfs in the reach with the most habitat.

Juvenile salmon and steelhead utilize somewhat different habitats for rearing. Salmon are found more often in pools, especially deeper and quieter pools than young steelhead (Bjornn et al. 1977).

Pool habitat can be particularly important summer rearing habitat for juvenile salmon. In coastal Oregon streams, Nickelson et al. (1979) estimated that pool volume alone accounted for 92% of the variation in the standing crop of juvenile salmon. Pool area explained 74% of the variation in standing crop, indicating that pool depth also is important to young salmon.

Juvenile salmon use pools as rearing habitat in winter as well as summer. Salmon have been reported to congregate near the bottom of pools during winter when water temperatures were low (Mason 1966). In Carnation Creek, British Columbia, deep pools that contained upturned roots and other forest debris were identified as important winter rearing habitat for salmon fry and yearlings (Tschaplinski and Hartman 1982). Yearling salmon were more frequently found under deeper banks and in the deepest part of pools (e.g., water depth 45 cm) than salmon fry (Tschaplinski and Hartman 1982).

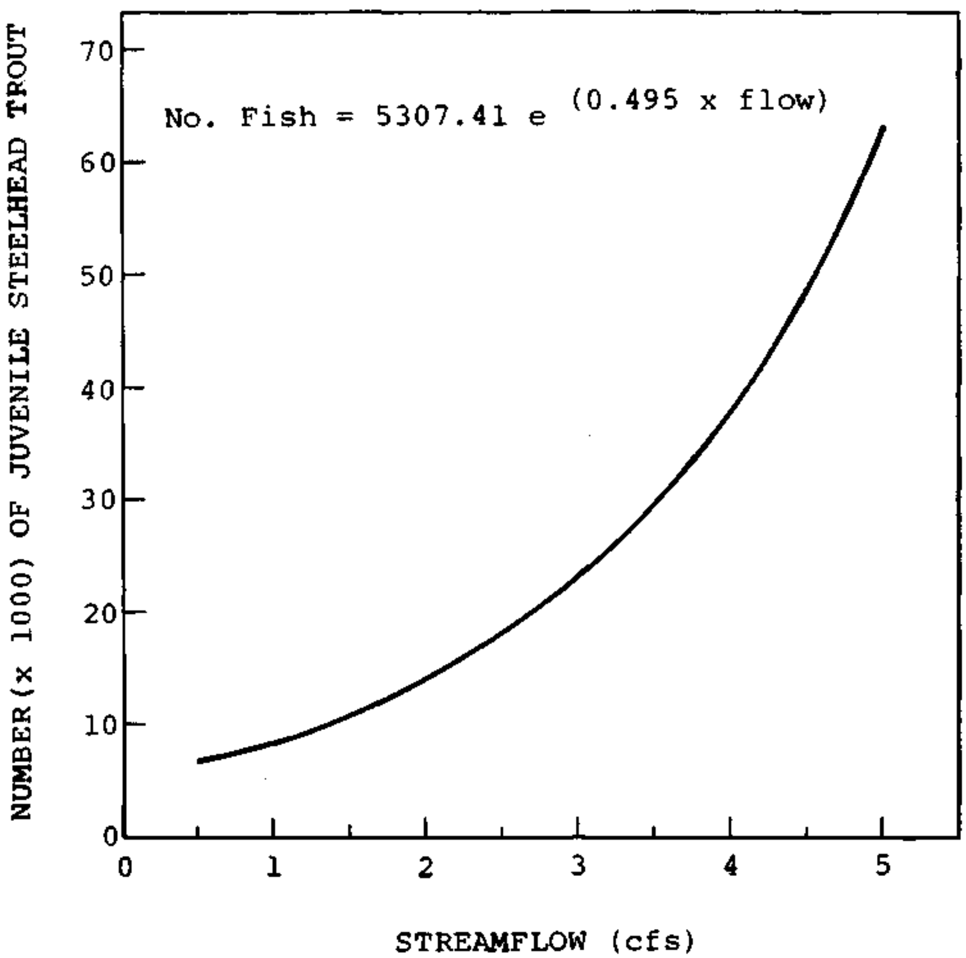

Figure 8-7. Relationship between calculated total summer rearing capacity and streamflow in Lagunitas Creek, from Shafter Bridge to Nicasio Creek, for juvenile steelhead trout. Relationship developed from equations that were based on population densities, channel morphology, and substrate measured at flows from 0.5 to 5 cfs during 1979 (Kelley and Dettman 1980).

Summer Water Temperature and Dissolved Oxygen Concentration

Water temperatures and dissolved oxygen concentrations were measured twice weekly from July through mid-October 1983. Measurements were taken in Lagunitas Creek in glides located immediately upstream of Shafter Bridge, Irving Bridge, and Devils Gulch Creek. Minimum and maximum water temperatures that occurred between measurements were noted from recording thermometers placed at each of the three locations. During summer and early fall of 1984, measurements were once again taken at the Shafter Bridge and Devils Gulch Creek stations, and also at the Tocaloma pipeline crossing in Lagunitas Creek about 500 ft upstream from Nicasio Creek.

Water temperatures were adequate for survival of juvenile salmonids in Lagunitas Creek. The upper lethal temperature for salmon fry has been reported as 77.2°F (Brett 1952). During July and August, water temperatures oftentimes increased 3 to 8 degrees Fahrenheit from Shafter Bridge to the Devils Gulch and Tocaloma stations located downstream, where maximum temperatures ranged from 63° to 70°F (Tables 8-1, 8-2). Mean temperatures, calculated as the average of the measured maximum and minimum temperatures, averaged 60°F (range 56.8°-62.8°F) and 61.2°F (range 58°-64.5°F) at the Devils Gulch station in 1983 and 1984, and 63.2°F (range 61.5°-67°F) at the Tocaloma station in 1984.

Although summer water temperatures were adequate for survival, they exceeded levels reported to provide for good growth of salmonids. The preferred temperature range of salmon fry, or range of temperatures they most frequently inhabit when provided with unrestricted movement in a temperature gradient, is from 53.6° to 57.2°F (Brett 1952). The standard environmental temperature (SET), or water temperature at which all physiological functions are optimal (i.e., immune response, tissue repair, digestion), has been estimated at 55°F for salmon and 59°F for rainbow trout (Klontz 1979). For several species studied, an average of 5% decrease in growth rate occurs for each degree F decrease from the SET. For all practical purposes, growth stops at 20 degrees Fahrenheit below the SET.

Growth rates also decrease at high water temperatures. As water temperatures increase, so do the metabolic rates of fish. Increased metabolic rate results in greater energy requirements to support basic life-sustaining physiological functions, as well as active physical functions such as feeding and predator avoidance. After fulfilling these metabolic requirements, any additional energy is converted into growth.

In Lagunitas Creek, juvenile salmonids apparently did not grow during the summer in 1984. Biologists from CF&G seined juvenile salmonids from pools located in the State Park Reach during reconnaissance surveys on July 20 and August 6, 1984. The young salmon we captured on June 25 averaged 76.8 mm in length. On August 6, 49 juvenile salmon captured by CF&G biologists averaged 77.2 mm in length. Juvenile steelhead averaged 61.5 mm long on June 25, and 86 fish collected on July 20 averaged only 62.7 mm in length. Salmon and steelhead were virtually the same length in late spring as in summer. We believe that this lack of growth resulted from the relatively

Table 8-1. Water temperatures and dissolved oxygen concentrations at the date and time of measurement, and minimum and maximum water temperatures since previous measurement at three locations in Lagunitas Creek, summer 1983.

DATE	SHAFTER BRIDGE					IRVING BRIDGE					DEVILS GULCH CREEK				
	Time	Temp. (°F)	D. 0. (mg/l)	Min. Temp. (°F)	Max. Temp. (°F)	Time	Temp. (°F)	D. 0. (mg/l)	Min. Temp. (°F)	Max. Temp. (°F)	Time	Temp. (°F)	D. 0. (mg/l)	Min. Temp. (°F)	Max. Temp. (°F)
Jul 6	1049	54	8.9	54	57	1106	57	9.9	55.8	58.5	1120	59	9.0	54	64
Jul 8	1015	52	11.0	46	61	0915	54	9.8	59	65	0945	55	9.2	47	67
Jul 11	0950	54	9.7	49	61	0912	55	9.6	58	64	0930	57	9.1	43.8	69.8
Jul 19	1151	55	9.5	54	63.5	1204	58	10.9	55	66	1225	60	7.8	49	66
Jul 21	1125	55	9.1	54.5	59.5	1110	57	10.3	56	63.5	1055	60	8.9	56	64
Jul 26	1140	55	—	55	62	1150	59	—	57	64	1205	61	—	—	—
Aug 2	1247	57	9.6	56	60	1257	62	10.4	58	64.2	1315	65	8.6	57	—
Aug 4	1145	56	9.1	55	63	1132	60	10.1	57	64	1117	61	8.8	55.5	70
Aug 9	1332	57	9.6	56	60	1351	63	10.1	57	64	1404	66	9.0	56	66
Aug 12	0950	54	8.8	56	60	1005	56	9.1	56	62	1020	60	8.4	56	67
Aug 16	1044	57	9.2	55.5	60	1057	59	9.9	58	65	1114	62	8.0	56	67
Aug 19	1100	55	8.7	56	60	1120	59	9.9	58	64	1130	61	7.8	59	66
Aug 23	1004	57	8.9	56	59	1017	58	9.6	56	65	1038	60	8.2	56	66
Aug 25	1106	57	9.1	56	59	1122	59	9.8	—	—	1140	61	8.8	58	63
Aug 30	1057	58	8.1	56	60	1120	60	9.6	—	—	1126	63	8.0	55.5	63
Sep 2	1135	58	8.9	58	61	1147	62	10.3	58	61	1202	64	8.2	57	64
Sep 6	1205	61	7.3	58	62	1225	63	9.3	58	65.5	1245	65	7.2	57	65
Sep 14	1044	55	10.3	53	58	1108	59	10.7	54	66	1119	62	9.1	54	63
Sep 19	0550	52	8.6	53	56	0815	55	9.5	56	62	0830	57	7.6	56	65
Sep 21	1111	61	7.3	54	60	1053	58	10.5	54	60	1035	63	8.7	55	65
Sep 28	0943	58	7.4	55	61	0900	52	9.8	54	60	0920	54	9.8	54	64
Oct 6	1428	64	7.8	57	—	1446	61	10.2	54	61	1502	63	9.8	53	64
Oct 11	0935	61	7.2	58	64	0921	56	9.7	56	64	0902	60	8.0	54	66
Oct 14	0920	55	7.4	57	—	0830	53	9.8	55	62	0900	53	9.1	52	60
Oct 17	1120	54	7.6	—	—	1153	53	10.0	50	61	1207	54	9.2	50	58

Table 8-2. Water temperatures and dissolved oxygen concentrations at the date and time of measurement, and minimum and maximum water temperatures since previous measurement at three locations in Lagunitas Creek, summer 1984.

DATE	SHAFTER BRIDGE					DEVILS GULCH CREEK					TOCALOMA PIPELINE CROSSING				
	Time	Temp. (°F)	D. 0. (mg/l)	Min. Temp. (°F)	Max. Temp. (°F)	Time	Temp. (°F)	D. 0. (mg/l)	Min. Temp. (°F)	Max. Temp. (°F)	Time	Temp. (°F)	D. 0. (mg/l)	Min. Temp. (°F)	Max. Temp. (°F)
Jul 9	0958	56	8.2	54	67	1016	59	9.5	57	66	1036	62	8.4	57	70
Jul 12	0848	58	8.7	53	59	0916	58	9.5	54	66	1005	62	8.6	57	68
Jul 16	1034	56	9.0	—	—	0955	64	9.0	58	68	1112	67	8.0	59	71
Jul 18	0925	58	9.1	—	—	1016	64	8.9	62	67	1024	68	7.5	64	70
Jul 23	1116	58	9.2	—	—	1138	60	10.3	58	67	1158	62	8.6	58	68
Jul 25	0825	57	8.5	—	—	0847	60	9.4	58	66	0915	64	7.8	58	68
Jul 31	1020	57	8.8	53	64	1030	61	9.4	58	65	1050	65	7.6	58	65
Aug 8	1023	58	8.6	55	67	0958	61	9.4	54	—	0925	65	8.0	63	68
Aug 14	1052	56	8.6	53	58	1112	60	10.1	57.5	68	1125	62	8.3	59	66
Aug 16	1004	56	8.1	56	60	0910	60	9.3	56	70	0943	64	7.5	58	66
Aug 21	1010	58	9.0	54	58	1030	60	10.6	55	62	1100	64	8.7	59	66
Aug 23	1058	57	9.5	53	57	1121	61	10.1	56	62	1111	65	9.6	60	65
Aug 28	1010	58	7.8	54	57	0921	60	8.8	54	62	0951	64	7.9	60	65
Aug 31	0956	58	7.4	56	60	0932	58	9.5	56	63	0905	60	8.1	58	66
Sep 5	1008	58	7.6	55	65	0910	60	9.6	54	62	0932	59	8.4	56	66
Sep 7	1146	62	7.7	58	62	1051	62	10.1	55	62	1107	62	8.6	60	66
Sep 12	1059	62	8.2	58	64	1121	60	9.9	54	66	1146	61	9.2	58	66
Sep 14	1238	67	—	58	63	1215	62	—	53	60	1152	64	—	58	63
Sep 18	1055	62	7.8	58	63	0945	62.5	8.5	56	62	1013	62	8.1	60	65
Sep 21	0910	61	7.9	59	62	0938	60	9.1	54	64	1015	64.5	8.4	57	64
Sep 24	0955	60	8.2	56	61	0855	56	9.6	52	64	0921	57	8.6	54	61
Sep 27	0835	59	7.6	59	64	0928	56	9.7	47	58	0954	56	8.8	52	59
Oct 1	0820	64	7.4	58	64	0950	60	9.2	52	60	1010	61	8.4	55	58
Oct 9	0930	—	7.8	56	65	0915	—	8.9	54	61	0855	64	8.0	57	62
Oct 16	0835	62	7.6	58	64	1041	55	—	52	60	1059	56	—	52	62
Oct 23	—	61	8.6	50	61	—	57	11.0	49	54	—	56	10.8	50	57
Oct 31	0920	60	8.6	56	61	1041	54	10.5	49	55	1101	54	9.8	50	57
Nov 6	1126	60	8.0	50	60	1330	58	9.9	47	56	1354	60	9.8	—	—

high water temperatures that occurred during the summer in Lagunitas Creek.

Dissolved oxygen concentrations were suitable for rearing juvenile salmonids throughout summer both years (Tables 8-1, 8-2). The minimum dissolved oxygen concentration required by salmonids is considered to be 5 mg/l, with 6-8 mg/l optimum for growth and muscle activity (Klontz 1979). Brett and Blackburn (1981) found that growth of fingerling salmon held at about optimum temperature (59°F) was independent of environmental dissolved oxygen at or above concentrations of 5 mg/l. Dissolved oxygen concentrations measured in Lagunitas Creek during summer in 1983 and 1984 were usually above 8 mg/l.

Acceptable but lower dissolved oxygen concentrations were observed at the Shafter Bridge station after September 19, 1983 and from late August to mid-October 1984. The reason for the decrease in dissolved oxygen concentration did not appear to be associated with streamflow. Flows released from Peters Dam only ranged from 4 to 4.6 cfs between September 1 and mid-October 1983 and from 3.9 to 4.5 cfs between late August and mid-October 1984. During the same time that decreased dissolved oxygen concentrations were measured at the Shafter Bridge station, high dissolved oxygen concentrations were measured at the downstream stations.

We do not anticipate the occurrence of low dissolved oxygen concentrations, based on the manner in which flows are discharged from Kent Lake into Lagunitas Creek. There are six usable outlets from which water can be withdrawn from Kent lake, each outlet separated by about a 20-ft vertical interval. Water is drawn from one of these outlets, pumped and discharged from a pipe onto a riprap berm, then flows down about 100 ft over rocks before entering the plunge pool below Peters Dam. Air is entrained in the water as it splashes onto and over the rocks. The water then passes through the sediment retention pond and begins flowing down Lagunitas Creek at a point located about 0.2 miles upstream from Shafter Bridge. The water is usually clear and well oxygenated when it begins flowing down Lagunitas Creek and is reoxygenated as it passes downstream (Tables 8-1, 8-2).

Conclusions - Summer Rearing of Juvenile Salmonids

Kelley and Dettman (1980) measured increases in juvenile steelhead rearing habitat with increases in flows up to 5 cfs in the State Park Reach and 12 cfs in the Tocaloma Reach. Smith (1986), using the IFIM method, estimated that juvenile steelhead and salmon habitat continues to increase with rising flows up to about 35 cfs.

The amount and quality of rearing habitat at any flow was extremely sensitive to streambed conditions. Increased sedimentation of the streambed will negate benefits of increased summer flows. If sedimentation can be reduced, the rearing capacity of Lagunitas Creek will increase.

Growth of both species is rapid in the spring but slows and in some years ceases when water temperatures reach late summer levels.

CHAPTER 9 - SALMONID EMIGRATION

Young salmonids rear in Lagunitas Creek and its tributaries from a few months up to 2 years, depending upon the species. In the spring, those that emigrate from the system undergo behavioral, morphological, and physiological changes in preparation for the transition from fresh to salt water. These changes are collectively referred to as smoltification.

Salmonid "smolts" move downstream through Lagunitas Creek and its tributaries to Tomales Bay and the Pacific Ocean where they grow to adults. Prior to this study little was known about the numbers of salmonid smolts emigrating from Lagunitas Creek, duration of the emigration period, or the effects of streamflows during this life stage. We investigated these and other characteristics of coho salmon and steelhead trout smolts including the age and size composition of the smolt populations.

SMOLT TRAPPING

A smolt trap was used to monitor the seaward migration of salmon and steelhead in Lagunitas Creek from 1983 to 1985. The trap consisted of a fyke net with rectangular metal support frames that measured 1.5 m x 0.9 m at its upstream mouth and decreased to 0.5 m x 0.6 m at the downstream cod end. The frames supported a knotless nylon net of 1.2 cm stretched mesh. A temporary weir presented an impassable barrier to the smolts and deflected the streamflow into the mouth of the net. The cod end of the net was attached to a 20.3 cm PVC pipe that funneled the water into a live box that held the fish.

In 1983 we also operated smolt traps in San Geronimo and Devils Gulch creeks. These traps were standard metal-screen inclined plane traps and were located approximately 200 m upstream from each of the tributaries' confluence with Lagunitas Creek. The trap in Lagunitas Creek was located approximately 150 m upstream from Nicasio Creek. CF&G, Region III provided all the traps, assisted in their installation, and partially supported the trapping operation.

The traps were installed as soon as they could effectively sample the entire streamflow. The Lagunitas Creek trap was installed on April 14 in 1983, and on March 7 and March 6 in 1984 and 1985. The trap was initially examined twice daily in 1983, once in the morning and once in the afternoon. Because few or no additional fish were captured, the afternoon effort was discontinued. The trap was examined daily from the date of installation through late June each year.

Each day the trap was cleaned of debris and water temperature was measured. Daily fluctuation in water temperature was measured with a maximum/minimum recording thermometer located immediately upstream of the trap.

All captured salmonids were classified according to the presence or absence of morphological characteristics associated with smoltification.

Classifications of fish included fry, resident, transition, or smolt. Fry were identified as such on the basis of small size, presence of distinct parr marks, and orange-colored fins. Smolts were identified by loss of parr marks, silver-colored body, darkened fins, and streamlined body form. Salmonids classified as transition exhibited incomplete development of smolt characteristics, and were considered to be emigrating smolts. The resident classification was primarily applied to steelhead of larger sizes that retained parr marks and were usually heavily spotted and dusky in appearance. These classifications were utilized to differentiate salmonids that were emigrating as smolts from other fishes captured in the trap. Captured salmonids were measured, weighed, and released.

FISH COLLECTED

A total of 11,741 fish representing 13 species were captured in the Lagunitas Creek trap over the 3-year study period (Table 9-1). Coho salmon and steelhead trout were the most abundant fishes, together comprising 70% (8,175 fish) of all fish collected.

In 1983, it is probable that the early portion of the emigration occurred before streamflows declined enough to allow for the installation of the trap. High streamflows resulting from heavy runoff temporarily disrupted trap operation on a few occasions during this study. The trap was either washed out or damaged from high streamflows and not in operation from April 27 to May 5 in 1983, March 19 to 21 in 1984, and from March 8 to 12 and March 26 to 31 in 1985. Because no reliable method was available, we did not estimate the number of salmonids that may have passed the trap when it was out of operation.

Streamflows exceeded the capacity of the weir to deflect the entire flow but the trap filtered a portion of the water and remained operable for 9 days in 1983, 6 days in 1984, and 5 days in 1985. During those days we visually estimated the percentage of the streamflow passing through the trap. The total number of salmonids passing the trap site on those days was estimated by dividing the actual number of fish captured by the fraction of the total streamflow that was filtered through the trap.

In addition to smolts, we captured fry of both species that did not exhibit any morphological characteristics of smoltification (Tables 9-1, 9-2). Compared with the other 2 years of trapping, higher numbers of steelhead fry were captured in the Lagunitas Creek trap during the spring of 1984. These data are an indication that competitive interaction among steelhead fry, and between steelhead and salmon fry, resulted in displacement and active downstream movement of steelhead. Due to high reproductive success the preceding fall and winter, numbers of fry in the creek probably exceeded carrying capacity during the spring of 1984. We believe that high numbers of steelhead and not salmon fry were captured because salmon were of larger size in the spring (Chapter 8), and occupied available pool habitat. Young salmon are reported to more aggressively defend territory in pools than young steelhead (Hartman 1965). "Surplus" steelhead fry were probably unable to occupy pools and were displaced downstream. In subsequent analyses and

Table 9-1. Fish and other animals captured in the Lagunitas Creek trap during spring of 1983, 1984, and 1985.

SPECIES	LIFE STAGE	1983	1984	1985
Coho salmon	smolt	640	742	1922
	fry	64	67	7
Steelhead trout	adult	0	30	16
	resident	20	13	13
	smolt	416	339	713
	fry	198	2605	389
Unidentified	fry	0	0	8
Pacific lamprey	adult	756	178	300
	ammocoete	1	6	8
Prickly sculpin		28	29	14
California roach		309	512	926
Threespine stickleback		22	47	354
Common carp		23	2	1
Bluegill		13	0	0
Golden shiner		0	0	1
Hitch		8	4	1
Sacramento sucker		9	7	2
Channel catfish		0	1	0
MISCELLANEOUS				
Turtle		4	2	6
Snake		0	0	1
Bullfrog		1	0	2
Crayfish		62	199	187
Syncaris pacifica		1	0	4
Newt		3	0	0

Table 9-2. Number of salmonids captured and estimates of the number of emigrant salmonids passing the Lagunitas Creek trap site, 1983-1985. Estimates of emigrants on the few days that the trap sampled a portion of the streamflow were obtained by applying the percentage of the streamflow that was filtered to the actual number of fish captured in the trap. Numbers of fish passing the trap site when the trap was not in operation were not estimated.

		1983		1984		1985	
		NUMBER		NUMBER		NUMBER	
SPECIES	LIFE STAGE	Captured	Estimated	Captured	Estimated	Captured	Estimated
Coho salmon	Smolt	640	713	742	744	1922	1922
	Fry	64	64	67	67	7	7
Steelhead trout	Smolt	416	758	339	346	713	730
	Fry	198	198	2605	2605	389	389

discussion, we differentiate between downstream movement of fry and emigration of smolts.

EMIGRATION FROM THE TRIBUTARIES

Few salmon were captured in the tributaries San Geronimo and Devils Gulch creeks (Figure 9-1). Low captures may partly result from inefficiency and inoperation of the traps during the high water and floods that occurred in the tributaries during the last week in April and first week in May, 1983. From the few fish that were captured, it appeared that salmon fry and smolts both moved downstream primarily during the first 3 weeks in April, and some fry moved downstream in June 1983.

More steelhead were captured in the tributaries than salmon. We observed differences in the time of emigration of steelhead smolts and downstream movement of fry (Figure 9-2). Nearly all smolts emigrated during the first 2 or 3 weeks in April, whereas, most fry moved downstream from mid-May through June.

Marked Fry

Nearly all of the fry of both species that were captured in the tributaries were marked with fin clips. Fish from San Geronimo Creek were marked with a notch in the leading edge of the upper lobe of the caudal fin, and fish from Devils Gulch Creek were marked with a notch in the leading edge of the lower lobe of the caudal fin. Very few of these marked fish were recaptured downstream in the Lagunitas Creek trap (Table 9-3). In 1983, no marked salmon fry and less than 1% of the steelhead fry were recaptured downstream. Most of the fry probably did not move downstream as far as our trap site, but took up residence upstream in Lagunitas Creek. Fry of both species were primarily captured in May and June as flows declined in the tributaries. Competitive interaction among fry in a diminishing habitat may have resulted in the downstream movement of fry from the tributaries into Lagunitas Creek.

Marked Smolts

Some of the smolts were marked in the same way as fry and released in the tributaries in early April. Some of these marked smolts may have emigrated from Lagunitas Creek from April 27 through May 5, 1983, when the Lagunitas trap was inoperable due to flooding. Also, some fish residualized in the creek. From Table 9-3 it can be seen that an additional seven salmon that were marked in 1983 were recaptured as smolts in 1984 and 1985. Five of these salmon were age 1+ and two were age 2+. Similarly, seven steelhead were recaptured in 1984 and 1985 as age 2+ smolts. These data indicate that some fish move out of the tributaries and rear in Lagunitas Creek for up to 2 years before emigrating from the stream.

In addition to fish that originated in the tributaries, we attempted to determine the contribution of the hatch-box program (Chapter 7) to salmon smolt production in Lagunitas Creek. A total of 14,972 spray-marked salmon

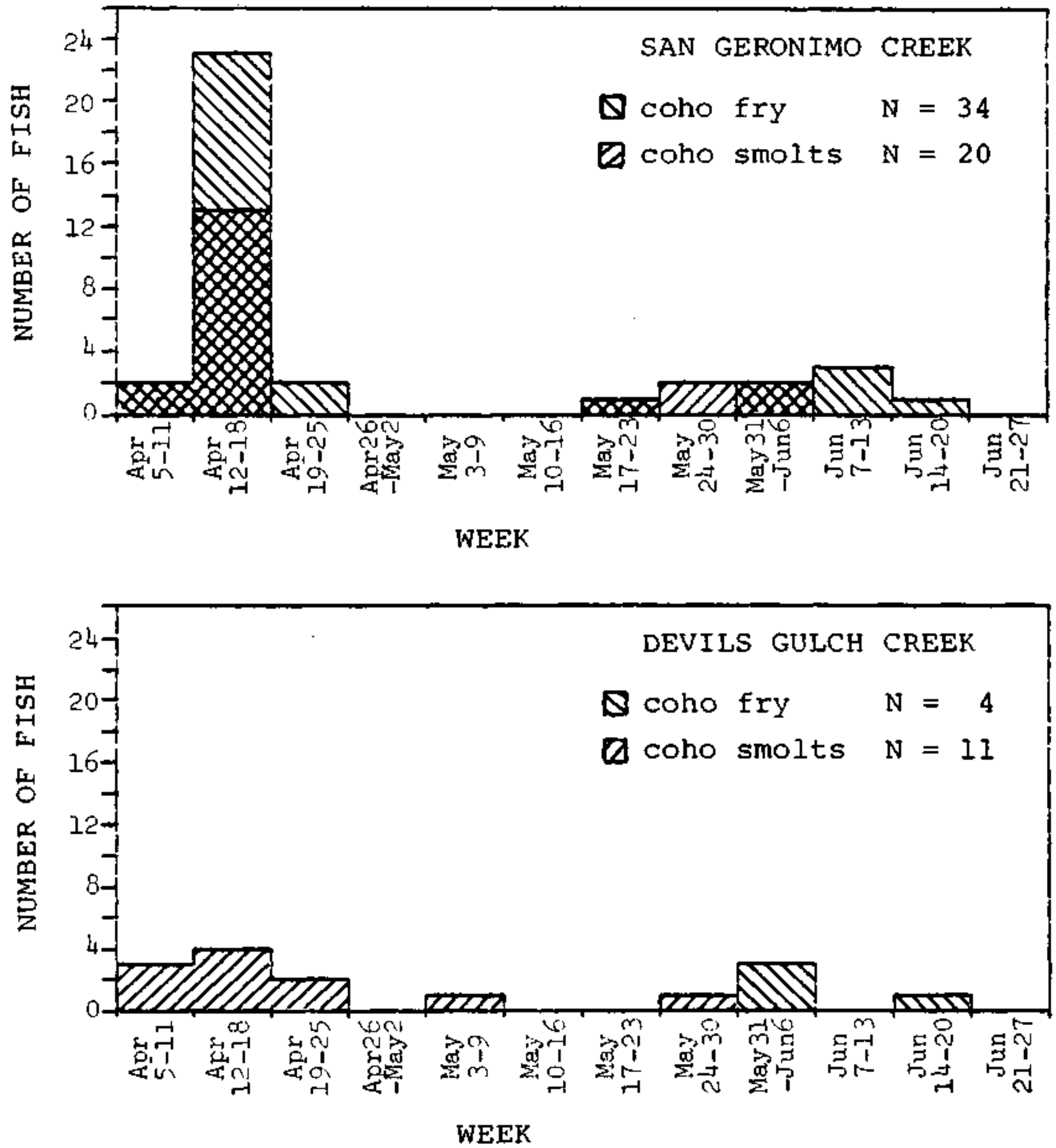

Figure 9-1. Number of coho fry and smolts captured weekly in the San Geronimo Creek and Devils Gulch Creek downstream traps, 1983. Most smolts emigrated from the tributaries in April, and fry continued to move downstream into June.

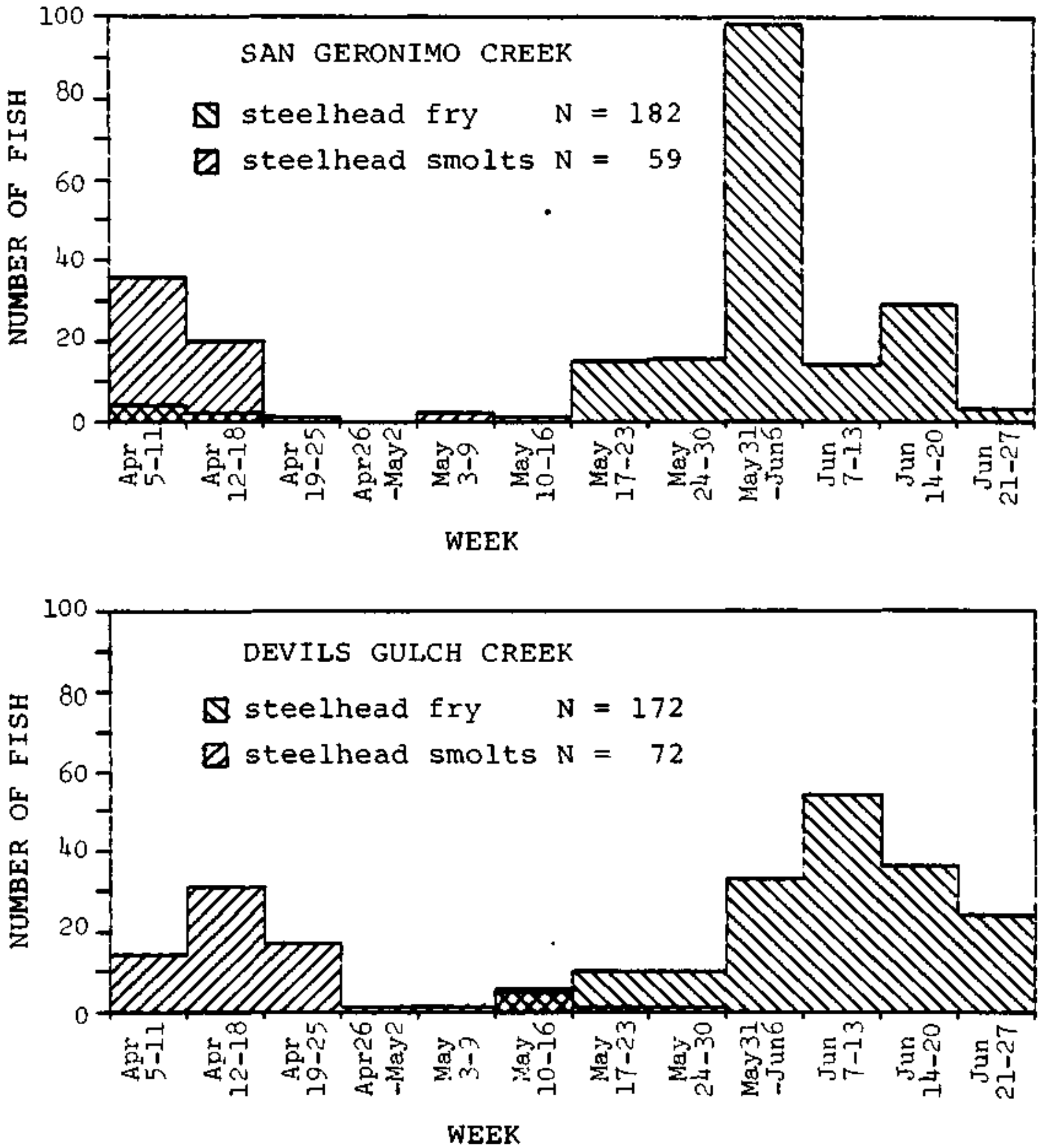

Figure 9-2. Number of steelhead fry and smolts captured weekly in the San Geronimo Creek and Devils Gulch Creek downstream traps, 1983. Most smolts emigrated in April, and most fry moved downstream from mid-May through June.

Table 9-3. Numbers of coho and steelhead captured, marked, and released in San Geronimo and Devils Gulch creeks in 1983, and numbers recaptured in the Lagunitas Creek trap in 1983, 1984, and 1985.

	COHO				STEELHEAD			
	San Geronimo		Devils Gulch		San Geronimo		Devils Gulch	
	SMOLTS	FRY	SMOLTS	FRY	SMOLTS	FRY	SMOLTS	FRY
MARKED	17	20	8	4	54	174	68	171
RECAPTURED								
1983	4	0	3	0	2	3	3	0
1984	3	0	2	0	4	0	2	0
1985	2	0	0	0	1	0	0	0
TOTAL	9	0	5	0	7	3	5	0
PERCENT	53	0	63	0	13	2	7	0

fry, ranging from 28 mm to 36 mm in length, were planted in the upper State Park reach of Lagunitas Creek on March 22, 1983. Although 93% of the control group of fish held in an aquarium retained their marks by June 23, 1983, none of the marked and planted fish were recovered at the Lagunitas Creek trap during this study. We suspect that they were washed downstream of our trap site soon after they were planted. Storm-induced runoff increased the mean daily flows measured at the SPTSP gage to 416 cfs on the day of planting and 691 cfs 3 days later, and flows remained above 100 cfs for the first 11 days after planting. Due to the disruptive flushing effect of high flows, the small salmon fry planted in 1983 probably did not contribute to smolt production in 1983 or 1984.

EMIGRATION PERIOD

Coho Salmon

Emigration of salmon smolts from Lagunitas Creek generally began in early April and ended in the latter part of June (Figure 9-3). In 1983, emigration probably began before mid-April when the trap was installed. Although we operated the smolt trap during March in 1984 and 1985, only a few individuals were captured during that month. The emigration period of salmon smolts from Lagunitas Creek is similar to the time of salmon emigration from Waddell Creek, Santa Cruz County which primarily occurred between April 8 and June 9 (Shapovalov and Taft 1954).

Most salmon emigrated from Lagunitas Creek during April and May, when 65%, 92%, and 96% of the total number of smolts were captured in 1983, 1984, and 1985, respectively. Peak numbers of smolts were captured during early May in 1984 and late April/early May in 1985. Peak emigration in 1983 is difficult to determine because high streamflows resulting from spring rainstorms temporarily interrupted our trapping operation in late April and early May.

Steelhead Trout

Emigration of steelhead smolts from Lagunitas Creek both began and ended about 3 weeks earlier than salmon emigration. Our trapping data indicate that steelhead emigration began in early March and was essentially over by June 1 (Figure 9-4). In all 3 years steelhead emigration was greatest in April and May, when 99%, 85%, and 82% of all smolts were captured in 1983, 1984, and 1985, respectively. Peak emigration of steelhead occurred during the third week in April in 1983 and 1984, and the second week in April in 1985. The period of peak steelhead emigration from Lagunitas Creek was similar to that observed for steelhead by Shapovalov and Taft (1954) in Waddell Creek, California.

In addition to smolts, we captured steelhead fry moving downstream in Lagunitas Creek. Relatively low numbers of steelhead fry were captured in May and June in 1983, and from mid-March through June in 1985 (Figure 9-5). High numbers of steelhead fry moved downstream in 1984 from mid-April through June with peak movement in late April and early May, 1 to 2 weeks after peak

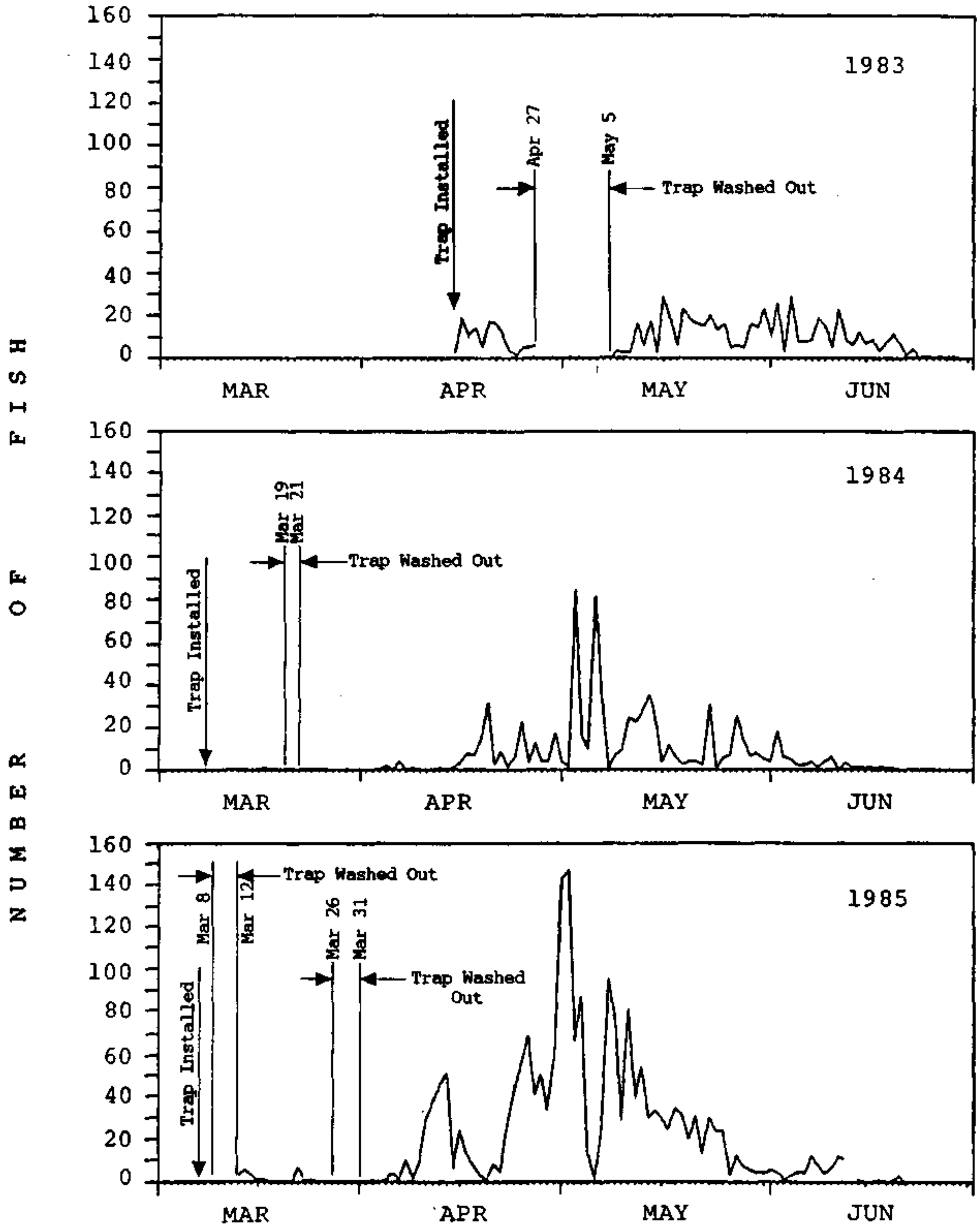

Figure 9-3. Number of coho salmon smolts captured daily in the Lagunitas Creek trap from March through June, 1983-1985. Emigration generally began in early April and ended in the latter part of June.

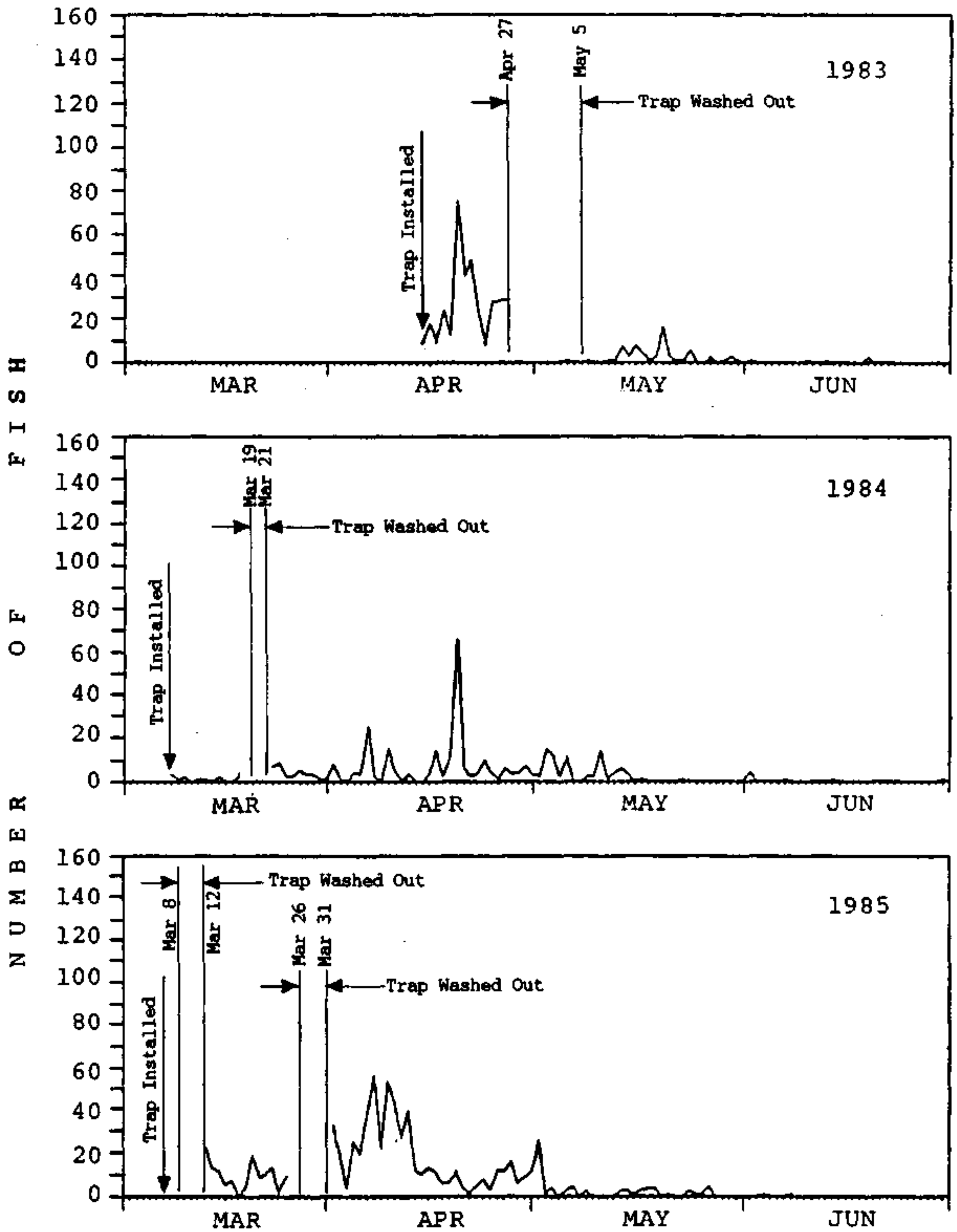

Figure 9-4. Number of steelhead trout smolts captured daily in the Lagunitas Creek trap from March through June, 1983-1985. Data indicate that emigration began in early March and was essentially over by June.

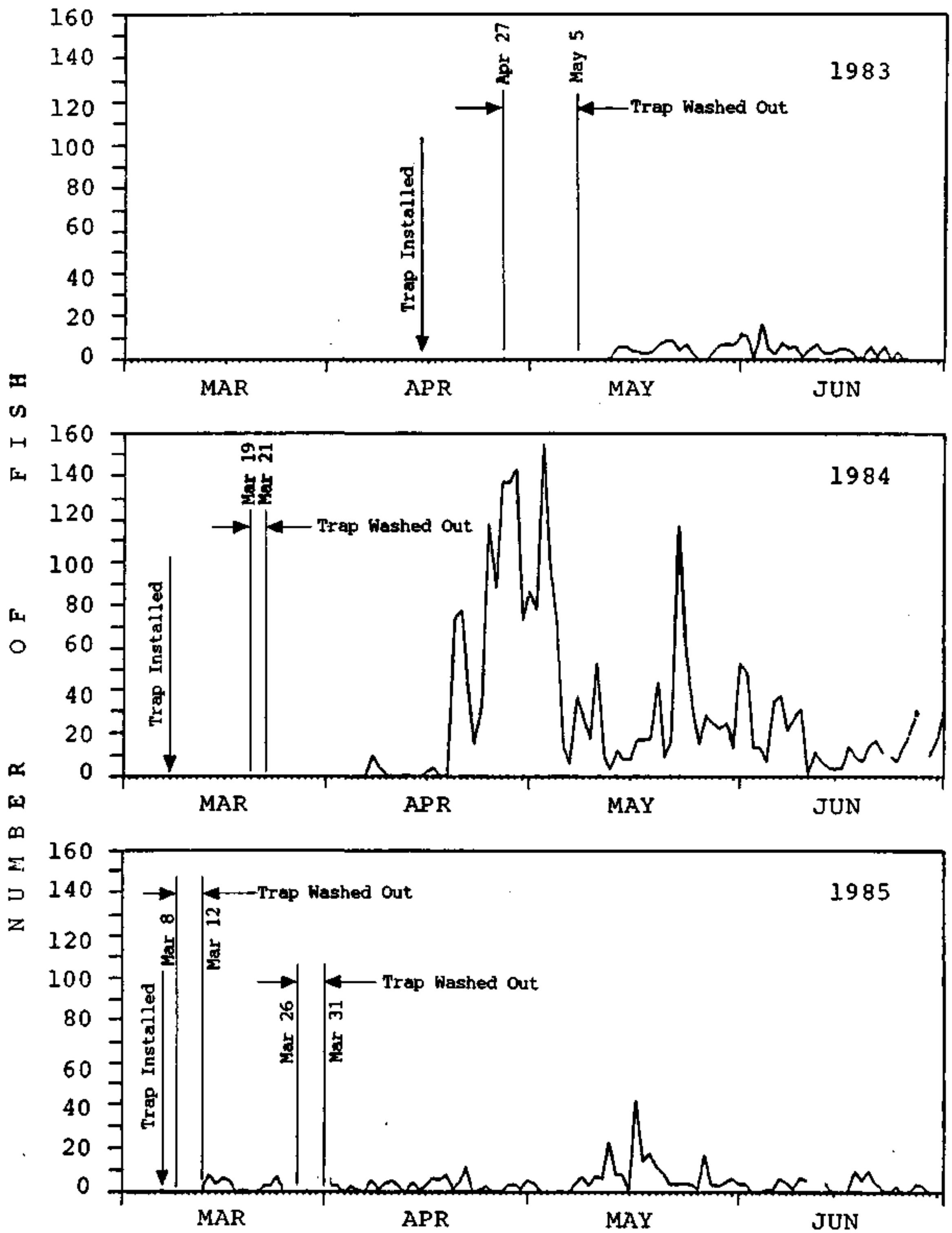

Figure 9-5. Number of steelhead trout fry captured daily in the Lagunitas Creek trap from March through June, 1983-1985. Relatively high numbers of steelhead fry were captured primarily from mid-April through mid-June, 1984.

emigration of steelhead smolts.

ENVIRONMENTAL VARIABLES AFFECTING EMIGRATION

Several environmental variables possibly influence the timing of salmonid emigration, on either a seasonal or even daily basis. Environmental variables associated with downstream movement of anadromous salmonids include streamflow (Hartman et al. 1982), water temperature (Fried et al. 1978; Hartman et al. 1982), photoperiod (Zaugg 1981), and lunar cycles (Mason 1975). Initiation of the seasonal emigration of salmonid smolts probably occurs in response to a combination of these environmental cues. Daily fluctuation in the number of emigrant salmonids may result from changes in instream conditions such as streamflow and water temperature.

Environmental Conditions

Streamflow patterns during the salmonid emigration period varied considerably among the 3 years that we examined. In 1983 mean daily streamflows measured at the SPTSP gage fluctuated tremendously, were generally very high (average = 157.1 cfs, March 1-June 30), and freshets exceeding 100 cfs occurred into May (Figure 9-6). In contrast, streamflows during the salmonid emigration season were generally stable and low when mean daily streamflows averaged only 13.1 cfs from March 1 through June 30 (Figure 9-7). With the exception of a large freshet in late March, streamflows during the emigration period were stable and moderate—averaging 21.2 cfs from March 1 through June 30 (Figure 9-8).

Water temperatures increased over the course of the emigration period (Figures 9-6, 9-7, and 9-8). Water temperatures that we recorded ranged from minimum values of 45°-47°F in March to maximum values of 68°-69°F in June. In a given month average mean daily temperatures, calculated as the mean of daily minimum and maximum recorded values, were similar among years (Table 9-4). Mean monthly water temperatures steadily increased and streamflows decreased as spring progressed.

Relationships Between Environmental Variables and Emigration

In 1983, a year with high winter and early spring streamflows, salmon emigration continued later into June and more smolts emigrated during June than in 1984 and 1985. Similarly, in 1983 more steelhead smolts emigrated after May 4, the day that we reinstalled the trap following high streamflows, in that year than in the other 2 years of sampling (Table 9-5). The high storm-induced streamflows that occurred during 1983 may have delayed emigration of salmonids from Lagunitas Creek either directly by forcing the fish to take refuge or, indirectly, by affecting other environmental variables that influence emigration. In 9 years of smolt trapping in Waddell Creek, Shapovalov and Taft (1954) also observed that salmon and steelhead smolt emigration was delayed in years of high streamflows.

Numbers of salmon and steelhead captured daily in the trap fluctuated widely. We examined possible relationships between seaward

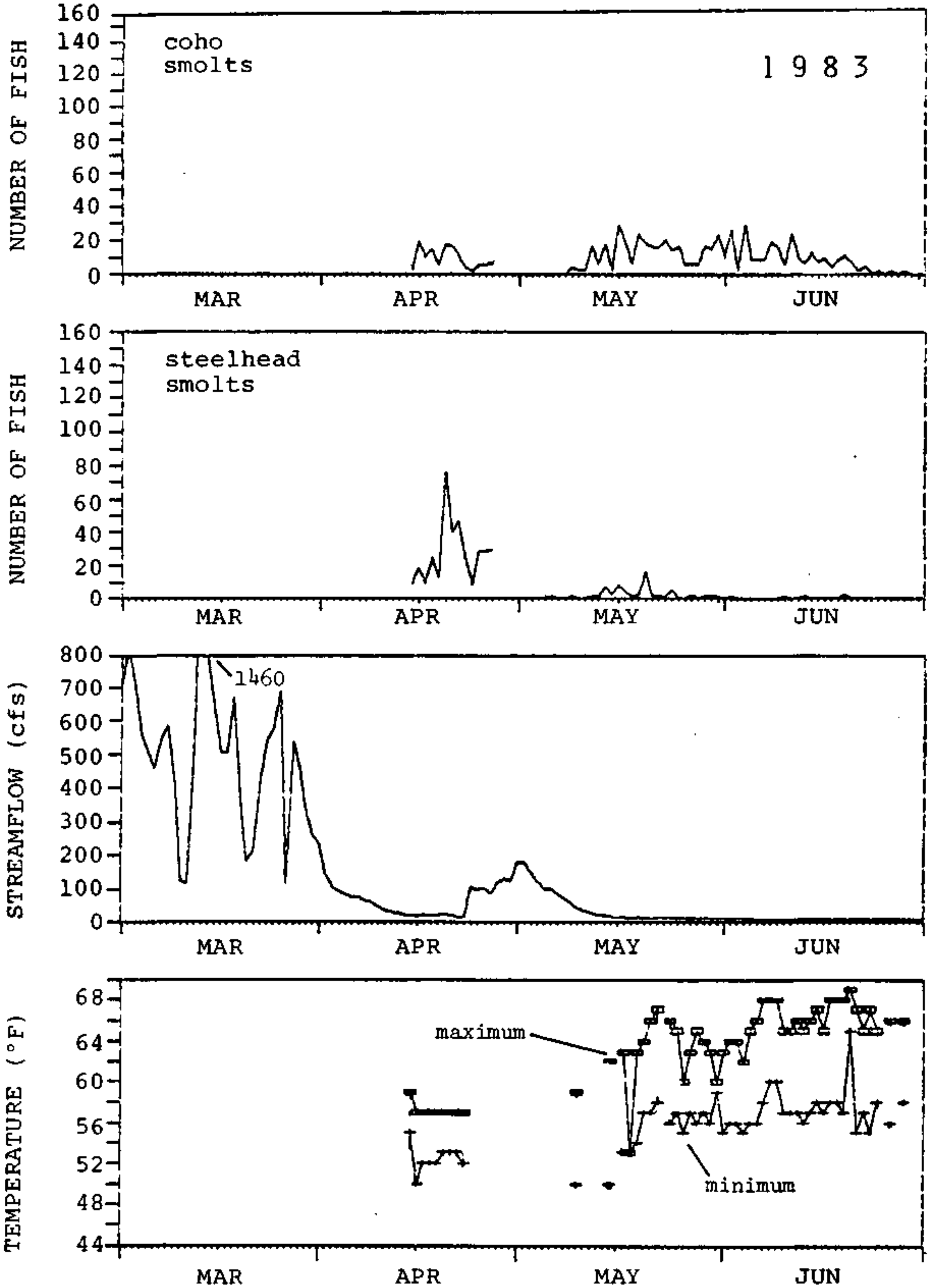

Figure 9-6. Number of coho salmon and steelhead trout smolts captured daily in the Lagunitas Creek trap, mean daily streamflow (measured at the SPTSP gage), and maximum and minimum water temperatures recorded daily at the trap, 1983.

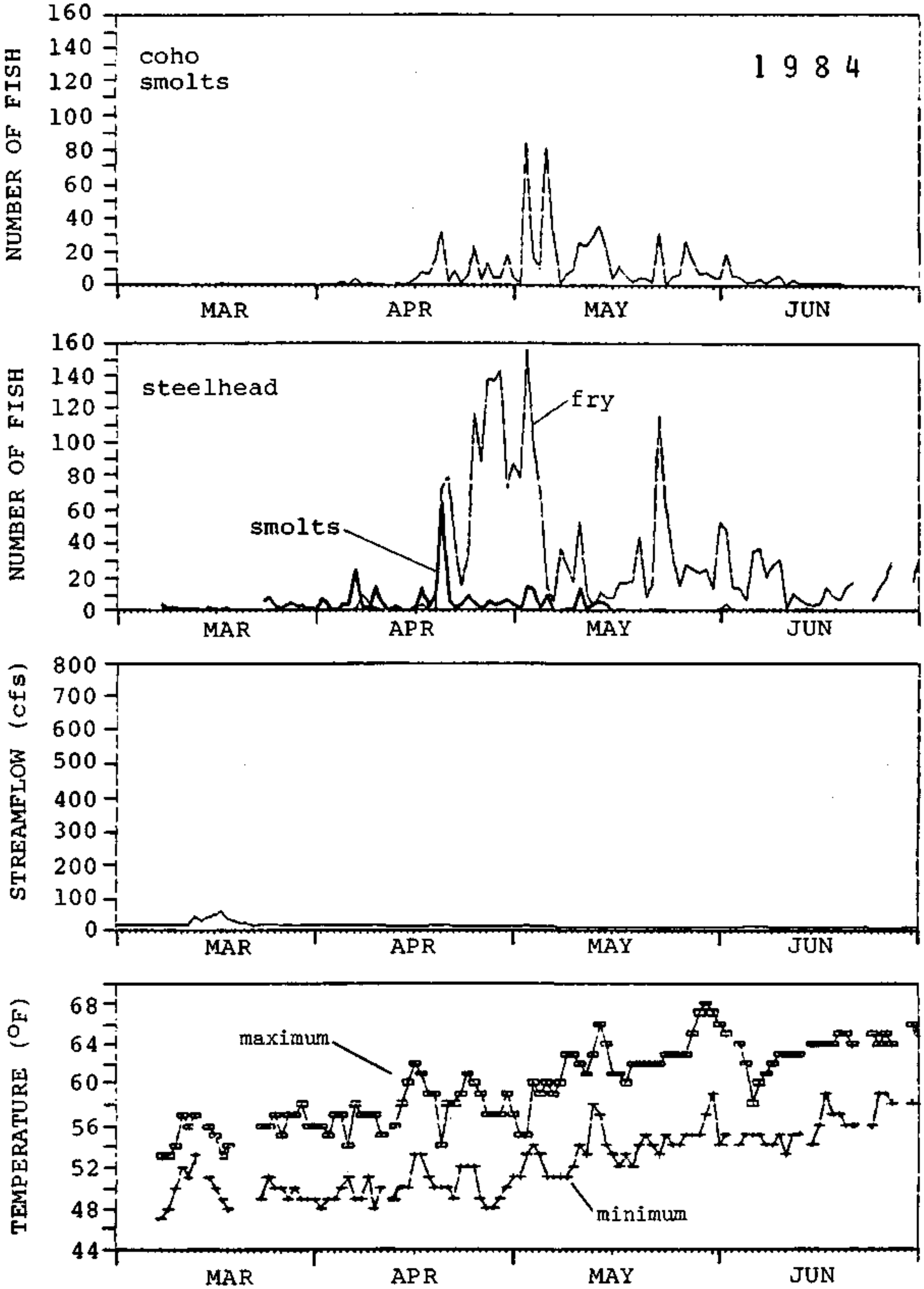

Figure 9-7. Number of coho salmon smolts, steelhead trout smolts, and steelhead trout fry captured daily in the Lagunitas Creek trap, mean daily streamflow (measured at the SPTSP gage), and maximum and minimum water temperatures recorded daily at the trap, 1984.

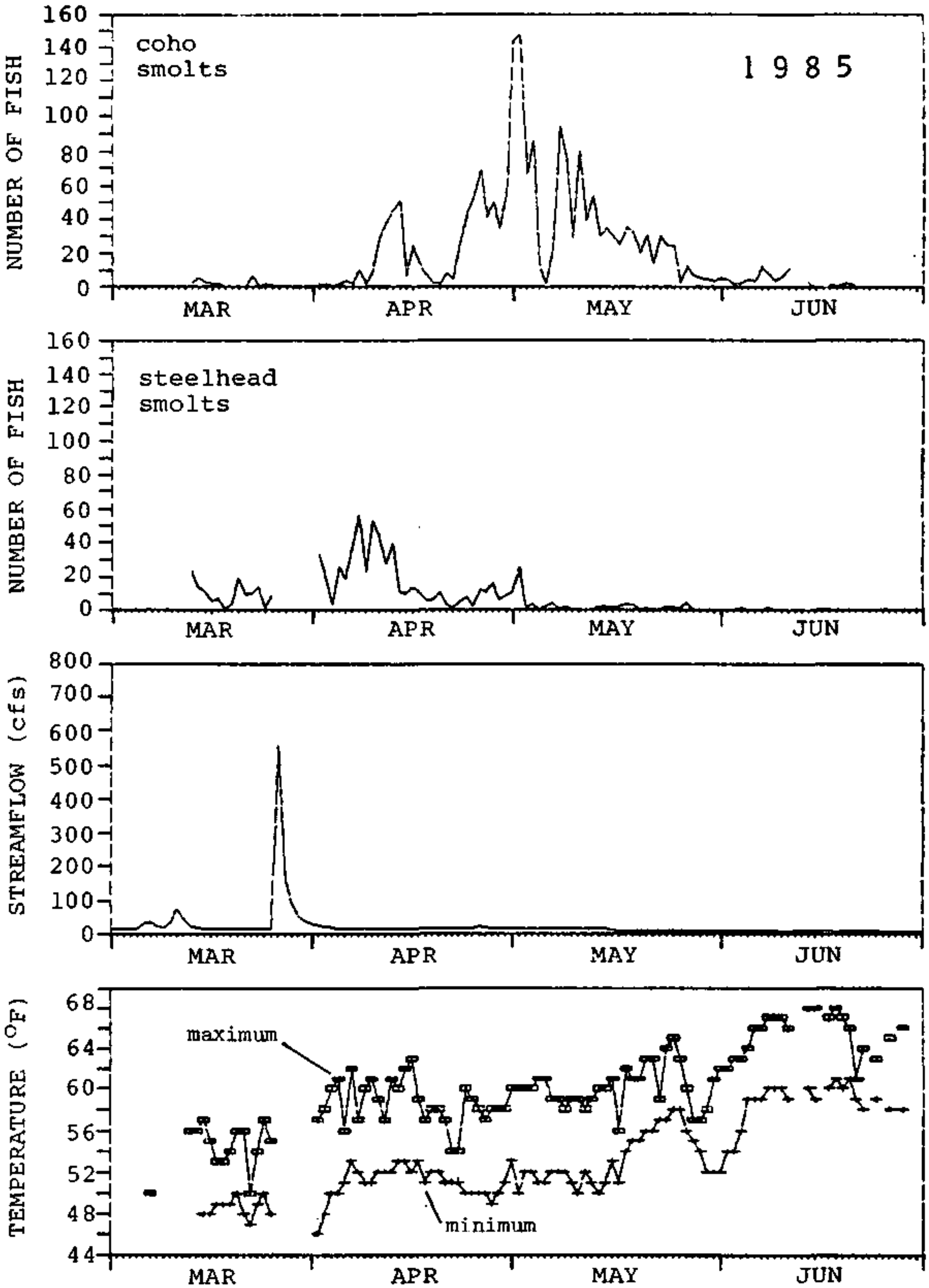

Figure 9-8. Number of coho salmon and steelhead trout smolts captured daily in the Lagunitas Creek trap, mean daily streamflow (measured at the SPTSP gage), and maximum and minimum water temperatures recorded daily at the trap, 1985.

Table 9-4. Mean monthly water temperatures, calculated as the average of daily mean maximum and minimum temperatures recorded near the smolt trap, and mean monthly flows measured at the SPTSP gage in Lagunitas Creek during the salmonid emigration period, 1983-1985.

YEAR	MONTH	MEAN MONTHLY FLOW (cfs)	MEAN MONTHLY WATER TEMPERATURE (°F)
1983	March	503.0	--
	April	67.3	54.8
	May	40.7	59.0
	June	9.7	61.7
1984	March	21.3	52.7
	April	12.6	53.9
	May	10.0	57.9
	June	8.3	59.7
1985	March	48.5	51.2
	April	17.2	54.8
	May	11.0	56.6
	June	6.7	62.1

Table 9-5. Comparison of average mean daily streamflows that occurred during the overall salmonid emigration period and number of late emigrants captured in Lagunitas Creek, 1983-1985. High storm-induced streamflows may have delayed salmonid emigration in 1983.

YEAR	AVERAGE MEAN DAILY FLOW (cfs) AT THE SPTSP GAGE FROM MARCH 1 - JUNE 30	NUMBER OF COHO SMOLTS CAPTURED DURING JUNE	NUMBER OF STEELHEAD SMOLTS CAPTURED AFTER MAY 4[1]
1983	157	224	64
1984	13	59	53
1985	21	59	32

[1] Day that the smolt trap was reinstalled following a period of high runoff in 1983.

movement of fish and environmental variables by conducting Pearson product-moment correlation analyses. In these analyses, we included two different expressions of seaward movement of fish—total numbers captured daily, and change in numbers captured on consecutive days. Environmental variables included in the analyses were absolute value and change in absolute value on consecutive days, for daily measures of streamflow, water temperature (maximum, minimum, and average), and photoperiod. Lunar phases, expressed as ranks of 1 for new moon, 2 for first and last quarter, and 3 for full moon, also were examined. Measurements of environmental variables and emigration of salmon and steelhead smolts during April and May, when nearly all movement occurred, were assessed for 1984 and 1985. Environmental variables and downstream movement of steelhead fry were assessed for the period from April through June for 1984 and 1985. Data from 1983 were excluded from the analyses because of incomplete records during the peak emigration period (Figure 9-6), and salmon fry were not assessed because few were captured during any year of this study (Table 9-1).

We found no significant relationship between daily numbers of emigrating salmon smolts and streamflow during either year examined, although change in streamflow was weakly ($r = 0.26$) associated with change in numbers emigrating during 1984 (Tables 9-6, 9-7). Daily emigration of salmon smolts was positively correlated only with photoperiod—the relative proportion of daylight hours to the total day during 1985.

Several environmental variables were associated with emigration of steelhead smolts. For both years examined, the numbers of steelhead smolts that emigrated daily were correlated with streamflow (Tables 9-6, 9-7), water temperature, and photoperiod. As spring progressed, the number of steelhead smolts emigrating decreased, streamflow decreased, and water temperature and photoperiod increased.

Downstream movement of steelhead fry was negatively correlated with water temperature and lunar phase for both years examined (Tables 9-6, 9-7). Higher numbers of steelhead fry moving downstream were weakly correlated with less illuminating lunar phases. Greater movement of fry during periods of low nighttime light intensity may be due to predator avoidance.

Peaks in seaward movement of salmon smolts, steelhead smolts, and steelhead fry were not associated with increase or decrease in streamflow. We considered peak movement to be at least a doubling of the number of fish captured on consecutive days, and compared peak movements to change in streamflow during the 1984 and 1985 emigration periods. For 36 peaks in movement of salmon smolts, 4 peaks occurred coincident with increase in streamflow, 11 occurred coincident with decrease in flow, and 21 occurred when flows were stable. For steelhead smolts, 4 peaks occurred with increase in streamflow, 7 occurred with decrease in flow, and 13 occurred with no change in flow. Peak movements of steelhead fry also were not associated with change in streamflow—4 peaks occurred when flows increased, 8 occurred when flows decreased, and 18 occurred when flows were stable.

Table 9-6. Correlations between environmental variables and number of coho and steelhead smolts[1] and steelhead fry[2] captured daily in the Lagunitas Creek trap, 1984. Significance levels of correlations are $P < 0.10$ unless indicated (* = $P < 0.05$).

1984	Number of Coho Smolts	Change in Number of Coho Smolts	Number of Steelhead Smolts	Change in Number of Steelhead Smolts	Number of Steelhead Fry	Change in Number of Steelhead Fry
Julian Day						
Streamflow[3]			0.44*			
Change in Streamflow		0.26*		0.26*		
Maximum[4] Temperature			-0.35*		-0.26*	
Change in Maximum Temperature				0.24		-0.30*
Minimum Temperature					-0.22	
Change in Minimum Temperature						
Average[5] Temperature			-0.30*		-0.26	
Change in Average Temperature						-0.21
Photoperiod[6]	-0.24		-0.28*			
Change in Photoperiod	-0.20				0.23*	
Lunar Phase[7]					-0.37*	

1 Based on collections and measurements taken during April and May when 92% and 85% of all coho and steelhead smolts were collected.

2 Based on collections and measurements taken during April, May, and June when all steelhead fry were collected.

3 Mean daily flow measured at the SPTSP gage.

4 Water temperatures recorded daily at the smolt trap.

5 Calculated as the average of recorded daily maximum and minimum water temperatures.

6 Relative proportion of daylight hours to the total day.

7 Expressed as ranks for new moon, first and last quarter, and full moon phases.

Table 9-7. Correlations between environmental variables and number of coho and steelhead smolts[1] and steelhead fry[2] captured daily in the Lagunitas Creek trap, 1985. Significance levels of correlations are $P < 0.10$ unless indicated ($* = P < 0.05$).

1985	Number of Coho Smolts	Change in Number of Coho Smolts	Number of Steelhead Smolts	Change in Number of Steelhead Smolts	Number of Steelhead Fry	Change in Number of Steelhead Fry
Julian Day						
Streamflow[3]			0.51*		-0.21	
Change in Streamflow						
Maximum[4] Temperature					-0.20	
Change in Maximum Temperature					-0.31*	-0.47*
Minimum Temperature			-0.23			
Change in Minimum Temperature						-0.23*
Average[5] Temperature						
Change in Average Temperature					-0.32*	-0.47*
Photoperiod[6]	0.34*		-0.69*		0.20	
Change in Photoperiod			0.51*			
Lunar Phase[7]			0.30*		-0.38*	

[1] Based on collections and measurements taken during April and May when 96% and 82% of all coho and steelhead smolts were collected.

[2] Based on collections and measurements taken during April, May, and June when 91% of all steelhead fry were collected.

[3] Mean daily flow measured at the SPTSP gage.

[4] Water temperatures recorded daily at the smolt trap.

[5] Calculated as the average of recorded daily maximum and minimum water temperatures.

[6] Relative proportion of daylight hours to the total day.

[7] Expressed as ranks for new moon, first and last quarter, and full moon phases.

Behavioral Considerations

In addition to environmental cues, fluctuations in the daily number of fish moving downstream are probably due, in part, to behavioral characteristics of the fish. On several occasions during the spring of 1985, when a relatively high number of salmon smolts emigrated from Lagunitas Creek, we observed schools of about 10 to 30 salmon smolts under riparian cover in the margin of a glide and in a deep pool located immediately upstream of our trap. Schooling behavior of seaward migrating salmon also was reported in Waddell Creek by Shapovalov and Taft (1954). They observed that schools of salmon smolts, when approaching irregularities or barriers in the creek, repeatedly darted upstream and "played around" before passing the irregularity as a group. A similar situation may have occurred at our trap site in Lagunitas Creek.

We conducted a simple mark-recapture study to assess the rate of downstream movement of salmonid smolts in Lagunitas Creek. On April 19, 1984 we captured 23 salmon and 54 steelhead smolts in the Lagunitas Creek trap, marked them with a pelvic fin-clip, and held them in a live-box for 1 day. On April 20 we captured 2 more salmon and 5 more steelhead, marked them, transported all fish approximately 7.9 miles upstream, and released them into Lagunitas Creek at Shafter Bridge. One steelhead smolt died in handling and was not released. Thirteen (52%) of the marked salmon smolts were recaptured in the Lagunitas Creek trap from 3 to 24 days after release. Of these, 6 were recaptured on May 2, 1984, 12 days after release. These fish either exhibited the same rate of downstream movement (0.7 mi/day), or formed a school above our trap site and entered the trap as a group.

Only 4 (7%) of the marked steelhead smolts were recaptured in the Lagunitas Creek trap, from 15 to 23 days after release. We suspect that many of the steelhead "desmolted" and reverted to freshwater residence. In a review of several studies, Hoar (1976) stated that if steelhead smolts are retained in fresh water past the time of emigration, they become less resistant to seawater and redevelop some of the characteristics of nonemigrant fish. In contrast, salmon smolts do not lose their salinity resistance if retained in fresh water past the emigration period.

AGE OF EMIGRANT SALMONIDS

To determine the age and growth of emigrant salmonids, scale samples were taken from fish captured in the trap. For each fish sampled a few scales were removed and placed in a coin envelope that had capture information such as date, species, and length of fish written on it, for later identification. Scale samples were transported to the laboratory, removed from their packets and placed in 70% ethanol for cleaning, then transferred to a spot plate and examined under a dissecting microscope. An average of five scales from each sample was selected for processing. Selection criteria were the smallest foci, greatest clarity, and fewest obvious defects in the scale. The scales then were mounted on a microscope slide using a gelatin/glycerin medium.

The scales were examined by W. C. Fields, Jr. of Hydrozoology, using methods outlined in Lagler (1952). Scales were viewed under a compound microscope at 150x magnification with an ocular micrometer to measure the distance from the focus to the first annulus, between annuli, and from the last annulus to the edge of the scale along the median radius. All measurements were made along the anterior radius of the scale.

Scale samples were collected from the entire range of sizes of salmon and steelhead captured in the trap. Because lengths of fish in different age groups overlapped for each species, the proportion of each age group represented in each 10 mm length interval over the range of sizes of fish collected was determined for each year examined. These proportions then were applied to the total number of individuals in each 10 mm length interval that were captured each year. This method was used because of variation in growth rates and size of fish among age groups during any given year, and for the same age groups among years.

Age of Salmon Smolts

Salmon generally spend one full year in fresh water prior to emigration. Some salmon, however, undergo smoltification and emigrate from fresh water the year in which they hatched. These fish are designated age 0+ smolts. Salmon that rear in fresh water and emigrate in the spring a year or slightly more after hatching are age 1+ smolts. Nearly all of the salmon smolts captured during the 9-year study conducted by Shapovalov and Taft (1954) in Waddell Creek, Santa Cruz County were age 1+ fish.

In Lagunitas Creek from 1983-1985, variable proportions of the emigrant salmon smolt population were age 1+ fish. The percentage of age 1+ smolts in the emigrant population ranged from only 25% in 1983 to 95% in 1985 (Table 9-8). Because most salmon smolts are normally age 1+ fish, the low proportions of age 1+ fish (and subsequent high proportions of age 0+ fish) in the emigrant salmon smolt population of 1983 and to a lesser extent in 1984 were unusual situations.

Several processes influence this age composition including:

1) the number of adults that successfully spawned in the two previous falls and winters;

2) reproductive success associated with stream conditions during the incubation, hatching, and emergence life stages of those years; and

3) rearing conditions and carrying capacity of the stream, particularly during the low-flow summer period of previous years.

Table 9-8. Estimated number percent age composition of the total number of coho salmon smolts[1] captured in the Lagunitas Creek trap each spring, 1983-1985. An unusually high percentage of Age 0+ smolts was evident in the emigrant coho smolt population in the spring of 1983 and, to a lesser extent, in 1984.

Year	Number and Percentage of Smolts by Age			
	Age	0+	Age	1+
	n	%	n	%
1983	474	75	158	25[2]
1984	168	23	572	77
1985	90	5	1821	95[3]

[1] In addition to smolts, 64, 67, and 7 age 0+ fry were captured in 1983, 1984, and 1985, respectively.

[2] One age 2+ coho smolt, 162 mm in length, also was collected in 1983.

[3] Two age 2+ coho smolts, 148 and 152 mm in length, also were collected in 1985.

For example, in Lagunitas Creek the January 4, 1982 flood[1] probably scoured away most of the salmon redds constructed during the 1981/82 spawning season and consequently reduced the number of age 1+ salmon smolts that emigrated in the spring of 1983. This in part explains the low percentage of age 1+ smolts that emigrated in 1983. Also, in 1983 we initiated the trap operation later in the year, and the trap operation was interrupted by high streamflows during what was probably the peak emigration period. Based on the other 2 years of sampling, any salmon that emigrated during these periods when the trap was out of operation may have been primarily age 1+ salmon. Consequently, our data may be somewhat biased and underestimate the number of age 1+ salmon that emigrated from Lagunitas Creek in 1983.

The increase in the percentage of age 1+ salmon smolts and corresponding decrease in age 0+ smolts that we captured in 1984 and 1985 was most likely due to higher reproductive success and improved rearing conditions during the preceding years. Scour was severe, but less catastrophic, during the 1982/83 incubation period and probably resulted in a higher, but still relatively low, proportion of age 1+ smolts that emigrated in the spring of 1984. Stream conditions and reproductive success were good during the 1983/84 spawning and incubation period, and streamflows during the 1984 summer low-flow period were augmented for the third consecutive year. We believe that the combination of high reproductive success and augmented summer flows resulted in a high (and probably more usual) percentage of age 1+ fish in the emigrant salmon smolt population in the spring of 1985.

Age of Steelhead Smolts

Steelhead trout generally rear in Lagunitas Creek from 1 to 2 years prior to emigrating to the ocean. Few steelhead, as age 0+ smolts, emigrate from the creek the year in which they hatched.

The age composition of the emigrant steelhead smolt population was similar between 1984 and 1985 when nearly one-half of all captured fish were age 1+ and one-half were age 2+. In 1983, however, only 20% of the steelhead smolt population was comprised of age 2+ fish (Table 9-9).

Mechanisms that influence the age composition of the steelhead smolt population that we captured during any given year are the same as those that we previously discussed for salmon. In addition, the influence of natural mortality and habitat constraints are even greater because of the longer freshwater residence of steelhead.

The low percentage of age 2+ fish in the steelhead smolt population in the spring of 1983 was probably due, in part, to streamflows that occurred during the 2 previous years. This age group of fish was produced in the winter and early spring of 1981. Flows were low in Lagunitas Creek during the summer of 1981, often less than 2.0 cfs (measured at the USGS gage near Point

[1] Mean daily flow measured at the USGS gage near Point Reyes Station was 10,700 cfs on January 4, 1982.

Table 9-9. Estimated number percent age composition of the total number of steelhead trout smolts[1] captured in the Lagunitas Creek trap each spring, 1983-1985. A relatively low percentage of age 2+ smolts was evident in the emigrant steelhead smolt population in the spring of 1983.

Year	Number and Percentage of Steelhead Smolts Captured by Age					
	Age 0+		Age 1+		Age 2+	
	n	%	n	%	n	%
1983	16	4	310	76	79	20
1984	7	2	149	44	182	54
1985	5	1	298	42	396	57

[1] In addition to smolts, 198, 2605, and 389 age 0+ fry were captured in 1983, 1984, and 1985, respectively.

Reyes Station) in June and approximately 5 cfs for 2 consecutive days during July. Rearing habitat availability may have limited the numbers of steelhead surviving their first summer. Then, as age 0+ fish in their first winter in the creek, they were subjected to the January 4, 1982 flood and possibly flushed down the creek or displaced into less suitable habitat. In 12 years of study of Carnation Creek, British Columbia, Holtby and Hartman (1982) found that approximately 51% of the total mortality observed over the 1 or 2 years of stream residence of salmon occurred during the winter. They suggested that the severe winter flow regime of the creek was largely responsible for the high mortalities. A similar situation most likely occurred during the winter of 1981/82 in Lagunitas Creek.

The increase in the percentage of age 2+ steelhead smolts that we captured in Lagunitas Creek in 1984 and 1985 was probably due to more favorable stream conditions during their freshwater residence periods. Streamflows were high during the winter of 1982/83 (Chapter 2) but did not approach the magnitude or severity of the January 4, 1982 flood, and flows during the winter of 1983-84 were generally low and stable in comparison. Augmentation of streamflows during the low-flow summer period began in the summer of 1982. During the summer, streamflows measured at the USGS gage near Point Reyes Station almost always exceeded 3.0 cfs in 1982, 5.5 cfs in 1983, and 4.0 cfs in 1984. We suggest that lower maximum winter flows and augmented summer flows resulted in higher percentage composition of older fish in the steelhead smolt populations that we captured in the spring of 1984 and 1985.

SIZE OF EMIGRANT SALMONIDS

The size of young salmonids is related to both their fresh water and ocean survival. The size of age 0+ fish at the beginning of their first winter in fresh water is positively related to their survival and subsequent production of age 1+ smolts the following spring (Holtby and Hartman 1982). The size of smolts at the time of emigration also is believed to be positively related to their marine survival. Large smolts experience higher early marine survival, probably because of reduced predation (Healey 1982).

Size of Salmon

Differences in the size distributions between salmon fry and salmon smolts that we captured in the Lagunitas Creek trap varied considerably among the 3 years of our study (Figure 9-9). Length-frequency distributions for fry and smolts overlapped considerably in 1983, slightly in 1984, and not at all in 1985. Overlap in the length-frequency distributions occurred in 1983 and to a lesser extent in 1984, primarily because of a relatively high percentage of smaller smolts represented in the collections.

The average size of salmon smolts that we captured emigrating from Lagunitas Creek increased over the 3-year study period. Salmon smolts averaged 96 mm, 113 mm, and 116 mm in 1983, 1984, and 1985, respectively.

The size distribution of the salmon smolts that emigrate during any given year is influenced by the age composition of the emigrant smolt

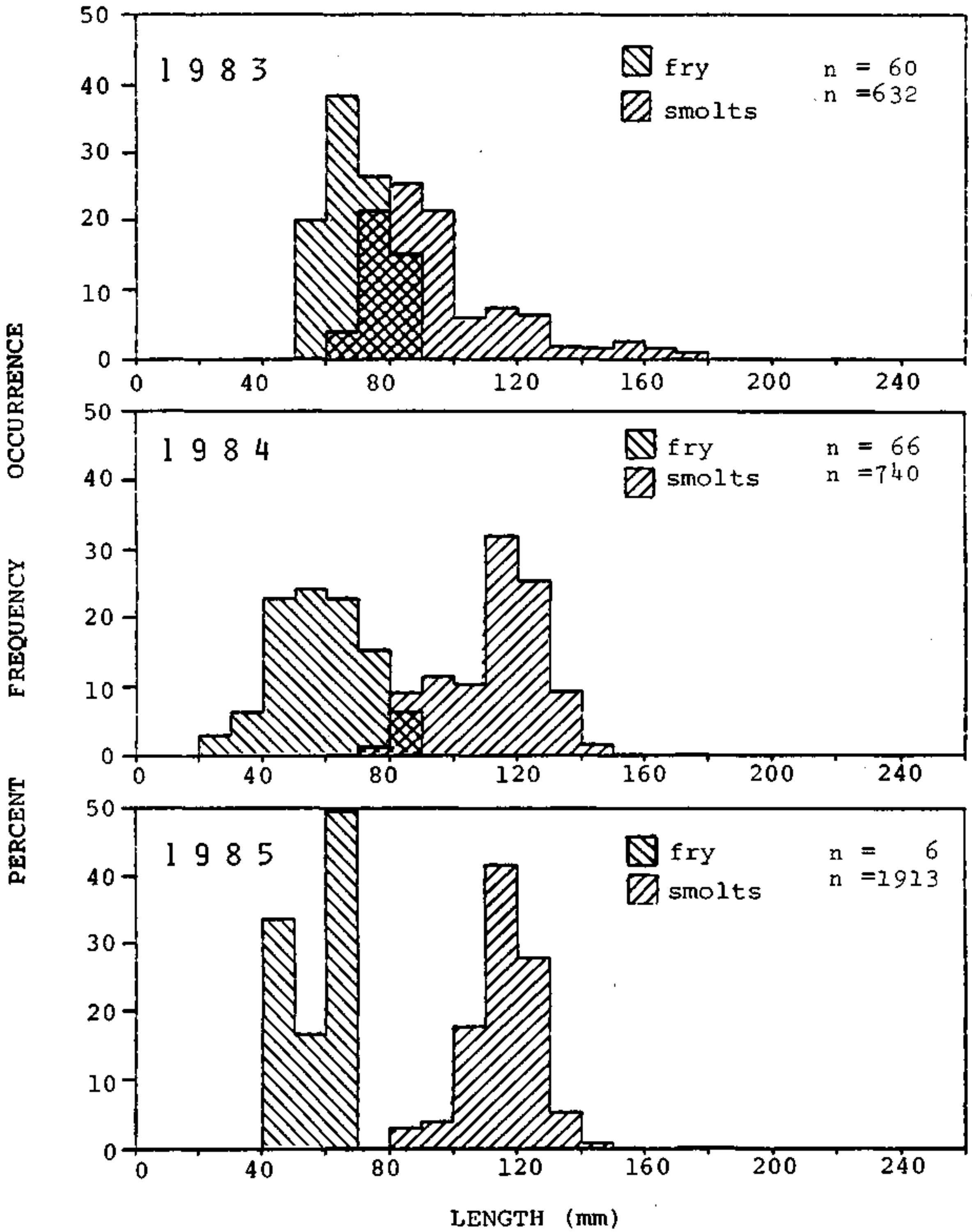

Figure 9-9. Length-frequency distribution for all coho salmon fry and smolts captured in the Lagunitas Creek trap and measured during the entire spring sampling period, 1983-1985. An unusually high percentage of smaller smolts were collected during the spring of 1983.

population. Also, both the size and age of the emigrating smolts change over time within a given season.

Length-frequency distributions and age compositions of all salmon smolts captured weekly in the Lagunitas Creek smolt trap for each year of our study are shown in Tables 9-10, 9-11, and 9-12. Examination of these tables illustrates that the larger, older smolts emigrated from Lagunitas Creek earlier in the spring than the smaller, younger smolts. Most age 0+ salmon smolts generally did not begin to emigrate from the creek until about the second week in May, after reaching at least 70 mm in length.

Size of Steelhead

Steelhead fry were distinctly smaller than steelhead smolts that we captured in the Lagunitas Creek trap during this study (Figure 9-10). Distributions in the sizes were similar among years for fry and also for smolts. Smolts generally ranged in size from about 80 mm to 240 mm. The slight overlap in the length-frequency distributions of fry and smolts in 1983 resulted from 14 age 0+ smolts, ranging from 10 mm to 80 mm in length, captured that year.

The average size of steelhead smolts that we captured emigrating from Lagunitas Creek was lower in 1983 than in the other 2 years of trapping. Steelhead smolts averaged 153 mm, 174 mm, and 165 mm in 1983, 1984, and 1985, respectively.

Length-frequency distributions and age compositions of all steelhead smolts captured weekly in the Lagunitas Creek trap each year are shown in Tables 9-13, 9-14, and 9-15. As previously discussed, the emigrant steelhead smolt population is almost completely comprised of age 1+ and age 2+ fish. These two age groups of smolts exhibited considerable overlap in length, and no discernible differences in time of emigration.

CONCLUSIONS-SALMONID EMIGRATION

Salmonid smolts emigrate from Lagunitas Creek from March through June although most emigration generally occurs during April and May. In 1983, streamflows were high during winter and spring and many smolts did not emigrate until June. Delayed emigration can adversely affect smolts by exposing them to elevated water temperatures in the Lagunitas Creek estuary during late spring (Chapter 10).

Peaks in seaward movement of salmonids were not associated with change in streamflow over the range of flows examined. Also, the general time of smolt emigration and periods of peak emigration were similar between 1984 and 1985. Flows measured at the SPTSP gage in April and May were relatively stable and averaged 12.6 cfs and 10 cfs in 1984 and 17.2 cfs and 11 cfs in 1985. Streamflows of this magnitude during April and May appear suitable for salmonid emigration from Lagunitas Creek.

Table 9-10. Length-frequency distribution and age composition[1] of all coho salmon smolts[2] captured in the Lagunitas Creek smolt trap by 1-week periods, 1983 (after Shapovalov and Taft 1954). The larger, older smolts generally emigrated from Lagunitas Creek earlier in the spring than the smaller, younger smolts.

Length (mm)	Mar 1-7	Mar 8-14	Mar 15-21	Mar 22-28	Mar 29 Apr 4	Apr 5-11	Apr 12-18	Apr 19-25	Apr 26 May 2	May 3-9	May 10-16	May 17-23	May 24-30	May31 Jun 6	Jun 7-13	Jun 14-20	Jun 21-27	Jun 28 Jul 4	Total
0 - 9																			
10 - 19																			
20 - 29											Age 0+								
30 - 39																			
40 - 49																			
50 - 59											1								1
60 - 69								2			12	7	3						24
70 - 79							1			1	48	53	20	11	2				136
80 - 89							1	2			5	34	34	44	31	10			161
90 - 99								1	2			1	21	33	51	26	1		136
100 - 109							2	8	2	1	2	2	3	3	4	8	2		37
110 - 119							8	5	5	1	10	7	2	2		2	4		46
120 - 129							8	14	3		11	1	1						38
130 - 139							3	6			1	1							11
140 - 149							4	4				1							9
150 - 159							8	5	1			2							16
160 - 169							6		3			1							10
170 - 179							6												6
180 - 189											Age 1+								
190 - 199							1												1
200 - 209																			
210 - 219																			
220 - 229																			
230 - 239																			
Totals Age 0+		—	—	—	—	—	—	2	—	1	66	95	78	91	88	46	7	—	474
Totals Age 1+		—	—	—	—	—	48	45	16	2	24	15	6	2	—	—	—	—	158[3]

[1] Age-group boundaries presented to the nearest 10 mm size break during any given weekly period for illustrative purposes.
[2] Eight coho salmon smolts captured during 1983 were not measured.
[3] One age 2+ coho smolt, 162 mm in length, also was captured.

Table 9-11. Length-frequency distribution and age composition[1] of all coho salmon smolts[2] captured in the Lagunitas Creek smolt trap by 1-week periods, 1984 (after Shapovalov and Taft 1954). The larger, older smolts generally emigrated from Lagunitas Creek earlier in the spring than the smaller, younger smolts.

Length (mm)	Mar 1-7	Mar 8-14	Mar 15-21	Mar 22-28	Mar 29 Apr 4	Apr 5-11	Apr 12-18	Apr 19-25	Apr 26 May 2	May 3-9	May 10-16	May 17-23	May 24-30	May31 Jun 6	Jun 7-13	Jun 14-20	Jun 21-27	Jun 28 Jul 4	Total
0 - 9																			
10 - 19																			
20 - 29											Age 0+								
30 - 39																			
40 - 49																			
50 - 59																			
60 - 69															1				1
70 - 79												2	5	1		1			9
80 - 89										1	2	8	31	14	5	5			66
90 - 99										2	9	18	24	24	6	1			84
100 - 109						1	3	6	11	13	24	10	4	3	1				76
110 - 119					2	3	14	35	46	59	64	5	8						236
120 - 129						1	11	28	52	53	34	5	2		1				187
130 - 139							5	6	18	25	13	1							68
140 - 149							2	1	2	6									11
150 - 159											1								1
160 - 169																			0
170 - 179											1								1
180 - 189																			
190 - 199																			
200 - 209											Age 1+								
210 - 219																			
220 - 229																			
230 - 239																			
Totals Age 0+		—	—	—	—	—	—	—	—	3	11	28	64	42	13	7	—	—	168
Totals Age 1+		—	—	—	2	5	35	76	129	156	137	21	10	—	1	—	—	—	572

1 Age-group boundaries presented to the nearest 10 mm size break during any given weekly period for illustrative purposes.
2 Two coho salmon smolts captured during 1984 were not measured.

Table 9-12. Length-frequency distribution and age composition[1] of all coho salmon smolts[2] captured in the Lagunitas Creek smolt trap by 1-week periods, 1985 (after Shapovalov and Taft 1954). The larger, older smolts generally emigrated from Lagunitas Creek earlier in the spring than the smaller, younger smolts.

Length (mm)	Mar 1-7	Mar 8-14	Mar 15-21	Mar 22-28	Mar 29 Apr 4	Apr 5-11	Apr 12-18	Apr 19-25	Apr 26 May 2	May 3-9	May 10-16	May 17-23	May 24-30	May31 Jun 6	Jun 7-13	Jun 14-20	Jun 21-27	Jun 28 Jul 4	Total
0 - 9																			
10 - 19																			
20 - 29											Age 0+								
30 - 39																			
40 - 49																			
50 - 59																			
60 - 69												1	1						2
70 - 79											1	1							2
80 - 89		3	1				1				2	12	15	10	13	1			58
90 - 99		3	2			6	10	1	3	2	4	9	5	11	14	2			72
100 - 109		1	1	2	1	33	44	28	69	51	56	35	14	2	1				338
110 - 119						32	59	79	228	161	142	69	16	6					792
120 - 129					1	15	27	78	191	87	73	47	4	2	1	1			527
130 - 139						4	5	14	38	20	13	8	1						103
140 - 149								1	8	1		1	1						12
150 - 159						1			1		1								3
160 - 169																			
170 - 179									1										1
180 - 189								1			Age 1+								1
190 - 199																			
200 - 209																			
210 - 219																			
220 - 229																			
230 - 239																			
Totals Age 0+		—	—	—	—	—	1	—	—	—	3	14	21	21	27	3	—	—	90
Totals Age 1+		7	4	2	2	91	145	202	539	322	289	169	36	10	2	1	—	—	1821[3]

[1] Age-group boundaries presented to the nearest 10 mm size break during any given weekly period for illustrative purposes.
[2] Eleven coho salmon smolts captured during 1985 were not measured.
[3] Two age 2+ coho smolt, 148 and 152 mm in length, also were collected in 1985.

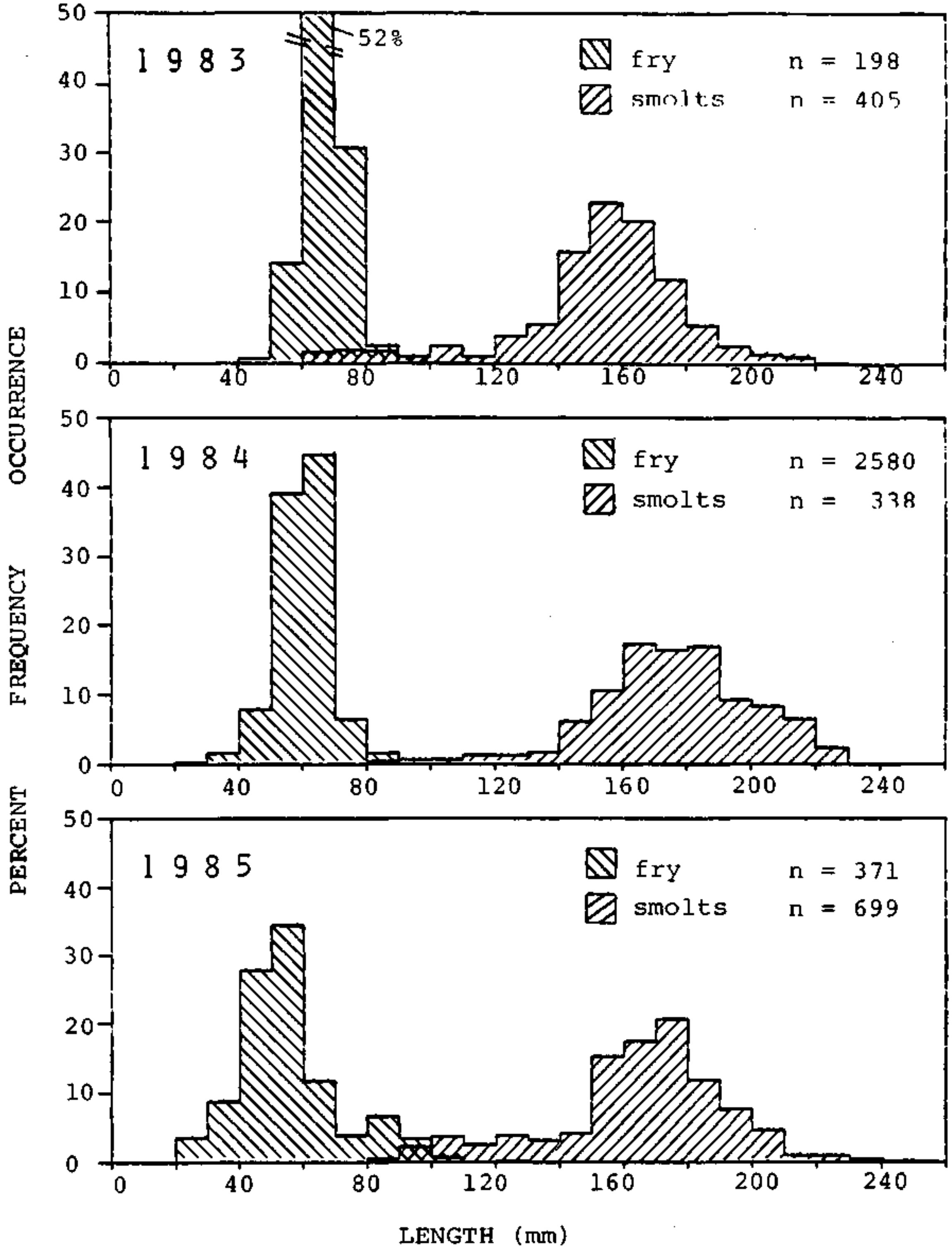

Figure 9-10. Length-frequency distribution for all steelhead trout fry and smolts captured in the Lagunitas Creek trap and measured during the entire spring sampling period, 1983-1985. Distributions were generally similar among years.

Table 9-13. Length-frequency distribution of all steelhead trout smolts[1] captured in the Lagunitas Creek smolt trap by 1-week periods and age composition of the smolt population, 1983. Age 1+ and age 2+ steelhead smolts exhibited considerable overlap in length and no distinct differences in time of emigration.

Length (mm)	Mar 1-7	Mar 8-14	Mar 15-21	Mar 22-28	Mar 29 Apr 4	Apr 5-11	Apr 12-18	Apr 19-25	Apr 26 May 2	May 3-9	May 10-16	May 17-23	May 24-30	May 31 Jun 6	Jun 7-13	Jun 14-20	Totals		
																	Age 0+	Age 1+	Age 2+
0 - 9																			
10 - 19																			
20 - 29																			
30 - 39																			
40 - 49																			
50 - 59																			
60 - 69											1	5					6		
70 - 79												8					8		
80 - 89								2			1	3		1			2	5	
90 - 99								1							2			3	
100 - 109							2	3			1	2	2					10	
110 - 119							1	2			1							4	
120 - 129							3	4	2		3	2				1		15	
130 - 139							7	10	1		3		1			1		23	
140 - 149							16	23	13	2	6	4						64	
150 - 159							18	54	13		6	1	1					62	31
160 - 169							10	47	22			2				1		55	27
170 - 179							4	24	19				1					48	
180 - 189							2	13	7									11	11
190 - 199								6	3		1							10	
200 - 209								3	2										5
210 - 219								2	2										4
220 - 229									1										1
230 - 239																			
240 - 249																			
250 - 259																			
260 - 269																			
Totals							63	194	85	2	23	27	5	1	2	3	16	310	79

[1] Eleven steelhead trout smolts captured during 1983 were not measured.

Table 9-14 Length-frequency distribution of all steelhead trout smolts[1] captured in the Lagunitas Creek smolt trap by 1-week periods and age composition of the smolt population, 1984 Age 1+ and age 2+ steelhead smolts exhibited considerable overlap in length and no distinct differences in time of emigration.

Length (mm)	Mar 1-7	Mar 8-14	Mar 15-21	Mar 22-28	Mar29 Apr 4	Apr 5-11	Apr 12-18	Apr 19-25	Apr 26 May 2	May 3-9	May 10-16	May 17-23	May 24-30	May31 Jun 6	Jun 7-13	Jun 14-20	Totals Age 0+	Totals Age 1+	Totals Age 2+
0 - 9																			
10 - 19																			
20 - 29																			
30 - 39																			
40 - 49																			
50 - 59																			
60 - 69																			
70 - 79																			
80 - 89														5			4	1	
90 - 99		1															1		
100 - 109		1						1									1	1	
110 - 119		1		1				2										4	
120 - 129				1		1				1	1							4	
130 - 139		1	2				1	2										6	
140 - 149		1		1		1	3	8	1	4	1							20	
150 - 159			1	2	2	3	6	11	3	5	1	1			1			33	3
160 - 169				5	5	5	6	20	6	5	6							34	24
170 - 179				5	4	11	7	10	7	5	7							12	44
180 - 189				7	3	11	4	13	9	4	6							15	42
190 - 199		2		2	1	3	4	8	8	2	1							8	23
200 - 209		1		3	2	9		6	4	1	2							7	21
210 - 219			1	1		6		7	2	2	2							4	17
220 - 229							2	3			2			1					8
230 - 239																			
240 - 249																			
250 - 259																			
260 - 269																			
Totals		8	4	28	17	50	33	91	40	29	29	1		6	1		7[2]	149	182

[1] Eleven steelhead trout smolts captured during 1983 were not measured.

[2] An additional age 0+ smolt 90 mm in length was captured on June 29, 1984

Table 9-15 Length-frequency distribution of all steelhead trout smolts[1] captured in the Lagunitas Creek smolt trap by 1-week periods and age composition of the smolt population, 1985 Age 1+ and age 2+ steelhead smolts exhibited considerable overlap in length and no distinct differences in time of emigration.

Length (mm)	Mar 1-7	Mar 8-14	Mar 15-21	Mar 22-28	Mar29 Apr 4	Apr 5-11	Apr 12-18	Apr 19-25	Apr 26 May 2	May 3-9	May 10-16	May 17-23	May 24-30	May31 Jun 6	Jun 7-13	Jun 14-20	Totals Age 0+	Totals Age 1+	Totals Age 2+
0 - 9																			
10 - 19																			
20 - 29																			
30 - 39																			
40 - 49																			
50 - 59																			
60 - 69																			
70 - 79																			
80 - 89	2						1										1	2	
90 - 99		4	3		1	5	3										4	12	
100 - 109		5	6	1	3	8		1	1									25	
110 - 119		6	1		2	6	3											18	
120 - 129		9	2		6	6	1	1		1								25	
130 - 139			7	1	5	9												22	
140 - 149			3		3	6	7	3	5	1								25	3
150 - 159		5	4	3	11	31	22	14	12	2	1	3						42	66
160 - 169		3	6	4	12	52	18	7	17		1	2	1					53	70
170 - 179		3	5	3	13	63	20	7	18	4	3	2	3					59	85
180 - 189			5	3	9	38	5	5	14	2	1		1					7	76
190 - 199		1	2	4	9	16	10	1	7	1			1	1				7	46
200 - 209			4	4	4	11	3	1	5										32
210 - 219						3	2				1								6
220 - 229			1		1	2	1					1							6
230 - 239						1		1				1							3
240 - 249						1													1
250 - 259							1												1
260 - 269					1														1
Totals	2	36	49	23	80	258	97	41	79	11	7	9	6	1			5	298	396

[1] Fourteen steelhead trout smolts captured during 1985 were not measured.

Numbers of smolts, and the age and size composition of the smolt population were highly variable among the 3 years we examined. Numbers, age, and size of smolts that emigrate in any given year depend on conditions that occurred earlier that same year and in each of the 2 previous years. Important conditions that influence the smolt population include the number of adults that successfully spawn, survival during the embryo incubation and fry emergence life stages, and rearing conditions and carrying capacity of the stream—especially during the low-flow summer period.

CHAPTER 10 - ESTUARINE ENVIRONMENT

Salmonid smolts emigrating from Lagunitas Creek must pass through the estuary en route to Tomales Bay and the Pacific Ocean. It is in the estuary that young salmonids first encounter brackish water and adapt to seawater. Some estuaries are nursery areas for juvenile salmonids. Such areas may be especially needed if high reproductive success results in large numbers of salmonids exceeding the rearing capacity of the creek, or if high flows in late spring displace fish downstream.

LAGUNITAS CREEK ESTUARY

The lowest reach of Lagunitas Creek extends approximately 15,000 ft downstream from the US Highway 1 Bridge in the town of Point Reyes Station before emptying into the southern end of Tomales Bay (Figure 10-1). This reach of Lagunitas Creek includes the estuarine zone, where saline and fresh water mix.

Much of the estuary is a diked tidal channel that varies in width from about 30 ft in the upper end to about 200 ft near its mouth. The uppermost 3,000 ft of the estuary contains some areas of water > 2 ft deep at low tide, and is wooded on the southern bank. The lower portion of the estuary is a wide, shallow channel bounded on each side by pastureland that provides virtually no instream or riparian cover. Usually each May a small earthen dam, locally known as Giacomini's Dam, is constructed about 14,000 ft upstream from the mouth of Lagunitas Creek about 1,000 feet below the head of tidewater. Fresh water impounded behind the dam is used to irrigate the pastures that border the estuary.

FISH SAMPLING

Fish were sampled in the estuary with a 100 x 6 ft bag seine constructed of 5/8 inch stretched mesh and a 30 x 4 ft straight seine of 1/4 inch stretched mesh. Sampling was conducted weekly from May 7 through June 24, 1983 at nine stations. These stations were distributed from 3,000 to over 14,000 ft upstream from the mouth of Lagunitas Creek at locations where seining was possible. Fish were sampled biweekly from April 13 through July 1, 1984 at seven stations ranging from 2,000 to over 14,000 ft upstream from the mouth of the creek. Sampling procedures consisted of setting the large seine parallel and approximately 30 ft from the shoreline then drawing the seine directly into shore. Three passes with the small seine were made along the shoreline at each sampling station. We captured a wide variety of freshwater or brackish water fishes. Threespine stickleback, delta smelt, northern anchovy, carp, California roach, and Staghorn sculpin were the most numerous of the 23 species (Table 10-1).

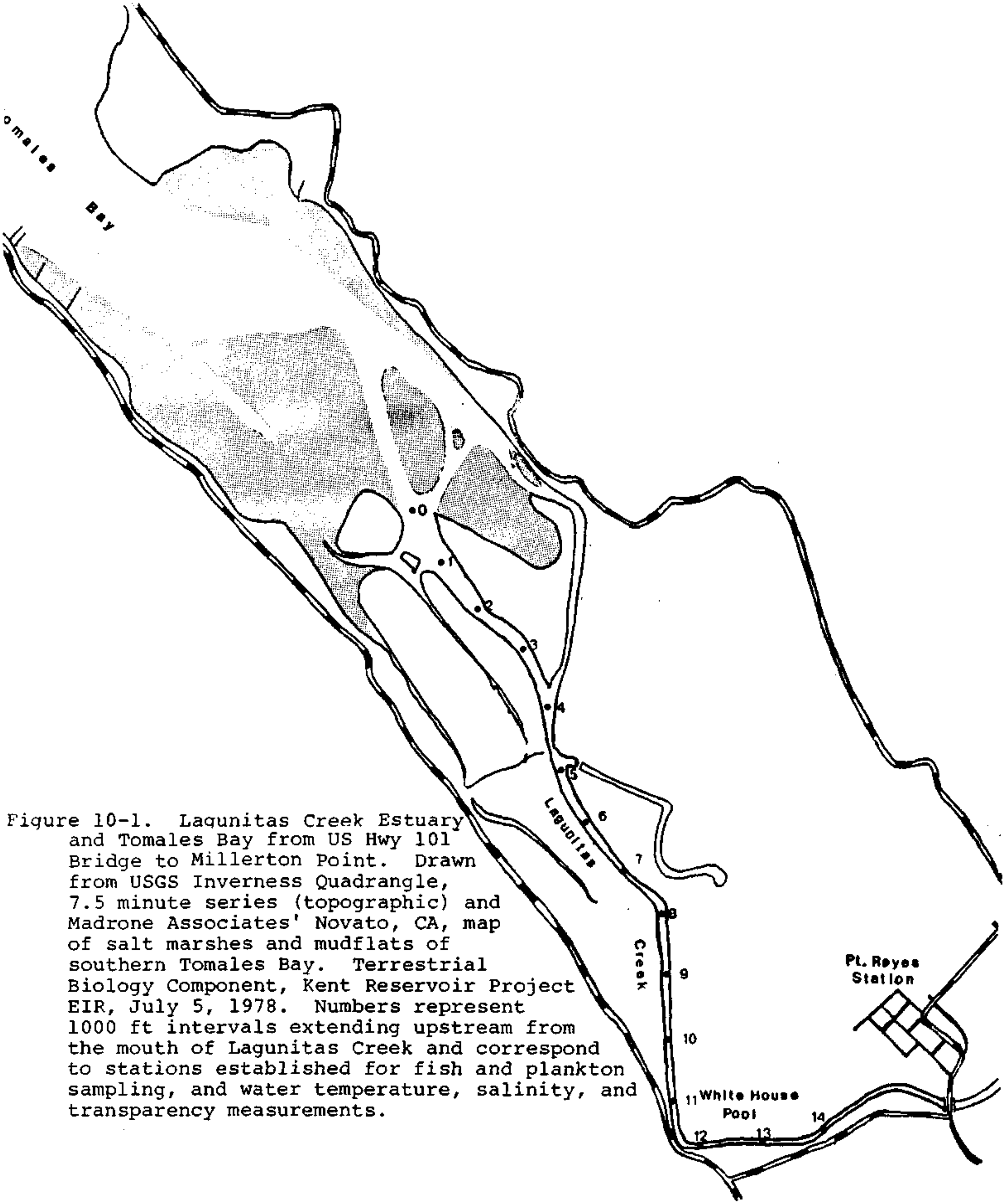

Figure 10-1. Lagunitas Creek Estuary and Tomales Bay from US Hwy 101 Bridge to Millerton Point. Drawn from USGS Inverness Quadrangle, 7.5 minute series (topographic) and Madrone Associates' Novato, CA, map of salt marshes and mudflats of southern Tomales Bay. Terrestrial Biology Component, Kent Reservoir Project EIR, July 5, 1978. Numbers represent 1000 ft intervals extending upstream from the mouth of Lagunitas Creek and correspond to stations established for fish and plankton sampling, and water temperature, salinity, and transparency measurements.

Table 10-1. Fish collected by seining in the Lagunitas Creek Estuary during the salmonid emigration period in the spring of 1983.

FAMILY	COMMON NAME	SCIENTIFIC NAME	NUMBER FISH CAPTURED
Clupeidae	Pacific herring	Clupea harengus pallasi	1
Engraulidae	Northern anchovy	Engraulis mordax	358
Salmonidae	Coho salmon	Oncorhynchus kisutch	46
	Steelhead trout	Salmo gairdneri	48
	Rainbow trout	Salmo gairdneri	55
Osmeridae	Surf smelt	Hypomesus pretiosus	34
	Delta smelt	Hyomesus transpacificus	843
Cyprinidae	Carp	Cyprinus carpio	186
	California roach	Hesperoleucus symmetricus	178
	Hitch	Lavinia exilicauda	8
	Golden shiner	Notemigonus crysoleucas	25
Catostomidae	Sacramento sucker	Catostomus occidentalis	23
Ictaluridae	Channel catfish	Ictalurus punctatus	2
Gasterosteidae	Threespine stickleback	Gasterosteus aculeatus	1123
Syngnathidae	Bay pipefish	Syngnathus griseolineatus	2
Percichthyidae	Striped bass	Morone saxatilis	3
Centrarchidae	Bluegill	Lepomis macrochirus	1
	Largemouth bass	Micropterus salmoides	1
	Black crappie	Pomoxis nigromaculatus	1
Embiotocidae	Shiner perch	Cymatogaster aggregata	15
Gobiidae	Yellowfin goby	Acanthogobius Flavimanus	17
Cottidae	Prickly sculpin	Cottus asper	33
	Pacific Staghorn sculpin	Leptocottus armatus	118
Pleuronectidae	Starry flounder	Platichthys stellatus	12

SALMONIDS

Distribution of Salmonids

Nearly all salmonids were collected in the upper section of the estuary, 11,000 ft or more upstream from the mouth of Lagunitas Creek (Figures 10-2, 10-3). No salmonids were captured less than 5,000 ft above the mouth. In addition to smolts, we captured several resident trout in 1983 and steelhead fry in 1984 in the upper estuary. Resident trout and steelhead fry were almost exclusively found in the impoundment or in the estuary immediately below Giacomini's Dam.

Temporal Abundance of Salmonids

Salmonids were captured throughout the spring sampling period in both 1983 and 1984 (Figures 10-4, 10-5). Peak numbers of coho salmon smolts were captured during the first half of June both years. Steelhead trout smolts were most abundant in the collections during early June in 1983 and the latter part of June in 1984.

Resident rainbow trout were primarily collected on June 8, 1983, when 45 specimens (75% of the total number) were captured in the impoundment behind Giacomini's Dam (station 15). These fish may have been desmolted steelhead residing in the lower reaches of Lagunitas and Olema creeks when they were impounded.

Increasing numbers of steelhead fry were collected from late May through July 1, 1984.

Factors Affecting the Distribution of Salmonids

We measured water temperature, salinity, depth, and water transparency in the estuary on a weekly schedule from May 7 through June 20, 1983. We measured these variables and water velocity on a biweekly schedule from April 11 through July 2, 1984.

We measured water temperature and salinity with a YSI salinity meter, from the surface of the water to the bottom at 1-ft intervals. Water transparency was measured with a Secchi disk. In 1983, each sampling run consisted of taking these measurements at or near the time of high tide, from near the mouth of Lagunitas Creek upstream until we encountered fresh water. To complete a sampling run we occasionally began sampling an hour prior to calculated high tide and finished sampling approximately 1 hour afterward. In 1984, measurements were taken at both high and low tide when fish and plankton were sampled from near the mouth of Lagunitas Creek every 3,000 ft upstream.

Nearly all salmonid smolts were captured in the upper estuary—where the water is cooler, less saline, and clearer than in the remainder of the estuary.

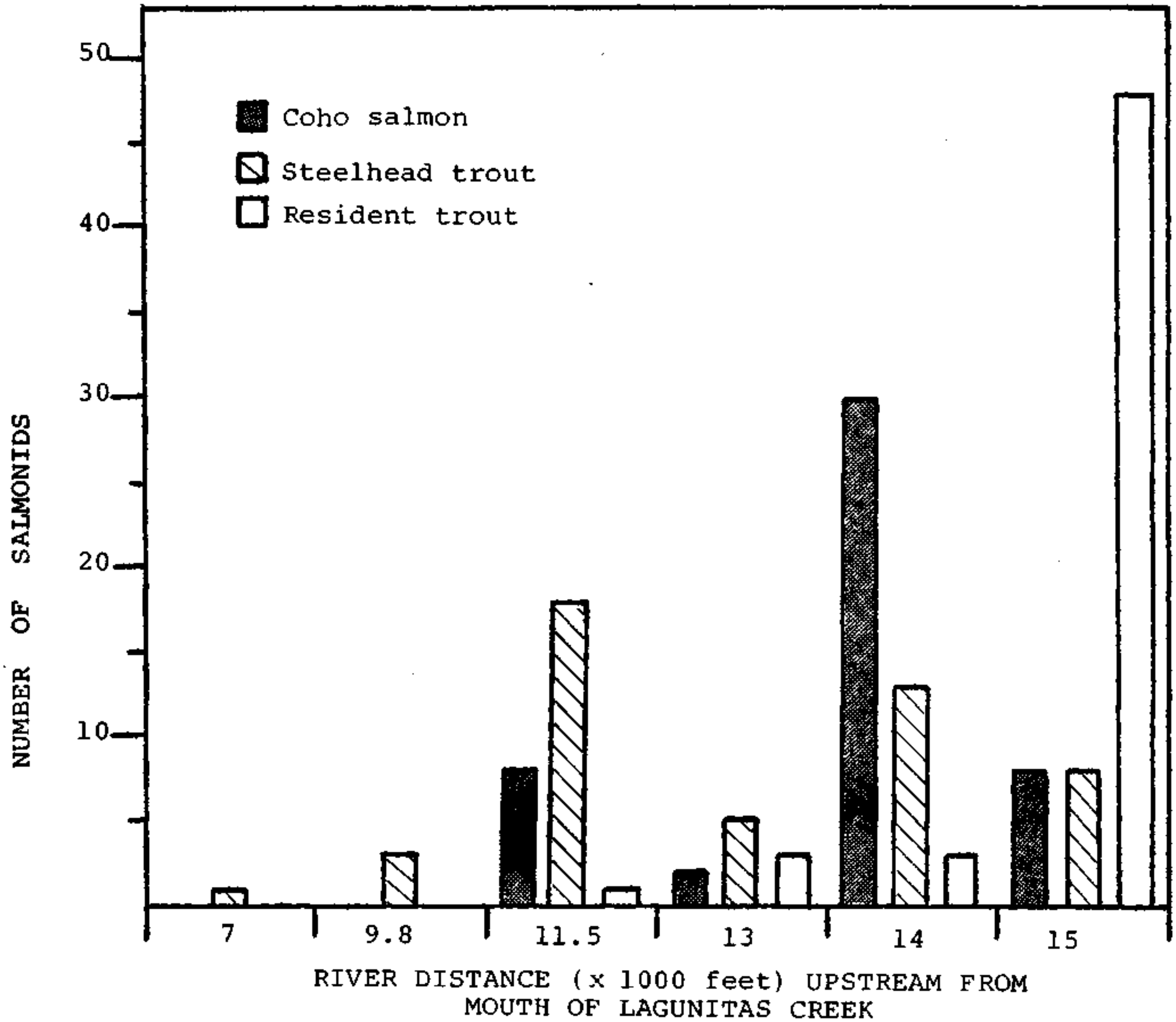

Figure 10-2. Total number of salmonids captured at each sampling station by seining Lagunitas Estuary at weekly intervals from May 7 through June 24, 1983. Nearly all salmonids were captured 11,500 ft or more upstream from the mouth of Lagunitas Creek. No salmonids were captured below station 7.

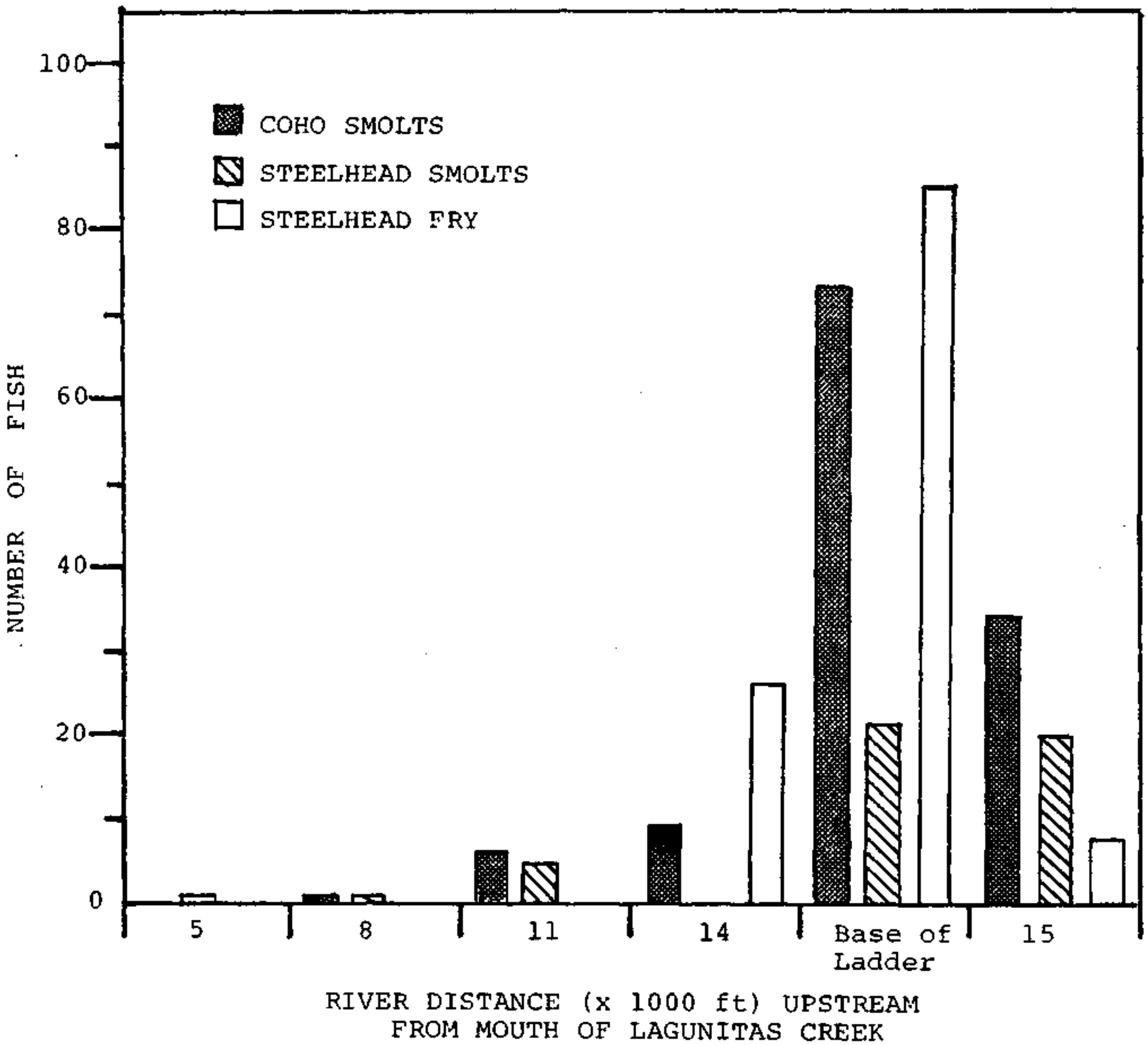

Figure 10-3. Total number of salmonids captured at each sampling station by seining Lagunitas Estuary at biweekly intervals from April 25 through July 1, 1984. Nearly all salmonids were captured 11,000 feet or more upstream from the mouth of Lagunitas Creek. No salmonids were captured below station 5.

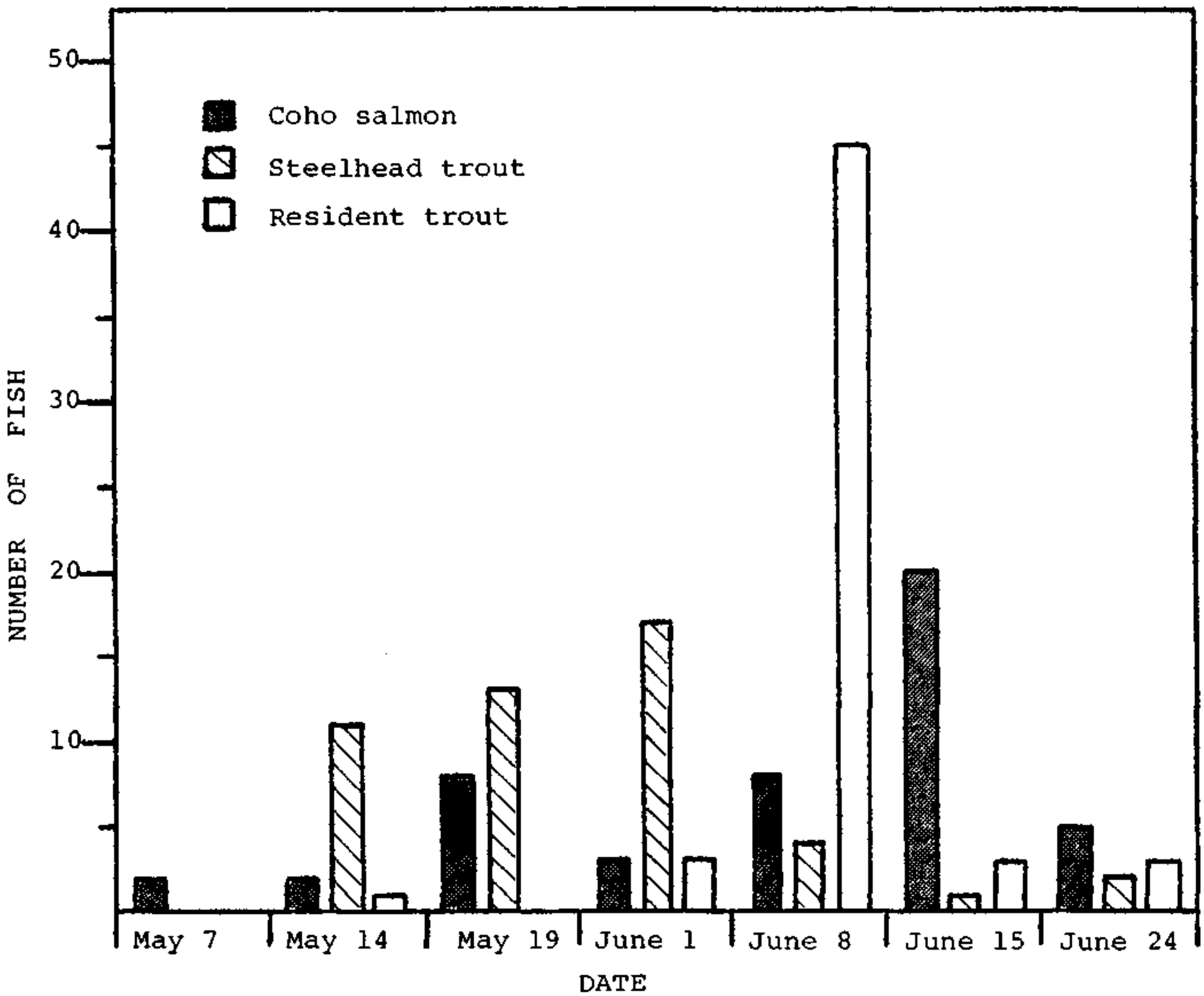

Figure 10-4. Total number of salmonids captured during each sampling period by seining the lowest reach of Lagunitas Creek, 1983. Sampling was conducted at nine stations located throughout this reach. Few steelhead trout smolts were collected after June 8, while the greatest number of coho salmon smolts were collected on June 15.

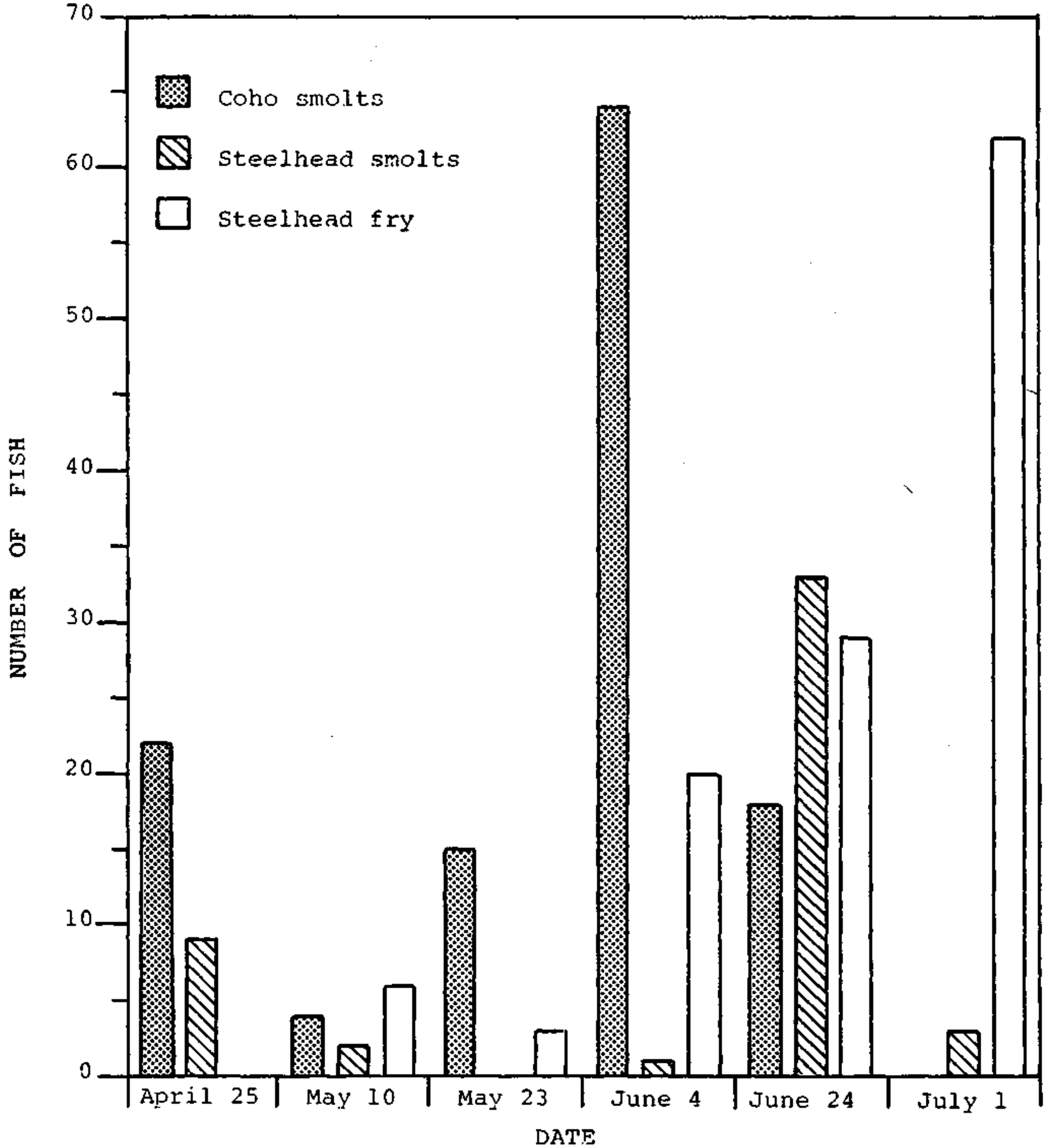

Figure 10-5. Total number of salmonids captured during each sampling period by seining at seven stations in the Lagunitas Creek Estuary in 1984. Most coho smolts were collected on June 4, steelhead smolts on June 21, and steelhead fry on July 1, 1984.

WATER TEMPERATURE

Water temperatures generally increased throughout the estuary as streamflows declined and air temperatures increased during spring (Figures 10-6, 10-7). By mid-June 1983 and late June 1984, water temperatures reached 75°F in much of the estuary—a level harmful to juvenile salmonids.

Relatively minor differences between surface and bottom temperatures were observed at stations sampled throughout the estuary. The greatest difference in surface-to-bottom water temperatures was 5 degrees Fahrenheit, measured during the late afternoon about 2 hours after high tide, while seining for fish at station 11.5 on June 24, 1983. At that time, surface temperature was 75°F while bottom temperature was 70°F.

At streamflows ranging from 146 to 25 cfs, from early to mid-May 1983, mean water temperatures were generally lower as we measured them upstream from the mouth of Lagunitas Creek. On and after June 1, 1983, at lower streamflows highest mean water temperatures were observed in the middle section of this reach, while cooler temperatures were observed at the mouth and upper areas. A similar pattern was observed in 1984. This phenomenon probably results from heating due to solar radiation and tidal exchange of water. During low tide, shallow water at the mouth of Lagunitas Creek and over the extensive mudflats beyond the mouth of the creek is warmed by the sun and transported upstream on the flood tide. Apparently these warmer and more brackish waters are what we measured at high tide in the middle section of the estuary. The cooler temperatures upstream result from freshwater inflow, and those near the mouth result from cooler seawater transported from Tomales Bay. Data collected in 1983 and 1984 indicate that day to day weather, especially cloud cover, is a major source of the variation in water temperature throughout the estuary.

SALINITY

The salinity gradient lengthened and higher salinities were measured farther upstream as streamflows declined throughout the spring. On May 7, 1983, outflow from Lagunitas Creek was 146 cfs and the entire channel from surface to bottom, downstream to within 3,000 ft of the mouth of Lagunitas Creek, was fresh water (Figure 10-8). Downstream from that point there was a very steep salinity gradient near the bottom, with fresh water flowing into Tomales Bay near the surface. Within a week, flows had declined to about one-third of their previous level (49 cfs at the USGS gage above Point Reyes Station) and the conditions at high tide in the estuary were completely changed. On May 13, surface and bottom concentrations were nearly equal, the salinity gradient had lengthened and its upper end had moved about 4,000 ft upstream. Thereafter, changes were persistent but much slower. Salinity concentrations in upstream areas continued to increase as streamflows declined throughout the spring.

Salinity concentrations measured at high tide remained below 1 ppt at station 14, located 100 ft downstream from Giacomini's Dam, throughout the spring sampling period in 1983. In contrast, 1984 salinity concentrations at

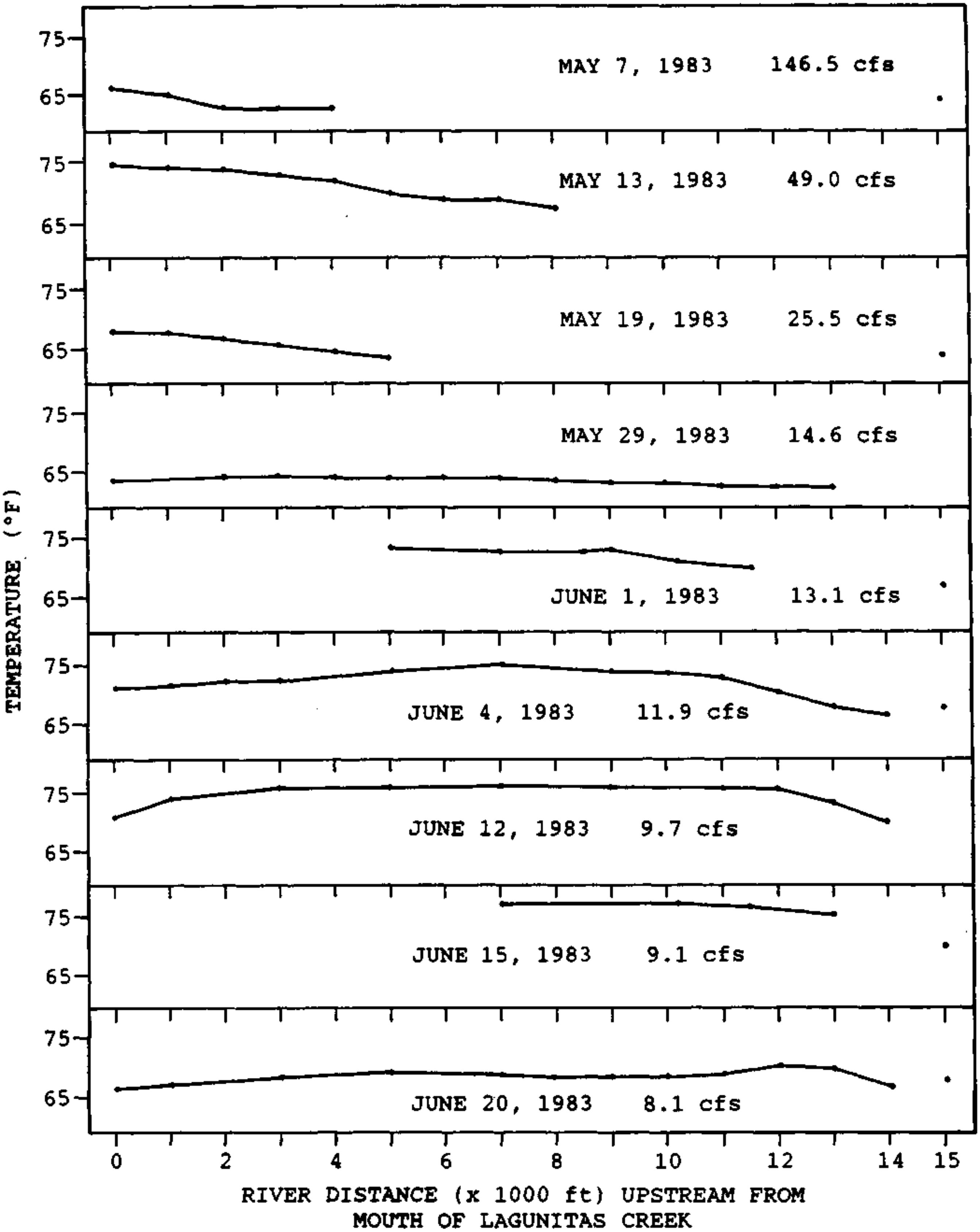

Figure 10-6. Mean water temperatures calculated from measurements taken at 1-ft intervals from the surface to the bottom on high slack tides in the estuary of Lagunitas Creek. Values at station 15 represent temperature of inflowing water from Lagunitas Creek, measured at a depth of 1 ft. Date of measurement and mean daily streamflow at the USGS gage near Point Reyes Station are indicated.

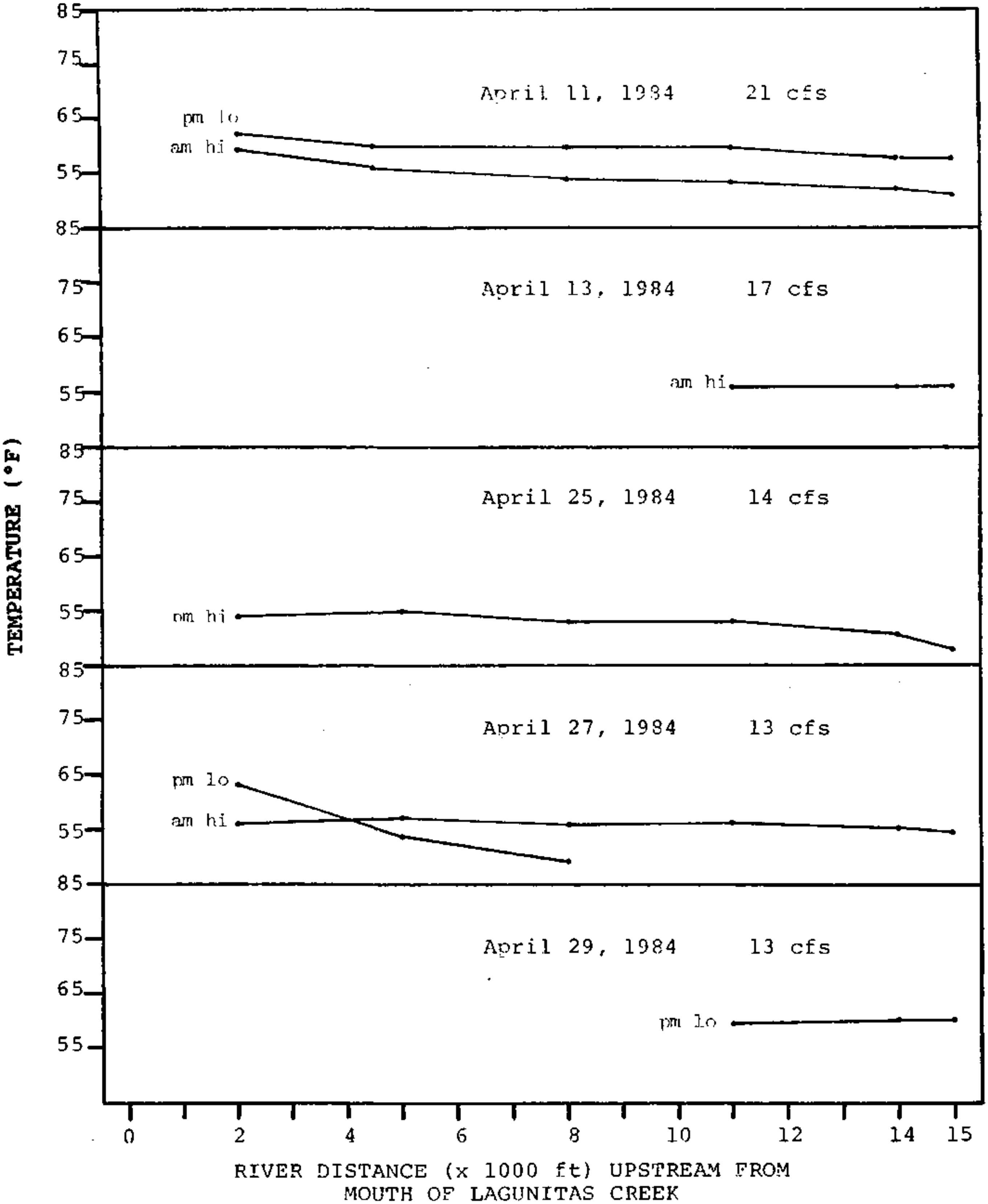

Figure 10-7. Mean water temperatures calculated from measurements taken at 1-ft intervals from the surface to the bottom in the estuary of Lagunitas Creek. Values at station 15 represent temperature of inflowing water from Lagunitas Creek, measured at a depth of 1 ft. Date of measurement, mean daily streamflow at the USGS gage near Pt. Reyes Station, time of day, and tidal stage are indicated.

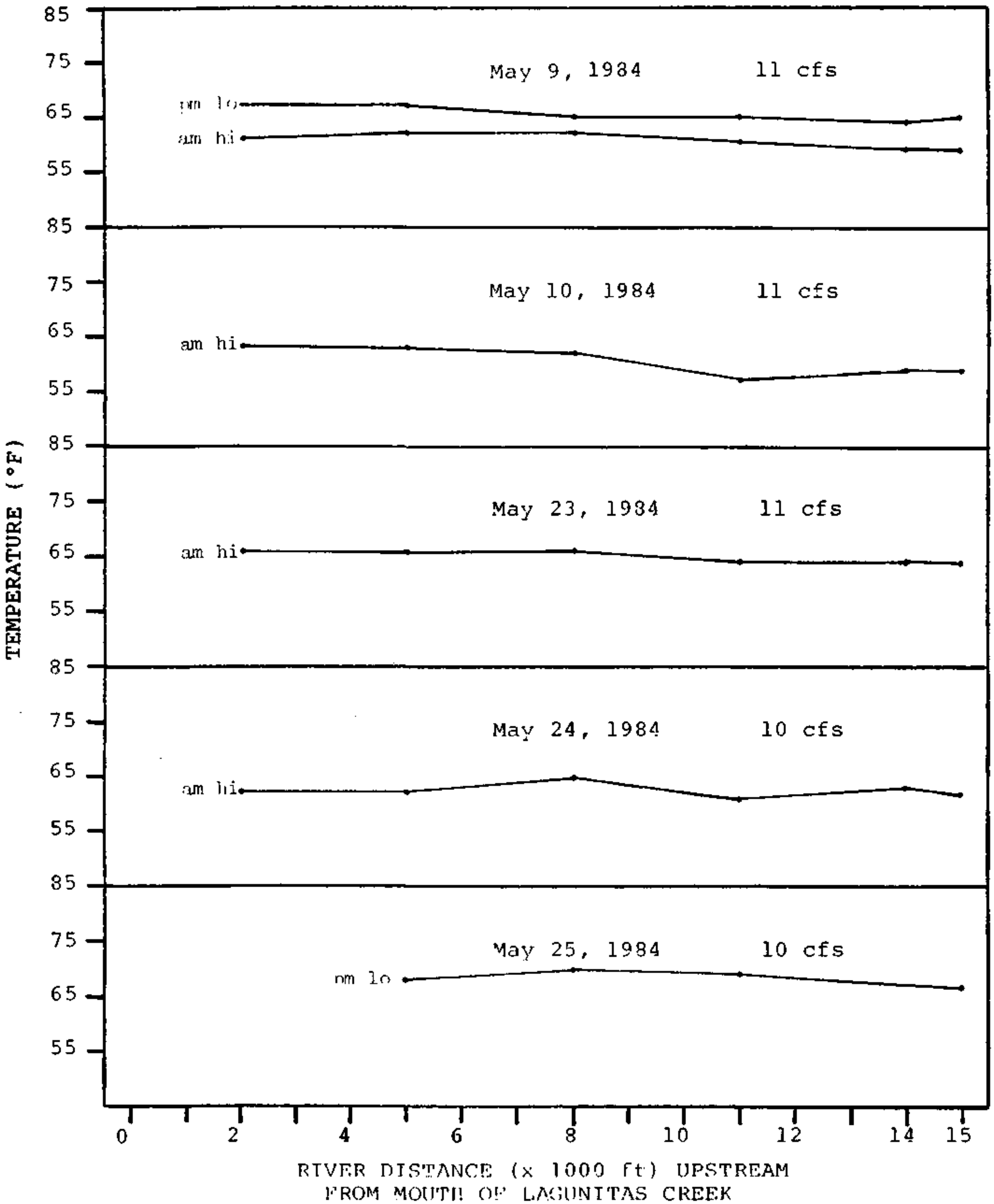

Figure 10-7 (continued). Mean water temperatures calculated from measurements taken at 1-ft intervals from the surface to the bottom in the estuary of Lagunitas Creek. Values at station 15 represent temperature of inflowing water from Lagunitas Creek, measured at a depth of 1 ft. Date of measurement, mean daily streamflow at the USGS gage near Pt. Reyes Station, time of day, and tidal stage are indicated.

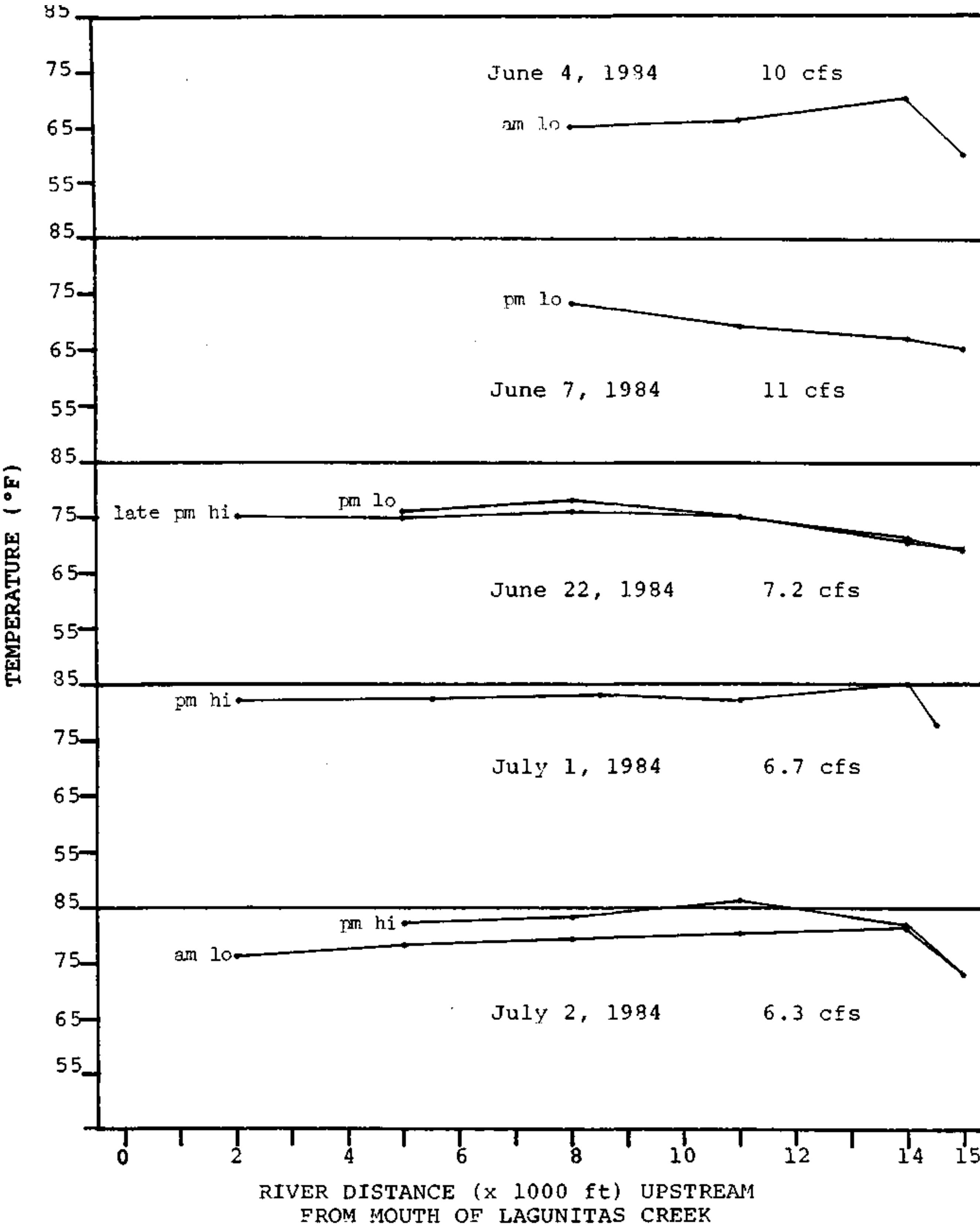

Figure 10-7 (continued). Mean water temperatures calculated from measurements taken at 1-ft intervals from the surface to the bottom in the estuary of Lagunitas Creek. Values at station 15 represent temperature of inflowing water from Lagunitas Creek, measured at a depth of 1 ft. Date of measurement, mean daily streamflow at the USGS gage near Pt. Reyes Station, time of day, and tidal stage are indicated.

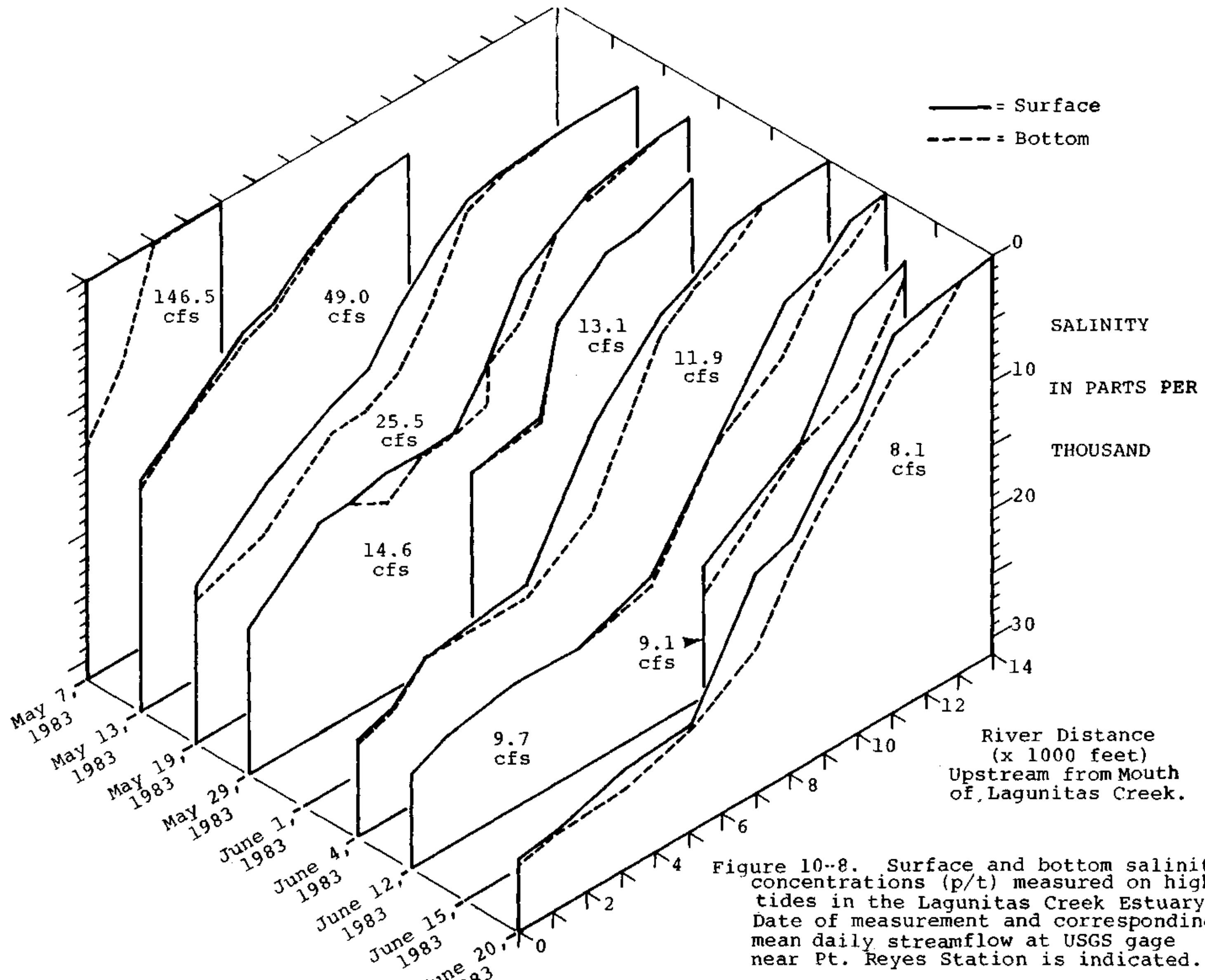

Figure 10-8. Surface and bottom salinity concentrations (p/t) measured on high tides in the Lagunitas Creek Estuary. Date of measurement and corresponding mean daily streamflow at USGS gage near Pt. Reyes Station is indicated.

high tide were 0.6 ppt on the surface and 6.4 ppt on the bottom of station 14 on June 22, and 1.0 ppt and 13.3 ppt on the surface and bottom on July 2 (Figure 10-9). The only area of fresh water was located immediately downstream from Giacomini's Dam by late June 1984. Partly saline water was measured at station 14 on those dates even at low tide. Salinities measured at low tide exhibited trends similar to those measured at high tide. High outflows introduced more fresh water into the southern end of Tomales Bay in 1983 and apparently delayed salinity intrusion in the Lagunitas Creek estuary that year.

WATER TRANSPARENCY

Water transparency was always low in the lower section of the estuary (Figure 10-10). Prevailing winds are from the northwest during the spring. Wind-induced wave action and subsequent agitation of silt and detritus results in low water transparency. Water transparency was higher in the upper section of the estuary both years.

FOOD HABITS OF SALMONIDS

The stomach contents of 19 salmon smolts and 16 steelhead juveniles and smolts, collected by seining the estuary between May 19 and June 24, 1983, were examined. Wayne C. Fields, Jr. of Hydrozoology identified and counted all recognizable food items in the cardiac portion of the stomachs. The food items were then assigned to one of three sources: terrestrial, plankton, or benthos. The volume of food from each source was determined by water displacement in a graduated cylinder. One empty salmon smolt stomach was not included in the calculations.

Planktonic organisms were the only valuable source of food, and all but a single one of the planktonic organisms were opossum shrimp (Neomysis mercedis) (Table 10-2).

The erection of Giacomini's Dam provided the fish in the impoundment above the dam with a captive pool of Neomysis upon which they fed (Figure 10-11). The stomachs of steelhead collected above the dam on June 8 contained an average of 205 Neomysis, but only negligible numbers of them or any other food organisms on June 24, 1983. The decreased utilization of Neomysis by salmonids was most likely the result of a declining population of Neomysis within the impoundment.

ABUNDANCE AND DISTRIBUTION OF NEOMYSIS MERCEDIS

Neomysis mercedis were sampled at approximately weekly intervals from May 13 through June 20, 1983 at various stations located throughout the estuary. A plankton net (5.25 ft in length, 1.64 ft diameter opening, 505 mesh) was towed at a speed of about 1.2 mph for a distance of 1,000 ft at or near high slack tide. The net was fastened to a sled frame and towed along the bottom where Neomysis were likely to be most abundant. Three tows were conducted each sampling period and approximately 11.5 cubic meters of water were sampled each tow. Collections were sorted and counted by Wayne Fields.

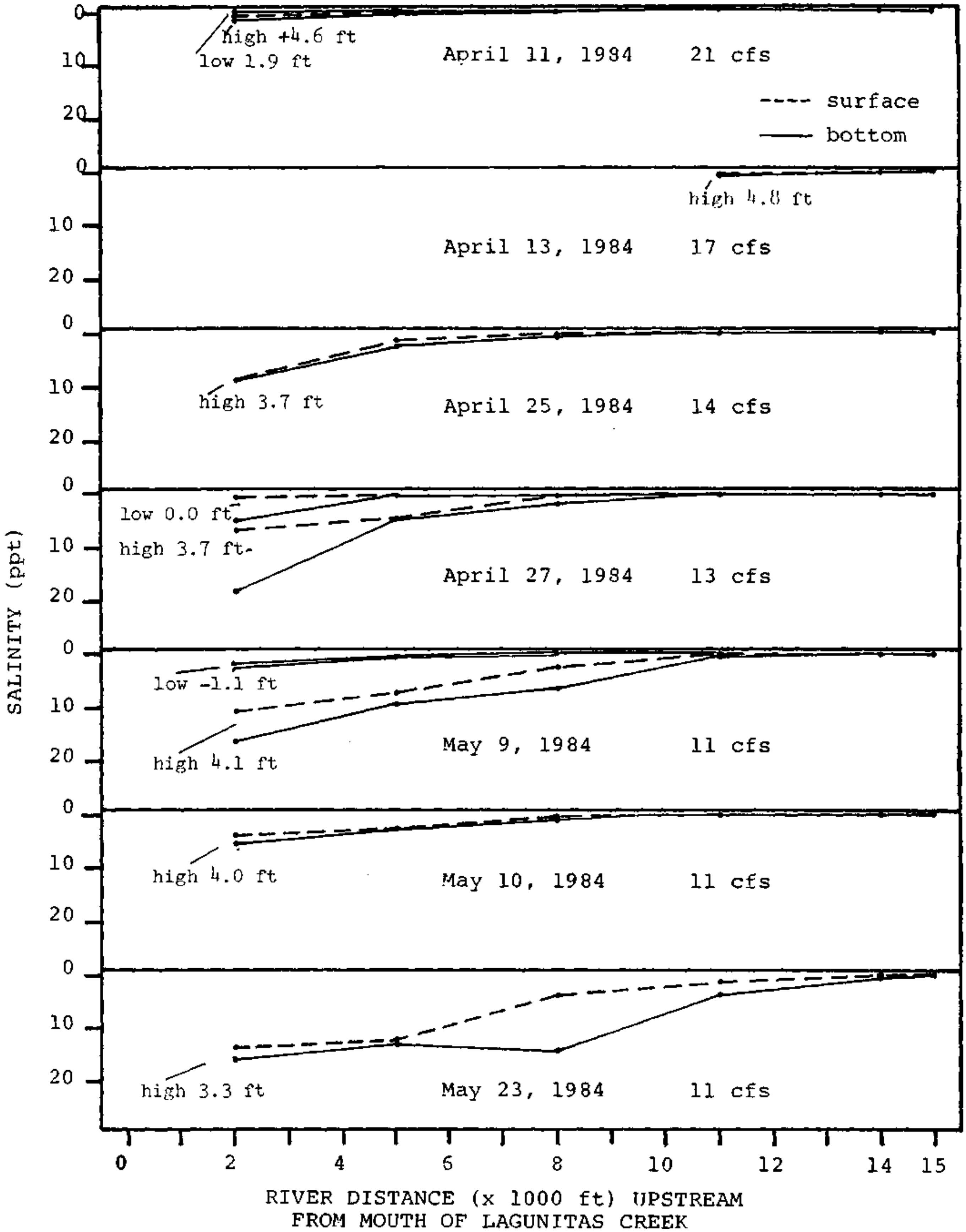

Figure 10-9. Surface and bottom salinity concentrations (p/t) measured in the Lagunitas Creek Estuary, 1984. Values at station 15 represent completely fresh water inflowing from Lagunitas Creek. Date of measurement, mean daily streamflow at the USGS gage near Pt. Reyes Station, tidal stage and height are indicated.

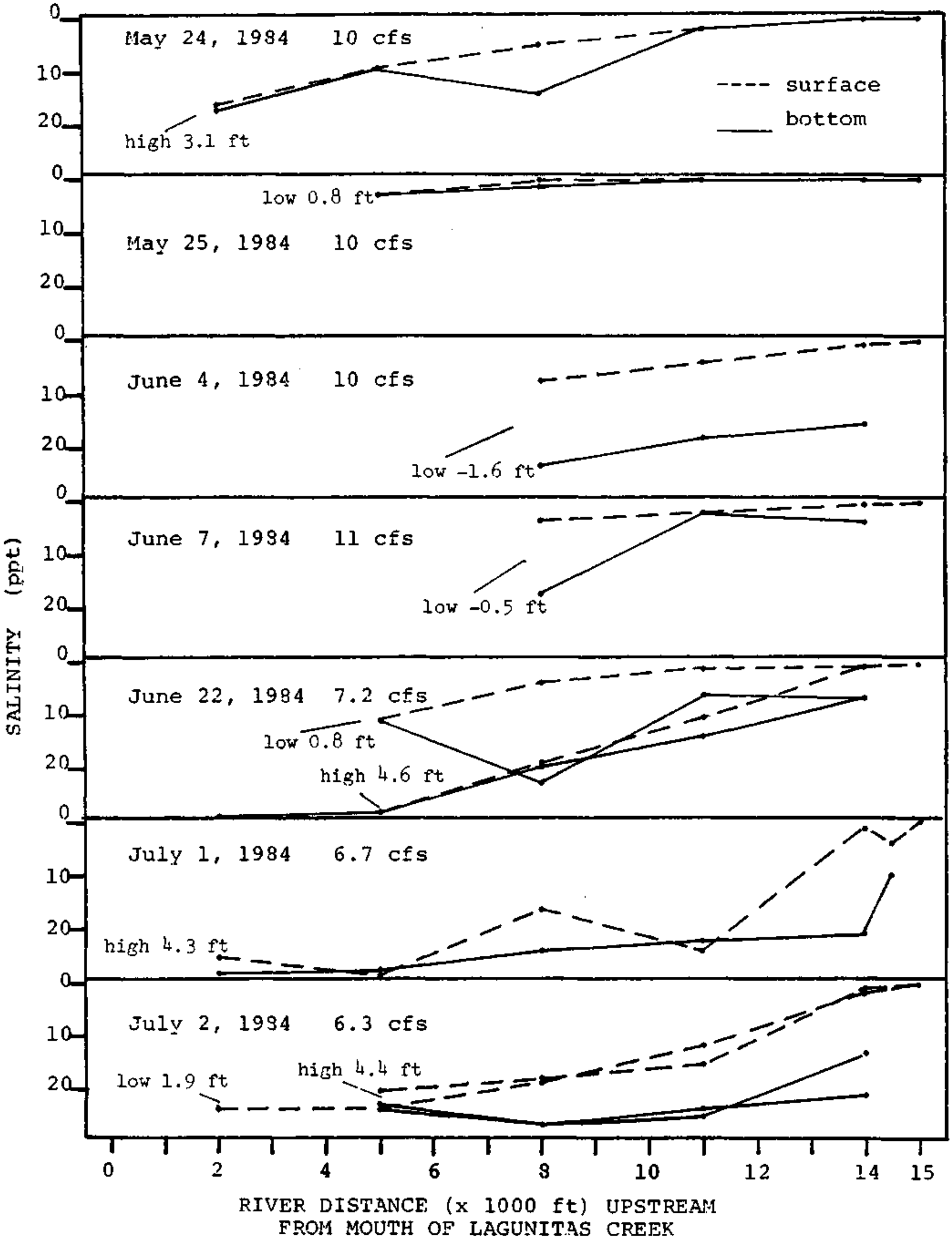

Figure 10-9 (continued). Surface and bottom salinity concentrations (p/t) measured in the Lagunitas Creek Estuary, 1984. Values at station 15 represent completely fresh water inflowing from Lagunitas Creek. Date of measurement, mean daily streamflow at the USGS gage near Pt. Reyes Station, tidal stage and height are indicated.

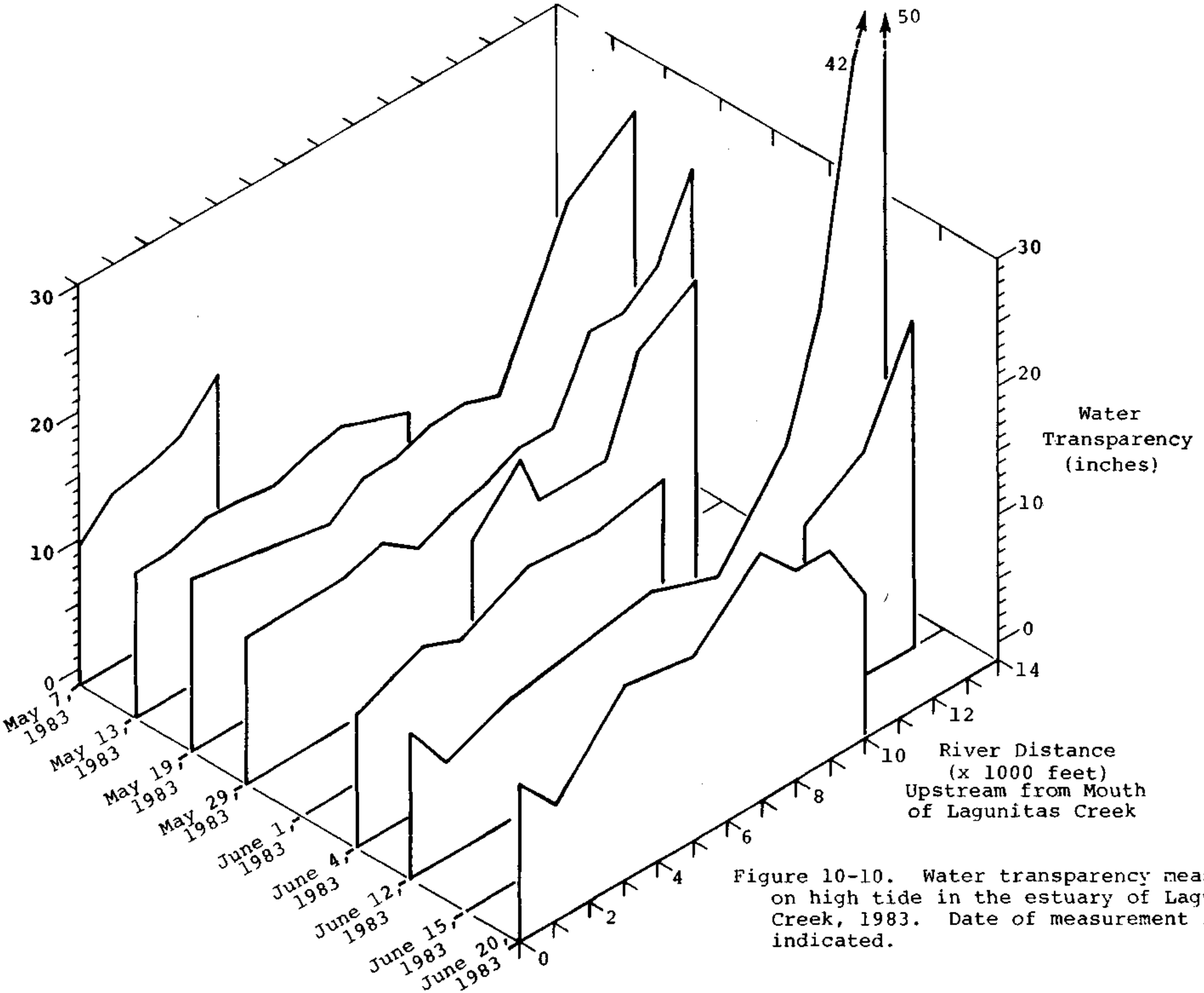

Figure 10-10. Water transparency measured on high tide in the estuary of Lagunitas Creek, 1983. Date of measurement is indicated.

Table 10-2. Analysis of stomach contents of coho salmon smolts and steelhead trout juveniles and smolts in the lowest reach of Lagunitas Creek, May 19-June 24, 1983. Planktonic opposum shrimp (Neomysis mercedis) was the predominant organism consumed by these fishes.

	n	FOOD SOURCE	MEAN NUMBER EATEN/FISH	% BY NUMBER	MEAN VOLUME EATEN (ml)	% BY VOLUME	% FREQUENCY OF OCCURRENCE
Coho salmon	18	planktonic	40.6	95.7	0.27	100.0	100.0
		terrestrial	0.7	1.7	—	0.0	44.4
		benthos	1.1	2.6	—	0 .0	33.3
Steelhead trout	16	planktonic	109.3	97.6	0.52	99.4	93.8
		terrestrial	0.3	0.2	—	0.0	18.8
		benthos	2.5	2.2	—	0.6	50.0

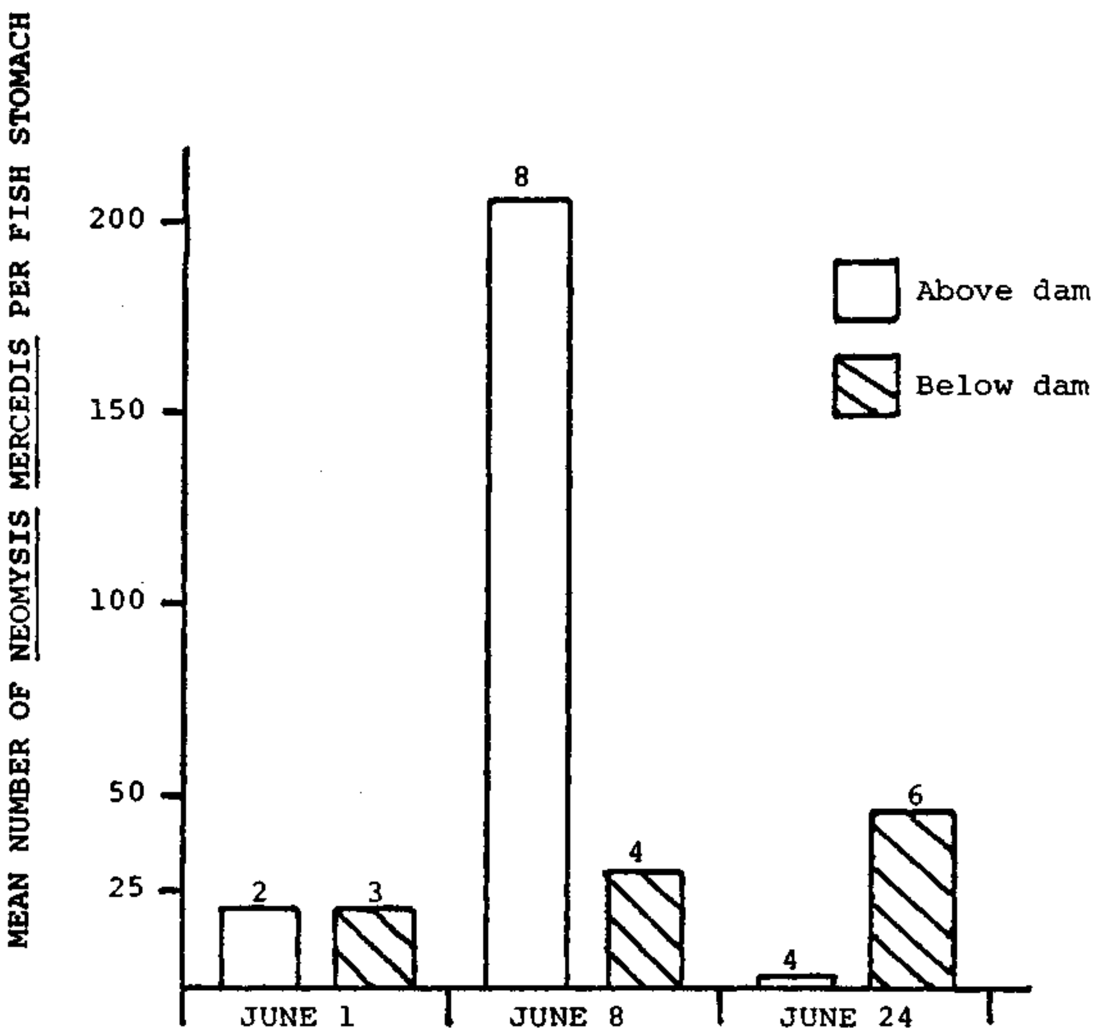

Figure 10-11. Comparison of mean number of Neomysis mercedis found in stomachs of salmonids above and below a small earthen dam in Lagunitas Estuary, 1983. Number of fish stomachs examined is indicated. Many Neomysis were consumed by fish above the dam on June 8, and few thereafter. The average number of Neomysis consumed by fish below the dam steadily increased through June 24.

Neomysis population densities were highest in the freshest end of the salinity gradient (Figure 10-12). Very few Neomysis were collected where salinity concentrations exceeded 13 ppt. Average population densities of Neomysis declined throughout May and June in 1983 (Figure 10-13).

Information gained from the first year of our study led us to revise our sampling methods during the spring of 1984. We sampled Neomysis populations from mid-April through July 2, 1984 at six stations located throughout lower Lagunitas Creek. Sampled stations were located at 2,000, 5,000, 8,000, 11,000, and 14,000 feet upstream from the mouth of Lagunitas Creek. One additional station located in the impoundment of Giacomini's Dam also was sampled.

Three standard plankton tows were conducted during daylight hours, at both low and high tides, at each sampling station during each sampling period. A standard tow consisted of drawing the sled frame with plankton net attached from wetted streambank to wetted streambank. Because cross-sectional distances varied and the water wasn't always deep enough at many stations in the estuary at low tide to fully cover the net, collections of Neomysis were expressed as number per tow. Water temperature, salinity, depth, velocity, and transparency were measured at the location and time of Neomysis sampling.

High population densities of Neomysis were collected in April, and the abundance of Neomysis declined throughout the spring (Figure 10-14). The population of Neomysis moved upstream as flows declined. By late June nearly all Neomysis were captured immediately below Giacomini's Dam. Few Neomysis apparently remained in the estuary by July 2, 1984.

Factors Affecting the Distribution of Neomysis Mercedis

Population densities of Neomysis were not significantly associated with either water transparency or velocity. However, they were negatively associated with salinity ($r = -0.63$) and water temperature ($r = -0.39$). Salinity appeared to be the most important factor affecting the distribution of Neomysis in the Lagunitas Creek estuary. Highest abundance of Neomysis was found at salinities less than about 5 ppt, and few specimens were collected at salinities exceeding 17 ppt. The abundance of Neomysis was variable at water temperatures up to 75°F, but few specimens were collected at higher temperatures.

CONCLUSIONS - ESTUARINE ENVIRONMENT

The narrow Lagunitas Creek estuary is habitat for a wide variety of fishes including salmon and steelhead smolts which emigrate through it from at least early April through June. It is primarily a 2.5-mile-long channel, approximately 2 meters deep at high tide and less than 0.5 meters deep at low tide. As flows decline in the spring, a salinity gradient develops along its length eventually extending from Tomales Bay upstream to the Giacomini Dam. The level of salinity in that gradient varies with the salinity of the bay, the volume of freshwater inflow from Lagunitas Creek, and the stage of the tide.

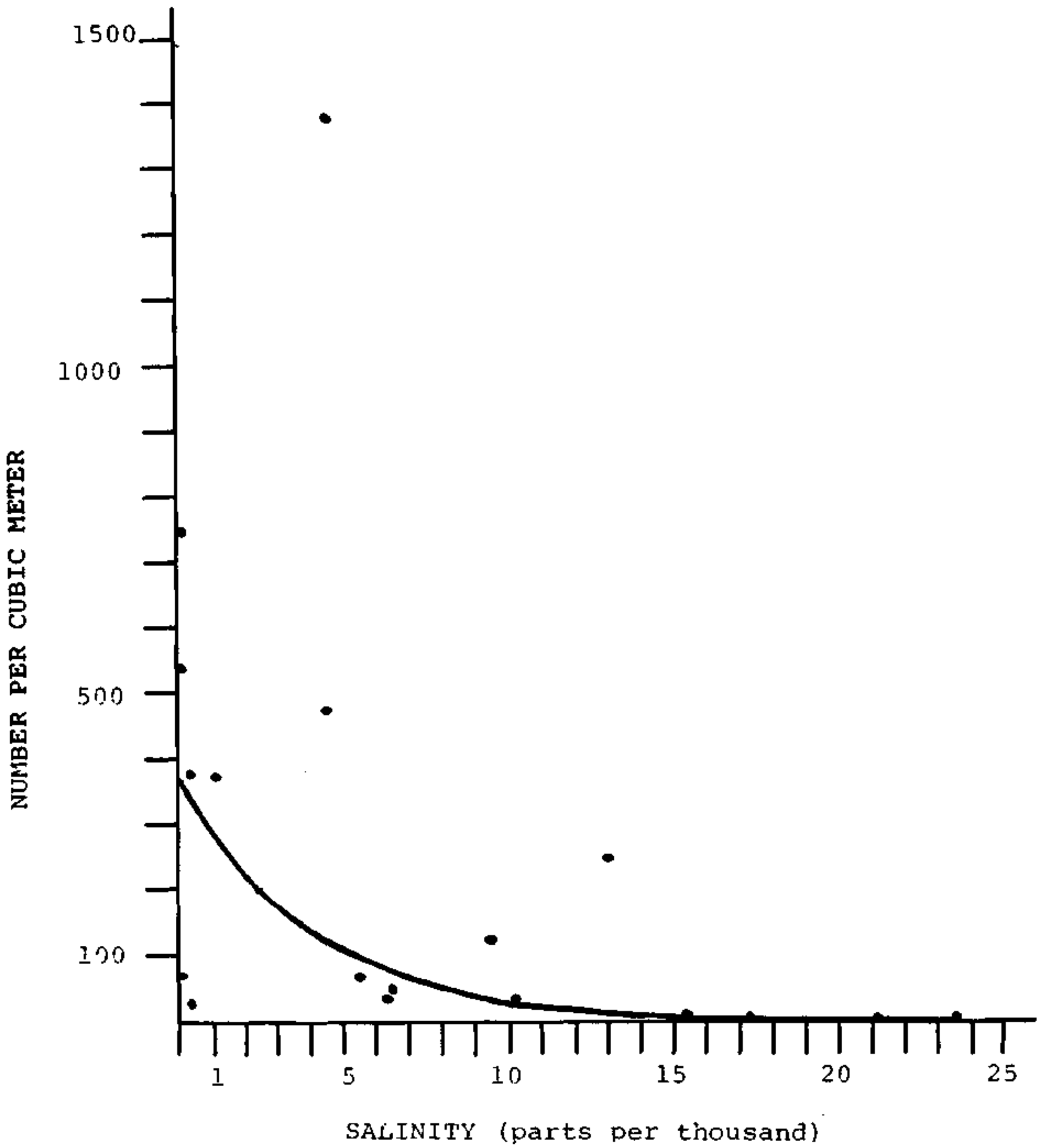

Figure 10-12. Number of Neomysis mercedis in relation to salinity measured weekly on high slack tides from May 13 through June 20, 1983, in the Lagunitas Creek Estuary. Population densities of Neomysis were highest in the upper end of the salinity gradient.

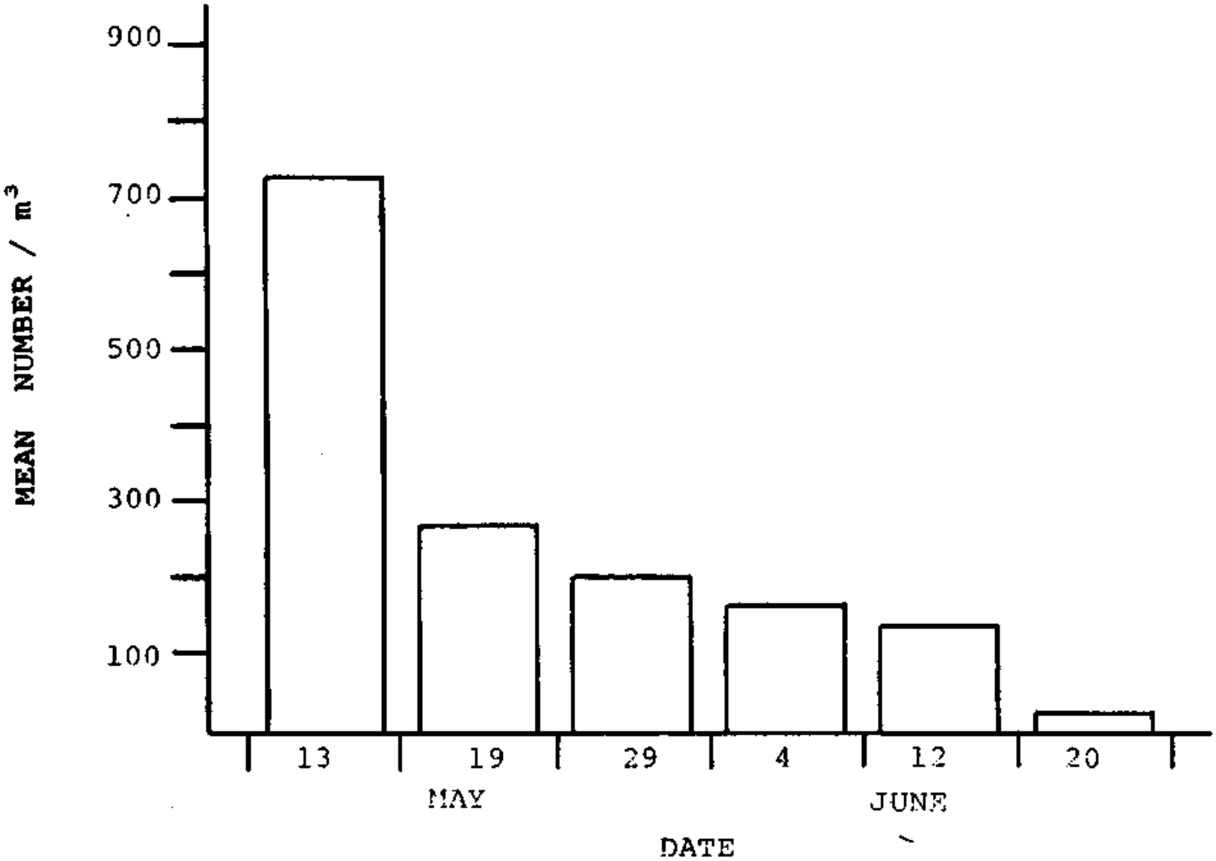

Figure 10-13. Mean number of Neomysis mercedis per cubic meter filtered water collected from May 13-June 20, 1983, in the Lagunitas Creek Estuary from station 14 downstream. Three standard 1000-ft tows were conducted during each sampling period. Mean densities of Neomysis declined throughout May and June.

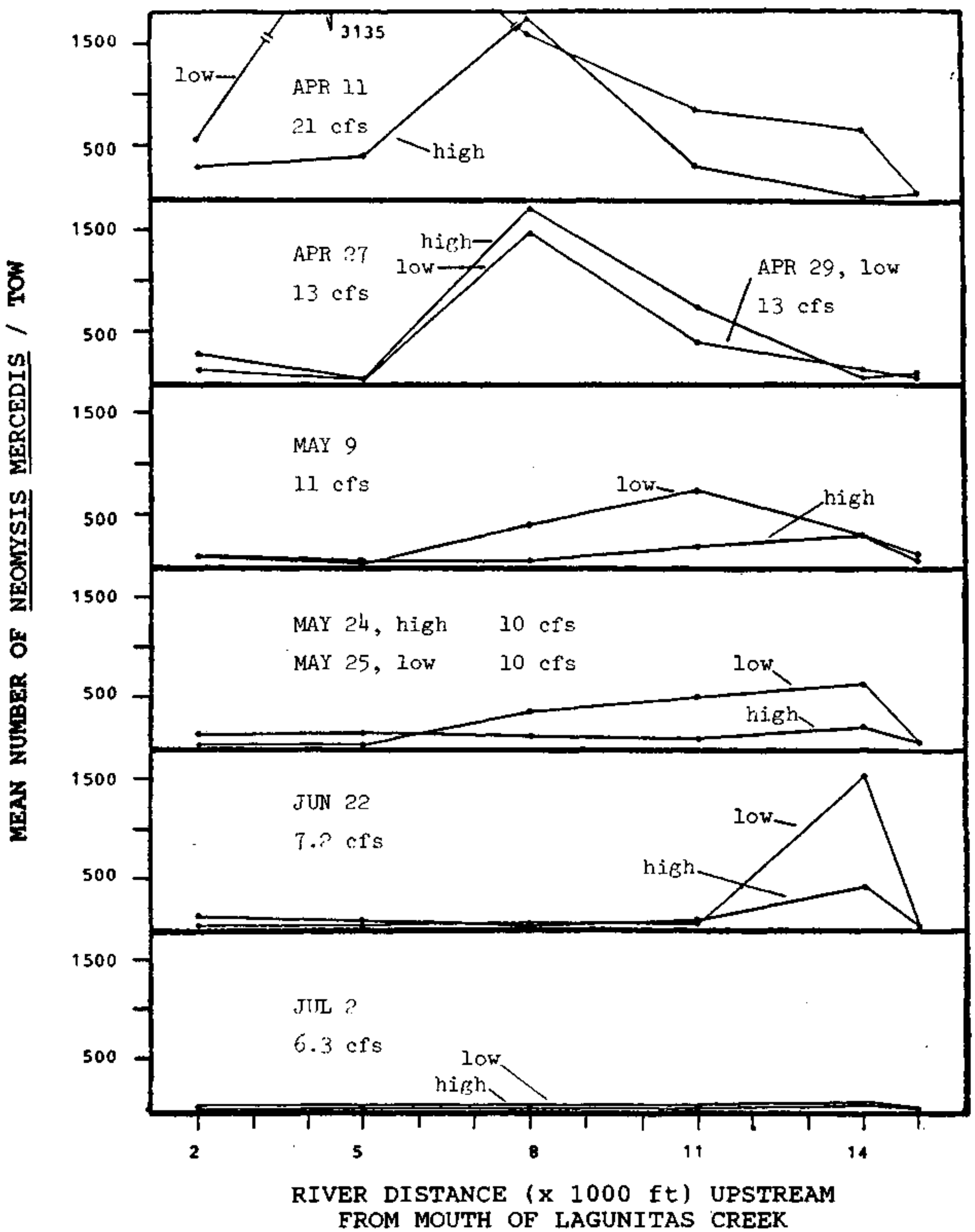

Figure 10-14. Mean number of Neomysis mercedis captured in three tows conducted at indicated stations in the Lagunitas Creek Estuary from April 11 through July 2, 1984. Date of collection, tidal stages, and mean daily flow at the USGS gage near Pt. Reyes Station are indicated.

This salinity gradient influences the distribution of the opossum shrimp, Neomysis mercedis, which is the most important food for the juvenile salmon and steelhead. Neomysis are abundant only where salinities are less than 13 ppt, and the population moves upstream throughout the spring as flows decrease and water temperatures increase.

Temperatures throughout most of this estuary are often undesirably warm for juvenile salmon and steelhead during the emigration period and are sometimes above lethal levels. These warm temperatures occur when large amounts of water warmed by the sun on the shallow tide flats in the south end of Tomales Bay move into the estuary on flood tides.

We have no direct evidence that these warm temperatures form a thermal block or are detrimental, but the warm water may be a serious risk for emigrating salmon and steelhead smolts during periods of clear weather after late May or early June. A large proportion of the smolts emigrate through the estuary at this time.

In spite of extensive sampling, we never found juvenile salmon or steelhead in the lower mile of the estuary. They were consistently most abundant in the cooler water at its upper end.

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