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HABITAT QUALITY AND ANADROMOUS FISH PRODUCTION ON THE WARM SPRINGS RESERVATION

FINAL REPORT

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TABLE OF CONTENTS

INTRODUCTION

The number of anadromous fish returning to the Columbia River and its tributaries has declined sharply in recent years. Changes in their freshwater, estuarine, and ocean environments and harvest have all contributed to declining runs of anadromous fish. Restoration of aquatic resources is of paramount importance to the Confederated Tribes of the Warm Springs (CTWS) Reservation of Oregon.

Watersheds on the Warm Springs Reservation provide spawning and rearing habitat for several indigenous species of resident and anadromous fish. These streams are the only ones in the Deschutes River basin that still sustain runs of wild spring chinook salmon *Oncorhynchus tshawytscha*. Historically, reservation streams supplied over 169 km of anadromous fish habitat. Because of changes in flows, there are now only 128 km of habitat that can be used on the reservation.

In 1981, the CTWS began a long-range, 3-phase study of existing and potential fish resources on the reservation. The project, consistent with the Northwest Power Planning Council's Fish and Wildlife Program, was designed to increase the natural production of anadromous salmonids on the reservation, especially spring chinook salmon and summer steelhead 0. *mykiss*, by fully developing existing and potential habitat. Bonneville Power Administration (BPA) and the CTWS jointly funded the effort. Below we describe the three phases.

Phase I: September 30, 1981 - January 31, 1982.

Goals:

- Compile and analyze physical and biological data on streams and indigenous anadromous fish resources within the Warm Springs Reservation.
- Recommend ways to develop data not in the existing data base.

This phase was done by CH2M HILL.

Phase II: June 1, 1983 - December 31, 1989.

Goals: (based on results and recommendations from Phase I)

- Estimate the anadromous salmonid production possible under current habitat conditions.
- Design enhancement projects and estimate their potential to increase production.

Phase III: July 6, 1984 - December 31, 1991.

Goal:

- Implement, monitor, and evaluate the enhancement measures identified in Phase II.

During the ten years of study, 26 km of reservation stream habitat were treated. In this report we discuss the activities and results of Phase III.

STUDY AREA

The Warm Springs Reservation lies within the Deschutes River basin of north central Oregon (Figure 1). The reservation is bounded on the west by the crest of the Cascade Mountains and on the south and east by the Metolius and Deschutes rivers, respectively. The basin consists of basalt that flowed over the region during the Pliocene and Pleistocene eras. During the late Pleistocene and early Holocene eras, basalt flows and landslides occurred within canyons, which have since eroded (Baldwin 1981).

Altitude varies from 3,202 m at the top of Mt. Jefferson to about 300 m where the Deschutes River flows along the Mutton Mountains to the northeastern comer of the reservation. From the western boundary of the reservation, the Cascade Range slopes eastward for 16 to 19 km, where it abuts upland plateaus with elevations between 730 and 1,100 m. Plateaus in the southeast are deeply dissected by the streams that drain eastward into the Deschutes River.

On the reservation, anadromous fish runs are now limited to the Warm Springs River, its principal tributaries, and Shitike Creek, which enter the Deschutes River downstream from Pelton Reregulating Dam (Rkm 160). They are but a few of the remaining free-flowing anadromous fish streams left in the Deschutes basin. Below we describe these streams in more detail.

The Warm Springs River is the largest tributary in the lower 160 km of the Deschutes River (Figure 2). It originates **on** the eastern slope of the Cascade Mountains. It flows southeasterly for about 92 km to its confluence with the Deschutes River.

- Source: Groundwater sources outside the reservation
- Drainage: *1,362* km^2
- Mean annual flow: 12.0 m^3/s (cubic meters per second)
- Minimum recorded flow: 4.2 m^3/s
- Maximum recorded flow: *261.5* m^3/s
- Potential anadromous fish habitat: 65.6 km on the mainstem

Wild spring chinook salmon and summer steelhead spawn and rear in the mainstem and major tributaries of the Warm Springs River. Coho salmon 0. *kisutch* were heavily planted in the Warm Springs River system for several years in the 1960s, but only a remnant run remains. In 1977 the Warm Springs National Fish Hatchery (WSNFH) was completed. It created a hatchery stock derived from the wild run of spring chinook that return to the Warm Springs River. All hatchery fish are marked externally with coded wire tags and fin clips so that hatchery and wild out-migrants can be distinguished at the floating scoop trap at Rkm 0.6 on the Warm Springs River, and returning adults can be separated from the wild stock at the WSNFH weir/trap. Adult hatchery fish are removed from the river at WSNFH; wild chinook are allowed to migrate upstream. This practice allows the CTWS to manage the Warm Springs River for both hatchery and wild stocks.

Mill Creek is the largest tributary to the Warm Springs River (Figure 3). It originates in a chain of lakes on the eastern slopes of the Cascade Mountains. It flows in an easterly direction for about 34 km, joining the Warm Springs River at Rkm 34.1,

- Source: Snowmelt and springs
- Drainage: 150 km^2
- Mean annual t-low: 1.8 m^3/s
- Minimum recorded flow: 1.1 m^3/s
- Maximum recorded flow: 4.5 m^3/s
- Potential anadromous fish habitat: 28.0 km

Beaver Creek is the second largest tributary to the Warm Springs River (Figure 4). It originates in the northwestern part of the reservation. It flows southeasterly for about 40 km, joining the Warm Springs River at Rkm 30.6.

- Source: Snowmelt and springs
- Drainage: 298 km^2
- Mean annual flow: 2.4 m^3/s
- Minimum recorded flow: 0.7 m^3/s
- Maximum recorded flow: 23.8 m^3/s
- Potential anadromous fish habitat: 34.7 km

Shitike Creek is the second largest drainage on the reservation (Figure 5). From Harvey Lake it flows easterly for 48.6 km to its confluence. with the Deschutes River.

- Source: Snowmelt and springs
- Drainage: 196.4 km^2
- **Mean** annual flow: 2.6 m^3/s
- Minimum recorded flow: 0.5 m^3/s
- Maximum recorded flow: 56.0 m^3/s
- Potential anadromous fish habitat: 41.1 km

Runs of both spring chinook salmon and summer steelhead are indigenous to Shitike Creek. Before 1983 inadequate passage facilities at a defunct community water intake dam (Rkm 11.5) impeded the upstream migration of both summer steelhead and spring chinook. The Tribes removed the dam in August 1983, opening an additional 29.6 km of stream to anadromous fish.

HABITAT MODIFICATIONS

Strawberrv Falls Proiect

- Location: Mill Creek, Rkm 14.6
- Date: July - August, 1984
- Activity: Bypass channel

Problem: Upstream passage of both summer steelhead and spring chinook was partially blocked by Strawberry Falls, a cataract formed by bedrock at about Rkm 14.6 on Mill

Creek.

Goal: Provide passage for adult anadromous salmonids.

Activities: Fill within an old channel that by-passed the falls was removed and used to berm the existing channel leading to the falls. Dynamite was used to open the bedrock at the upper end of the by-pass. (This was one of several alternatives developed by Dr. John F. Osborne of Washington State University.)

Beaver Creek (Dahl Pine) Enhancement Project

- Location: Beaver Creek
  - Reach A: Rkm 22.7 - 23.4
  - Reach B: Rkm 30.0 - 31.7
  - Reach C: Rkm 32.6 - 32.8
  - Reach D: Rkm 33.5 - 33.8
- Date: July 30 - August 19, 1986
- Activities:
  - 7 log weirs
  - 6 double log wings (12 logs)
  - 9 single log wings
  - 55 boulder jetties
  - 47 boulder clusters
  - 61 boulder singles
  - 457 m^3 rip-rap

Problem: In 1949 U.S. Highway 26 was constructed through the reservation (Figure 6). As a result about 5 km of Beaver Creek were channelized between Rkm 21.9 and 35.2. The highway changed the upper section of Beaver Creek from a meandering stream with high physical diversity to a stream that alternates between natural meandering and shallow, straight channels with little or no habitat diversity. Habitat diversity provides juvenile salmonids with instream cover, which they use for feeding, hiding, and resting. Habitat diversity is also important for adults before and during spawning. Pools and cover provide adult fish with the habitat they need to escape predators and disturbances before and during redd construction and spawning.

Goals:

- Provide adequate depths for passage and holding of adult anadromous salmonids.
- Provide rearing areas for juvenile salmonids.

Activities: (see Table 1)

Log weirs were placed in Beaver Creek to provide instream cover. Weirs increase pool-to-riffle ratios by controlling water depth. They trap gravel upstream from the structure, which then creates a pool downstream from the structure. The weirs were constructed from 18-m long Douglas fir or tamarack trees with base diameters of 0.9 m or larger. Stream banks and channels were excavated to allow the logs to be keyed into the bank from 3.0 - 4.5 m at each end (Figure 7). Before bank materials were backfilled, trenches were dug across the channel to assure proper height and level of the weirs relative to the existing water level.

Once the log was in place, hogwire (25.4 x 50.8 mm mesh) was stapled to it. Then geotextile filter cloth was placed on top and attached to the log with wood lath. Fill, 0.46 m deep, was then piled on the filter cloth and hogwire. The cloth sealed the structure and the hogwire provided strength to hold the fill in place.

Table 1. Structure types and materials used in Beaver Creek enhancement project.

		Log structures (no.)			Boulder structures (no.)			
			Wings					
Reach	Length (m)	Weir	Double	Single	Jetties'	Clusters[a]	Singles	Rip-rap (m^3)
A	700	7	6	9	11	16	35	457
B	1700	--	--	--	25	18	8	--
C	163	--	--	--	5	5	3	--
D	317	--	--	--	14	8	15	--
Total	2,880	7	6	9	55	47	61	457

‘Contained more than one boulder.

A notch, of adequate width and depth to pass low flow while maintaining a wetted log, was then cut in the center of the log, creating a 30 - 45° angle to ease juvenile and adult fish passage during low water. Boulders were placed on the stream banks to armor the disturbed soils and to assist in keying the logs.

Wing logs were placed to narrow the stream channel and provide greater water depth and instream cover. Red cedar logs from 7.6 - 9.1 m long were used. Their base diameters were 0.56 m or greater. They were similar to those used for log weirs, except that the logs were keyed into the banks at 45° angles and no cloth was used (Figure 8).

Boulders were placed for jetties, in clusters, and as singles. Their purpose was to create cover, velocity breaks, pocket pools and to allow for structure recruitment. In general, a pool was excavated the width of the boulder and about 1.5 - 3.0 m long. The boulder was placed in the upstream end of the pool and partially backfilled with the excavated material (Figure 9). From 0.1 - 0.2 m of the boulder protruded above the water surface during low flows to ensure proper function and to minimize potential damming.

Mill Creek (Potter's Pond) Enhancement Project

- Location: Mill Creek, Rkm 9.7 - 12.1 (Figure 3).
- Date: 1987
- Activities:
  155 instream structures using 700 boulders, each > 1 m^3
  Dike wall sloping and terracing
  Reseeding

Problem: In the late 1940s, earthen dams were built on Mill Creek near Rkm 10.2 to create log storage ponds. In December 1980 the dams broke during floods and scoured the stream channel. Although there were efforts to stabilize the banks with plantings and gabions, they were unsuccessful. The lack of quality riparian vegetation and stable banks led to increased water temperatures and turbidity in Mill Creek. With few or no pools and an unstable channel, this section of Mill Creek provided fish with little instream cover.

Goals:

- Increase salmonid habitat diversity.
- Increase stream depth.
- Create pools.
- Reduce erosion, turbidity, and sedimentation.

Activities: (see Table 2):

Table 2. Structure type and materials used in the Potter's Pond enhancement project.

Structure type	Number of structures	Number of boulders
Rock weir dams	6	160
Double wing	16	90
Single wing	40	230
Armor	60	134
Single	22	22
Turning rock clusters	4	40
Clusters	7	25

Tnstream structures of several types were placed at various heights to accommodate low, medium, and high water levels. All instream structures consisted **of** boulders larger than **one** cubic meter. About 700 boulders were stockpiled near the project site. A skidder transported them to key areas near the stream bank. To minimize impact on existing riparian vegetation, haul roads were designated away from the stream. Environmentally sensitive areas, such as spawning gravels and wetlands, were flagged and patrolled to keep construction equipment away from delicate areas. Such equipment was limited to specific stream crossings.

- Rock weir dams were designed to create salmonid resting pools and to increase stream depth (Figure 10). At the project's downstream boundary, a weir dam was placed with the help of the Bureau of Indian Affairs (BIA) Roads Department and Fire Control. The deep pool that formed behind the dam provided salmonid habitat as well as a water source for fire control.
- Double-wing and single-wine structures were constructed to narrow the stream channel and to provide greater water depth and instream cover (Figure 11).
- Rock clusters were layered along stream channels to provide salmonid cover by forming pocket pools and by trapping woody debris to create instream structure (Figure 12).
- Turning rock clusters were designed to stabilize the stream channel and increase salmonid habitat diversity and stability by: 1) dividing the water flow into smaller streams, 2) causing more flow to turn away from the outside bank, and 3) dissipating energy to reduce bank scour (Figure 13).

Stream bank work was also part of this project.

- Sloped and terraced dike walls of old dams along stream banks to reduce erosion, turbidity, and sedimentation (Figure 14).
- Armoring, using a backhoe to push boulders into soft banks, was done to support eroding stream banks (Figure 11). Excess substrate material from channel work was used to secure the boulders.
- Planting and seeding: After instream and stream bank work was done, a wheat grass, orchard grass, and domestic grass mix was broadcast on disturbed banks at 20 pounds/acre. Straw mulch and a 16-20-o fertilizer mix also **was** added at 200 pounds/acre. These areas were then watered.

Lower Beaver Creek Juniper Rip-Rapping Project

- Location: Beaver Creek, Rkm 0.9 - 2.6
- Date: July - October, 1988
- Activities:
  Stream bank stabilization using 160 junipers and 180 boulders

Problem: Removal of riparian vegetation and some minor agricultural use of lower Beaver Creek contributed to the loss of fish habitat. Livestock use also reduced the stability of the riparian zone.

Goals:

- Stabilize 707 m of badly eroded stream bank.
- Establish vegetative cover.
- Enhance salmonid capacity for adult passage, egg incubation, and juvenile rearing.

Activities:

Junipers, secured by boulders, were placed along banks in two separate bottom lands in a remote and rugged area of Beaver Creek (Figure 15). Warm Springs BIA Fire Management provided a small CAT backhoe and a Jet Ranger III helicopter, which allowed cost-effective transport of personnel and materials to the remote site with minimal disturbance to fragile riparian and upland areas.

About 160 junipers, each 6 - 10 m long, were cut from the uplands near the project site. Half of the branches from each tree were removed. Using a longline and choker sling, the helicopter transported each tree from the cutting area to the stream bank. Junipers were placed in high stream bank and low stream bank areas (Figure 16). In both cases, trees were overlapped to form a structural chain to trap sediment, thus allowing native vegetation to take root.

About 180 boulders, each 0.5 m^3, secured the junipers in place. They were obtained near the site and transported by helicopter using a longline and choker slings. After they were placed next to the trees, or in holes previously excavated for them, the boulders were drilled using a Hilti GP 22 gas-powered hammer drill, after which 1/4-inch cable was secured into the boulders using the Hilti Epoxy Anchoring System. The other end of the cable was fastened around the end of the tree with cable clamps. This anchored the trees against high water.

The holes in which the boulders were placed were backfilled by hand. Annual/perennial grass seed mix and straw mulch were applied at 20 pounds/acre to all ground disturbed by project construction.

Lower **Shitike Creek Habitat Improvement Project**

- Location: Shitike Creek, Rkm 1.4 - 4.6 (Figure 5)
- Date: Phase I--July 10 - August 10, 1988
  Phase II--July 15 - August 7, 1989
- Activities:
  - 7 rock berms
  - 9 log weirs
  - 26 log deadmen
  - 164 junipers for rip-rap
  - 764 rock clusters and turning rock structures
  - 230 m^3 of pit run material
  - 122 m^3 of top soil
  - Excavation of 3,850 m^3 of gravel bars and stream banks

Excavation of 1,133 m^3 of point bar cobble
Reseeding

- Heavy Equipment:
  - One Komatsu track-mounted excavator
  - One rubber-tired front-end-loader
  - One log truck with self-loader
  - Several ten-yard dump trucks

Problem: The lower reach of Shitike Creek (Rkm 0.0 - 11.5) is close to the city of Warm Springs. Community projects and impacts, including a flood in 1964, severely altered this reach. The stream channel downstream from Rkm 11.5 had shallow/wide wetted perimeters, extreme water temperatures, unstable banks, few holding and resting pools for adult salmonids, an altered channel (i.e., channelization), and lacked riparian vegetation that provided shade. Stream channel morphology, water column shape and quality, and stream banks all needed improvement.

Goals:

- Improve 3.2 km of riparian and instream anadromous salmonid habitat.
- Improve adult passage to upstream areas.
- Increase the spawning and rearing potential of the stream.

Activities:

Instream structures made of juniper logs or boulders were placed in several areas. To limit riparian damage from heavy equipment, travel was restricted to existing roads and designated trails, and equipment was constantly monitored for fluid leaks. Material delivery and construction was done in three stages:

1) Trucks brought junipers and boulders to general stockpile areas near the stream.
2) A front-end-loader moved materials from the general stockpiles to instream stockpile sites (Figure 17). These sites were within the working reach of the excavator (Figure 18) to limit instream travel and to increase construction effectiveness and efficiency.
3) The excavator placed the boulders, logs, and junipers according to detailed plans.
   - Seven rock berms were used to provide instream cover by controlling water depth and stabilizing the streambed. Berm design was modified from that used in the 1987 Potter's Pond Project by placing the boulders in a semicircle with the berm center facing the thalweg (Figure 19).
   - Nine log weirs were fashioned as described for the Beaver Creek (Dahl Pine) Enhancement Project. Their purpose was to control water depth and trap gravel upstream from the weir, thus increasing pooi-to-riffle ratios and providing ins tream cover.
   - Log deadmen (or log anchors) were buried for most of their length (keyed) in the stream bank to improve stability (Figure 20), and then juniper trees were cabled to them.
   - Juniper trees were fabricated (stripped of half their branches) and placed by

the excavator using techniques similar to those used in the Juniper Rip-Rapping Project on lower Beaver Creek (Figure 16). The purpose was to protect stream banks by trapping sediment, thus allowing native vegetation to take root. They were also placed over other structures to provide cover and habitat diversity.

- Rock clusters and turning rocks were used to create cover, velocity breaks, pocket pools, and to protect stream banks.

A total of 2,359 boulders, each 1 m^3, were used to construct the rock berms and clusters and to secure log weirs, deadmen, and juniper trees. In addition, 3,850 m^3 of gravel bars and stream banks were excavated and sloped. The deepened-stream channel helped restore a more stable flow, and improved the migration corridor to upstream spawning areas.

To protect the project structures after construction, 230 m^3 of pit-run material and 122 m^3 of top soil were added to form a new bank line on which native vegetation could grow. In addition, disturbed areas were seeded and mulched with an annual/perennial grass seed mixture at 20 pounds/acre. Rooted stock alder and willow trees were also planted. Fences removed for equipment access were replaced.

FENCING PROJECTS

Mill Creek (Potter's Pond)

- Location: Rkm 10.1 - 11.3 on Mill Creek (Potter's Pond)
- Date: January - April, 1989

Goals:

- Increase salmonid liabitat.
- Increase egg and juvenile survival.

Objectives:

- Promote growth of existing riparian vegetation.
- Protect Mill Creek Enhancement Project structures.
- Reduce sediment loading.
- Stabilize channels and banks.

Activities: Exclude livestock from the Potter's Pond area.

- Construct 2.1 km of new five-strand fence.
- Repair and upgrade 1.2 km of existing fence.

Beaver Creek (Dahl Pine)

- Location: Rkm 23.3 - 25.7 on Beaver Creek
- Date: October 1988 to April 1989

Goal:

- Maximize indigenous spring chinook salmon and summer steelhead trout spawning, rearing, holding, and passage habitat.

Objectives:

- Promote growth of riparian vegetation.
- Protect Beaver Creek Enhancement Project structures.
- Reduce instream sediment loading.

Activities: Exclude livestock from the Dahl Pine area.

- Construct 2.7 km of new fence.
- Repair 2.3 km of existing fence.

Both fencing projects were planned in cooperation with local tribal grazing groups, the tribal range committee, and the Tribal Council. In August 1988, the fencing projects were contracted to the lowest bidder, who defaulted on the contract. After a second round of bids, another contractor was chosen in October 1988.

MONITORING AND EVALUATION

The original study intended to use a modified version of the Binns (1982) Habitat Quality Index (HQI) to assess carrying capacity and monitor population trends on reservation streams. The U.S. Fish and Wildlife Service was to modify the HQI methodology, which was developed for resident trout in Wyoming, for use with anadromous salmonids. The results obtained from sampling reservation streams in 1983 and other areas in the Pacific Northwest were combined to describe the model for anadromous species. The combined data, however, inadequately described carrying capacity on reservation streams, thus a model could not be developed. HQI data collection ceased in 1984.

In 1984, field studies attempted to identify factors that limited anadromous fish production by describing relationships between fish populations and physical habitat characteristics in 17 sites on reservation streams. This study failed because of poor logistics and inadequate support.

Beginning in 1986, a better monitoring program was implemented that would assess the effects of stream restoration on fish populations and their physical habitat. Fish abundance, biomass, and habitat parameters were measured at 9 sites throughout the Warm Springs River basin and Shitike Creek during the summer low flow period (Table 3). Generally, HQI sites were used for habitat and population sampling. Additional sites were placed near enhancement and passage projects (completed and proposed), and selected according to characteristics representative of the stream, such as gradient, pool-riffle ratio, and flow changes. Physical and biological stream factors were measured with techniques described by ODFW et al. (1985). Photos of project sites, both before and after treatment, were taken from specific points to assist the evaluation. Also, in 1988, four additional habitat (bioengineering) sampling sites were established on Lower Shitike Creek (Table 3).

Table 3. Name, location, and variables measure; at each monitoring site in the Warm Springs basin and Shitike Creek.

Stream	Site	Location (Rkm)	Variables
Beaver Creek	Lower Island	0.9	Fish/Habitat
	Reach A - Test	23.1	Fish/Habitat
	Reach B - Test	31.1	Fish/Habitat
	Reach B - Control	31.6	Fish/Habitat
Mill Creek	Potter's Pond	10.5	Fish/Habitat
	Below Strawberry Falls	11.9	Fish/Habitat
	Above Strawberry Falls	14.8	Fish/Habitat
Shitike Creek	Habitat (bioengineering) #1	1.6	Habitat
	Habitat (bioengineering) #2	2.4	Habitat
	Habitat (bioengineering) #3	4.0	Habitat
	Habitat (bioengineering) #4	4.5	Habitat
	Headworks	11.4	Fish/Habitat
	Upper Crossing	20.1	Fish/Habitat

Habitat Measurements

Habitat parameters were measured at most monitoring sites along five equally-spaced transects (Platts et al. 1983). In the four bioengineering sites on Shitike Creek, habitat **was** measured along 10 equally-spaced transects. Below we describe the habitat parameters that were measured.

- The widths of pool, riffle, slow run, pocket water, fast run, backwater, and side channel (Irving et al. 1983) were measured to the nearest 0.05 m. The sum of transect widths was multiplied by the distance between transects to calculate surface area of a site.
- Stream depths were measured on each transect at the shoreline and at points 1/4, 1/2, and 3/4 the width of the transect.
- Undercut banks were measured at points where the bank protruded the most and where it was cut in the deepest at each transect.
- Major cover features for fish were classified into six types:
  1) logs, boulders, debris below water surface

2) logs, boulders, debris above water surface
3) overhanging vegetation within < 0.3 m of water surface
4) aquatic vegetation
5) undercut banks
6) depth with surface turbulence

- Points were measured on each transect to estimate stream depths > 0.15 m and < 1.0 m deep in order to determine usable stream area.
- Substrate within a riffle of each site or in the nearest riffle upstream of each site was classified on three transects. The riffle length was divided by 4 to obtain the transect spacing. At each transect, visual analysis measurements (Platts et al. 1983) were taken at 25 points and the substrate was classified by an 8-rank system (Table 4). Substrate was ranked by average particle size and the composition of each transect was described as the percentage of the substrate within each particle size class.
- Water temperatures and stream flows were measured at selected sites throughout the Warm Springs River basin and Shitike Creek. These data are reported in Appendix A.

All habitat data were reported on habitat field forms. Sites were mapped and comments were made on the back of the forms. "Left" and "right" banks were determined when facing downstream. Habitat data are reported in Appendix B.

Table 4. Classification of stream substrate in riffles by particle size.

Rank	Particle size (diameter in mm)	Particle description
1	--	Organic cover
2	less than 2	Sand
3	2-5	Pea gravel
4	5-25	Small gravel
5	25-50	Large gravel
6	50-100	Small cobble
7	100-250	Large cobble
8	greater than 250	Boulder

Fish Populations

Fish populations were sampled at monitoring sites with a multiple-pass removal method (Zippen 1958; Seber and LeCren 1967; Seber and Whale 1970) using Dirago 700 backpack electrotishers and 3.1-mm-mesh blocking nets placed at upstream and downstream ends of the sites. Depending on the size of the stream, three or four electrofishing units were used to capture fish. Crews sought confidence limits of less than 10% of the estimated abundance of the different salmonid species. To accomplish this, passes with electrofishers were continued until a 70% to 80% reduction in fish numbers from the preceding pass were reached. Juvenile spring chinook were the indicator species for this reduction. If chinook were not present, rainbow trout were used. Each salmonid was measured to the nearest 1 .O mm (fork length) and weighed to the nearest 0.5 g. Only lengths were taken on non-salmonids, excluding Cottids, which were only counted. Data were recorded on fish-density field forms. Biomass of salmonids was estimated from fish population estimates and mean weights. We report fish population data in Appendix B.

Spawning Ground Surveys

Between 1969 and 1982, spawning grounds of spring chinook salmon were surveyed in September in three “historical” areas in the Warm Springs River basin. In 1982 the surveys expanded into Shitike Creek and covered more of the Warm Springs River basin. Since then, surveys for spring chinook redds have been conducted in 22 index areas in Shitike Creek and the Warm Springs River basin (Figures 2 and 5; Table 5). These index areas account for over 95% of the total spring chinook redds found on reservation streams. Spawning grounds of summer steelhead have also been surveyed since 1982, but because of high turbidity and inaccessibility of spawning areas during spring flows, counts of steelhead redds were limited and therefore are not discussed in detail in this report. For completeness, however, we report steelhead redd counts in Appendix B.

Spawning ground surveys monitored adult passage, redd numbers, and disease. A two-pass survey method was used to increase accuracy of redd counts. Before 1986, during the first survey pass all redds were marked with a painted rock placed near redds or by placing surveyor’s tape on banks near redds. Since 1986, only surveyor’s tape was used to mark the locations of redds during the first pass. Carcasses were enumerated and examined for bacterial kidney disease and egg voiding, and the tail was cut off to prevent double counting. Second-pass surveys tabulated marked and unmarked redds and examined and counted unmarked carcasses. Escapements of adult chinook to the Warm Springs River are monitored by the U.S. Fish and Wildlife Service at the WSNFH. There, a weir/trapping system allows upstream migrants to be counted.

Out-Migrants

Since 1976, a floating scoop trap at Rkm 0.6 on the Warm Springs River has captured anadromous and resident juvenile fish that egress the Warm Springs River system. The trapping provided an index of juvenile abundance and a population estimate of juvenile migrants. The trap was operated periodically in February and March, and 3 - 7 days a week from April to mid-June, and from mid-September to mid-December. Dates of operation depended on water and weather conditions.

Captured salmonids were counted, measured to the nearest 1.0 mm (fork length), and weighed to the nearest 0.5 g. Only lengths were taken on non-salmonids, except Cottids,

Table 5. Name and location of spawning index areas in the Warm Springs basin and Shitike Creek.

Stream	Index area	Location (Rkm)
Warm Springs River	Above WSNFH (historical)	43.8 - 66.4
	Culpus Bridge - WSNFH	a.2 - 17.1
	Badger Creek - McKinley Arthur	43.8 - 46.6
	McKinley Arthur - He-He	46.6 - 49.4
	He-He - Schoolie	49.4 - 60.3
	Schoolie - Bunchgrass	60.3 - 66.4
Beaver Creek	Beaver Creek (historical)	0.8-13.3; 19.8-31
	Island Area	0.8 - 2.6
	Island - Powerline	2.6 - 12.0
	Powerline - Old Bridge	12.0 - 13.3
	Canyon - Dahl Pine	19.8 - 23.0
	Dahl Pine - Robinson Park	23.0 - 31.0
	Robinson Park - Reach D	31.0 - 33.8
Mill Creek	Mill Creek (historical)	7.4 - 14.6
	Boulder Creek - Potter's Pond	7.4 - 10.1
	Potter's Pond - Strawberry Falls	10.1 - 14.6
	Strawberry Falls - Old Mill	14.6 - 17.3
	B-241 Road Bridge Area	23.7 - 26.9
Shitike Creek	Mouth - Community Center	0.0 - 3.8
	Community Center - USGS Station	3.8 - 7.5
	USGS Station - Headworks	7.5 - 11.5
	Headworks - Bennett Place	11.5 - 15.2
	Bennett Place - Upper Xing	15.2 - 20.0
	Upper Xing - Powerline	20.0 - 23.0
	Peter's Pasture	24.1 - 25.6

which were only counted. When possible, weekly migrant trap efficiency tests were conducted to estimate sampling rates. Between 50 and 150 chinook migrants were fin-clipped (small nip on the caudal lobe), transported 2.0 Rkm upstream, and then released. A minimum of 50 fish per release group was considered adequate. It was necessary during some tests to clip and transport migrants more than one day each week to obtain the desired number. Weekly test groups were given alternating top and bottom small clips on the caudal fin. Numbers of juvenile chinook that escaped from the live box were assessed by clipping a small part of the dorsal tin of 10-15 fish and returning them to the live box. The next day the remaining dorsal-clipped fish were counted and released.

All data collected at the trap were recorded on a field trap form. The total out-migration of spring chinook juveniles was calculated from the total catch expanded by the trap efficiency. The methods of ODFW (Aho et al. 1979) were used to calculate a juvenile index. Water temperatures, staff gauge heights of the Warm Springs River (USGS flow station at Culpus Bridge), and water turbidity (visual inspection) were also reported.

STATISTICAL METHODS

Population and Habitat Data

Before testing statistical hypotheses, all physical habitat, fish abundance, biomass, and mean weight data were screened for normality assumptions, missing-value patterns, and variance patterns. Data from each sampling site were screened separately. This screening was necessary to assess if the data met the assumptions of statistical tests, e.g., t-tests and analysis of variance (ANOVA). Substrate and cover in the Strawberry Falls sites on Mill Creek, the Headworks and Upper Crossing sites on Shitike Creek, and the Reach B-Control site on Beaver Creek could not be tested statistically because three of the five data points were not collected. For each site, both Pearson and Spearman-rank correlation matrices were calculated to assess if habitat correlated with sampling period, and if fish abundance, biomass, and weight correlated with habitat changes. To further examine how well the data fit the assumptions of statistical tests, differences between the Pearson and the Spearman correlation coefficients were calculated. Large differences indicated the presence of outliers, nonlinearity, or non-normality.

Time-series linear-trend analysis assessed if fish populations increased or decreased after habitat modification. Because most data were collected after treatment, population trends before treatment were assumed to be horizontal. A t-test determined if the slope of the linear trend differed significantly from a horizontal line. In streams that had both treatment and control sites, population trends (slopes) in treatment sites were compared with those in control sites, assuming that the control sites were independent of treatment sites. In the Lower Island site on Beaver Creek, data were collected before (1986-1987) and after (1989-1990) the site was treated with juniper rip-rap. There, a two-sample randomization test (Manly 1991), with significance estimated from 5,000 randomizations, compared mean densities, biomass, and weights of fish before and after treatment. Trend analysis identified time series relationships in habitat variables after stream rehabilitation.

For each stream treated, a one-way ANOVA or an unpaired t-test assessed differences in fish populations and habitat variables among sampling sites. Data collected during each sampling period served as independent replicates. An F-ratio test compared the variances among groups. If variances differed significantly, the unequal-variance formula calculated the t statistic. "Power" of each statistical procedure was calculated with methods described in Hintze (1991). Here, the power of a statistical test is the probability of rejecting the null hypothesis (hypothesis of no difference) when it is false. Peterman (1990) recommends that statistical tests maintain at least 80% power.

Redd Counts

Since 1982, chinook salmon redds have been counted in most of the 22 index areas on Beaver Creek, Mill Creek, the Warm Springs River, and Shitike Creek. Also, since 1969, salmon redds have been enumerated in three "historical" areas in the Warm Springs basin. Time-series analysis described trends in those data. A separate analysis was run for each of the index areas. Both data and autocorrelation plots described the series. Linear-trend analysis assessed if numbers of salmon redds increased in index areas and in entire streams over the study periods. A t-test examined whether the slope of the trend lines differed significantly from a horizontal line.

Out-Migrants

Time-series analysis described trends in numbers of chinook salmon that emigrate in fall and spring from the Warm Springs River basin. The series included migrant data, with no missing observations, from brood years 1975 through 1990. Data plots and autocorrelation plots described the time series. Autocorrelations identified if successive observations were correlated, i.e., if numbers of out-migrants in one year were correlated with numbers of out-migrants in another year. Trends from the series were removed before interpreting autocorrelations. Linear trend analysis assessed if numbers of out-migrant chinook salmon increased over the study period. A t-test assessed if the slope of the trend lines differed significantly from a horizontal line.

We tested a stock-recruitment relationship between numbers of redds (stock) of chinook salmon in the Warm Springs River basin and the total number of out-migrants (recruits) that they produced. Simple linear regression tested the hypothesis that the logarithm of out-migrants per redd was constant (i.e., $slope=0$; a density-independent relationship). That hypothesis was rejected, thus nonlinear regression was used to fit the Ricker and Beverton-Holt models to the data. We report the results of the Ricker model ($R^2=0.37$) because it explained more of the variation in out-migrant numbers than did the Beverton-Holt model ($R^2=0.27$).

Correlation analysis and data plots tested the relationships between mean monthly flows (Appendix A6-7) and numbers of juvenile chinook that egress the Warm Springs system during fall and spring. Analyses included out-migrant data from brood years 1975 through 1990 and flow data from 1976 through 1991. Warm Springs River flows were measured near Kahneeta Hot Springs at Rkm 8.2.

Results of all statistical analyses are reported in Appendix C.

RESULTS

Mill Creek

Juvenile chinook salmon. Densities, biomasses, and mean weights did not differ significantly among sampling sites on Mill Creek (Appendix Cl-5). Densities and weights of wild salmon upstream and downstream from Strawberry Falls were similar, and they showed similar declining trends (Figures 21 and 22). In those sites, their densities and weights correlated with pool size. After the Potter's Pond site was rehabilitated in 1986, densities and biomasses of wild salmon increased sharply in 1987, but thereafter declined to levels below those measured in 1986 (Figure 23). Except in 1991, summer water temperatures in the Potter's Pond site remained within the optimal range of juvenile chinook (Appendix Al). Problems with the thermograph in 1991 recorded higher than actual temperatures during the summer. Salmon densities and biomasses correlated directly with cover and, unlike Strawberry Falls sites, inversely with pool size.

Juvenile steelhead. Densities were significantly more abundant in the Potter's Pond site than in the Strawberry Falls sites. Although mean densities were similar between the Strawberry Falls sites, they increased upstream from the falls during the study period, while they declined slightly downstream from the falls (Figures 24 and 25). Steelhead densities and biomasses also declined in the Potter's Pond site during the study (Figure 26). Water temperatures were adequate for steelhead growth and survival (Appendix Al). Their weights and densities correlated with increasing depth and surface turbulence.

Total salmonids. Densities differed significantly among the three sampling sites on Mill Creek. Mean densities and biomasses of salmonids were greatest in the Potter's Pond site, In that site, however, densities and biomasses declined during the period of the study (Figure 27). Salmonid biomasses typically increased during the study in both the Strawberry Falls sites (Figures 28 and 29). In contrast, trends in densities of salmonids increased upstream from the falls and decreased downstream from the falls. Increased densities of brook trout *Salvelinus jiintinulis* upstream from the falls contributed to the increased salmonids there. Brook trout densities and weights correlated strongly with increased pool habitat.

Chinook salmon redds. Numbers of redds did not increase significantly after the bypass channel around Strawberry Falls was added (Figure 30). Numbers of salmon redds in historic index areas have declined slightly since 1969, and in 1990 and 1991 were below the long-term average of 25 redds. In the B-241 Road Bridge index area (most upstream area on Mill Creek), numbers of salmon redds declined significantly from 1982 to 1986 in part because outplants of salmon has ceased there. Since then, no salmon have spawned in that area. Throughout the study, more salmon spawned downstream from the falls than upstream.

Beaver Creek

Juvenile chinook salmon. In contrast to Mill Creek, densities differed significantly among the four sampling sites on Beaver Creek (Appendix C5-11). Although densities, biomasses, and mean weights of juvenile salmon had similar trends and fluctuations in Reach B test and control sites, numbers and weights of salmon were greater in the test site (Figures

31 and 32). Salmon numbers and weights did not correlate with habitat variables in the control site; however, they correlated inversely with depth and directly with small cobble in the test site. Unlike in Reach B sites, numbers and biomasses of juvenile salmon increased during the study period in Reach A Test site (Figure 33). In the latter site, numbers and weights of salmon correlated directly with gravel and indirectly with amount of organic cover. Although not significant statistically, mean densities and weights of salmon in Lower Island site increased ninefold after the addition of juniper rip-rap (Figure 34) and correlated positively with the addition of cover. Water temperatures during the summer were higher in Beaver Creek than Mill Creek, but remained well below the lethal limit for juvenile chinook salmon (Appendix A2).

Juvenile steelhead. Densities, biomasses, and mean weights differed significantly among sampling sites. Densities and biomasses were consistently greater in Reach B sites than in the Reach A Test and Lower Beaver Creek sites. Unlike chinook salmon, densities of steelhead were greater in the control than in the test site in Reach B, and densities and biomasses decreased more rapidly in the test site than in the control (Figures 35 and 36). Steelhead densities also decreased in the Reach A Test site (Figure 37). On the other hand, densities and biomasses increased threefold in the Lower Island site after juniper rip-rap was added (Figure 38). Again, however, that increase was not statistically significant. As with chinook salmon, steelhead densities typically correlated directly with cover, e.g., overhanging vegetation, organiccover, undercut banks, mean cover, aquatic vegetation, and structures below water surface.

Total salmonids. Densities did not differ significantly among sites on Beaver Creek, although total salmonid biomass did. Salmonid densities and biomasses decreased during the study in both the test and control sites in Reach B, but the decline was most rapid in the test site (Figures 39 and 40). In Reach A Test site, densities increased slightly during the study (Figure 41) and correlated inversely with organic cover and large gravel. The greatest increase in salmonid densities and biomasses occurred in the Lower Island site; both mean densities and biomasses increased fourfold after site treatment.

Chinook salmon redds. Numbers of chinook salmon redds did not increase significantly after the stream was treated. Numbers of redds declined in five of the six index sites. Since 1969, numbers have increased only slightly in historic index sites (Figure 42). In the last two years of sampling, numbers were well below the long-term average of 77 redds.

<u>Shitike Creek</u>

Habitat. Habitat in the four bioengineering (habitat sampling) sites changed significantly over the study period (Appendix C5 and C12-16). After pooling the sites (i.e., each site served as an independent replicate), the study showed that both backwater area and percentage of logs and boulders below the water surface changed significantly. When each site was analyzed separately, several habitat variables correlated with time (sampling period). For example, in site #1, depth (and thus volume) and cover (including overhanging vegetation and undercut banks) increased during the study. On the other hand, riffle, side channel, and backwater areas decreased. In both sites #2 and #3, cover and backwater areas typically decreased with time while small substrates increased. In site #4 overhanging banks and vegetation increased, and depth, backwater, and side channel areas decreased.

Juvenile chinook salmon and steelhead. Mean densities, biomasses, and weights did not differ significantly in the two fish sampling sites on Shitike Creek. In the Headworks and Upper Crossing sites, densities, biomasses, and weights of salmon increased, but not significantly, during the study (Figures 43 and 44). Steelhead densities also increased insignificantly in both sites over time (Figures 45 and 46). Mean weights of steelhead, however, declined in the two sites. Both steelhead and salmon densities correlated with stream depth. Summer water temperatures near the sampling sites remained within the optimal range for both juvenile chinook and steelhead (Appendix A3-4). Temperatures near the mouth of Shitike Creek, however, occasionally reached the upper lethal limit for both species.

Total salmonids. Mean densities and biomasses were similar in both sites and they increased, but not significantly (Figures 47 and 48). Bull trout *Salvelinus confluentus* were a small fraction of the total salmonid population in the Upper Crossing site, and their densities and biomasses fluctuated little about a horizontal trend. In contrast, their mean weights decreased significantly and correlated directly with backwater area that decreased during the period of study.

Chinook **salmon redds.** Numbers of chinook salmon redds did not increase significantly after the dam was removed in 1983 (Figure 49). In most index areas on Shitike Creek, numbers of redds declined but not significantly. Numbers of redds increased slightly over time only in the Upper Crossing-to-Bennett Place and Headworks-to-USGS Station areas.

Warm Springs River

Salmon redds. Stream modification in the Warm Springs basin did not increase the number of salmon redds in the Warm Springs River or in the Warm Springs basin (Figures 50 and 51). Since 1977, numbers of salmon redds decreased, but not significantly, in both the Warm Springs River and its basin. Most of the salmon in the Warm Springs River spawned upstream from WSNFH, and numbers of salmon redds there decreased during the study. That decrease is primarily because of the significant decline in numbers of salmon redds in the Bunchgrass Creek-to-Schoolie index area (Appendix C5). Although fewer salmon spawned downstream from the WSNFH, numbers of their redds fluctuated about a horizontal trend. Throughout most of this reach, water temperatures approached the upper limit for chinook spawning (Appendix A5).

Wild juvenile chinook salmon migrants. Although not significant statistically, numbers of spring, fall, and total wild juvenile chinook salmon that egress the Warm Springs basin tended to increase after stream modification (Figure 52). This suggests that egg-to-migrant survivals may have increased because numbers of redds in the basin decreased, while out-migrants increased. According to the Ricker curve (Figure 53), numbers of out-migrants in the Warm Springs basin increase as the number of redds increase to about 620, then numbers of out-migrants decrease slightly. This relationship is supported by the fact that numbers of chinook salmon redds in Mill Creek, Beaver Creek, and the Warm Springs River have significant negative four-year autocorrelations (Appendix C5). This suggests that adults from a large number of redds in one year may produce fewer redds four years later. These four-year cycles comport with the work of Lindsay et al. (1989), who report that age-4 fish dominate the return of adult chinook salmon to the Deschutes River. We caution that these analyses are preliminary and do not conclusively demonstrate cause-and-effect relationships. For example, in constructing the Ricker relationship, the assumption of stationarity, i.e., the average relationship is constant over time (Walters 1987), was violated. Also, the relationship lacked observations at the extremes.

Mean monthly flows in the Warm Springs River had little to no affect on numbers of wild chinook that egress the basin (Appendix C17). There was, however, a hint of a direct relationship between numbers of fall migrants and mean December flows (i.e., when the eggs were still in the gravels). There also appeared to be a weak direct relationship between numbers of migrants and mean April and May flows (i.e., during and after fry emergence). The former suggests that dewatering of redds may be a problem in some areas. That is, with decreasing flows in December, fewer fall migrants are produced from those redds. The latter relationship suggests that higher spring flows produce greater numbers of migrants. Again, these correlations do not demonstrate cause-and-effect relationships, but identify hypotheses that should be tested.

SUMMARY

Most wild chinook salmon in the Warm Springs basin spawned upstream from the National Fish Hatchery, and numbers of redds there decreased during the study. This decline was related to the decrease in adult escapements into the basin. Therefore, because of inadequate escapements, we cannot determine if stream modification (e.g., removal of barriers) increased spawning habitat in the basin. However, numbers of out-migrant chinook salmon produced from redds in the Warm Springs basin increased over the period of study, and the relationship between numbers of redds and numbers of out-migrants appeared to follow a Ricker-type function. Thus, stream modification may have increased egg-to-migrant survival of wild chinook salmon in the Warm Springs basin.

On Mill Creek, after a bypass channel around Strawberry Falls was added, mean densities and biomasses of wild juvenile chinook salmon and steelhead upstream from the falls increased until they were similar to densities and biomasses downstream from the falls. In the Potter's Pond area, densities and biomasses of both chinook salmon and steelhead declined after treatment. Numbers of wild chinook salmon redds in Mill Creek did not increase significantly after the bypass channel was added. This is most likely because of inadequate adult escapements, but may be also related to problems with passage in the bypass channel.

On Beaver Creek, stream alteration in the Dahl Pine treatment area resutted in greater densities and biomasses of wild juvenile chinook salmon in test sites than in the control site. Dahl Pine alteration had no influence on densities or biomasses of juvenile steelhead. After juniper rip-rap was added to the Lower Island site, mean densities and biomasses of juvenile chinook salmon increased ninefold and tenfold, respectively, and both mean densities and biomasses of juvenile steelhead increased threefold. Both chinook salmon and steelhead densities and biomasses typically correlated directly with increasing cover in the Lower

Island site. Probably because of low escapements, numbers of wild chinook salmon redds did not increase significantly in index areas after Beaver Creek was treated.

On Shitike Creek, after a defunct dam at Rkm 11.5 was removed, mean densities and biomasses of wild juvenile chinook salmon and steelhead upstream and downstream from the dam site were similar. Although densities of both juvenile chinook salmon and steelhead increased during the study, numbers of chinook salmon redds did not. Habitat changed significantly during the study in the four habitat (bioengineering) sites on lower Shitike Creek. In general, cover increased in sites #1 and #4, and decreased in sites #2 and #3. Backwater areas decreased over time in all sites.

CRITIQUE OF THE MONITORING DESIGN

In some cases fish populations did not appear to respond to treatments. This could be because the factors that limited the populations were not removed and/or the monitoring design was insensitive to the treatments. It is basic that one cannot expect to increase fish production unless one alters the habitat that limited the population (Everest et al. 1991; Hunter 1991). If an invalid monitoring design is used, however, one cannot assess whether the lack of response (positive or negative) resulted from adding an unnecessary treatment (i.e., not removing the limiting factor), or because the monitoring design was unable to identify a true treatment effect. For example, in this study, populations may have responded favorably or unfavorably to some treatments, but because fish were not sampled consistently in treatment and control sites for a longer period of time (under-replicated and hence low statistical power), the statistics could not identify significant treatment effects. Furthermore, most data were collected after stream treatment. Therefore, we could not compare, in most cases, pretreatment data with post-treatment data. When treatment sites were compared with control sites, however, some populations appeared to respond favorably to treatments. Below we describe in more detail how the monitoring designs used in this study could be improved.

To detect a treatment effect monitoring designs must be able to differentiate between natural fluctuations (natural variation) in population parameters and changes that result from treatment (treatment variation). Valid monitoring designs use both spatial and temporal controls (reference sites) to account for natural and treatment variations (Hairston 1989; Manly 1992; National Research Council 1992; Skalski and Robson 1992). Without both types of reference sites, one cannot be sure that changes recorded in the treatment site would have occurred in the absence of the treatment. In this study, for example, salmonid densities and biomass increased several-fold in the Lower Island site on Beaver Creek after the site was treated with juniper rip-rap. Because fish populations fluctuate widely seasonally and annually (Hall and Knight 1981; Platts and Nelson 1988), we cannot be certain that treatment caused the observed increase. In fact, the observed increase in fish may reflect underseeding before treatment. As another example, we did not find an increase in salmonid density and biomass in the Potter's Pond site on Mill Creek after it was treated. That observation suggests that treatment did not benefit the population. We would conclude differently, however, if we found that density and biomass in a temporal reference site decreased rapidly and fell well below those observed in the Potter's Pond site. That is, although we did not see an increase in the population after treatment, observations in the reference site suggest that the density and biomass in the treatment site would have decreased rapidly if left untreated.

Valid monitoring designs, therefore, should consider changes in fish populations within treatment and reference sites (or streams) both before and after treatment. Such designs are known as BACI or Before-After-Control-Impact designs (Stewart-Oaten et al. 1986; Stewart-Oaten et al. 1992; Smith et al. 1993), CTP or Control-Treatment Paired designs (Skalski and Robson 1992), Comparative Interrupted Time Series designs (Manly 1992), or Interrupted Time Series with Nonequivalent Control Group designs (Cook and Campbell 1979). Although names differ, these designs are essentially the same. That is, they require that data are collected simultaneously at both treatment and reference sites before and after treatment, These data are paired in the sense that the treatment and reference sites are as similar as possible and sampled simultaneously. Replication comes from collecting such paired samples at a number of times (dates) both before and after treatment. The pretreatment sampling serves to evaluate success of the pairings and establishes the relationship between treatment and reference sites before treatment. This relationship is later compared to that observed after treatment.

The success of the design depends on fish populations at treatment and reference sites "tracking" each other, i.e., maintaining a constant proportionality (Skalski and Robson 1992). The design does not require exact pairing; populations simply need to "track" each other. The National Research Council (1992) reported that such synchrony occurs among populations if they are influenced by similar climatic and environmental conditions. They recommended that populations in the treated reach be compared to populations in reference sites in streams of the same order in the same ecoregion. Precision of the design can be maximized further if treatment and reference stream reaches are paired according to a hierarchical classification approach (Naiman et al. 1992). Thus, fish populations in stream reaches with similar climate, geology, geomorphology, and habitat will track each other more closely than those in reaches with only similar climates.

Similar stream reaches are paired and fish populations are surveyed in those pairs for at least five years (pretreatment sampling). These observations are used to assess if populations track each other and to establish relationships between reference and treatment sites. It is critical that reference and treatment sites be independent; that is, fish cannot move back-and-forth among sites. The design is confounded if, after treatment, fish move from the reference sites into the treated sites. The National Research Council (1992) recommends that reference data come from another stream or from an independent reach in the same stream. The design will also be confounded if the sites are not fully seeded. When numbers of fish are allowed to vary naturally within sites, variations associated with underseeding can incorrectly be attributed to treatment. To remove this confounding, during both pretreatment and post-treatment periods, biologists can saturate the sites in late spring with fish.[1] Furthermore, successive observations become independent (i.e., the number of fish in a site in one year do not influence numbers in that site in other years) if sites are fully seeded with fish each year. Thus, more powerful statistical tests can be used to test cause-effect relationships.

After the pretreatment period, biologists should randomize treatments to sites. Randomization eliminates site location as a confounding factor and removes the need to make model-dependent inferences (Skalski and Robson 1992). Hence, conclusions will generally be more reliable and less controversial. Post-treatment observations should be made simultaneously in both treatment and reference sites for at least five years, but preferably for ten years (Hunter 1991). Without a long-term time series, the effects of treatment are confounded with the effects of streamflow fluctuations (National Research Council 1992).

Manly (1992) identified three methods that can be used to analyze the time series design: (1) a graphical analysis, which attempts to allow subjectively for any dependence among successive observations, (2) regression analysis, which assumes that the dependence among successive observations in the regression residuals is small enough to ignore, and (3) an analysis based on a time series model that accounts for dependence among observations. Cook and Campbell (1979) recommend using autoregressive integrated moving average (ARIMA) models and the associated techniques developed by Box and Jenkins (1976). Skalski and Robson (1992) introduced the odd's-ratio test, which looks for a significant change in the proportional density or biomass of fish in reference-treatment sites between pretreatment and post-treatment phases. A common approach includes analysis of difference scores. Differences (density of fish in reference site minus density in treatment site) are calculated between paired reference and treatment sites. These differences are then analyzed for a before-after treatment effect with a two-sample t-test, Welch modification of the t-test, or with nonparametric tests like the randomization test, Wilcoxon rank sum test, or the Mann-Whitney test (Stewart-Oaten et al. 1992; Smith et al. 1993). Choice of test depends on the type of data collected and whether those data meet the assumptions of the tests.

This monitoring design is one of the best for assessing treatment effects, but its success depends on a sound sampling program. Control of the sampling program must be maintained throughout the period of study (about 10 to 15 yrs). Changes in the sampling. program must be avoided, e.g., changing sampling techniques, adding or dropping sampling sites, or changing the time when annual samples are collected. In other words, all aspects of the sampling program, including funding and support, must remain constant throughout the study. In this study, for example, we could not analyze changes in substrate and cover in the Strawberry Falls sites on Mill Creek, the Upper Crossing sites on Shitike Creek, or the Reach B-Control site on Beaver Creek, because those variables were not sampled consistently throughout the study (original sampling design was abandoned early in the study). Also, it is useful and relatively inexpensive to collect supplemental information, such as streamflows and water temperatures, because they can be used to assess effects and assign causes. Finally, it is important not to overemphasize statistical significance (as opposed to biological

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[1] Seined fry or fingerlings from other stream areas in the same drainage can be used. As a last resort, hatchery fry could be used.

or economic significance), because statistical significance is tied to sample size, alpha-level, capture probabilities, magnitude of the treatment, magnitude of temporal variance, and temporal covariance between reference and treatment sites through time (Skalski and Robson 1992). We believe biological significance, based on valid monitoring, is more important in assessing treatments and making environmental decisions.

RECOMMENDATIONS

The statistical assessment of the data collected in the treated areas of the Warm Springs Reservation found few “significant” treatment effects. In many cases this was because of inadequate adult escapements and, hence, low seeding levels. Also, inadequate funding and support during the study resulted in inconsistencies in the monitoring design and the short duration of the sampling program. Research experience shows that valid monitoring designs implemented over several years (10 or more years) are needed to show treatment effects. Without proper replication in both space and time, statistical models generally cannot demonstrate significant treatment effects even if true changes exist.

Because streams on the Warm Springs Reservation are the only ones in the Deschutes River basin that still have runs of wild spring chinook salmon, it is necessary to continue monitoring the status of this population. In light of the concern for other indigenous species, such as steelhead, Pacific lamprey *Lampetra tridentata*, and others, the status of those populations should also be monitored since they occur in streams on the reservation. Therefore, we recommend continued monitoring of numbers of wild adults that escape to the basin and enumeration of the number of redds and out-migrants that they produce. Concomitantly, it is necessary to measure water quality and quantity, and stream temperatures, so that the influence of these variables on numbers of out-migrants and egg-to-migrant survivals can be assessed. Finally, it is necessary to monitor juvenile salmonid production with a valid sampling design. This will identify important relationships between fish production and habitat use. It will also identify treatment effects and can be used to describe the production of resident salmonids.

GLOSSARY

Backwater: A pool formed either by 1) an eddy along channel margins downstream from obstructions such as bars or boulders; or 2) from back-flooding upstream from a blockage. Sometimes separated from the channel by sand/gravel bars.

Depth with surface turbulence: The vertical distance from the water surface to the stream bed that is associated with surface disturbance and uneven surface level.

Floating scoop trap: A floating inclined-plane fish trap for catching fish migrating downstream.

Gabion: A wire basket filled with stones, used to stabilize banks.

Geotextile filter cloth: An erosion-control cloth that is permeable.

Instream structure: Any object, usually large, in the stream channel that controls water movement.

Pit-run material: Excess dirt and rock from a quarry.

Pocket water/pool: A series of small ponds surrounded by swiftly flowing water, usually caused by eddies behind boulders, rubble, logs, or by potholes in the stream bed.

Point bar: A ridge-like accumulation of sand, gravel, or other alluvial material forming a bar found on the inside of meanders.

Point surface visual analysis measurements: A technique used to determine the composition of the channel substrate.

Riffle: A shallow rapids where the water flows swiftly over completely or partially submerged obstructions to produce surface agitation.

Run (stow/fast): An area of flowing water, without surface agitation, which approximates uniform flow and in which the slope of the water surface is roughly parallel to the overall gradient of the stream reach.

Side channel: A braid of a stream with flow appreciably lower than the main channel.

Thalweg: The line connecting the lowest or deepest points along a. stream bed.

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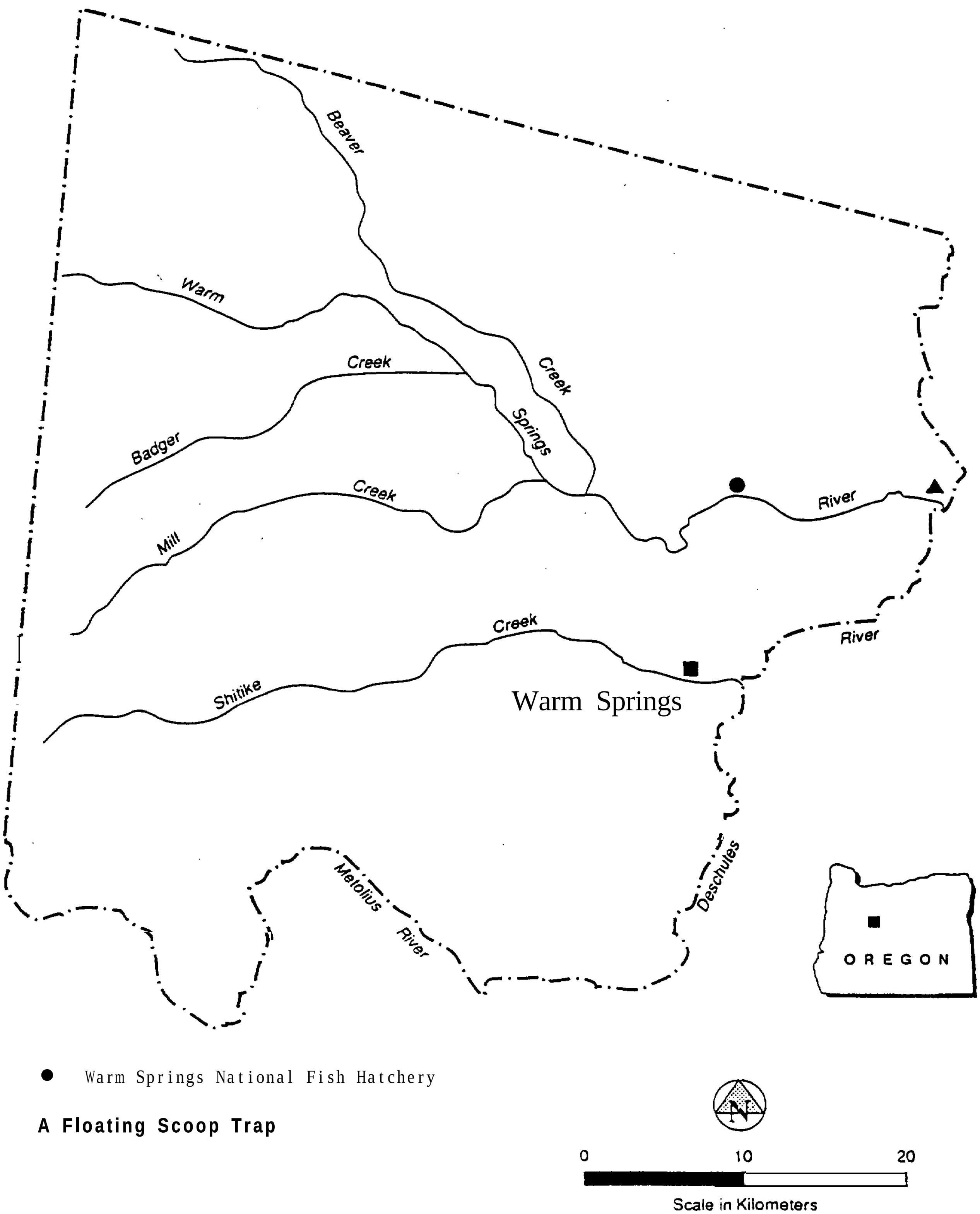
Figure 1. The Confederated Tribes of the Warm Springs Reservation of Oregon.



● Warm Springs National Fish Hatchery

▲ Floating Scoop Trap

Figure' 2. Map of Warm Springs River study sites and principle tributaries.

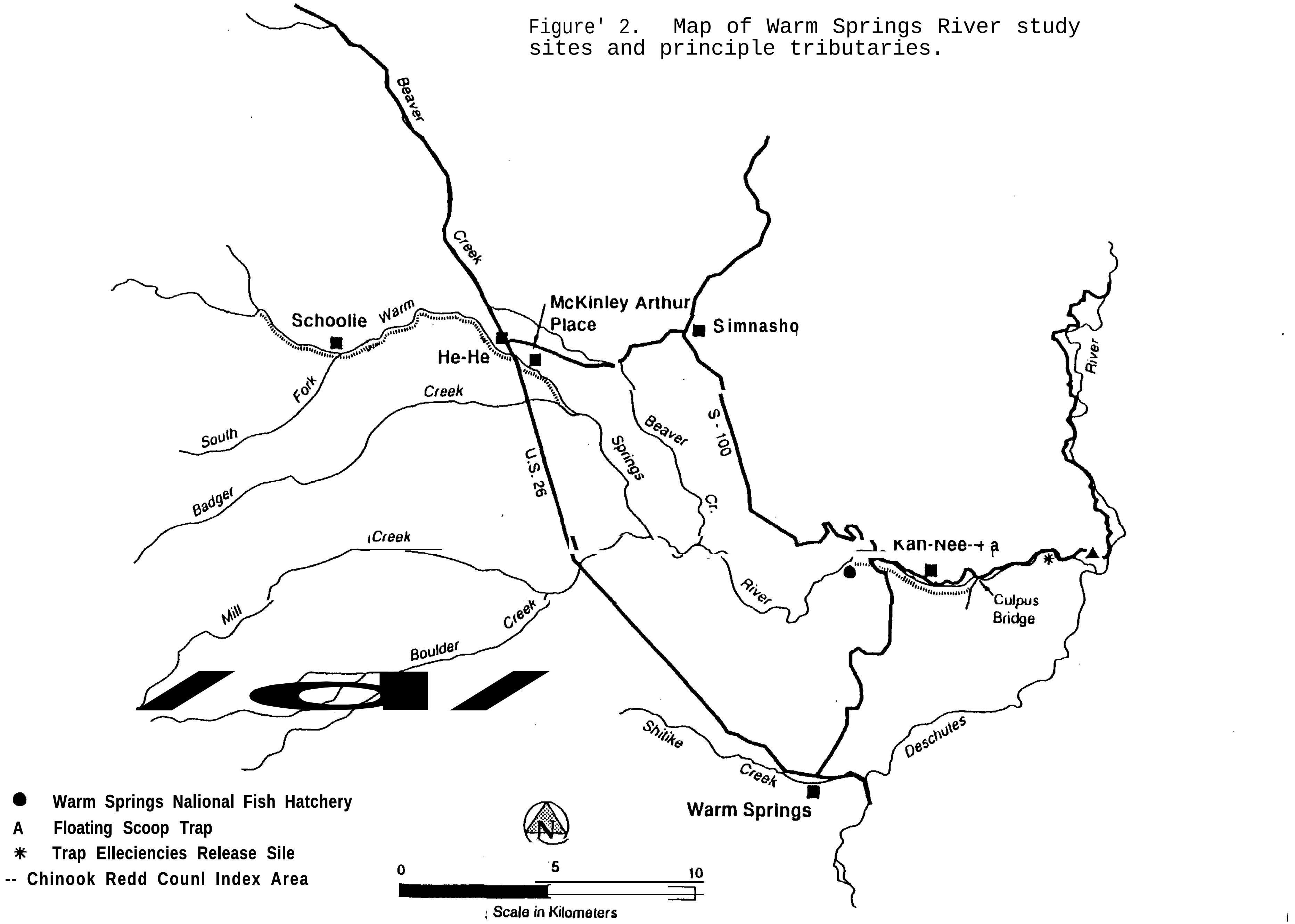


Figure 3. Map of Mill Creek indicating project sites monitoring sites and redd count index areas.

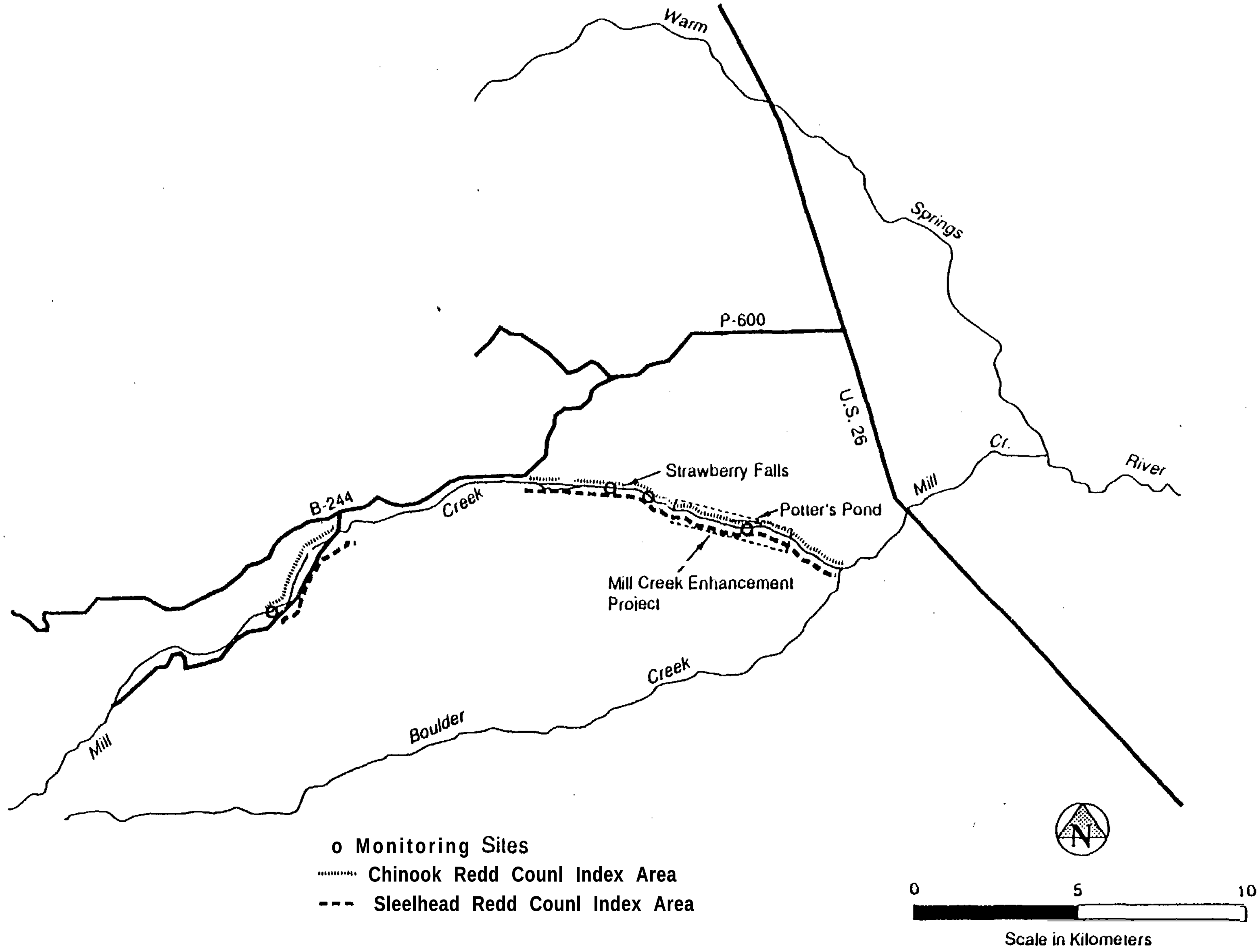


Figure 4. Map of Beaver Creek indicating project sites, monitoring sites and redd count index areas.

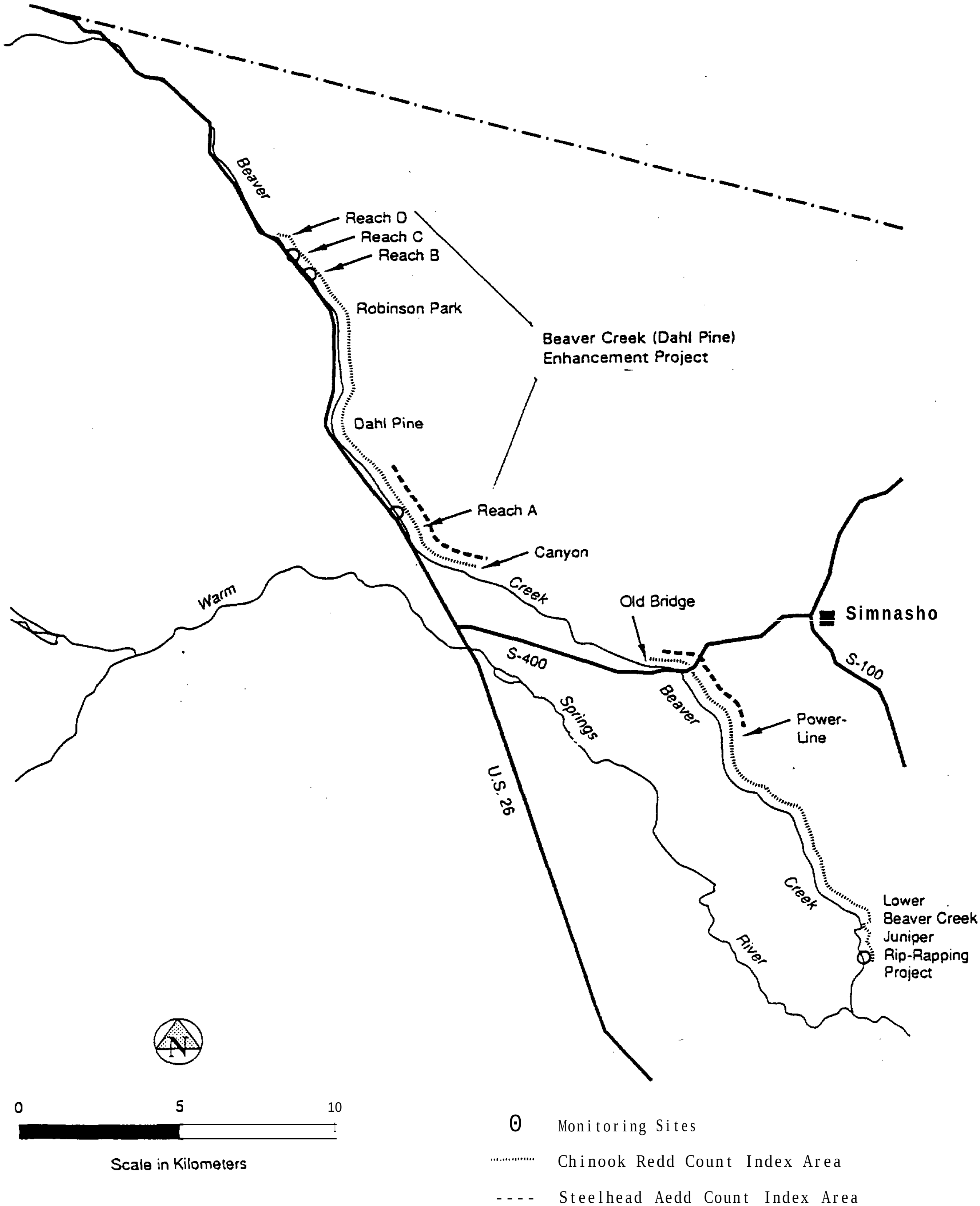


Figure 5. Map of Shitike Creek indicating project site, monitoring sites and redd count index areas.

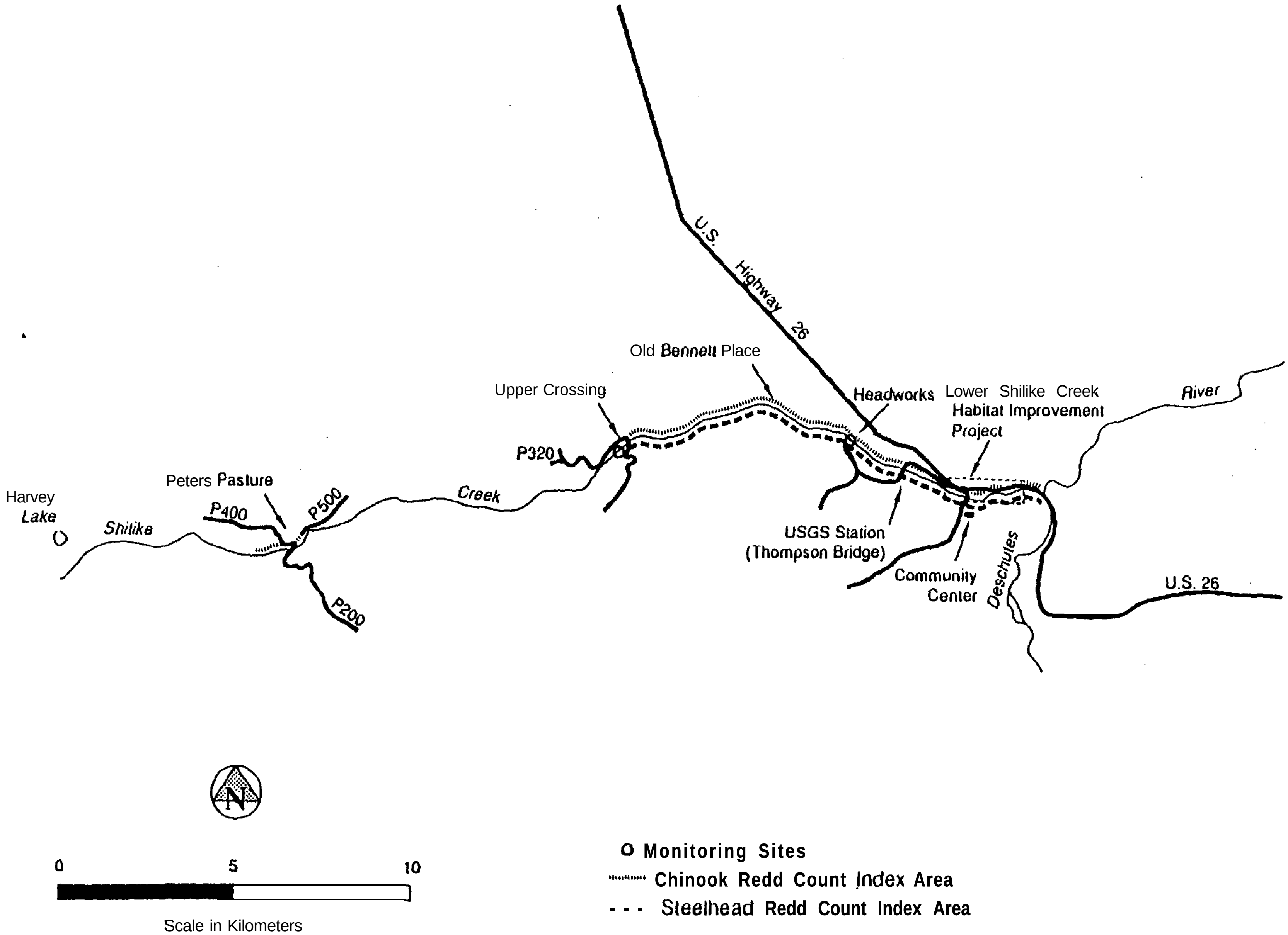


Figure 6. Beaver Creek (Dahl Pine) enhancement project, 1986.

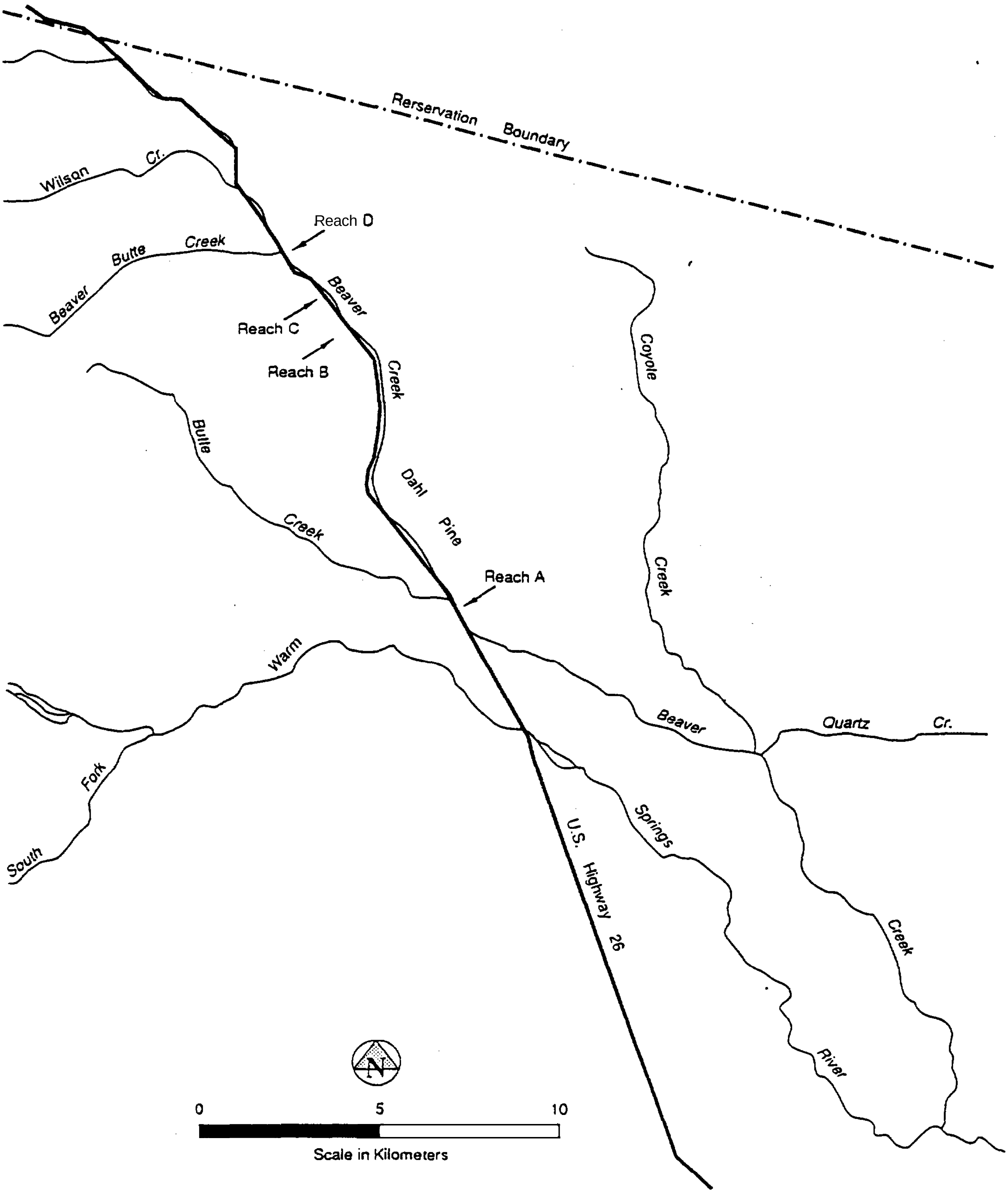


Figure 7. Log weir construction technique used in the Beaver Creek (Dahl Pine) enhancement project.

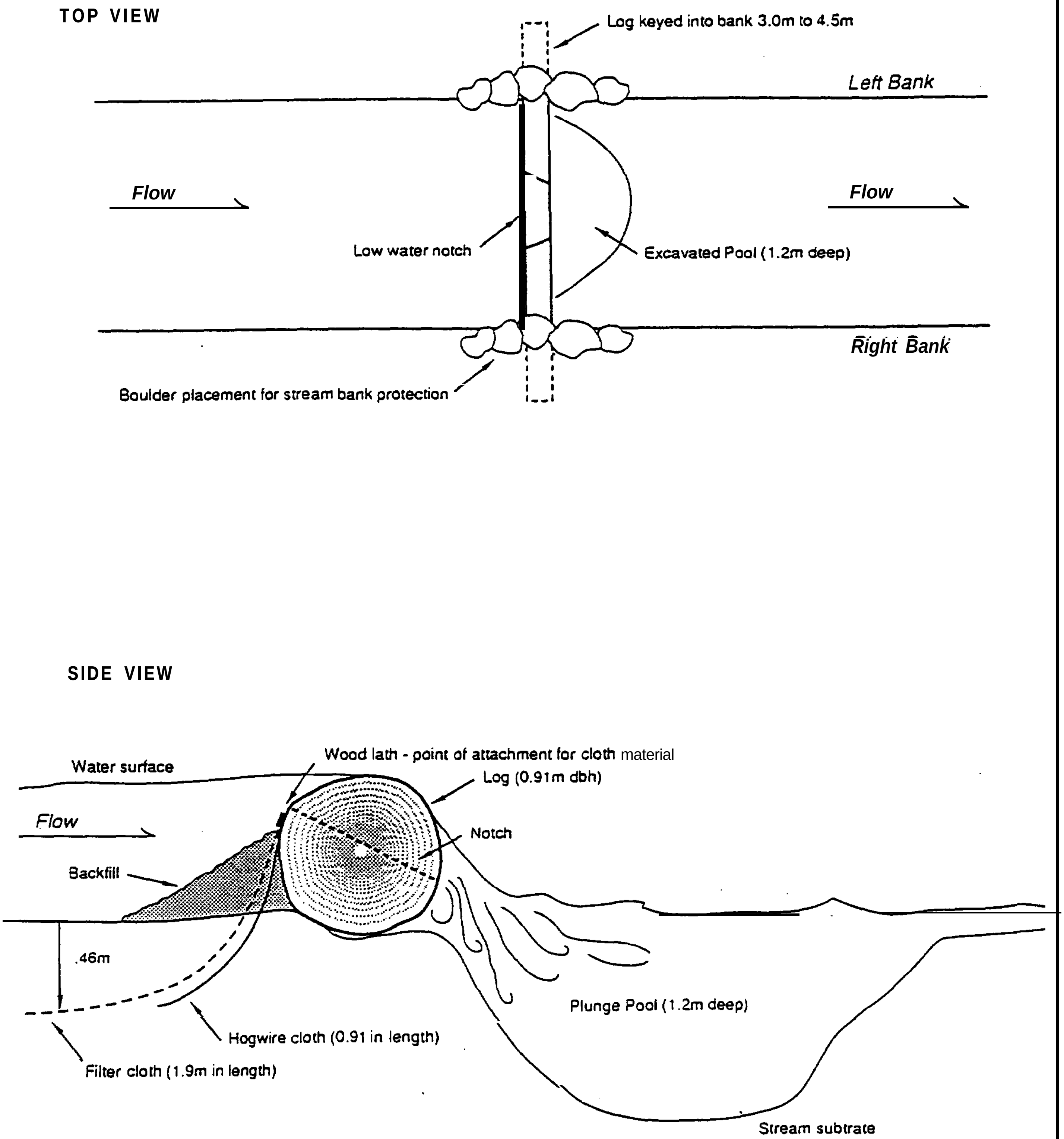
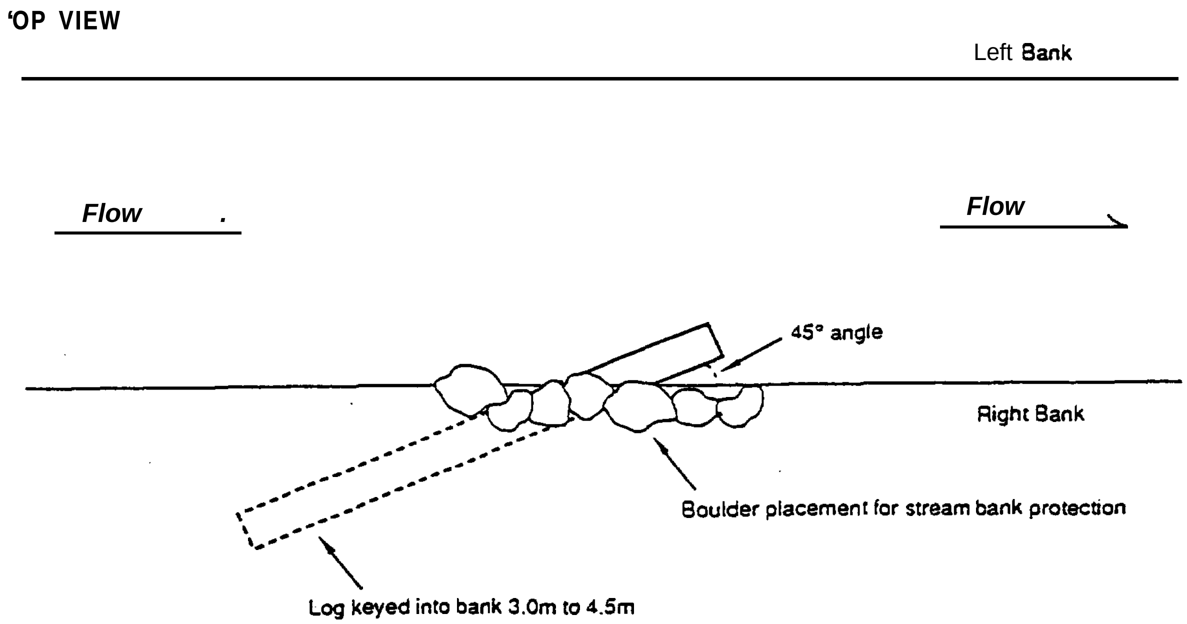


Figure 8. Single wing deflector log construction technique used in the Beaver Creek (Dahl Pine) enhancement project.



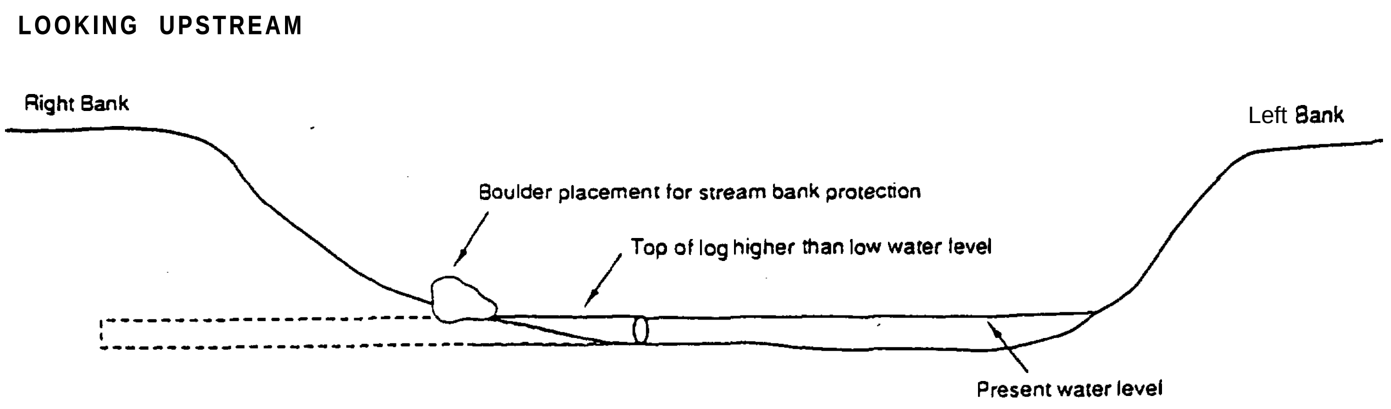


Figure 9. Schematic diagram of large rock forming pool with cover used in the Beaver Creek (Dahl Pine) enhancement project.

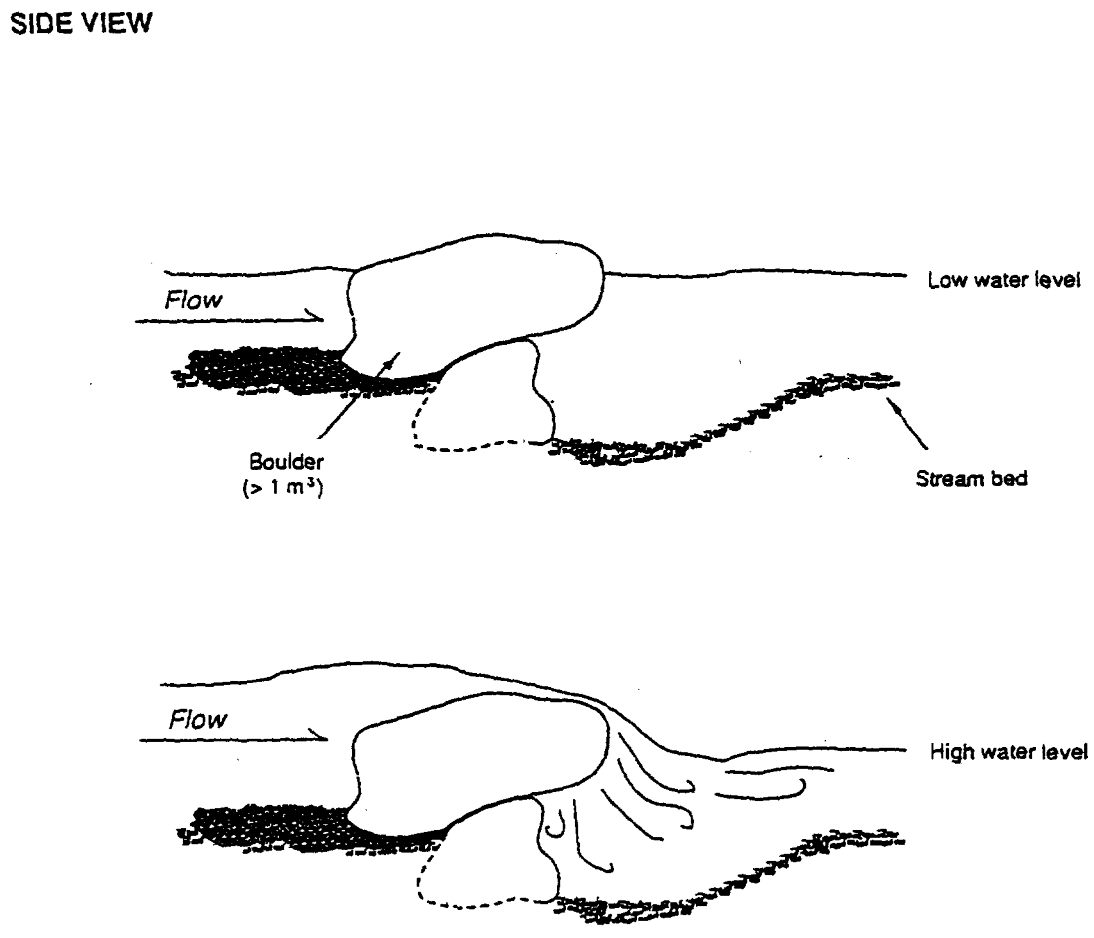


Figure 10. Schematic diagram of rock weir dam used to control water surface elevation and stabilize stream bed used in the Potters Pond enhancement project.

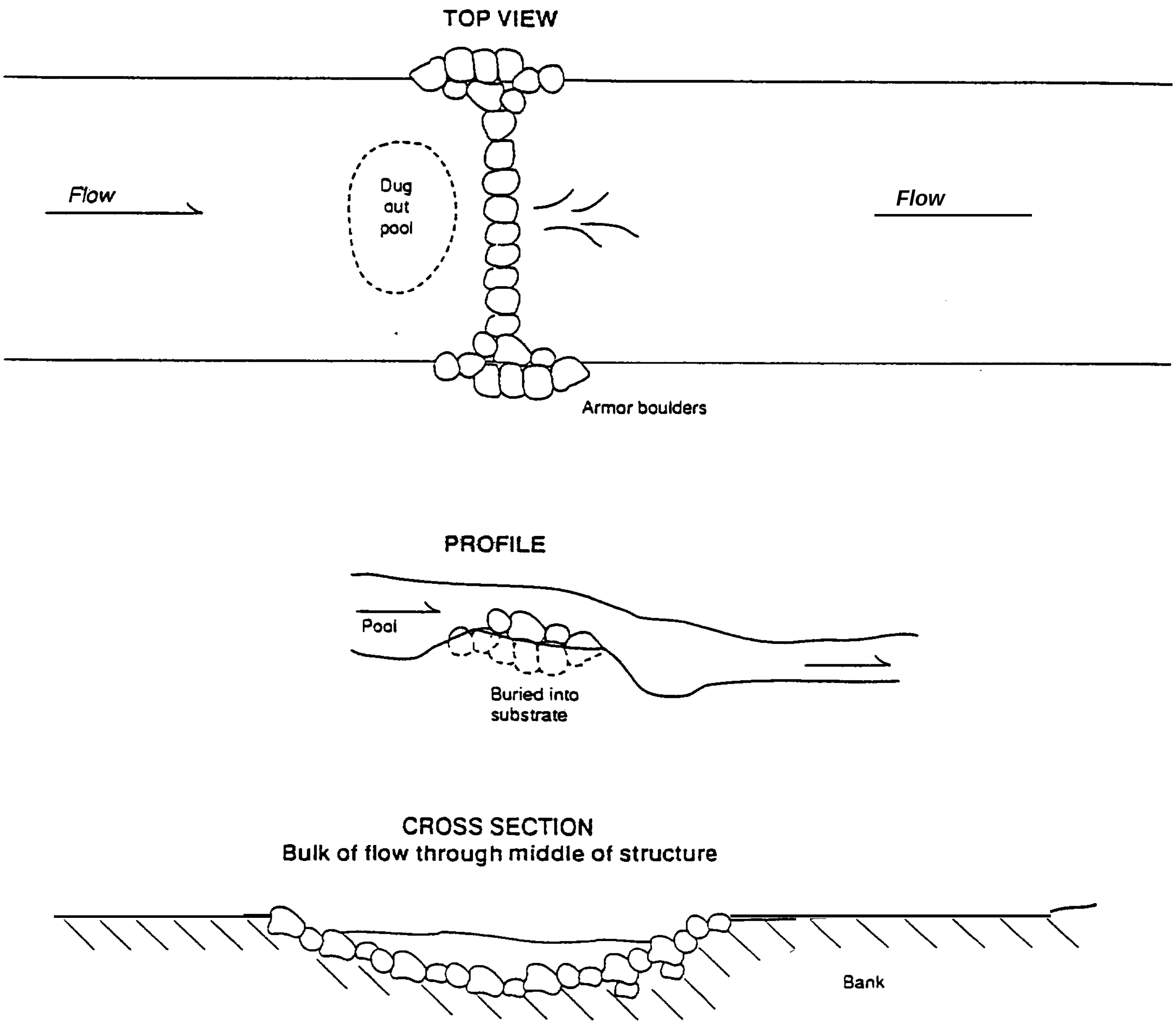


Figure 11. Plan view of rock structures used in the Potters Pond enhancement project.

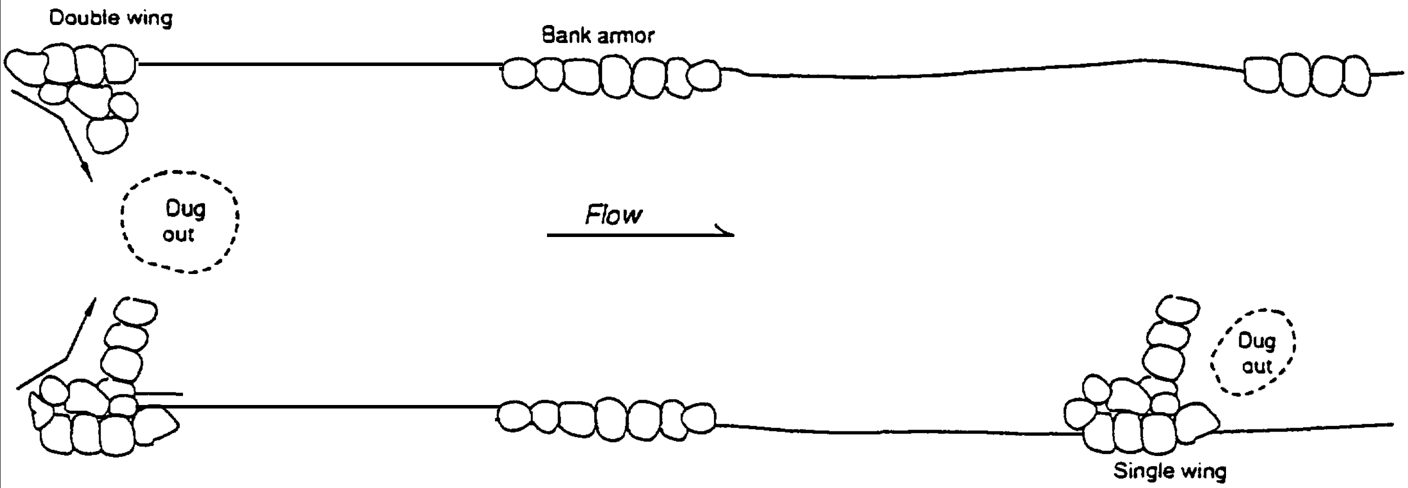


Figure 12. Plan view of rock clusters used in the Potters Pond enhancement project.

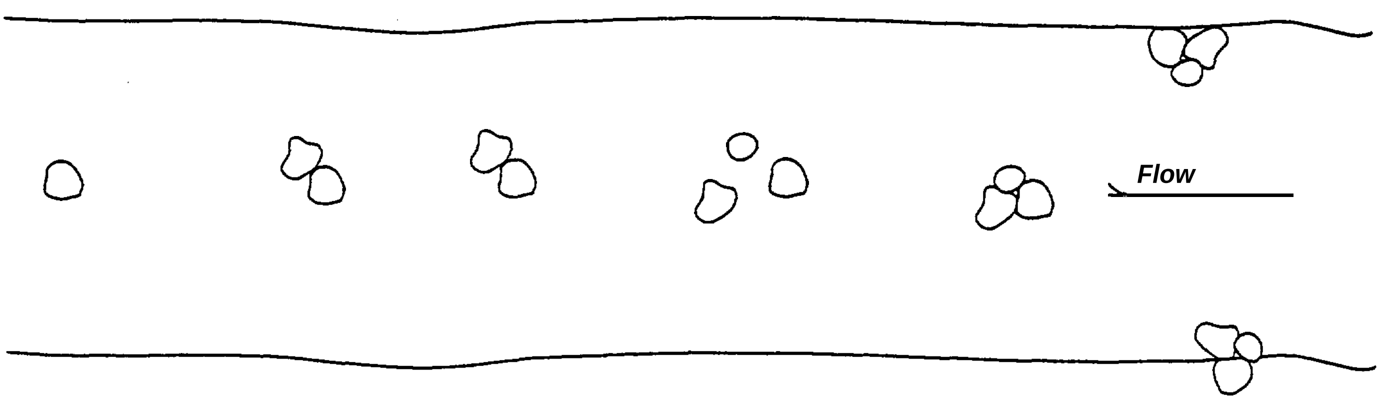


Figure 13. Plan view of turning rock clusters used in the Potters Pond enhancement project.

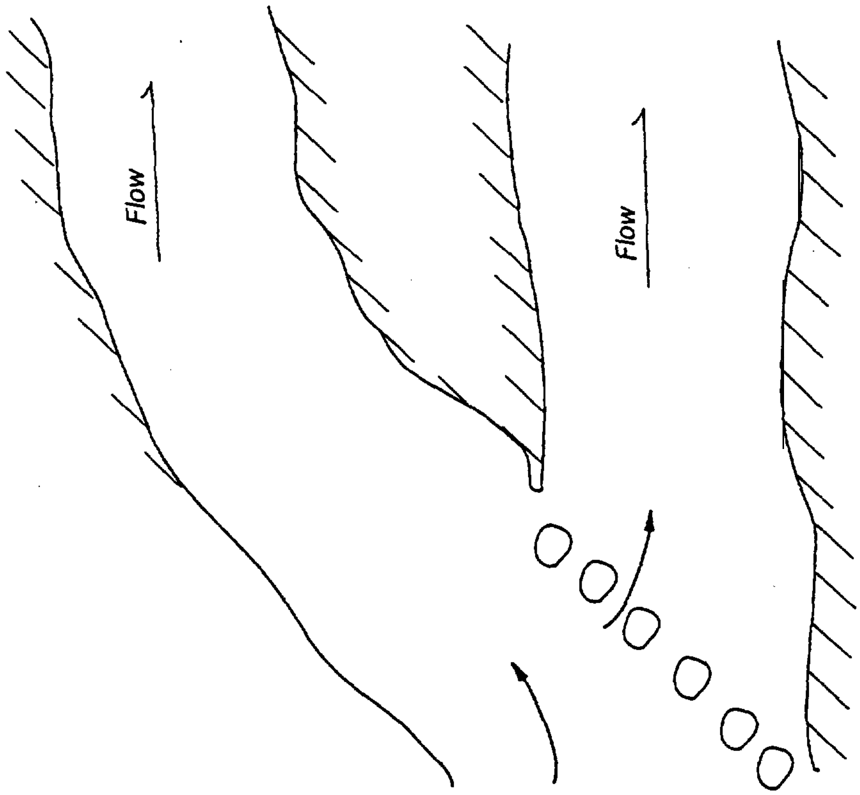
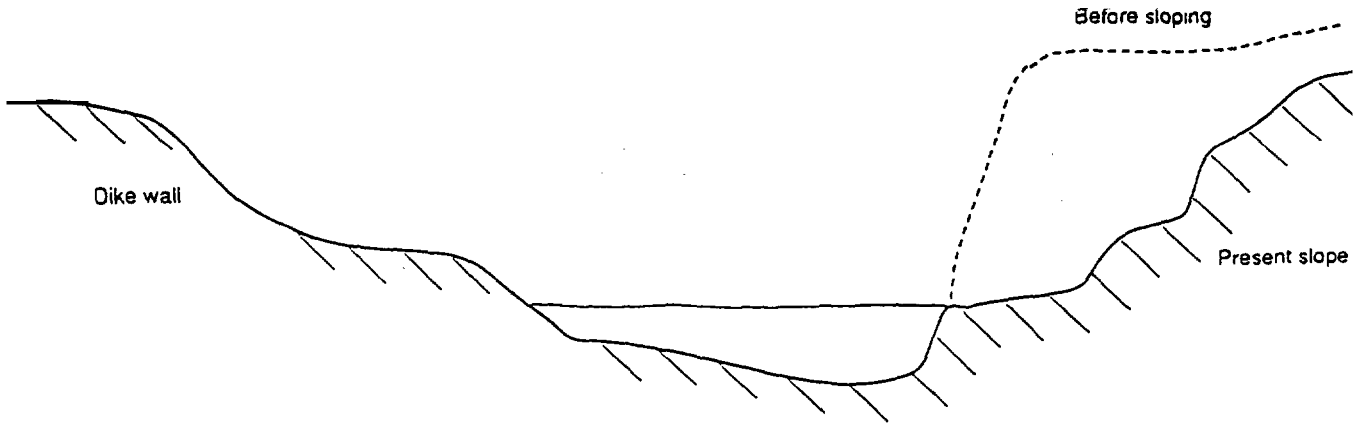


Figure 14. Cross section of dike wall sloping in the Potters Pond enhancement project.



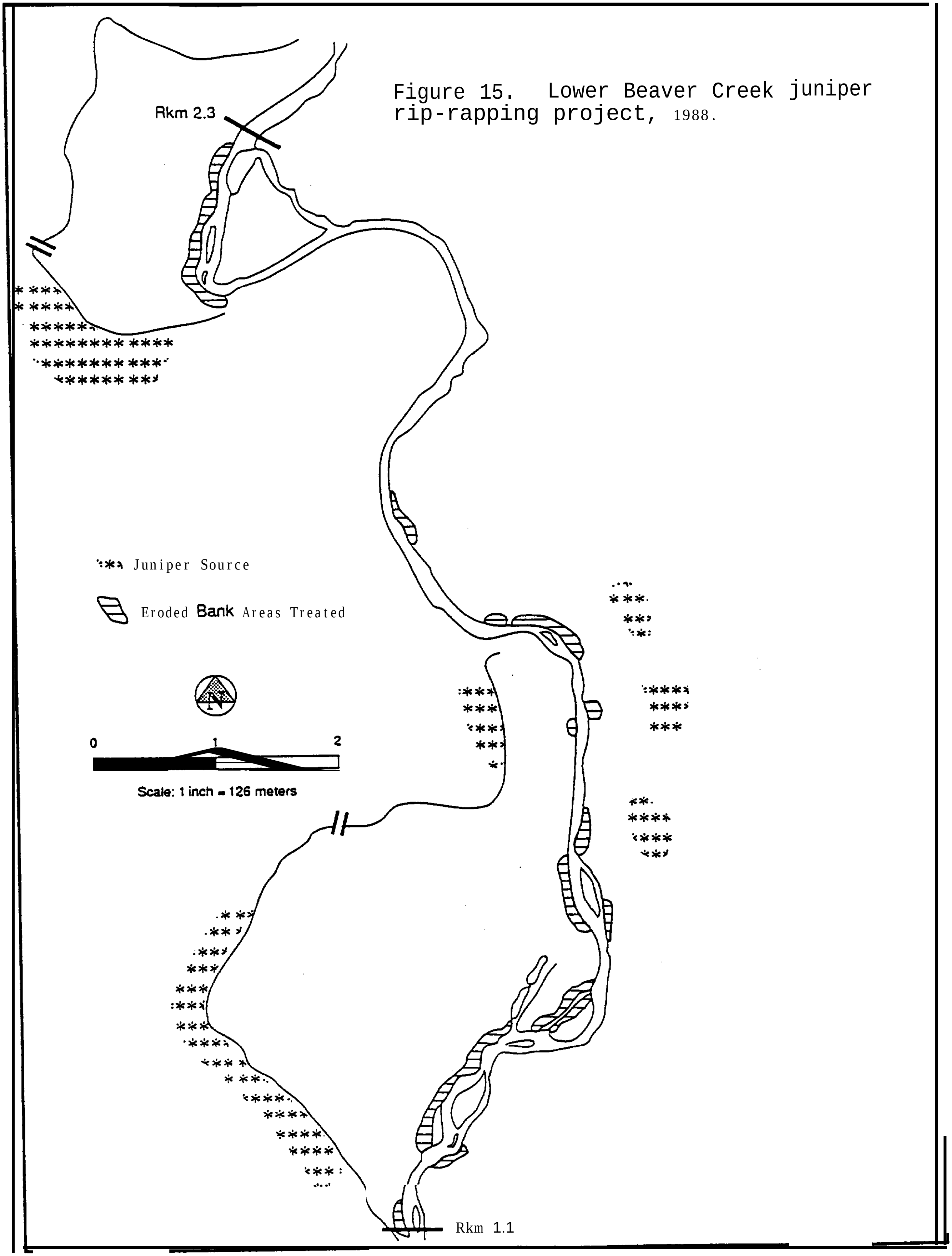
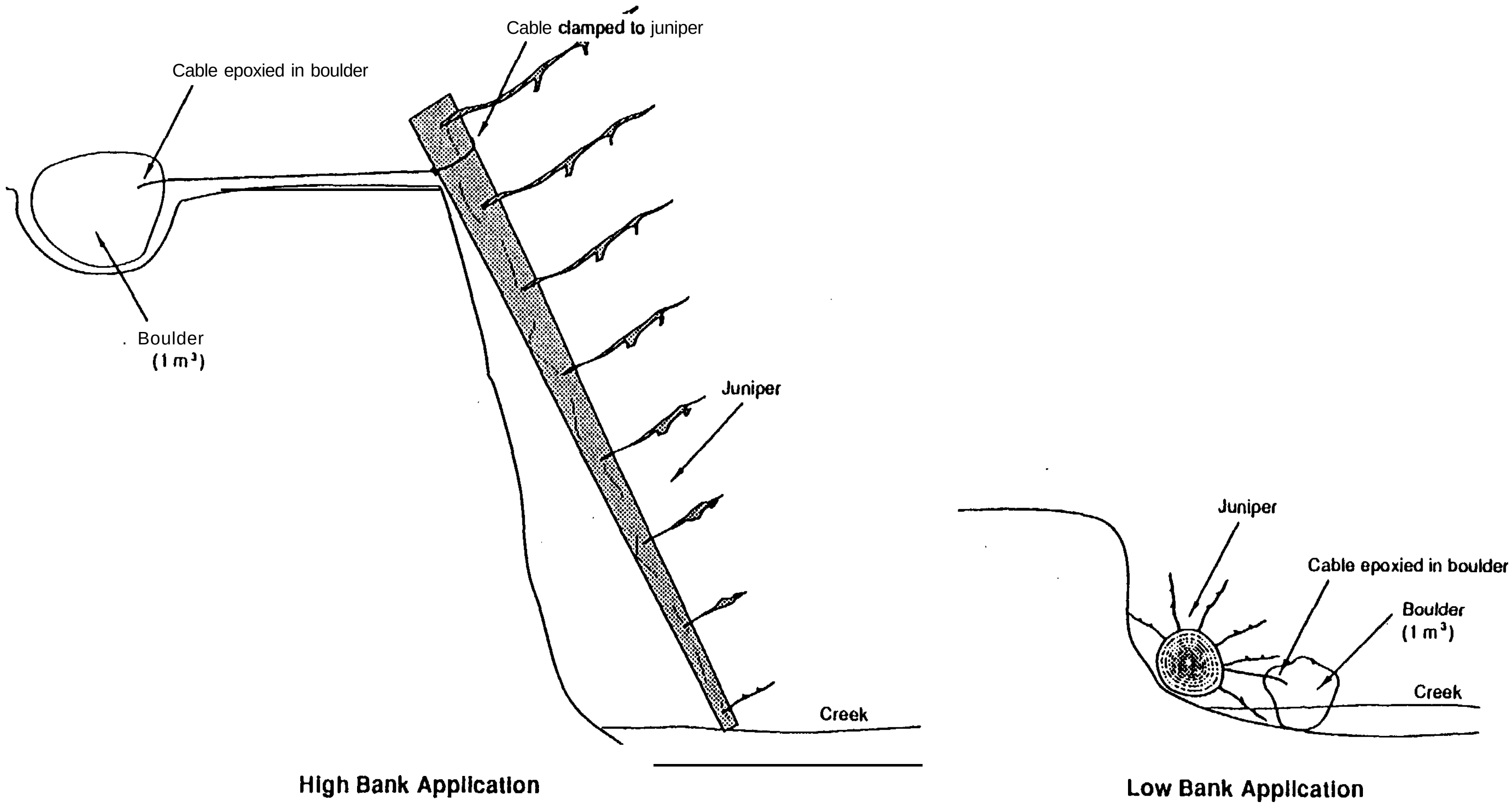


Figure 15. Lower Beaver Creek juniper rip-rapping project, 1988.

Figure 16. Structure details of the lower Beaver Creek and lower Shitike 'Creek juniper rip-rapping project.



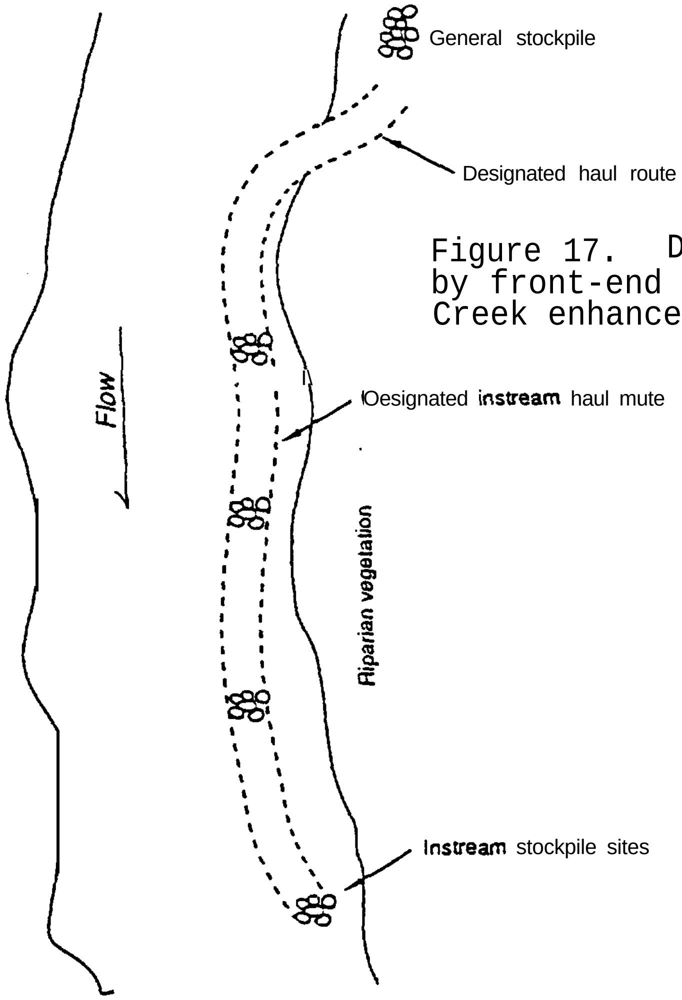


Figure 17. Designated haul routes used by front-end loader for the lower Shitike Creek enhancement project.

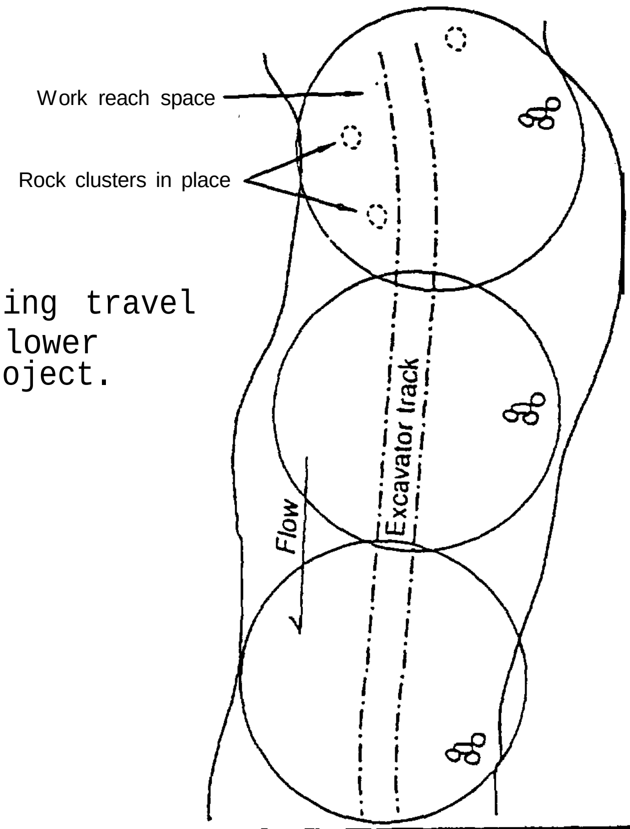


Figure 18. Work area, limiting travel on stream substrate for the lower Shitike Creek enhancement project.

Figure 19. Rock berm construction technique used in the lower Shitike Creek project.

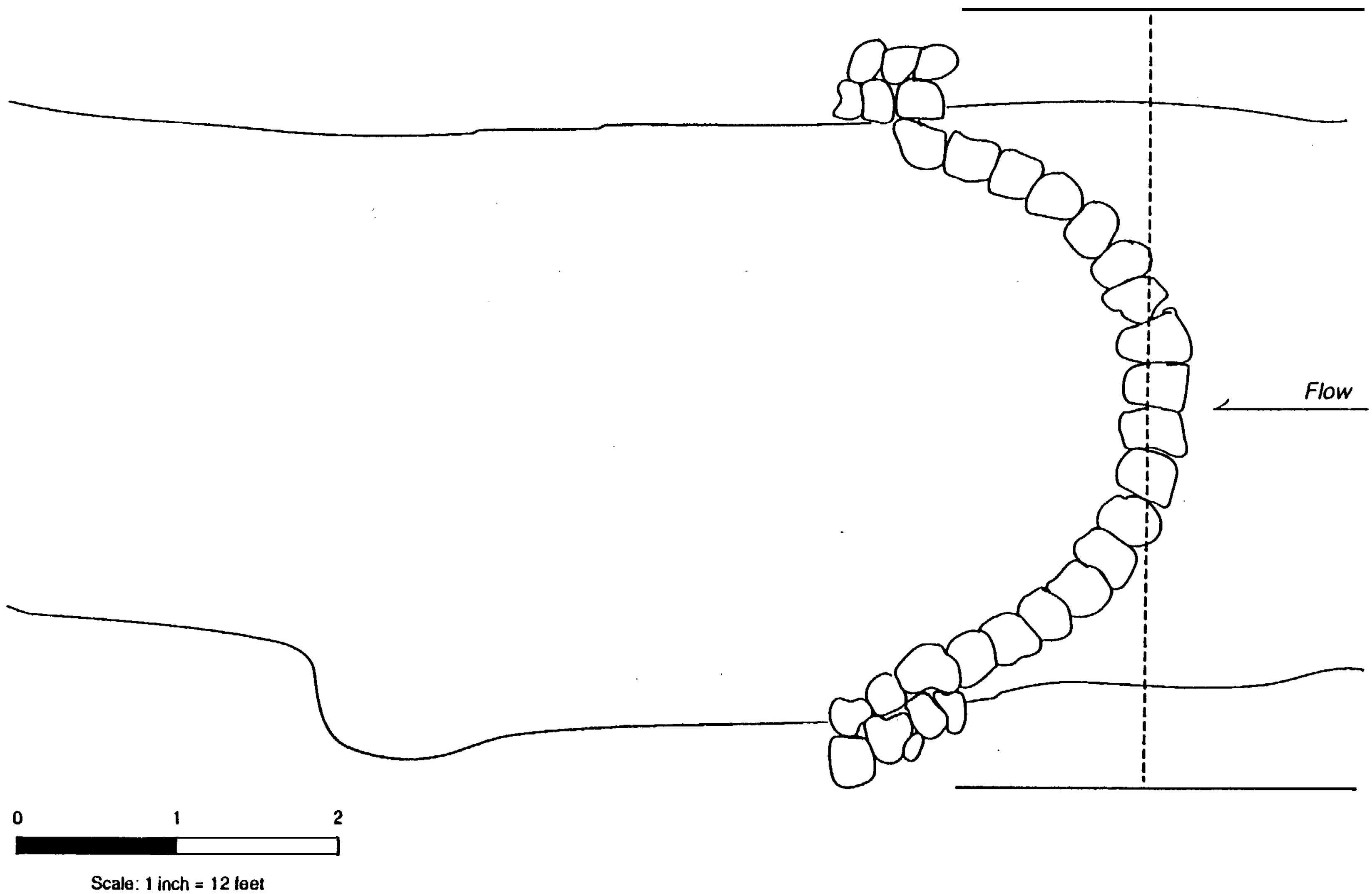
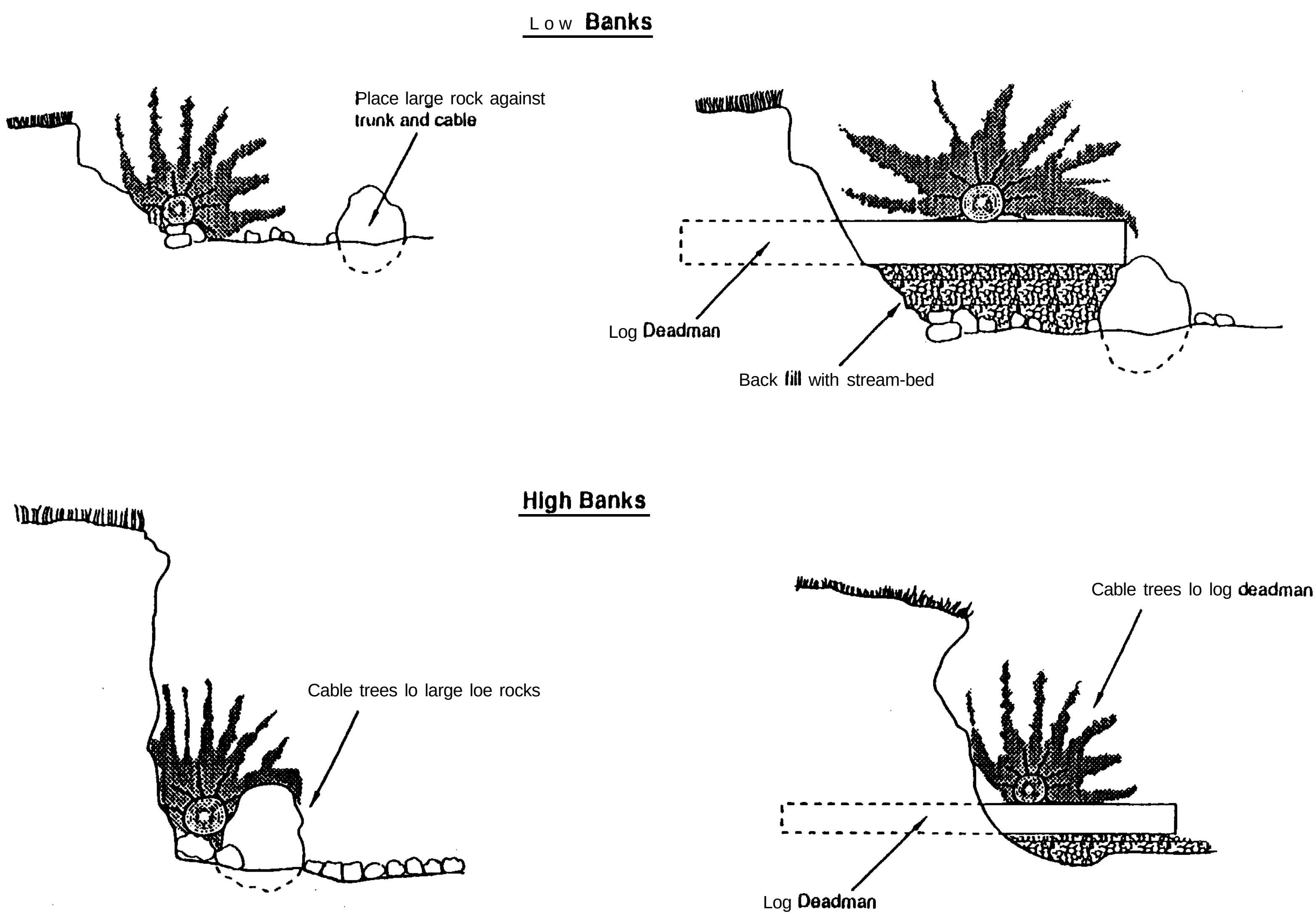


Figure 20. Log deadman construction details used in the lower Shitike Creek enhancement project.



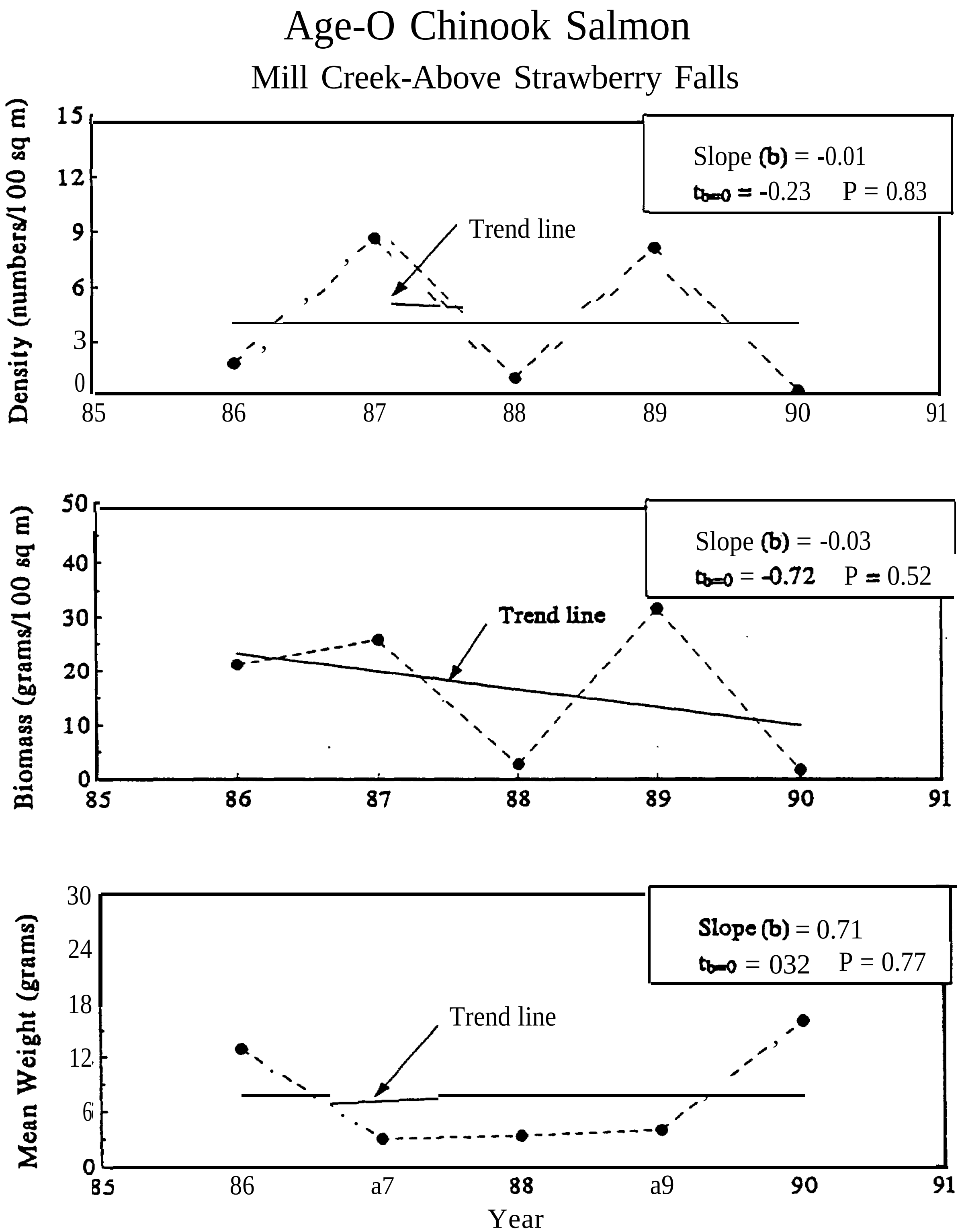


Figure 21. Time series of densities, biomasses, and mean weights of juvenile chinook salmon in the above Strawberry Falls site on Mill Creek, Oregon.

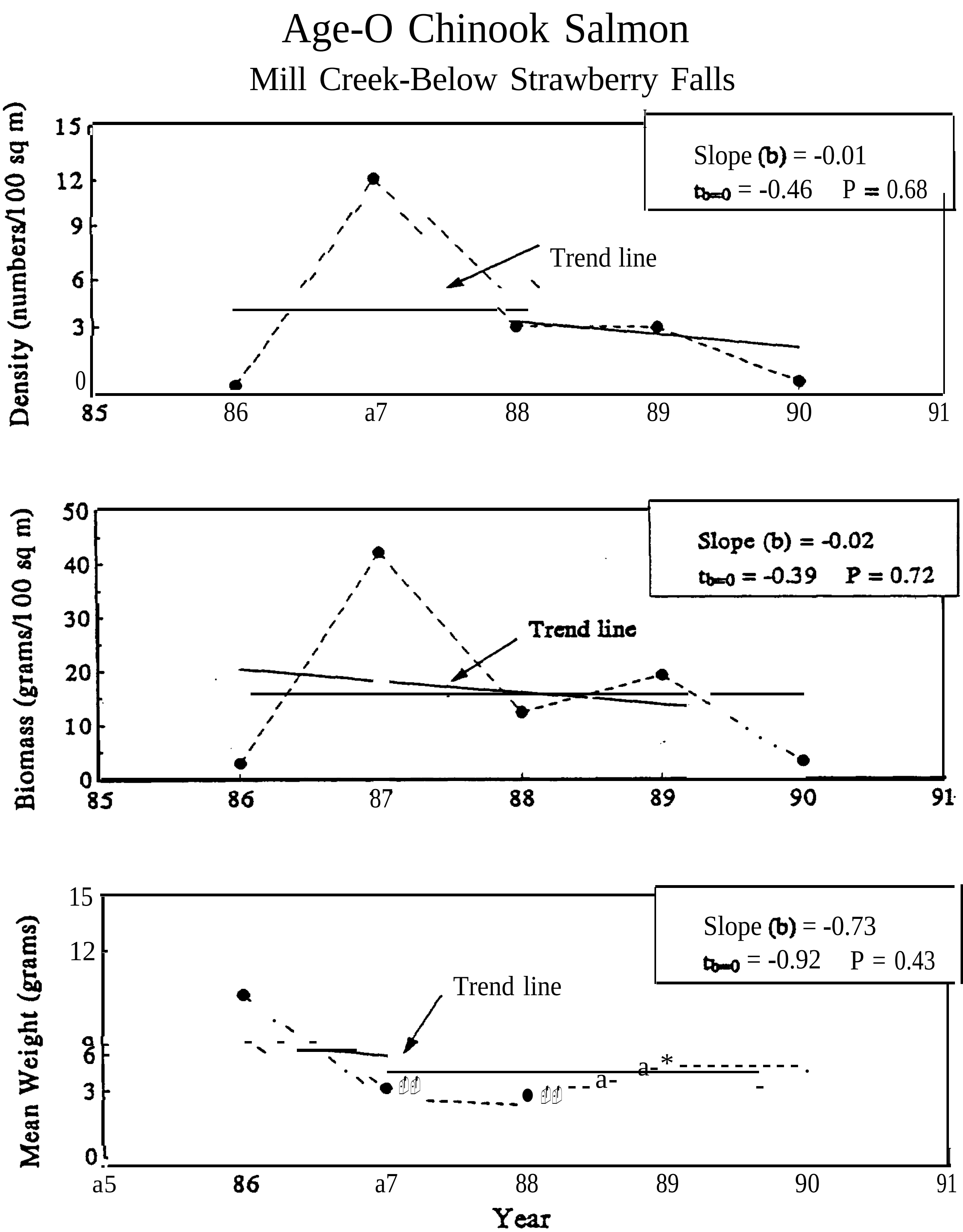


Figure 22. Time series of densities, biomasses, and mean weights of juvenile chinook salmon in the below Strawberry Falls site on Mill Creek, Oregon.

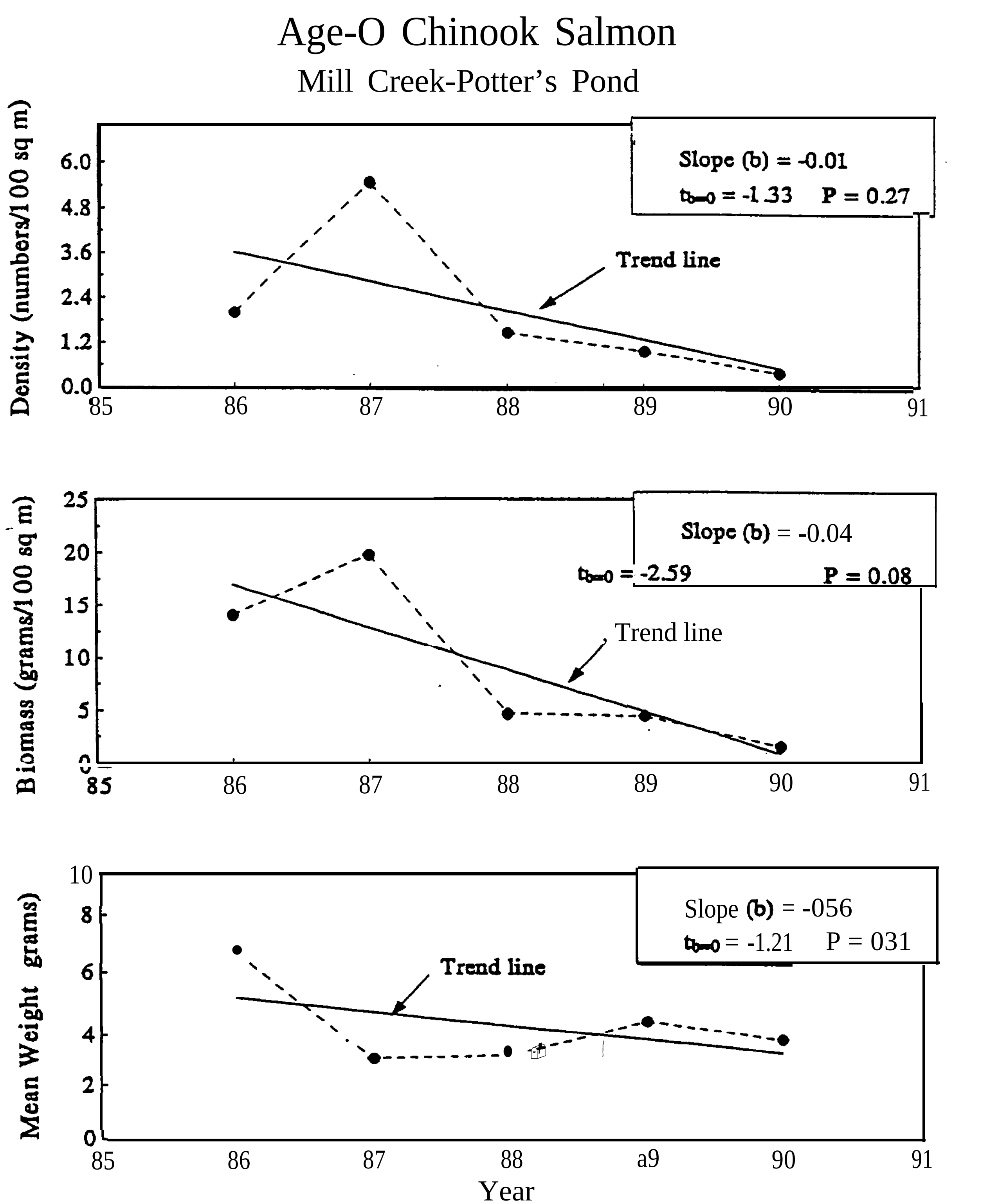


Figure 23. Time series of densities, biomasses, and mean weights of juvenile chinook salmon in the Potter's Pond site on Mill Creek, Oregon.

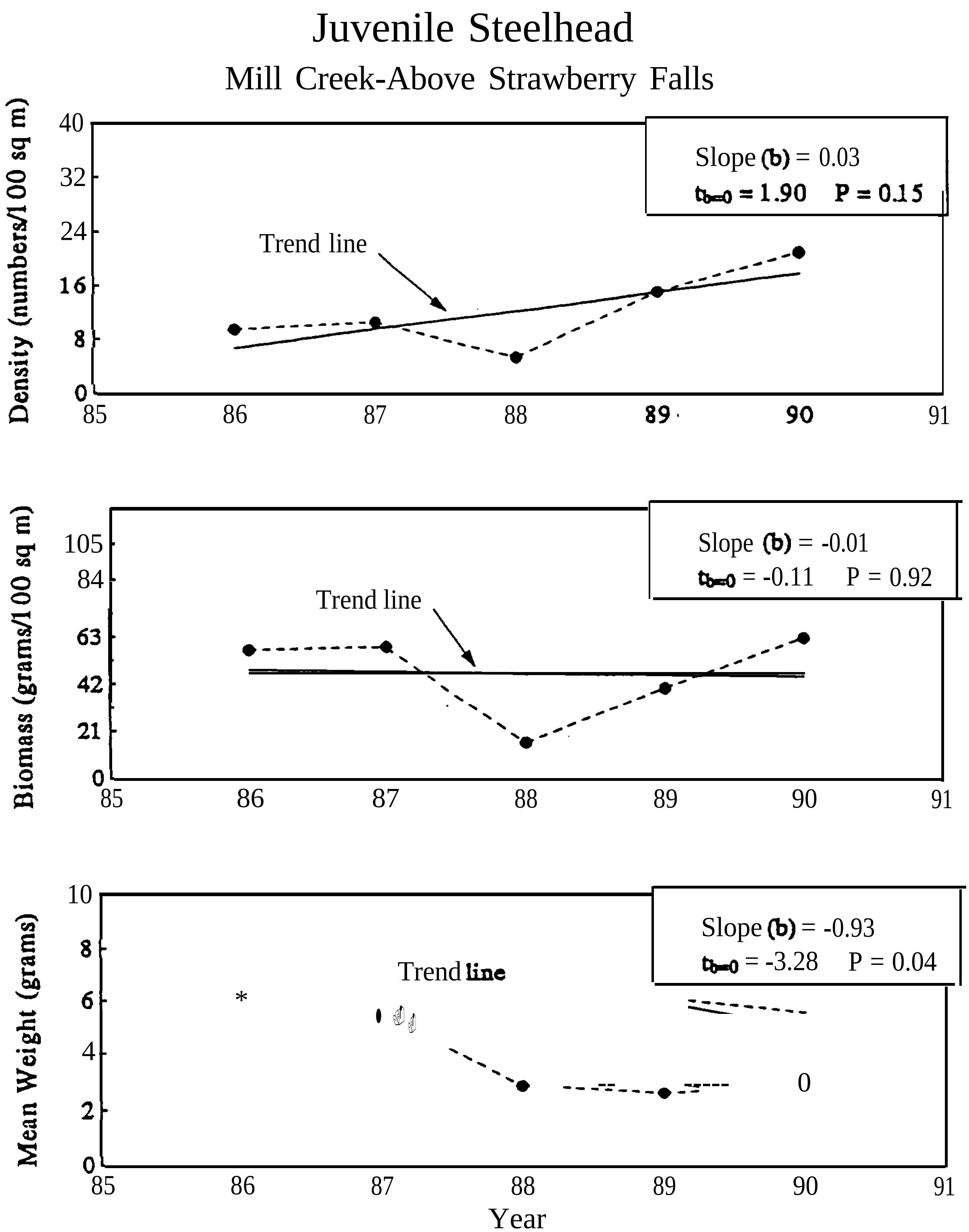


Figure 24. Time series of densities, biomasses, and mean weights of juvenile steelhead in the above Strawberry Falls site on Mill Creek, Oregon.

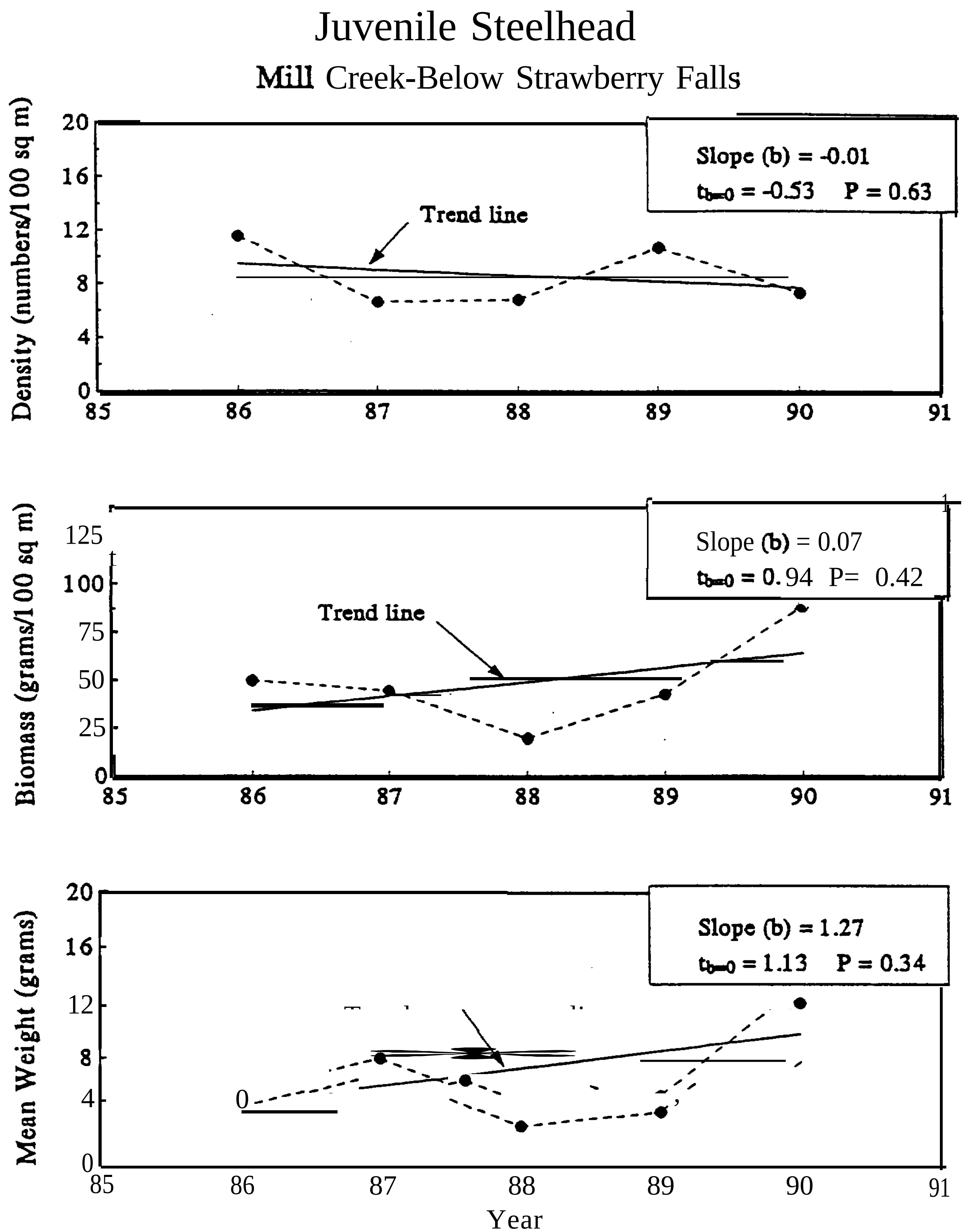


Figure 25. Time series of densities, biomasses, and mean weights of juvenile steelhead in the below Strawberry Falls site on Mill Creek, Oregon.

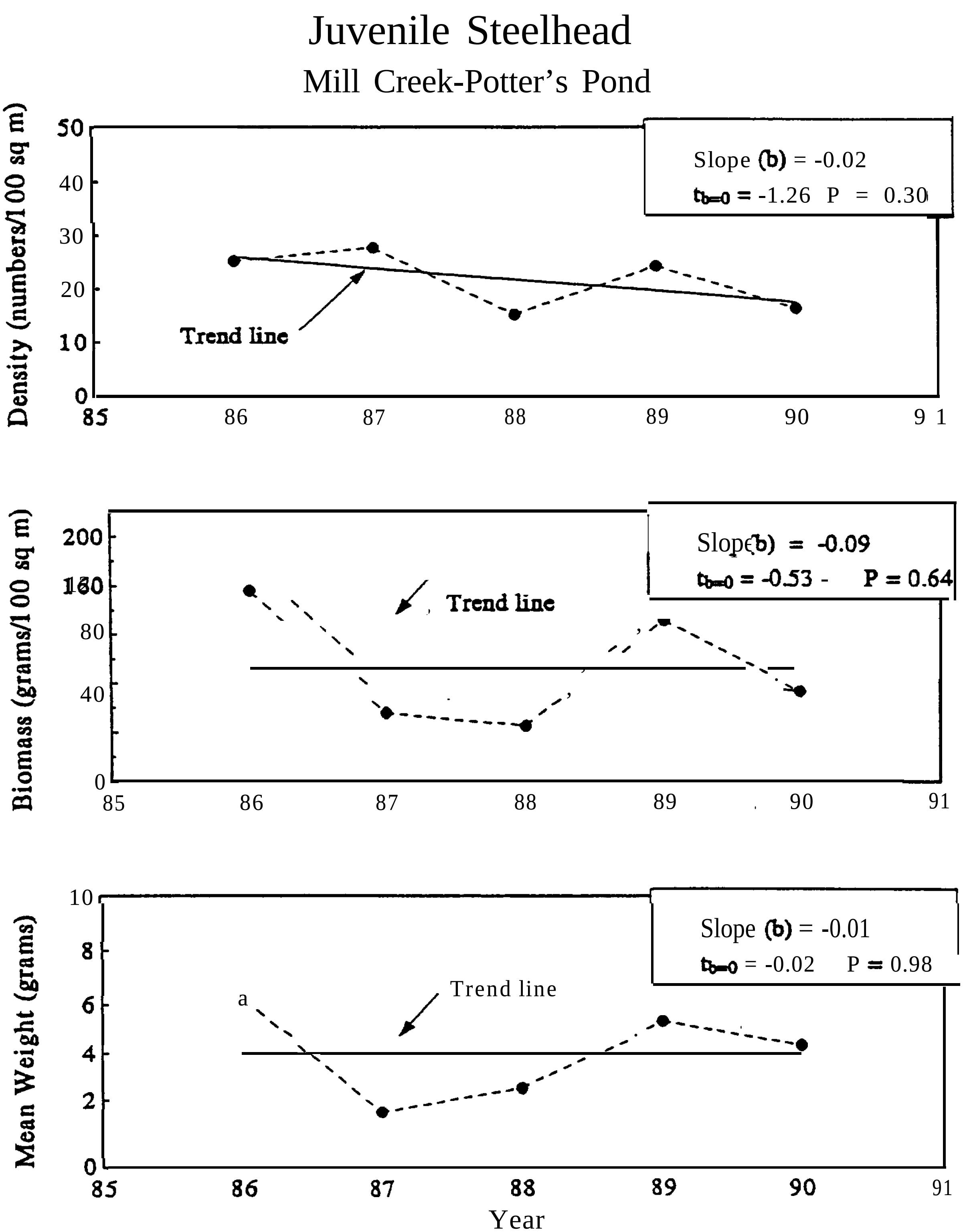


Figure 26. Time series of densities, biomasses, and mean weights of juvenile steelhead in the Potter's Pond site on Mill Creek, Oregon.

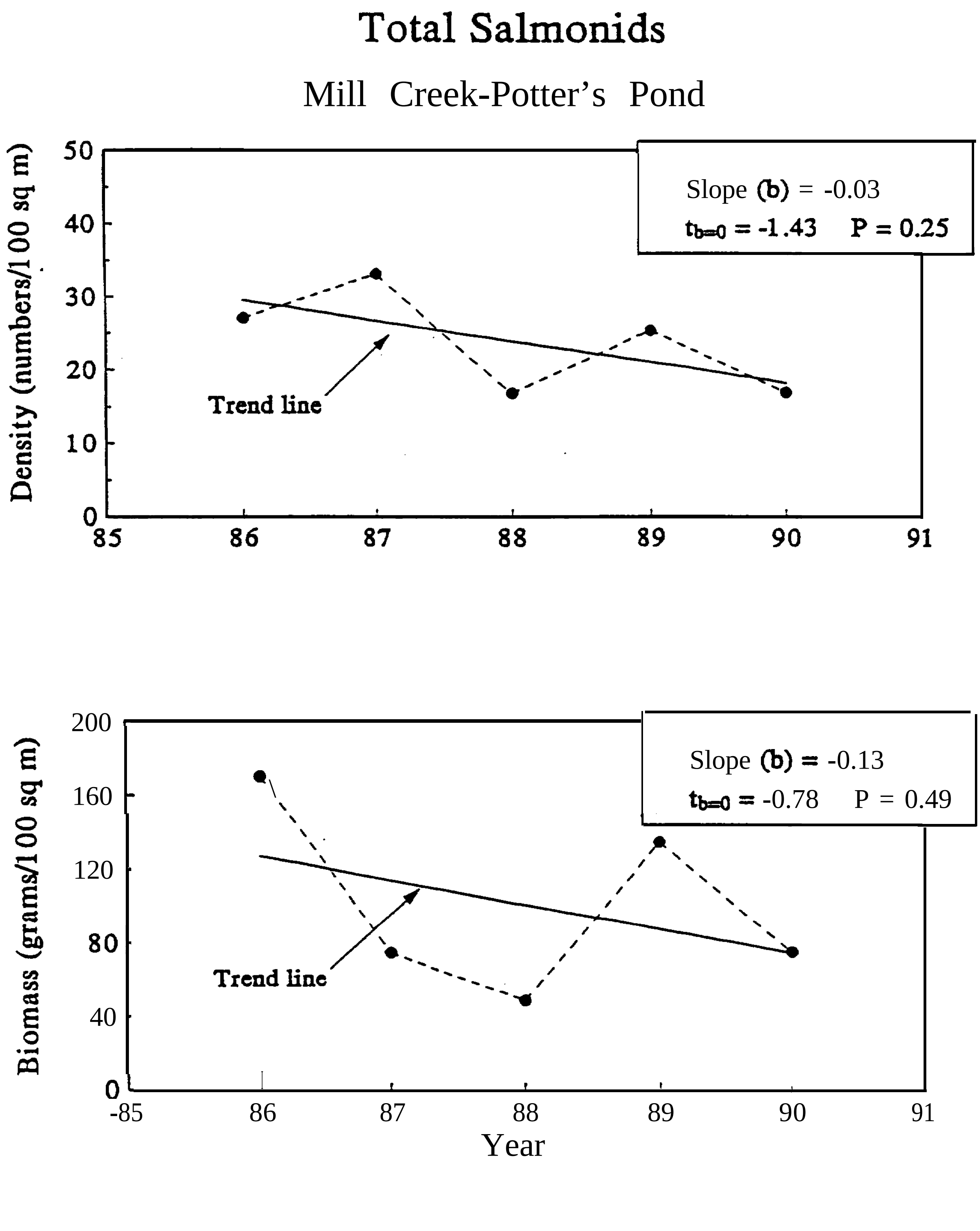


Figure 27. Time series of densities and biomasses of all salmonids in the Potter's Pond site on Mill Creek, Oregon.

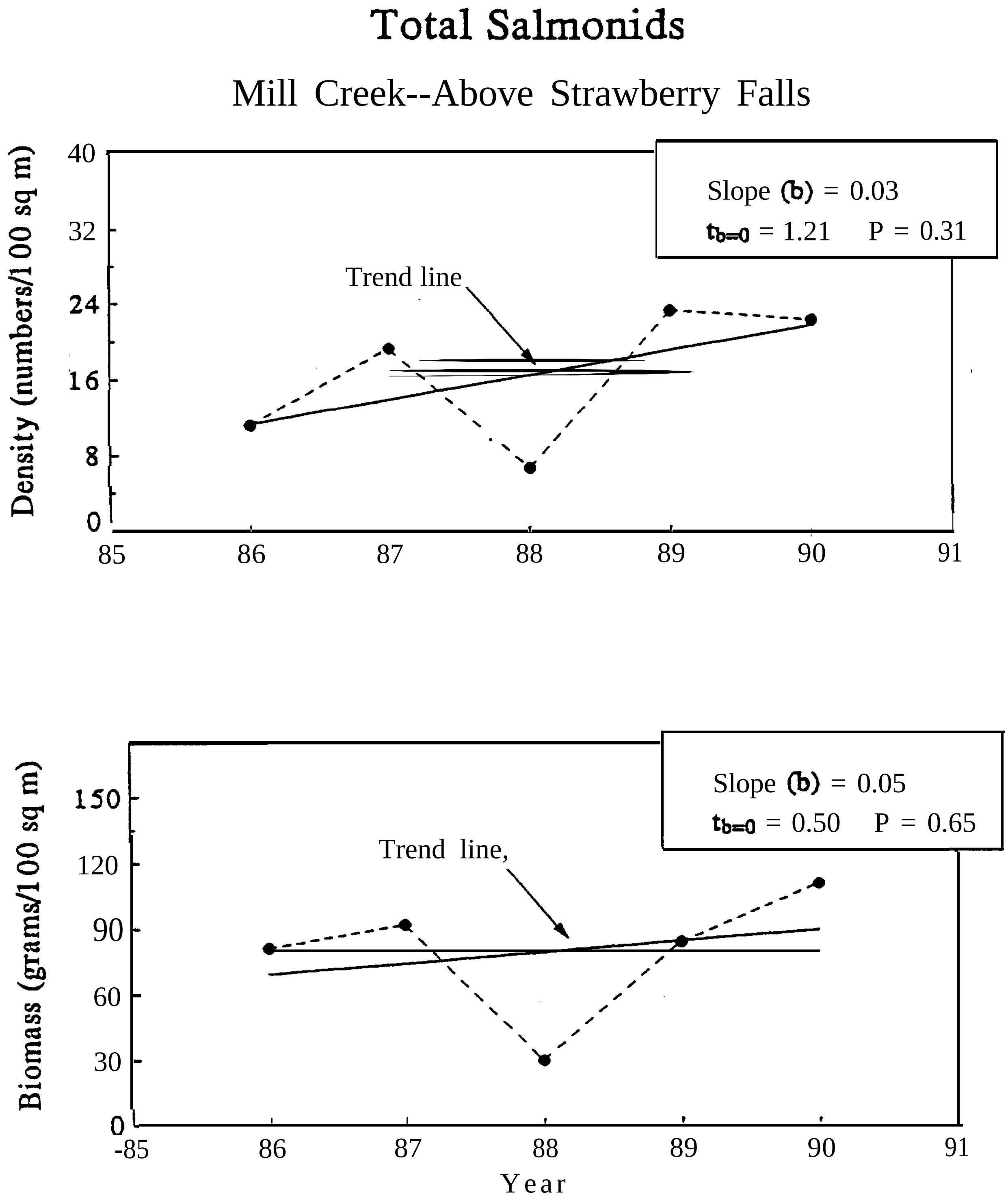
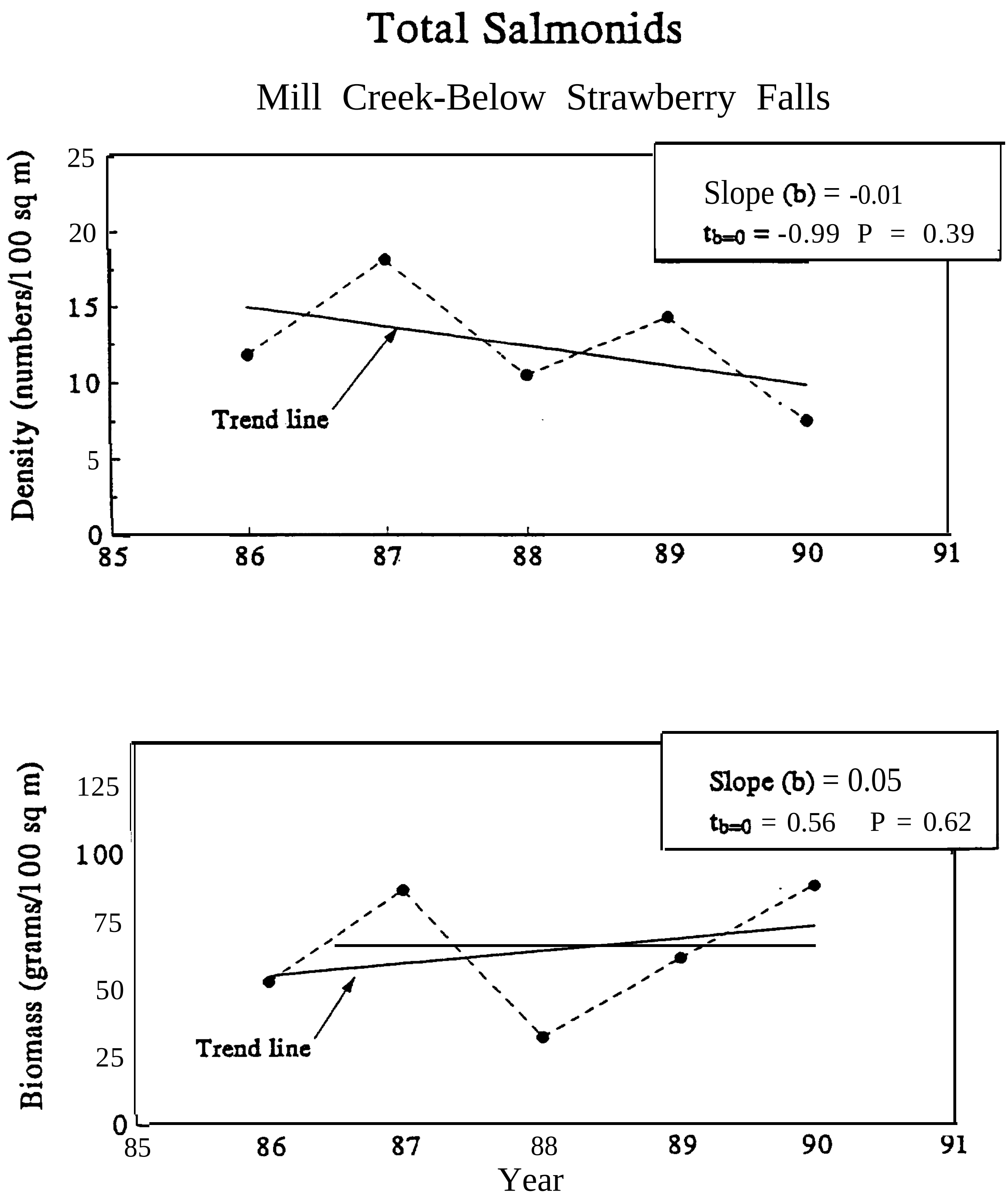


Figure 28. Time series of densities and biomasses of all salmonids in the above Strawberry Falls site on Mill Creek, Oregon.



'Figure 29. Time series of densities and biomasses of all salmonids in the below Strawberry Falls site on Mill Creek, Oregon.

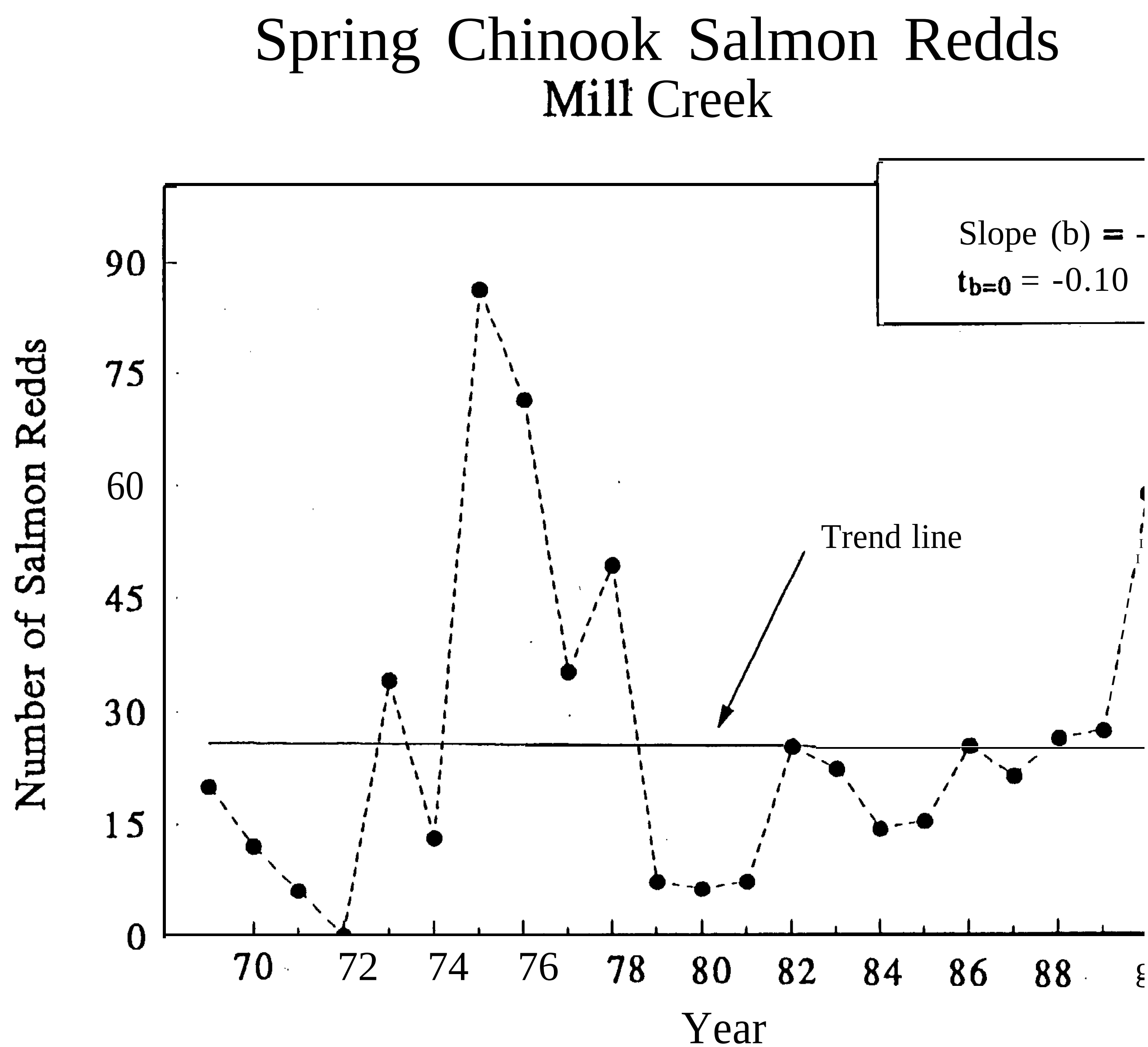


Figure 30. Time series of numbers of chinook salmon redds in historical i
areas on Mill Creek, Oregon.

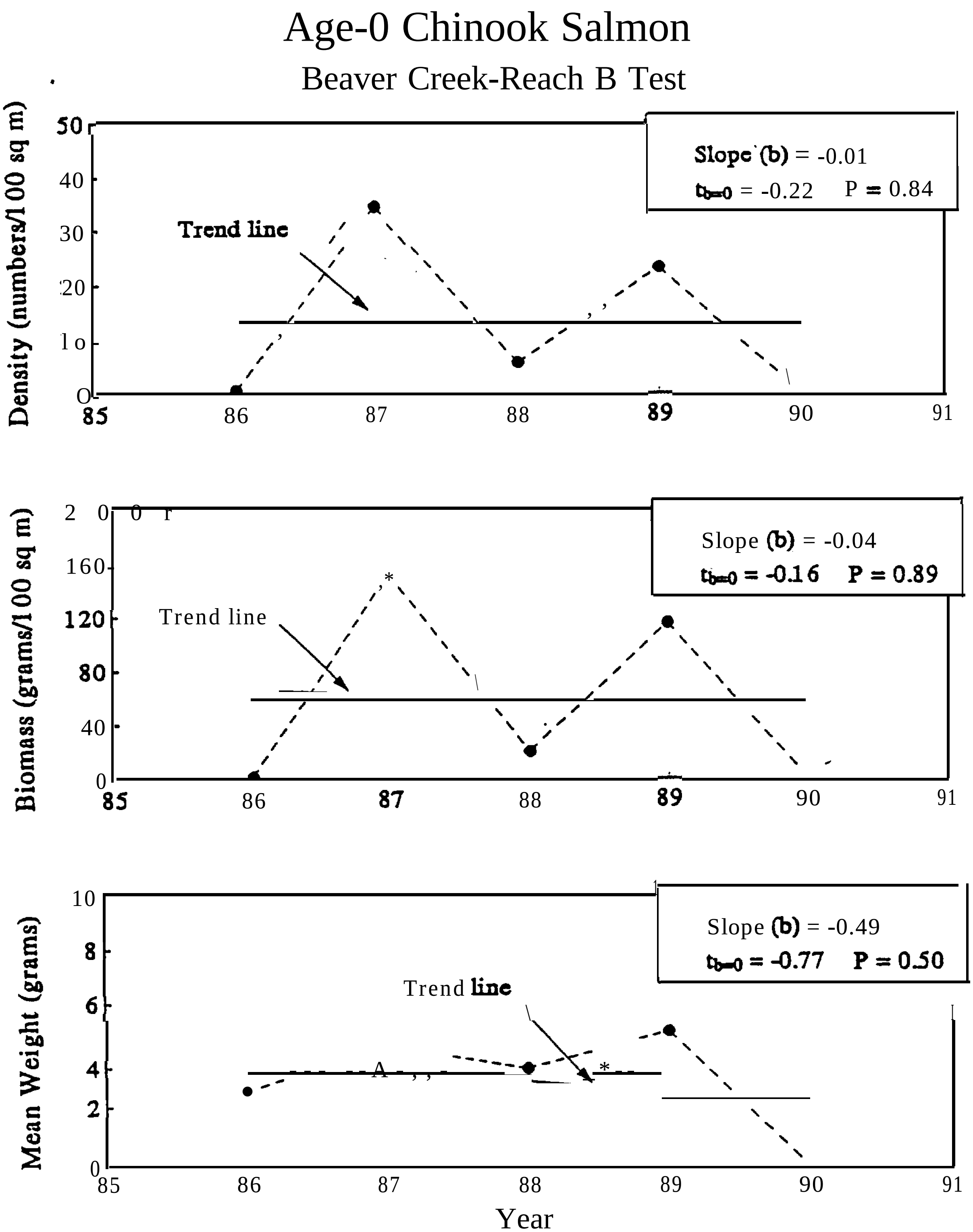


Figure 31. Time series of densities, biomasses, and mean weights of juvenile chinook salmon in the Reach B Test site on Beaver Creek, Oregon.

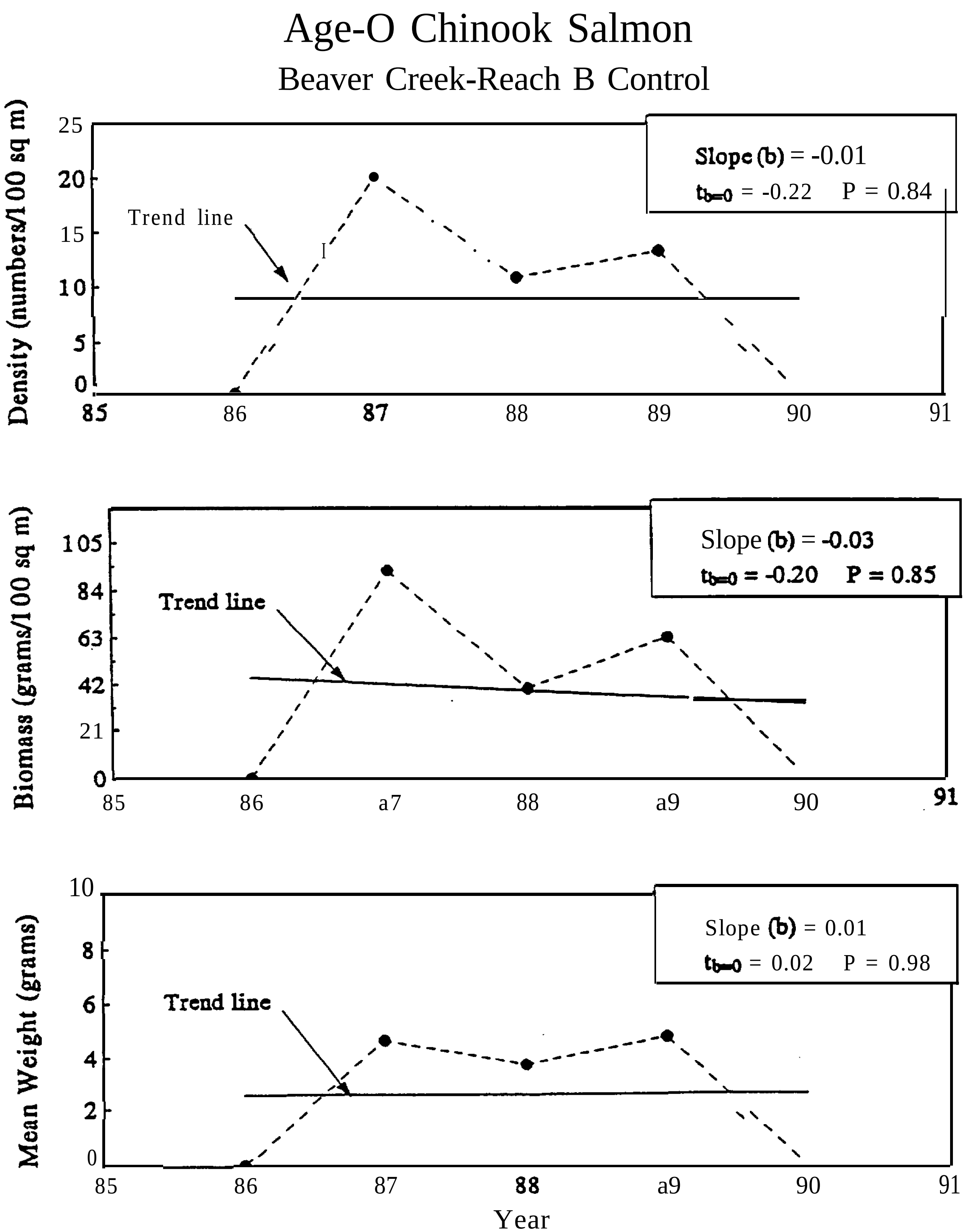


Figure 32. Time series of densities, biomasses, and mean weights of juvenile chinook salmon in the Reach B Control site on Beaver Creek, Oregon.

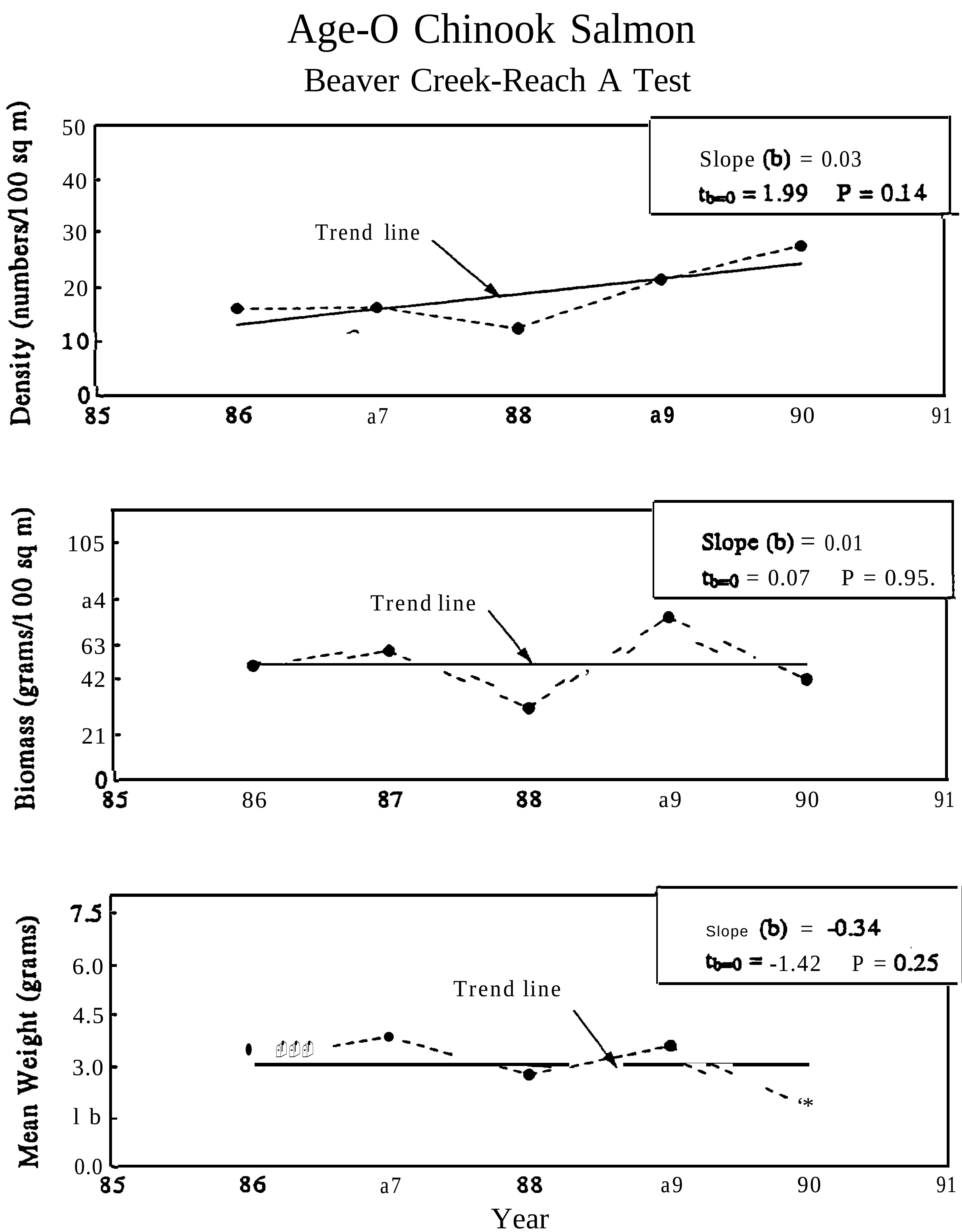


Figure 33. Time series of densities, biomasses, and mean weights of juvenile chinook salmon in the Reach A Test site on Beaver Creek, Oregon.

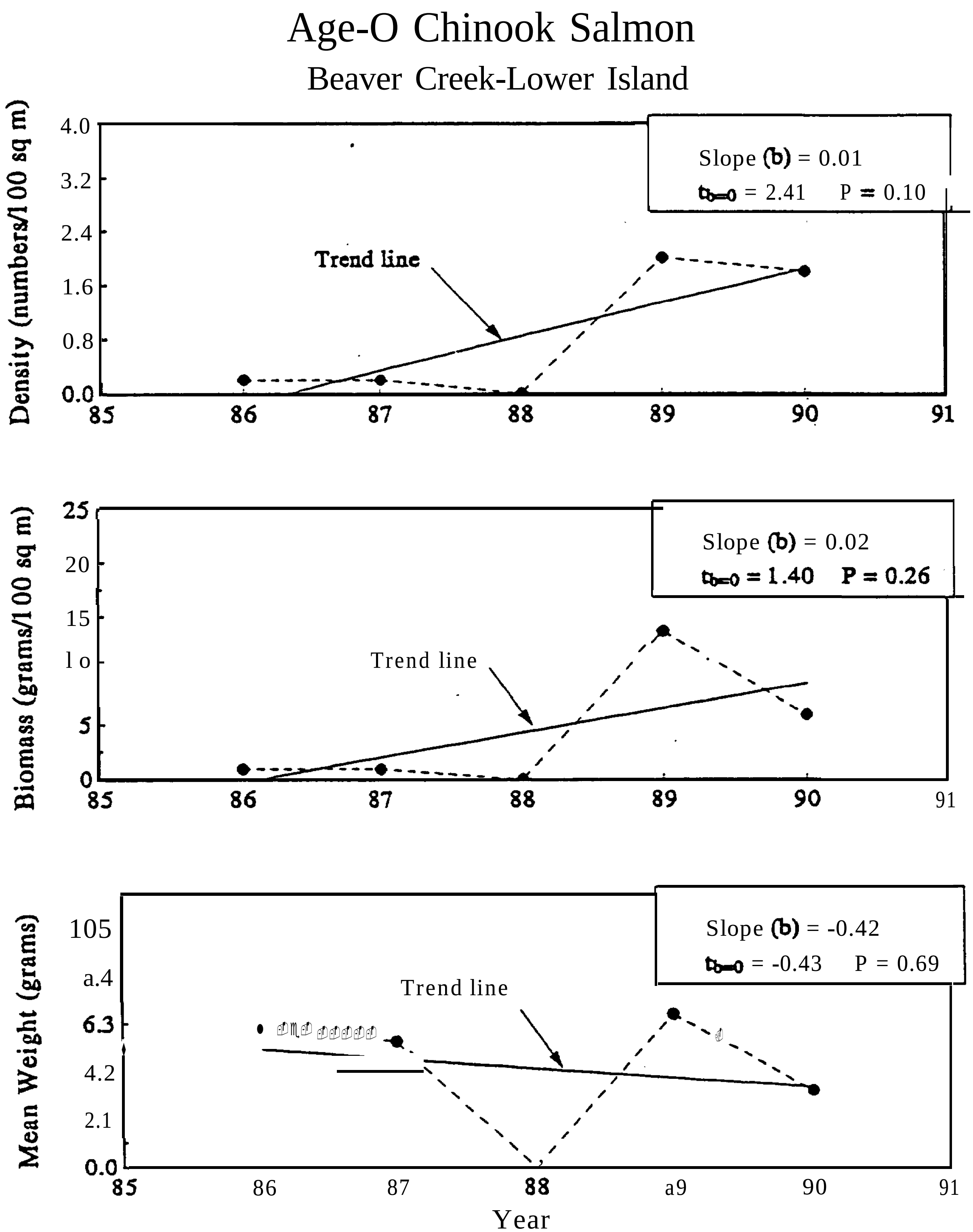


Figure 34. Time series of densities, biomasses, and mean weights of juvenile chinook salmon in the Lower Island site on Beaver Creek, Oregon.

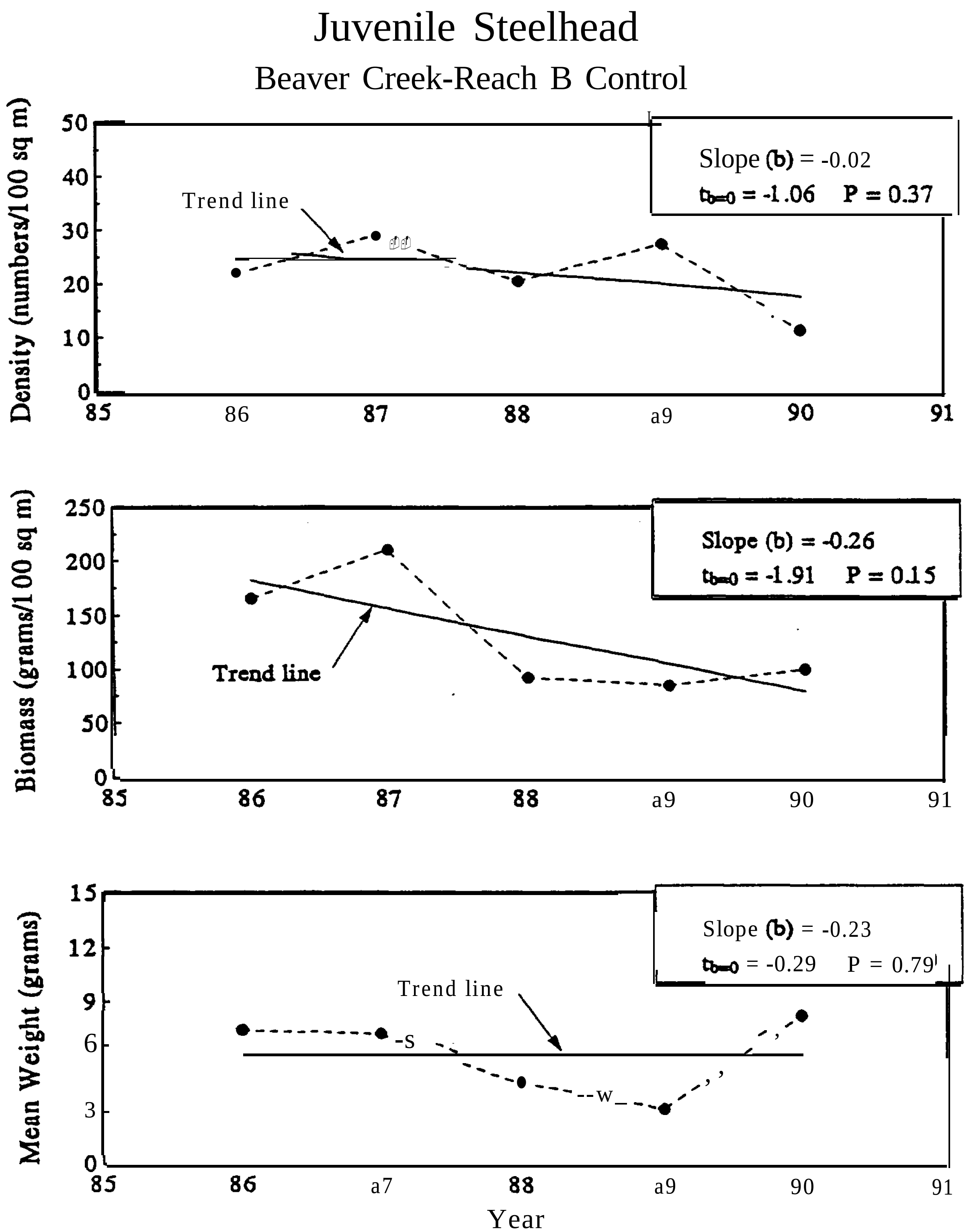


Figure 35. Time series of densities, biomasses, and mean weights of juvenile steelhead in the Reach B Control site on Beaver Creek, Oregon.

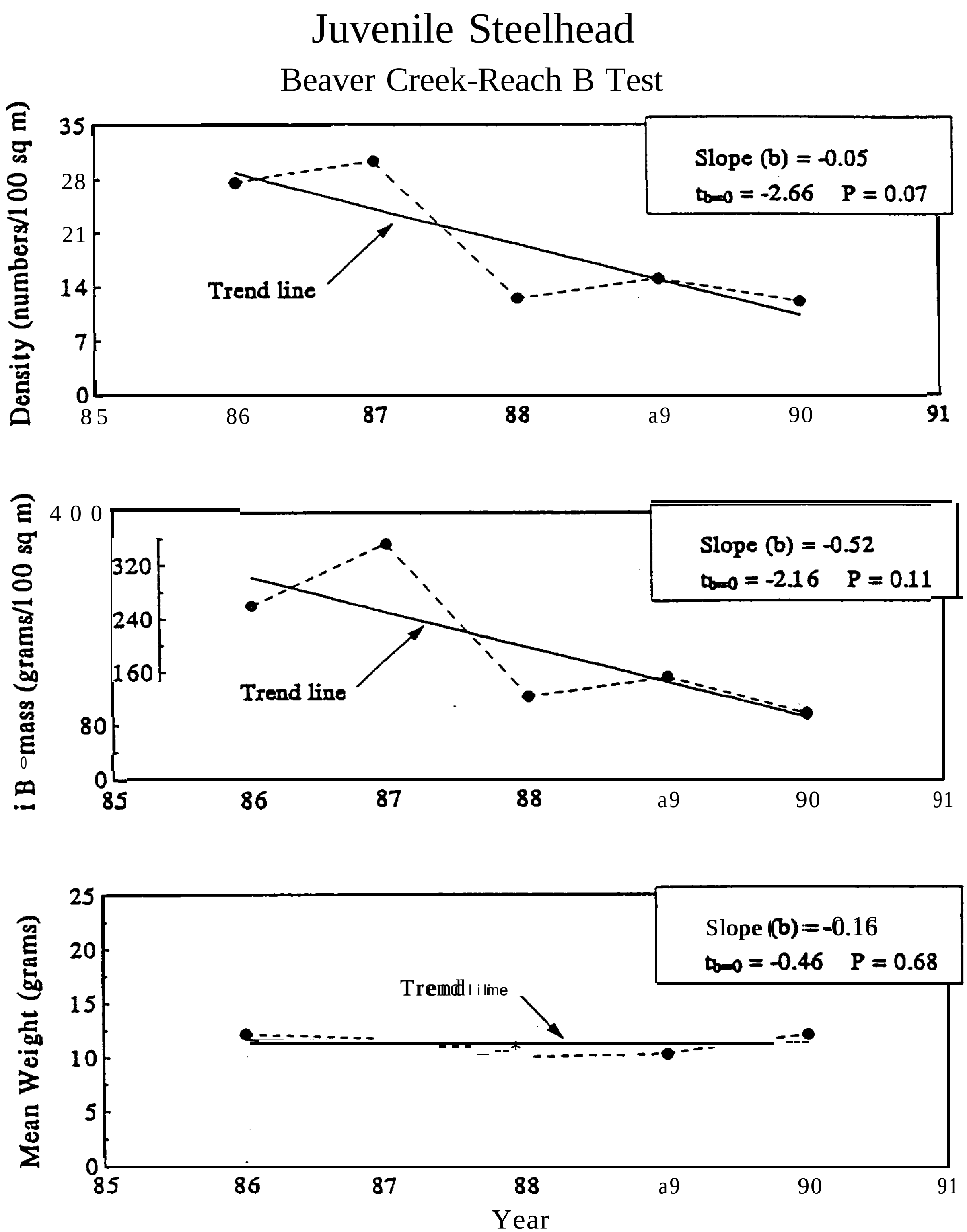


Figure 36. Time series of densities, biomasses, and mean weights of juvenile steelhead in the Reach B Test site on Beaver Creek, Oregon.

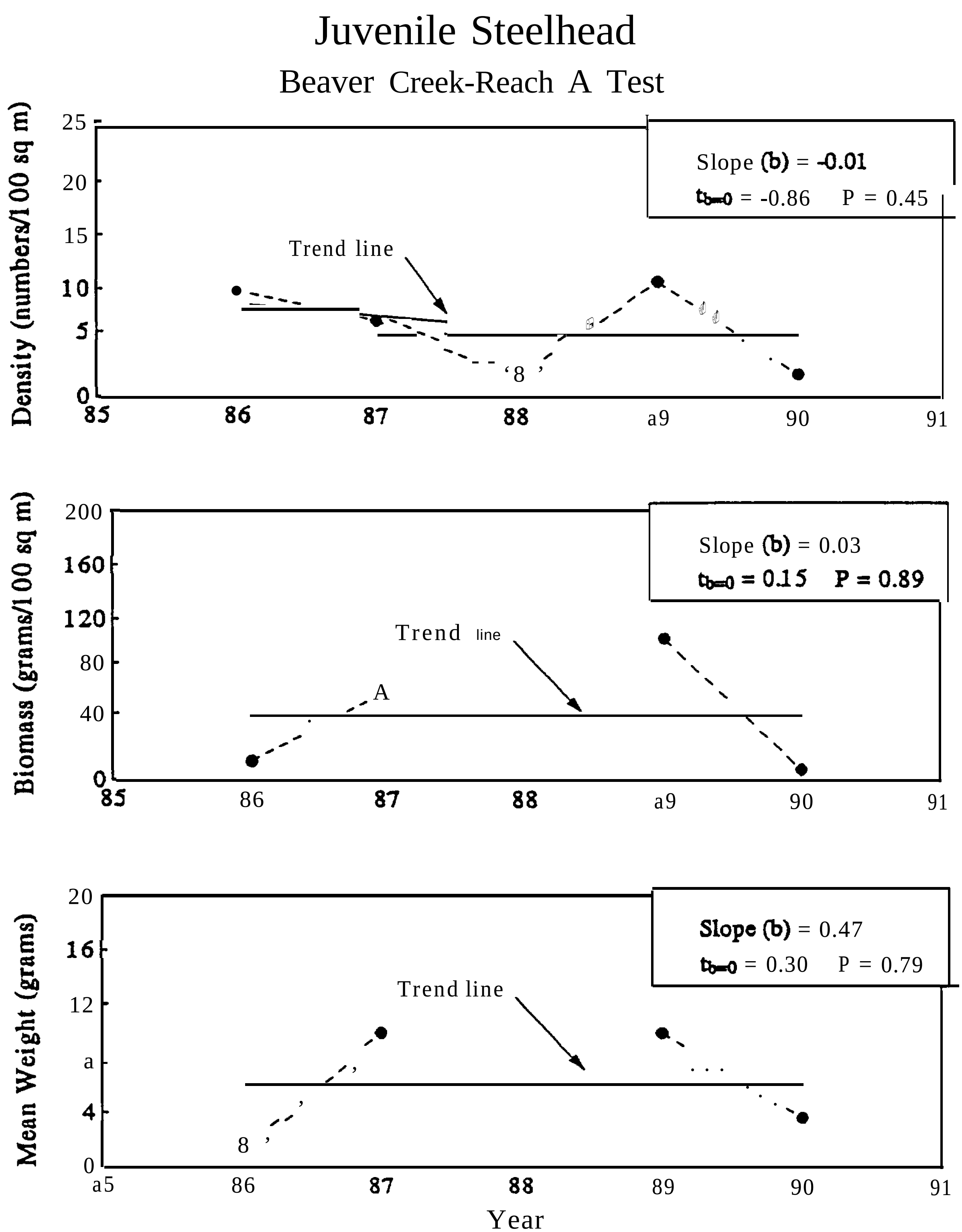


Figure 37. Time series of densities, biomasses, and mean weights of juvenile steelhead in the Reach A Test site on Beaver Creek, Oregon.

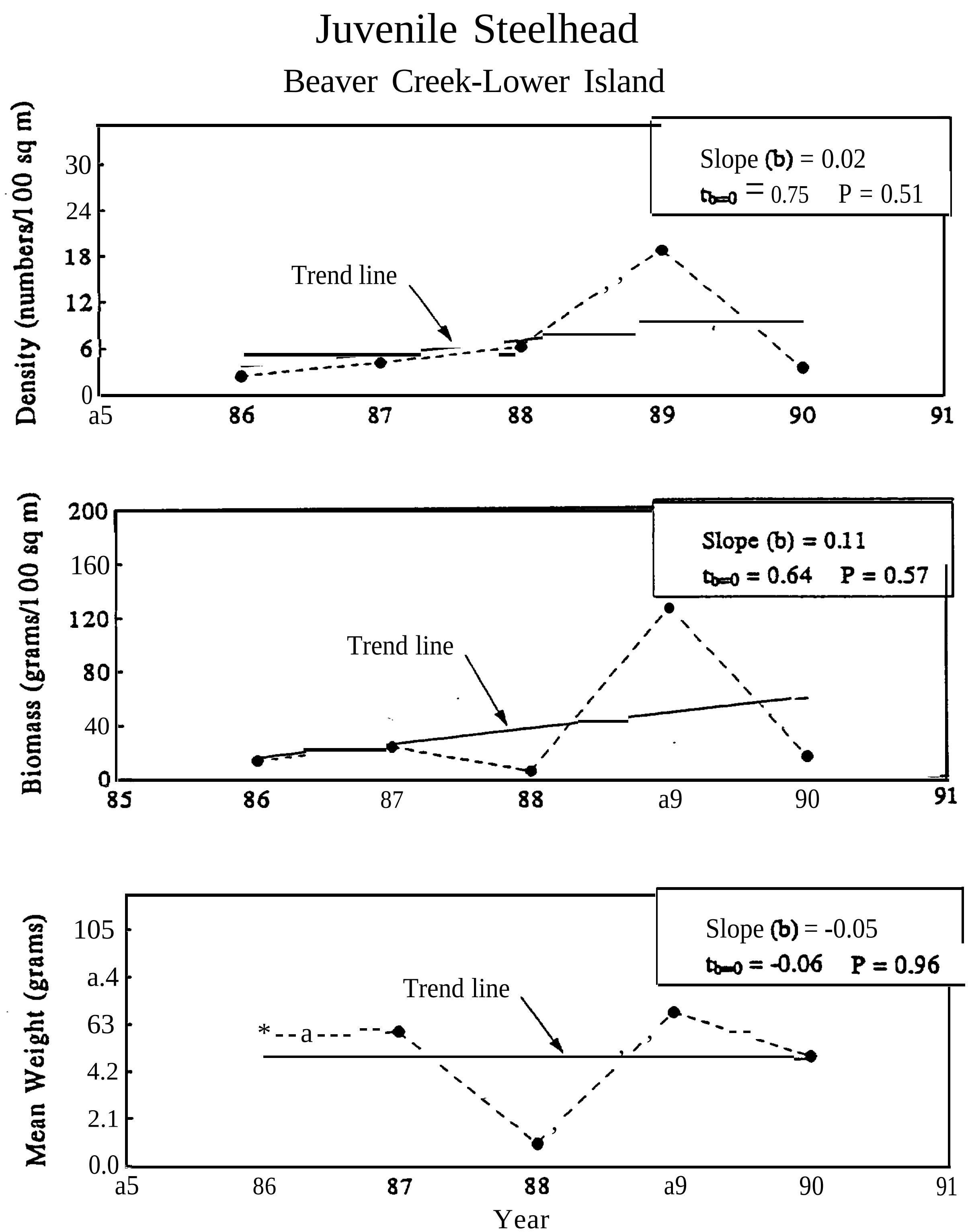


Figure 38. Time series of densities, biomasses, and mean weights of juvenile steelhead in the Lower Island site on Beaver Creek, Oregon.

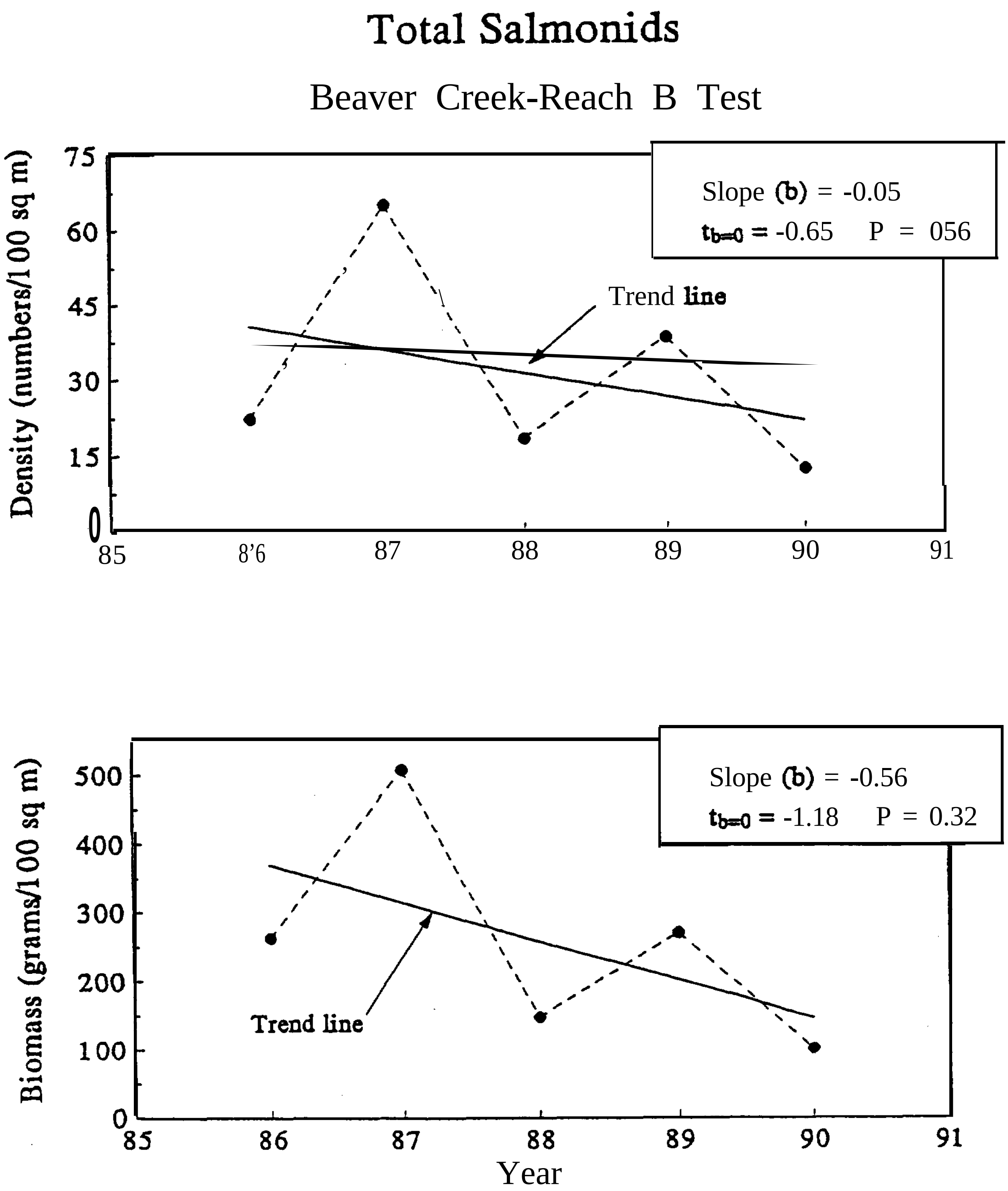


Figure 39. Time series of densities and biomasses of all salmonids in the Reach B Test site on Beaver Creek, Oregon.

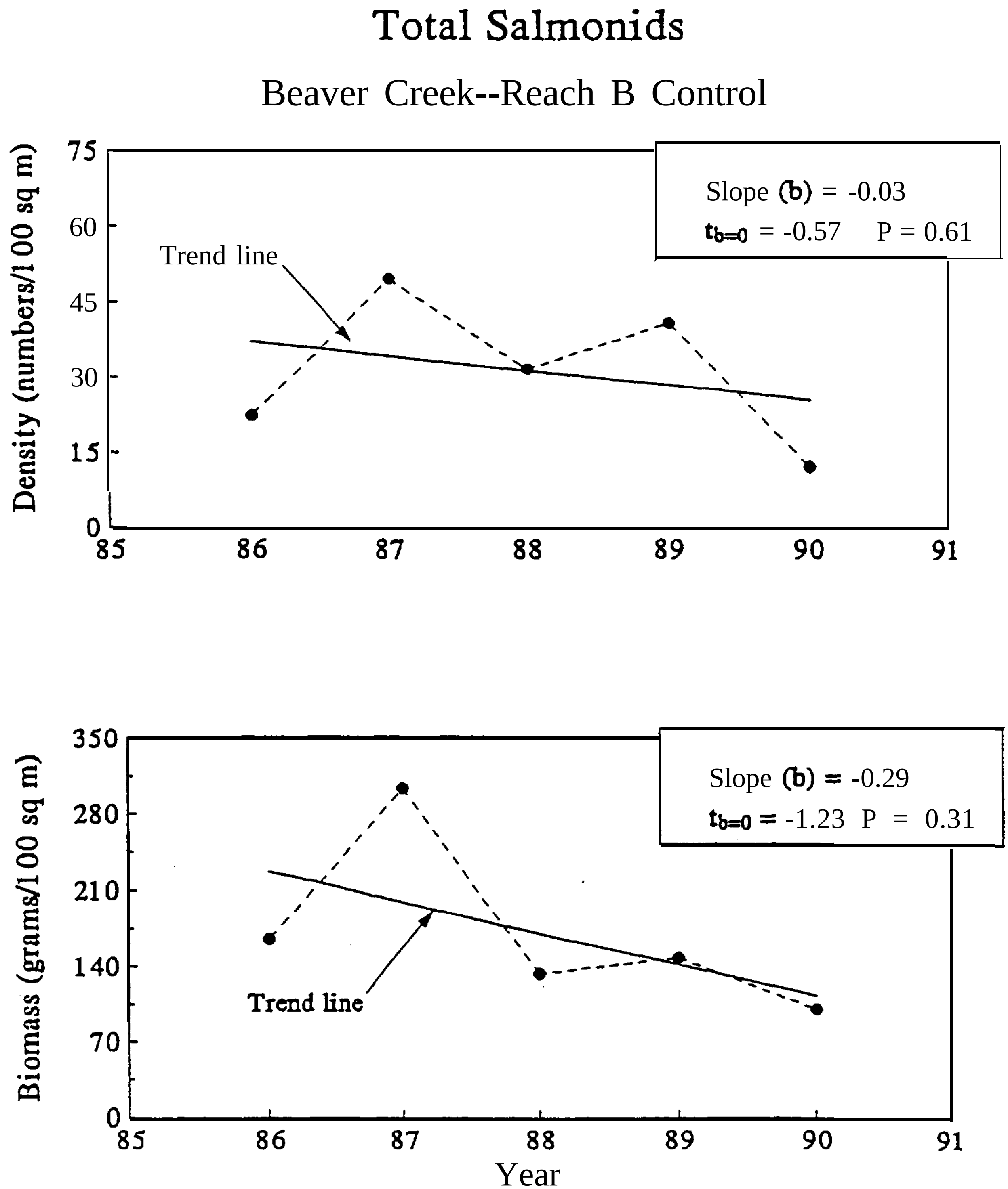


Figure 40. Time series of densities and biomasses of all salmonids in the Reach B Control site on Beaver Creek, Oregon.

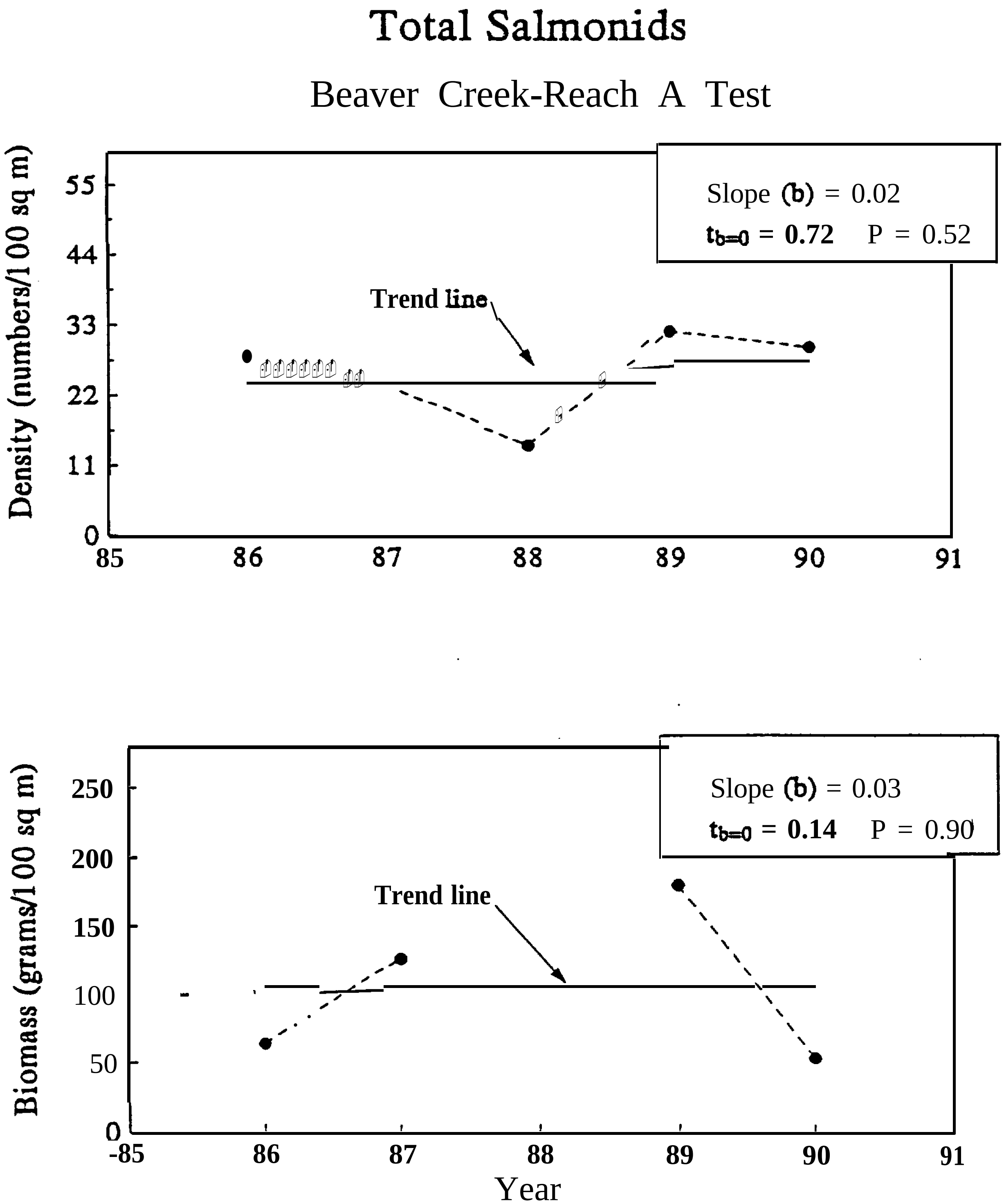


Figure 41. Time series of densities and biomasses of all salmonids in the Reach A Test site on Beaver Creek, Oregon.

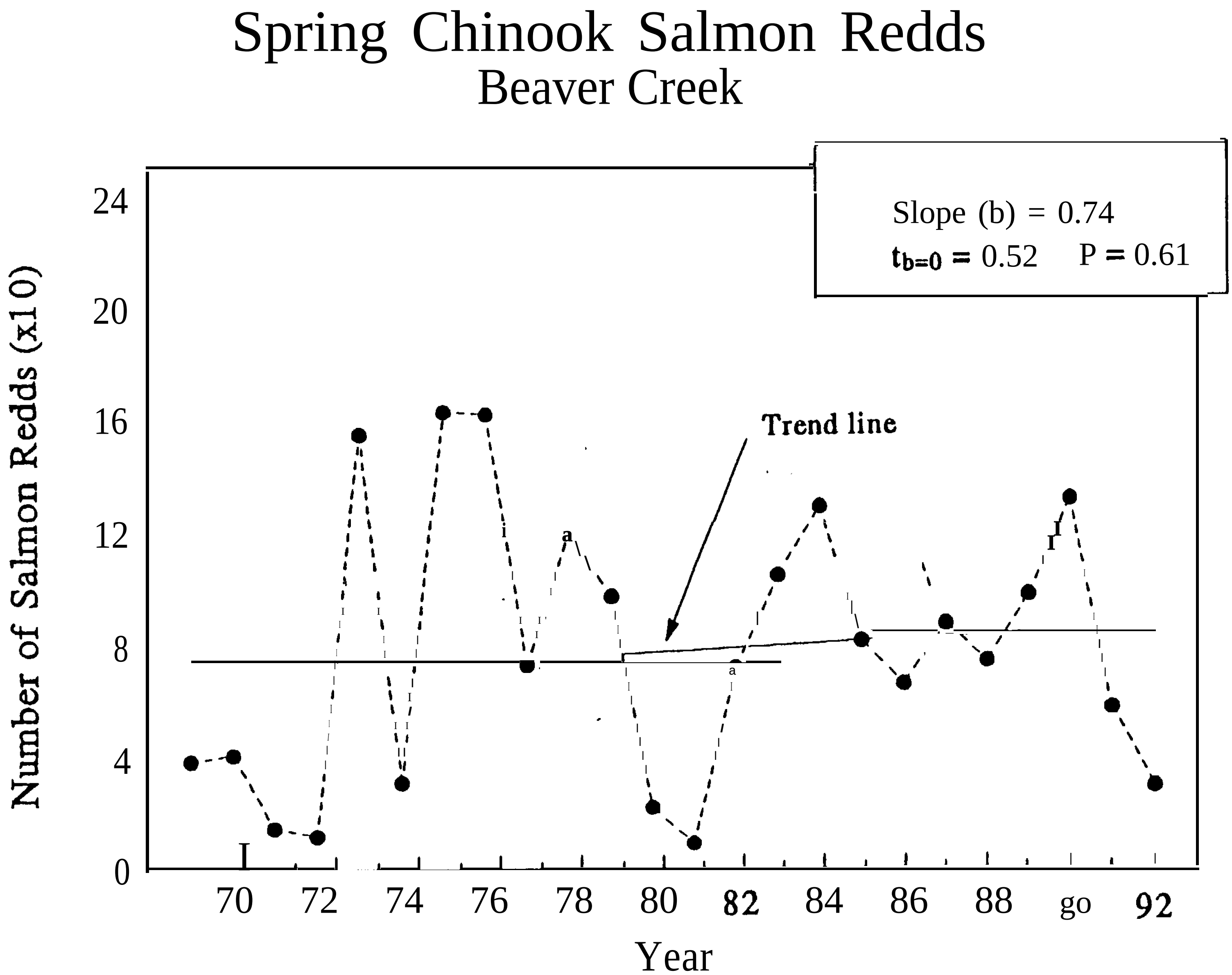


Figure 42. Time series of numbers of chinook salmon redds in historical index areas on Beaver Creek, Oregon.

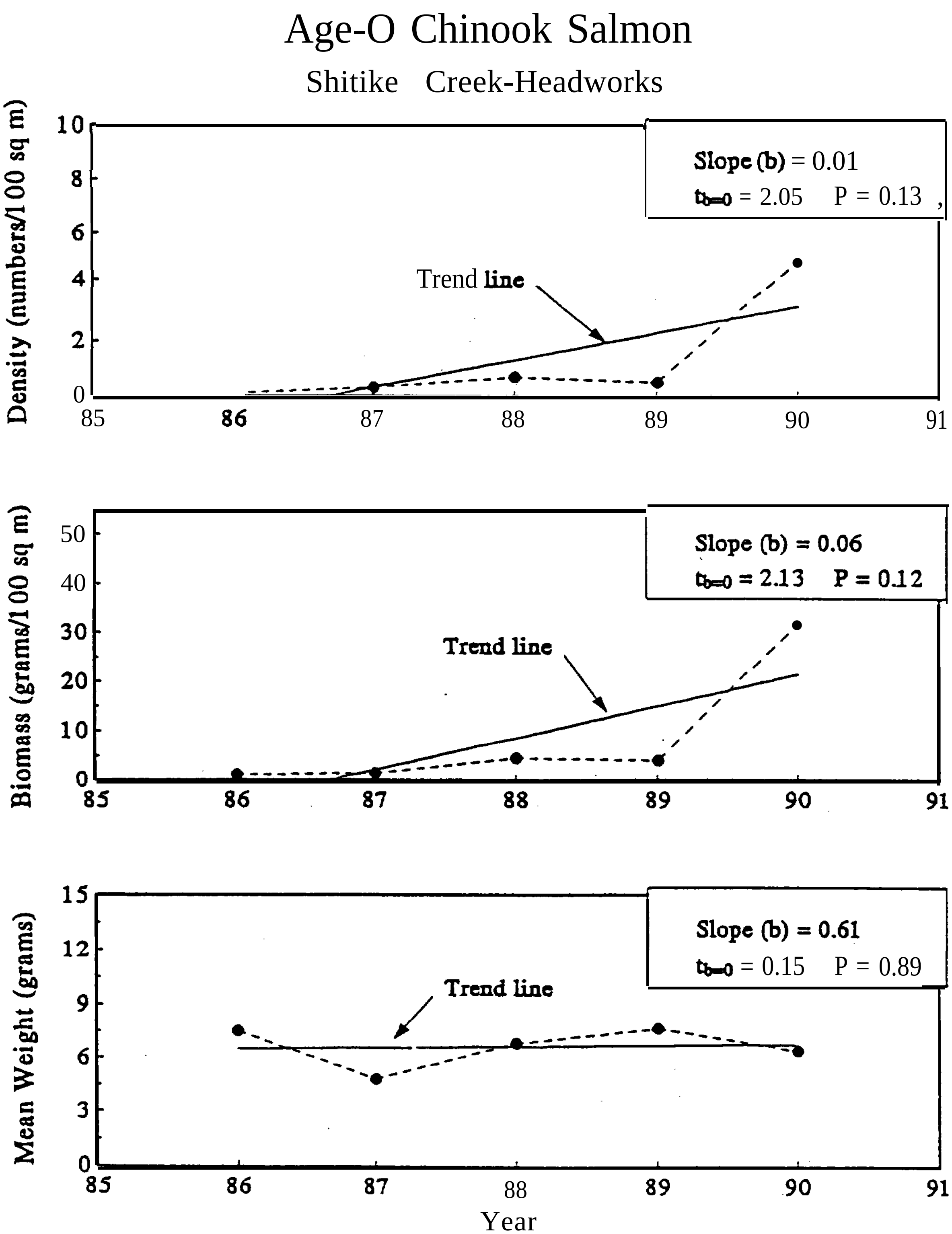


Figure 43. Time series of densities, biomasses, and mean weights of juvenile chinook salmon in the Headworks site on Shitike Creek, Oregon.

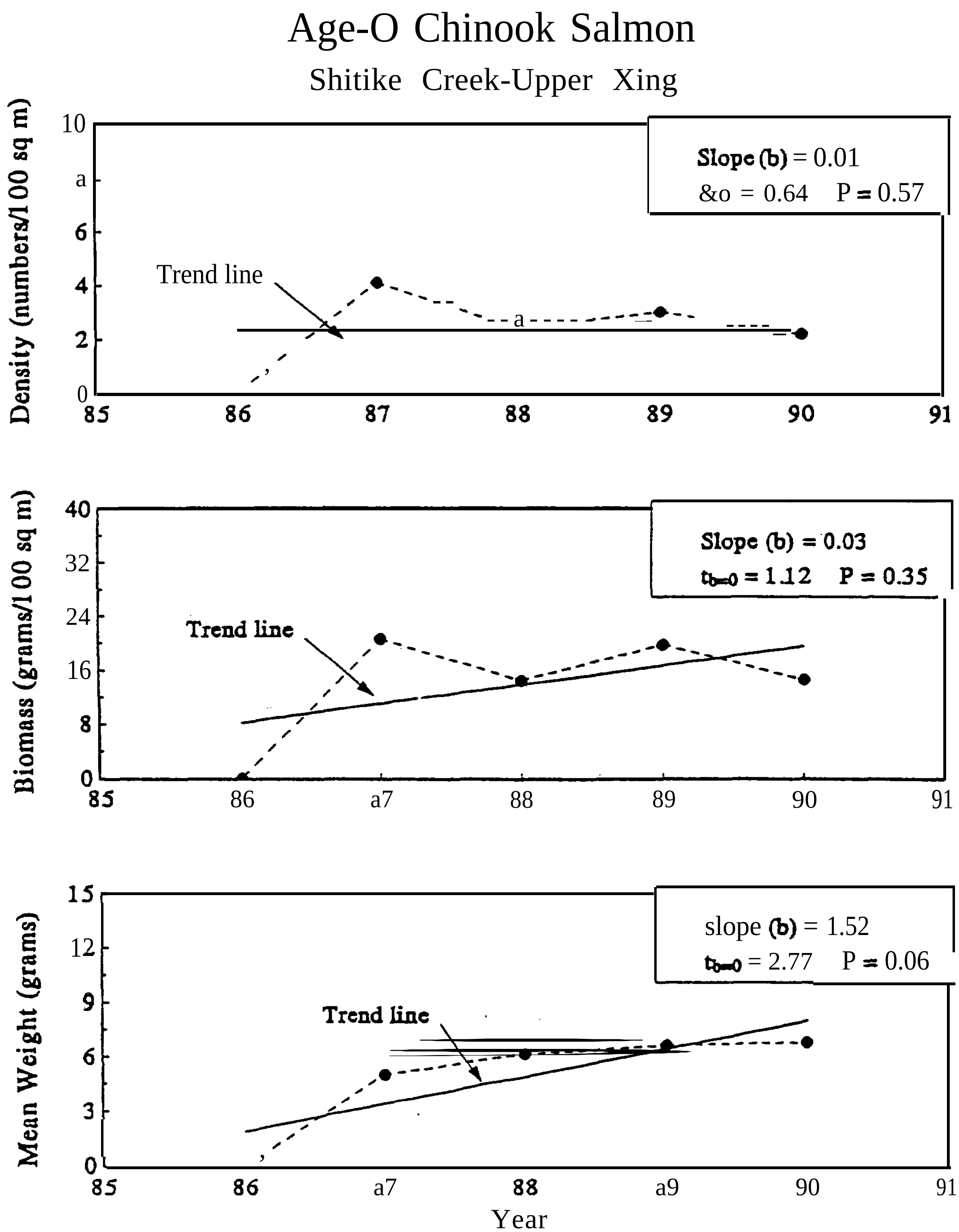


Figure 44. Time series of densities, biomasses, and mean weights of juvenile chinook salmon in the Upper Crossing site on Shitike Creek, Oregon.

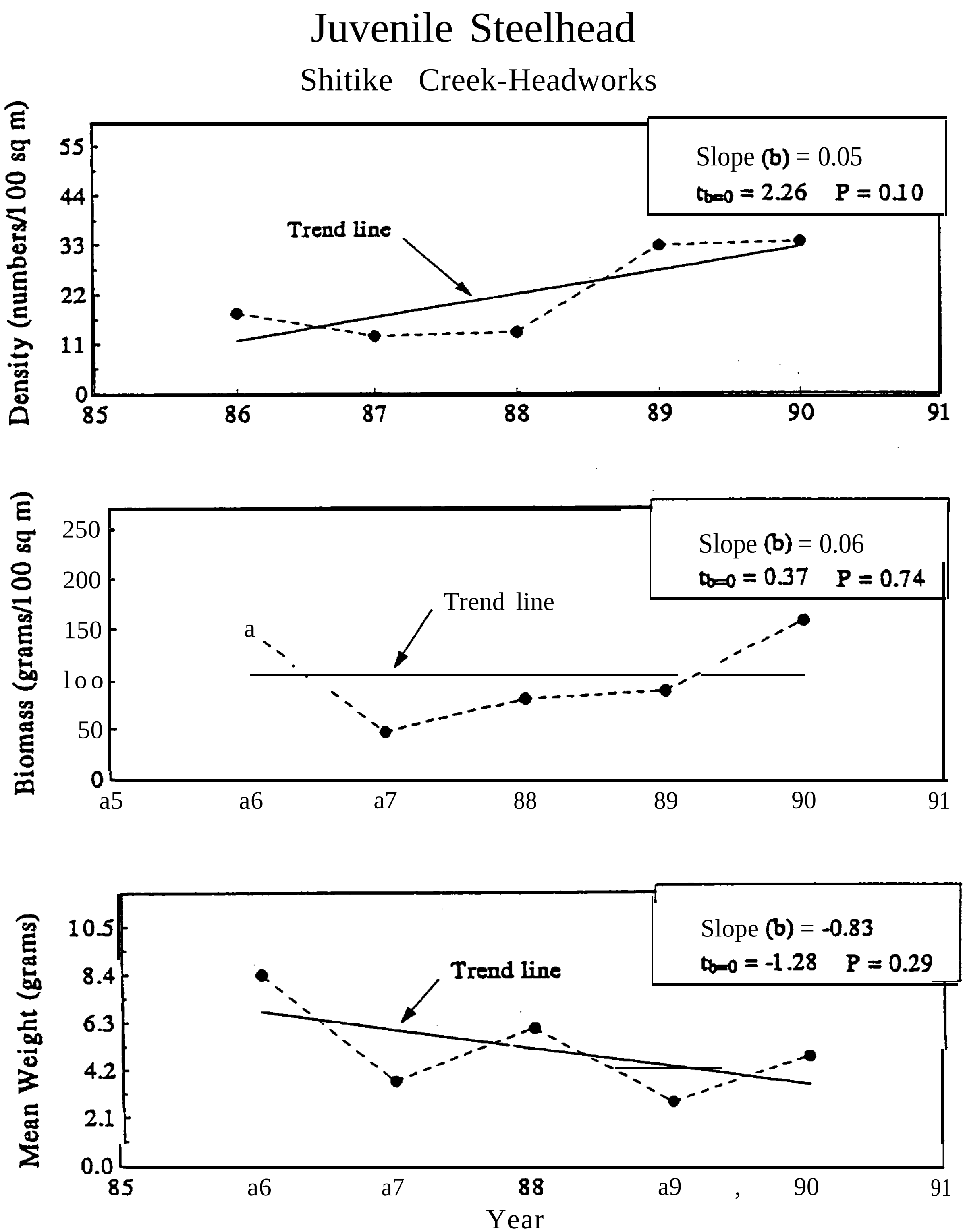


Figure 45. Time series of densities, biomasses, and mean weights of juvenile steelhead in the Headworks site on Shitike Creek, Oregon.

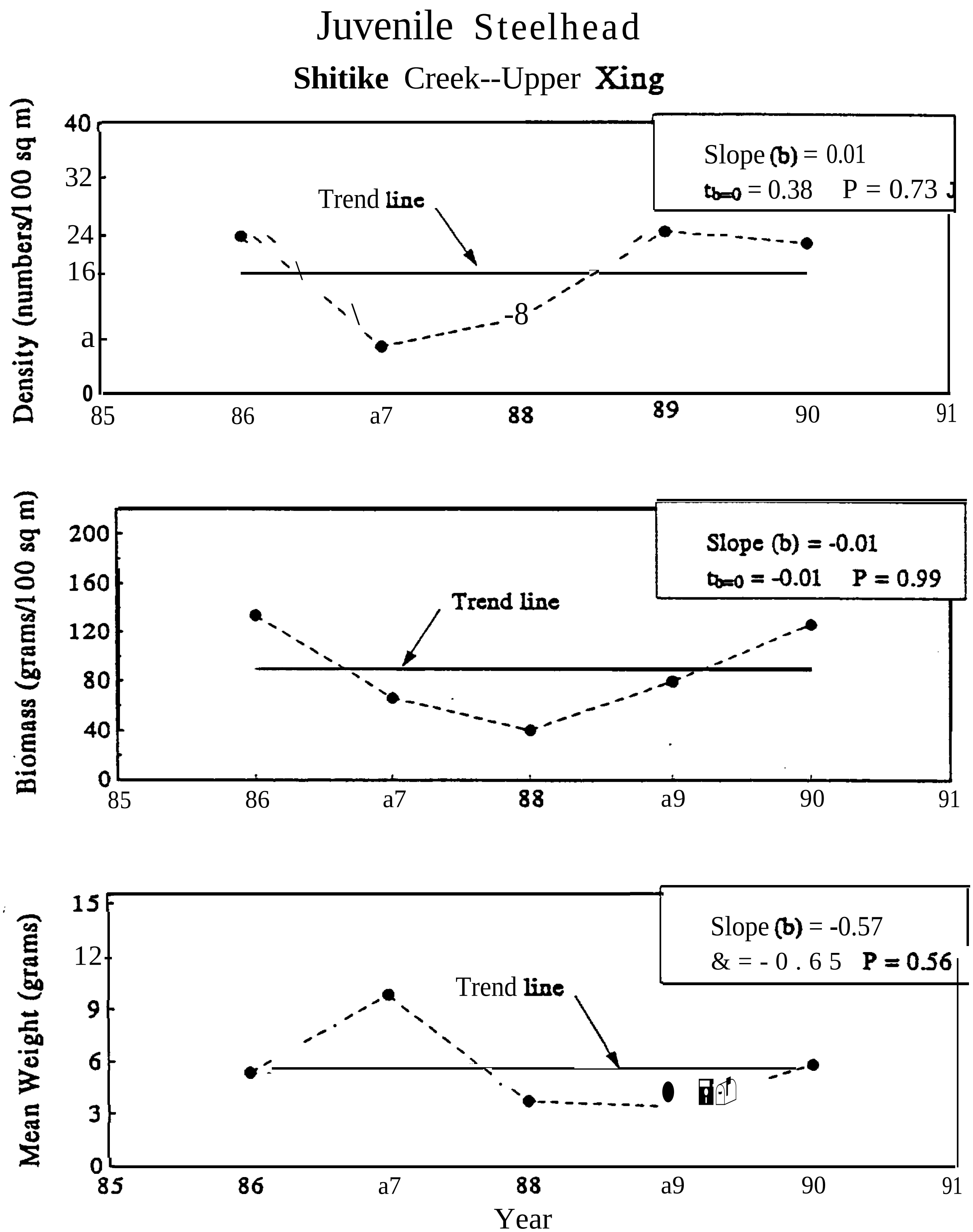


Figure 46. Time series of densities, biomasses, and mean weights of juvenile steelhead in the Upper Crossing site on Shitike Creek, Oregon.

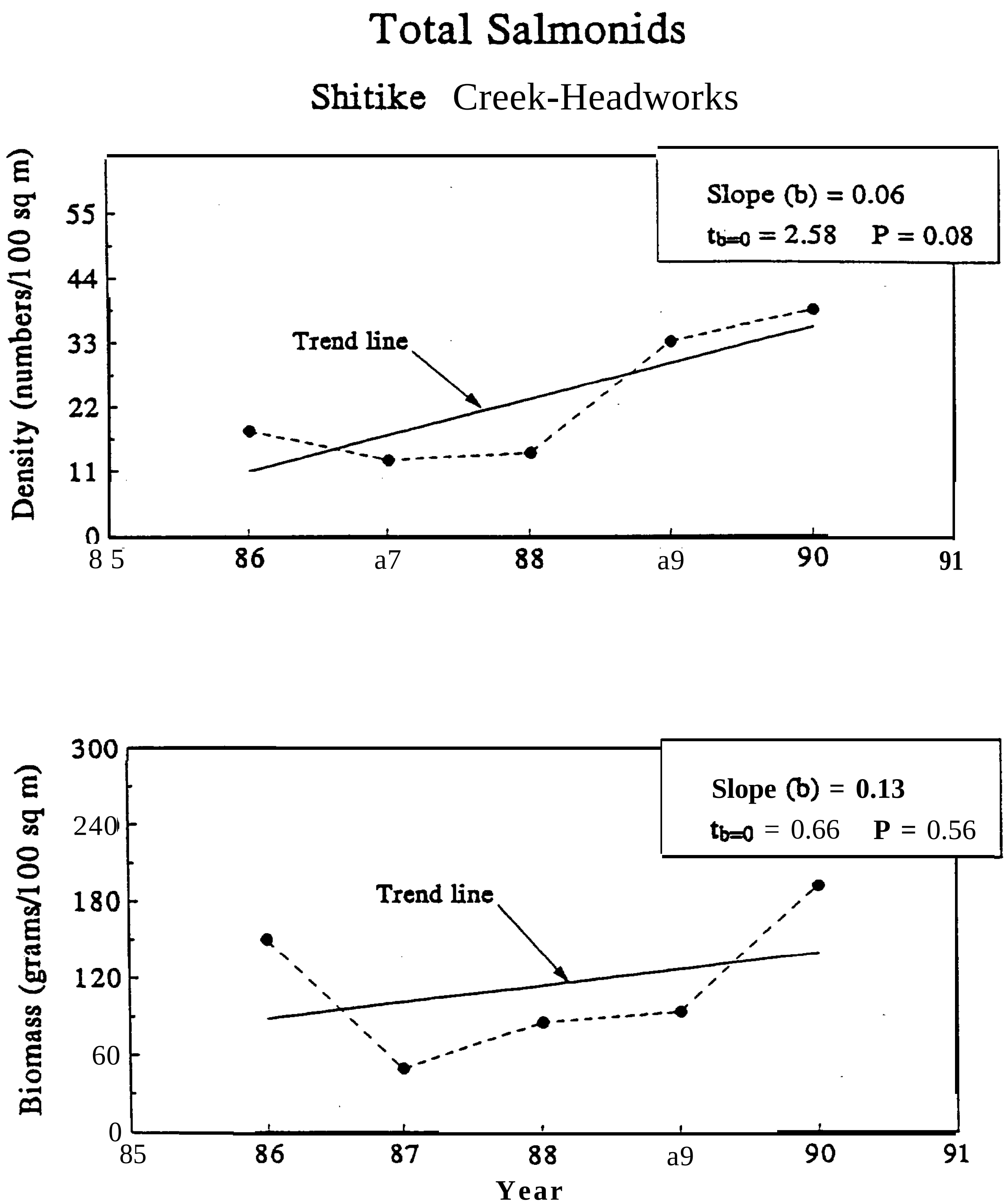


Figure 47. Time series of densities and biomasses of all salmonids in the Headworks site on Shitike Creek, Oregon.

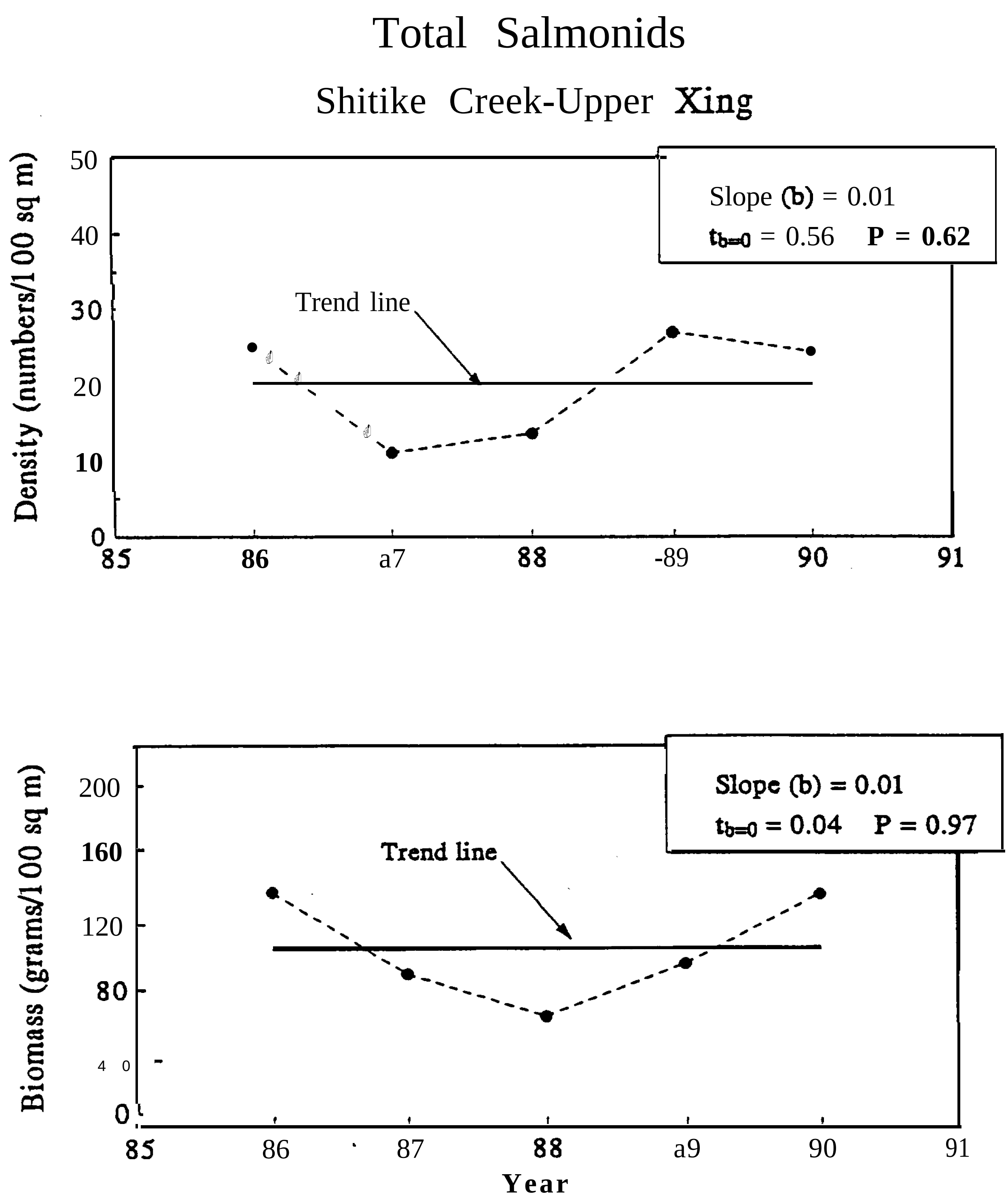


Figure 48. Time series of densities and biomasses of all salmonids in the Upper Crossing site on Shitike Creek, Oregon.

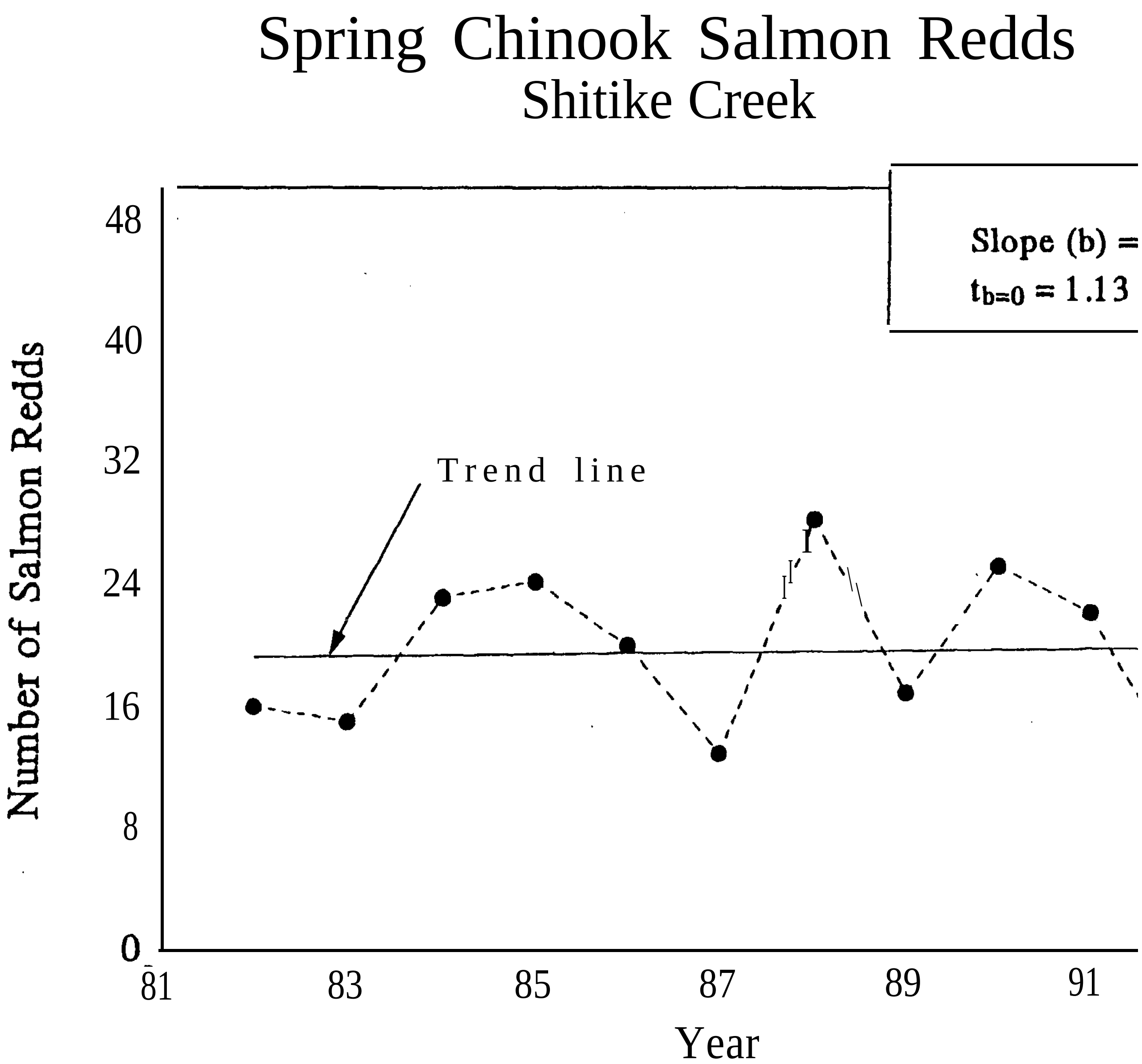


Figure 49. Time series of numbers of chinook salmon redds in index ar
Shitike Creek, Oregon.

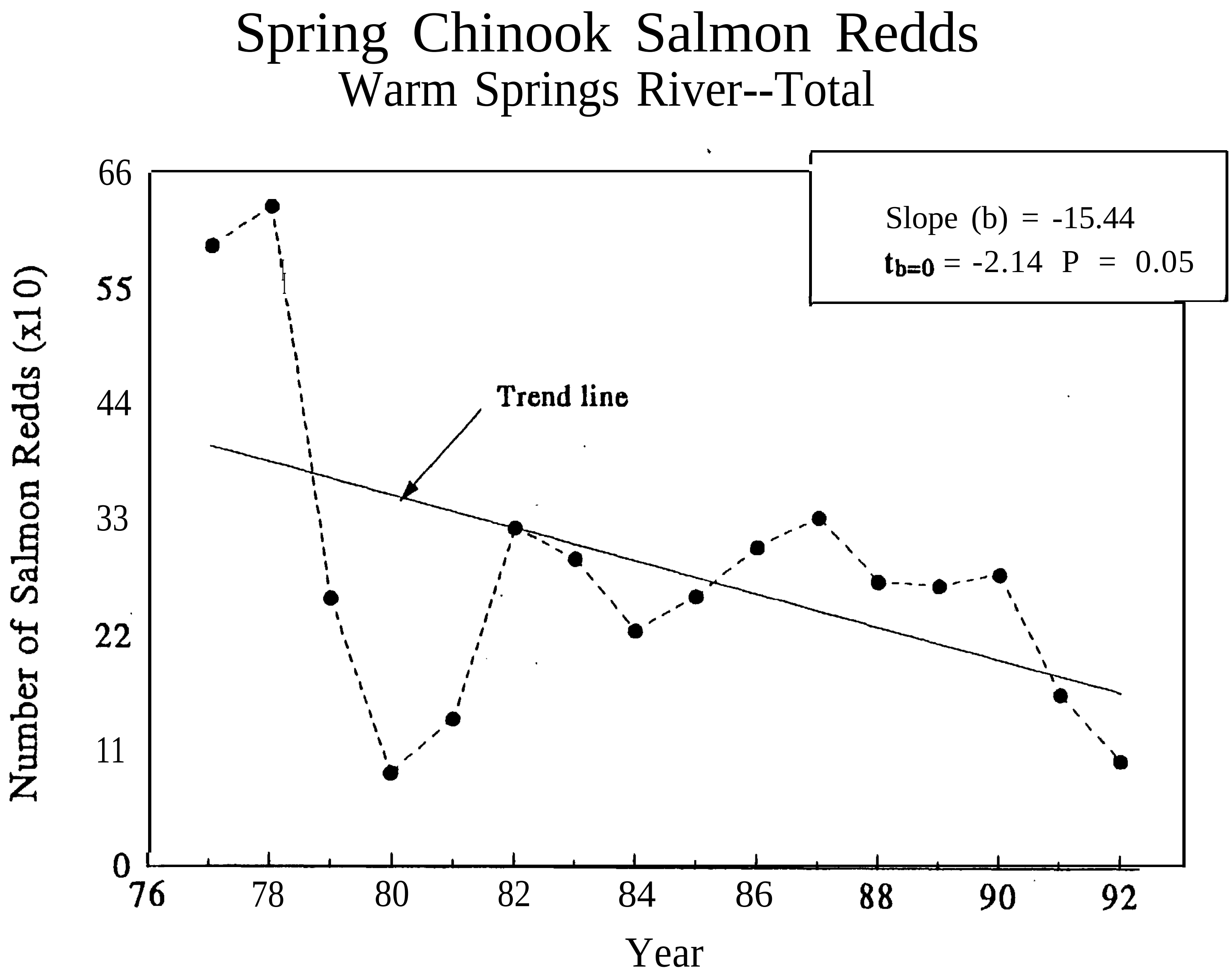
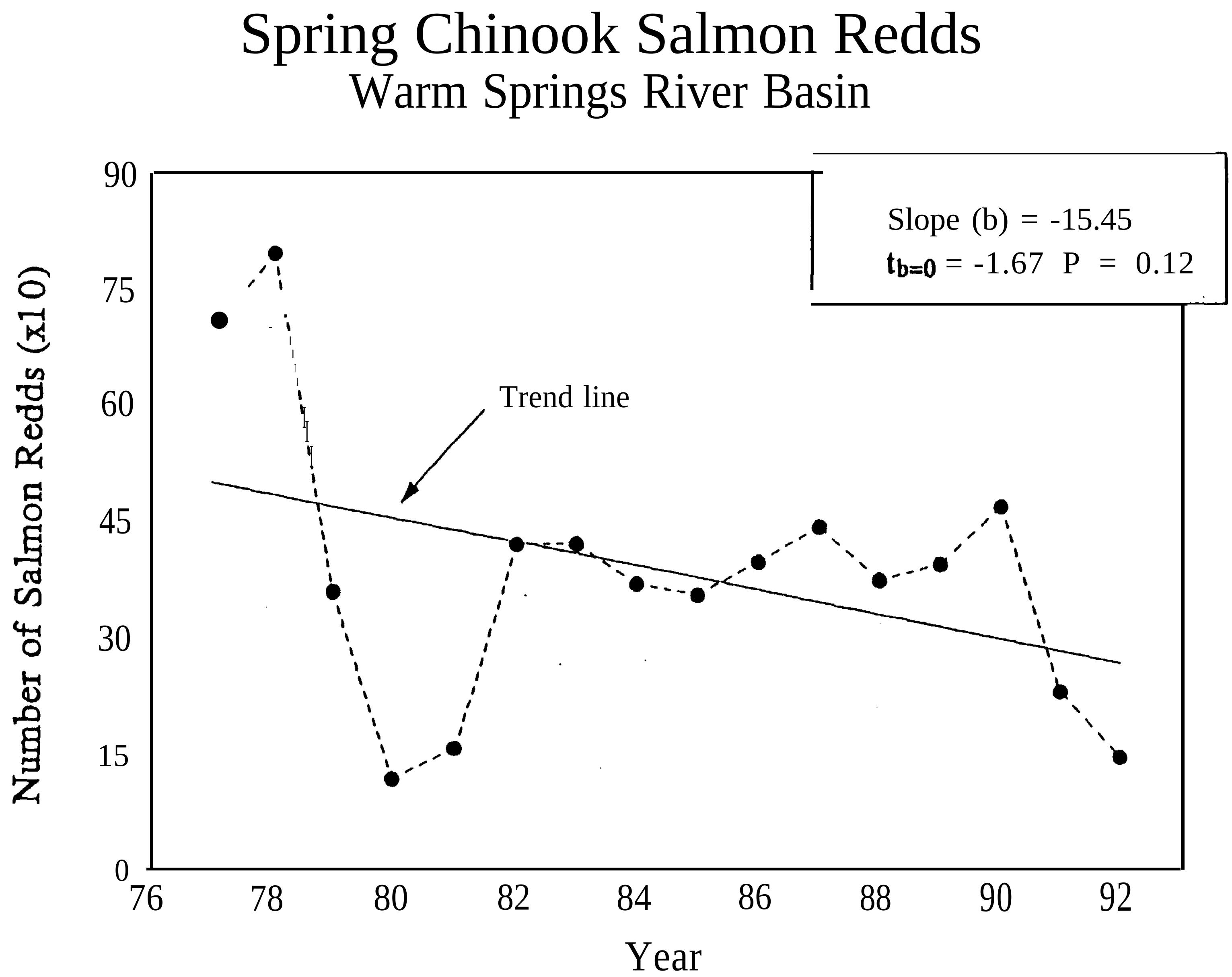


Figure 50. Time series of numbers of chinook salmon redds in index areas on the Warm Springs River, Oregon.



Figure' $1. Time series of numbers of chinook salmon redds in index areas on Mill Creek, Beaver Creek, and the Warm Springs River, Oregon.

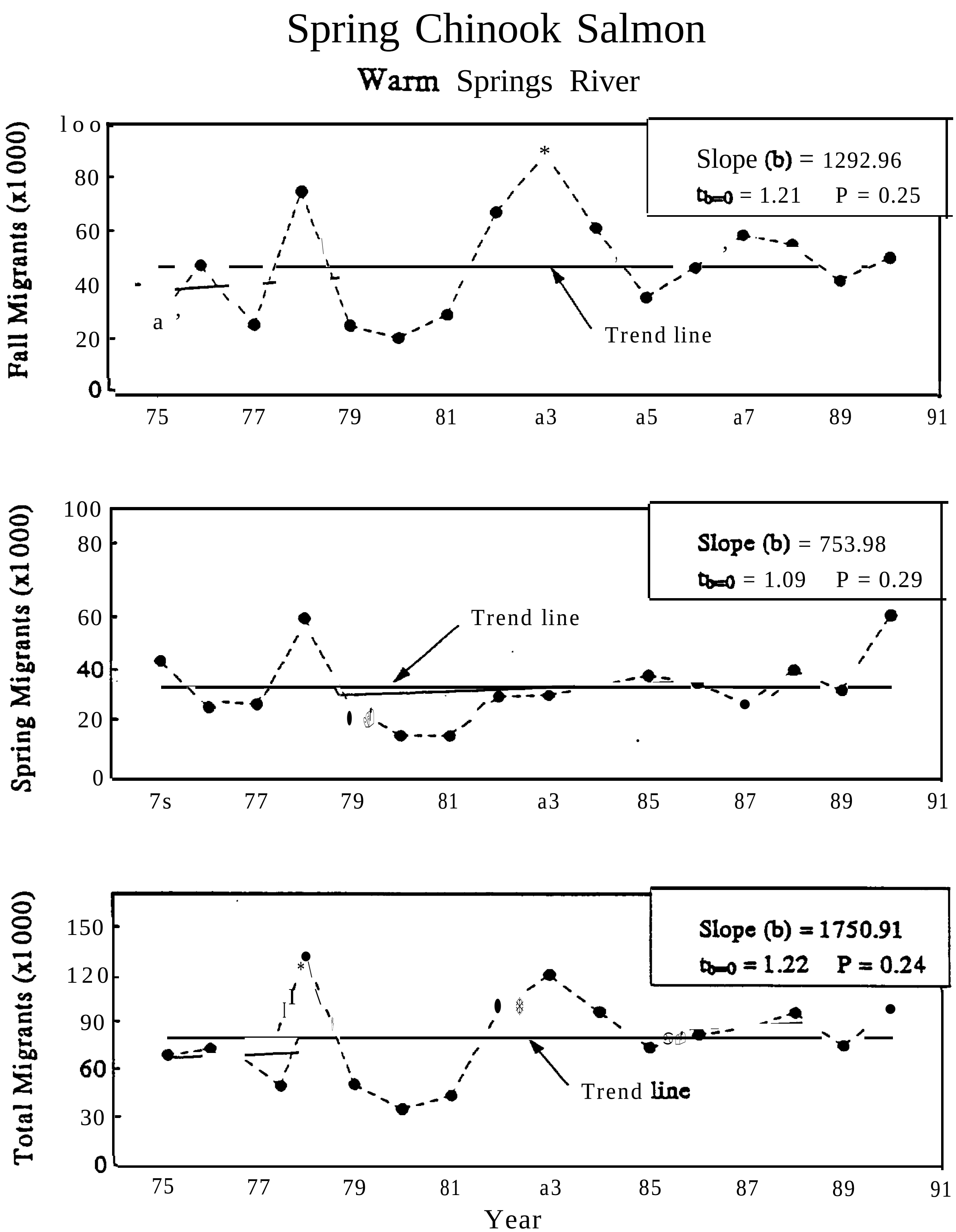


Figure 52. Time series of numbers of juvenile chinook salmon that migrated out of the Warm Springs River in the fall, spring, and fall and spring combined.

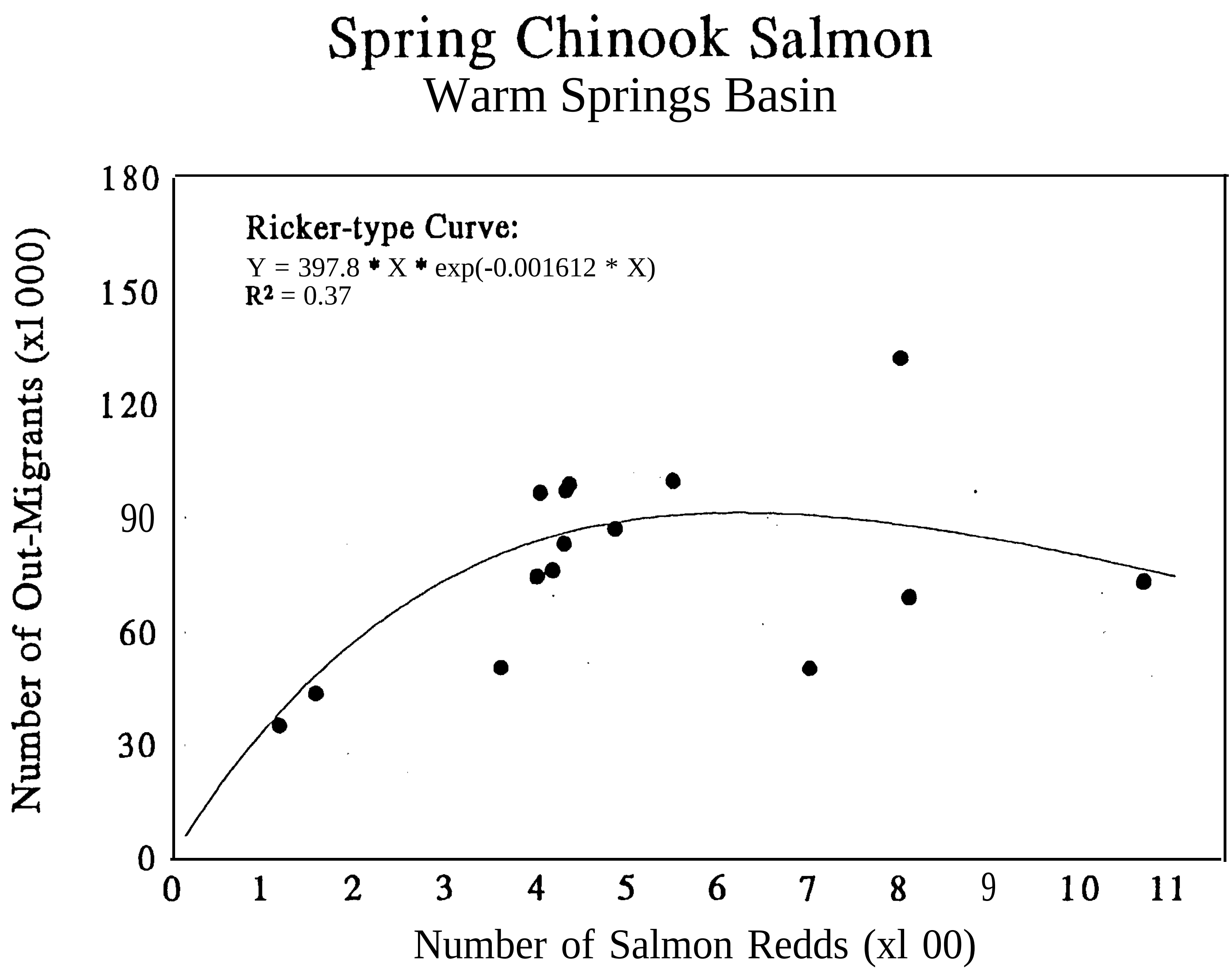
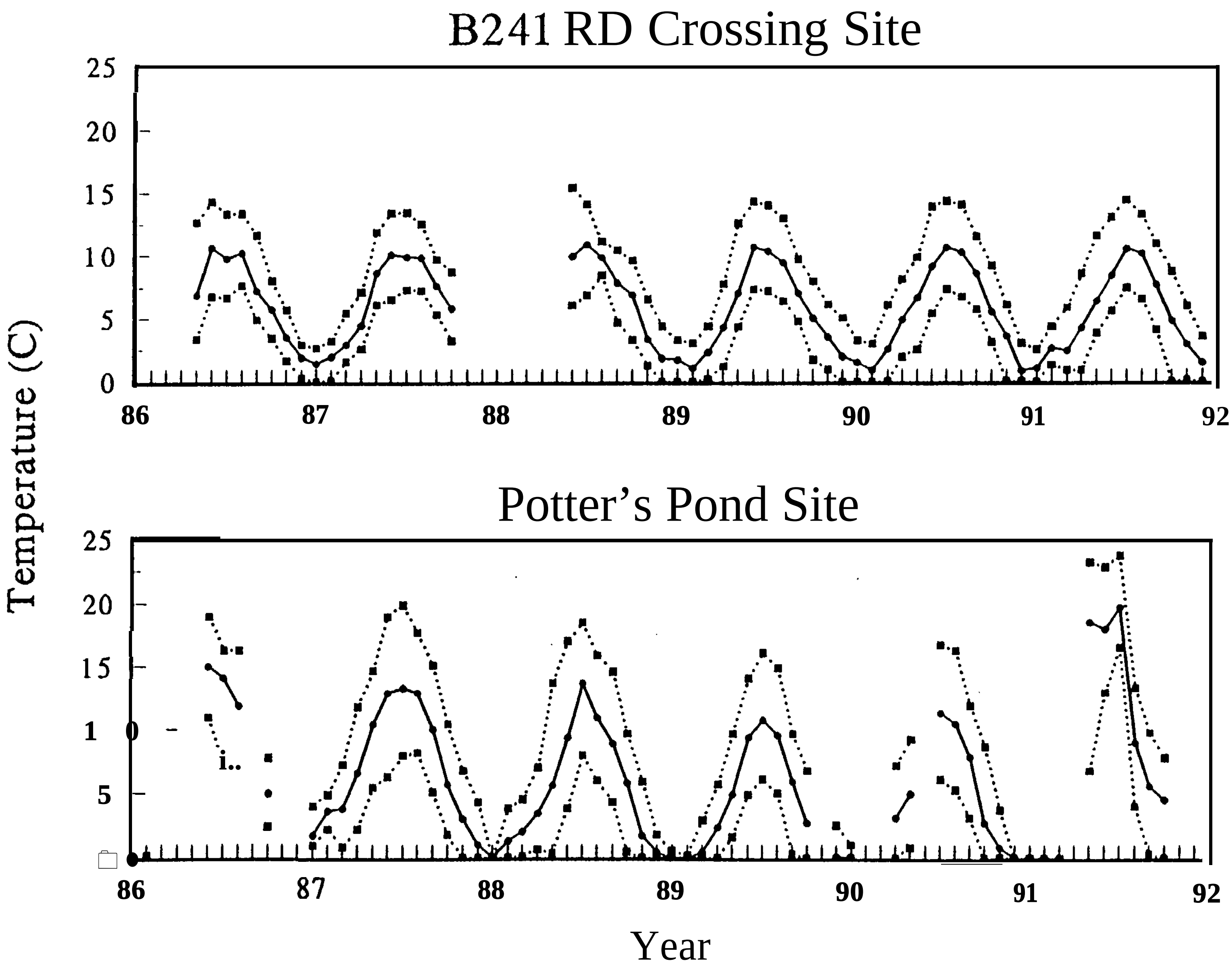


Figure 53. Redd-migrant relation for chinook salmon in the Warm Springs basin. The **Ricker** curve was fitted by nonlinear regression.

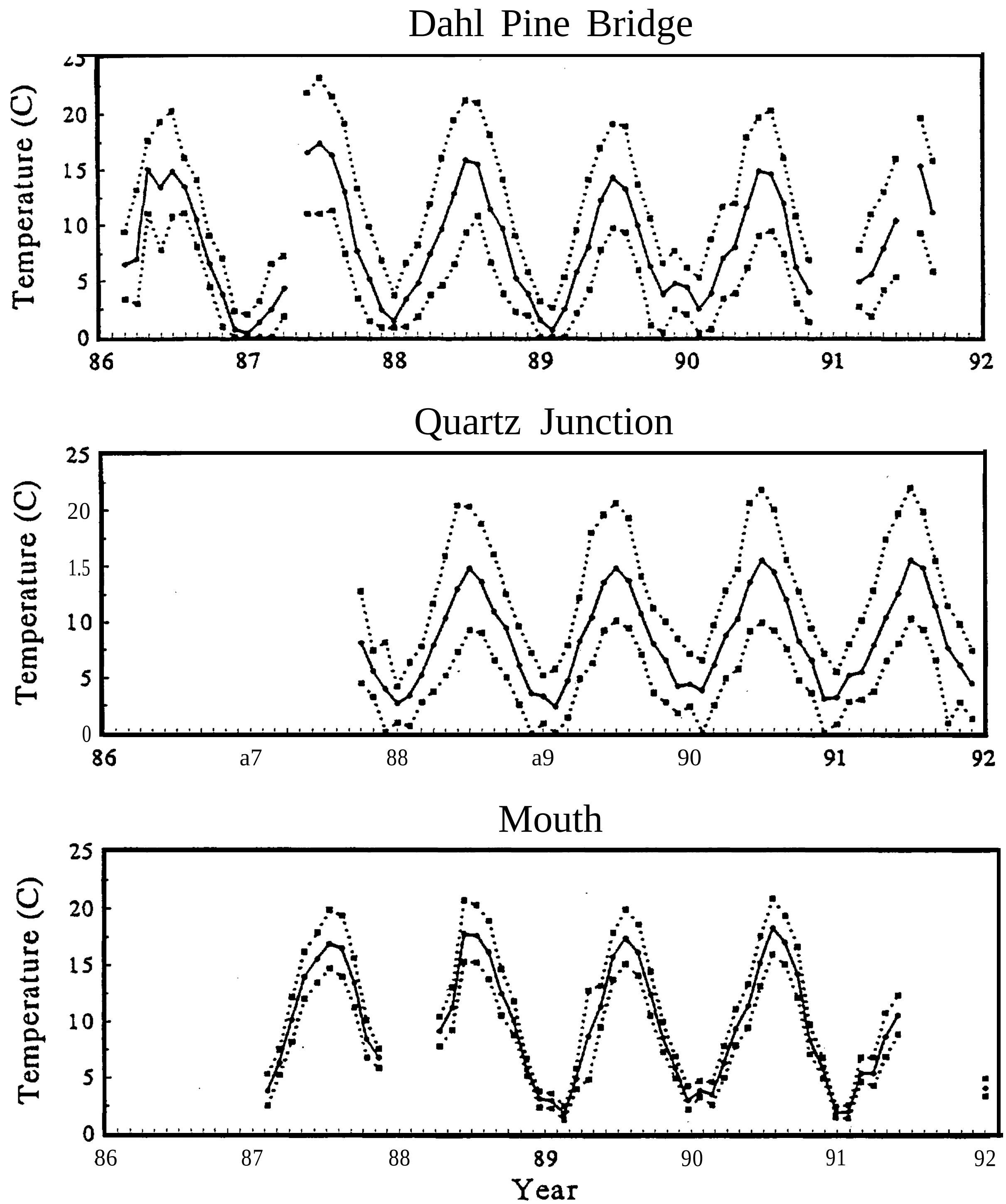
APPENDICES

Mill Creek Water Temperatures

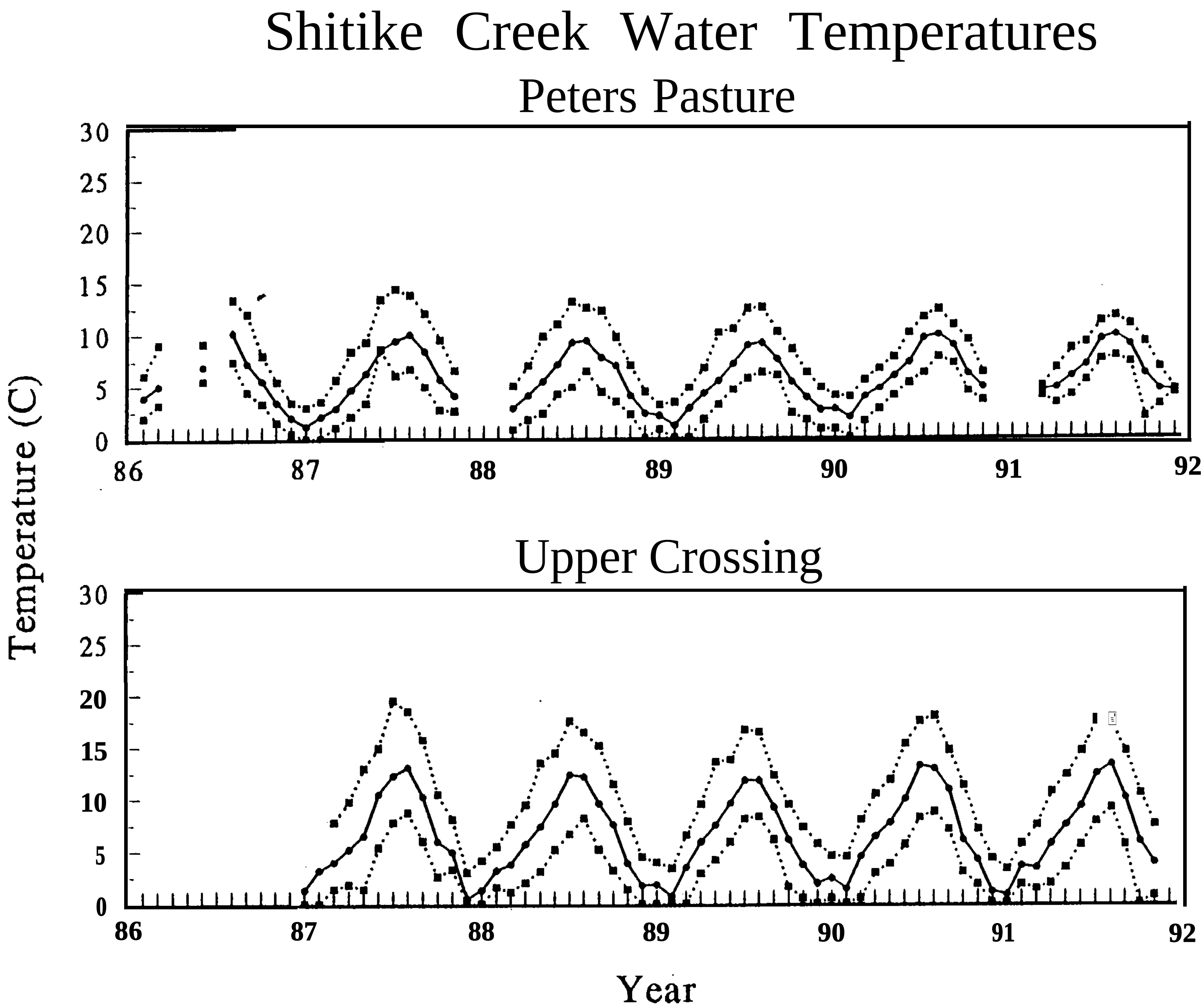


Appendix Al. Mean minimum, maximum, and average water temperatures between 1986 and 1992 at the B241 Road Crossing site (Rkm 23.7) and Potter's Pond site (Rkm 10.2) on Mill Creek, a tributary of the Warm Springs River.

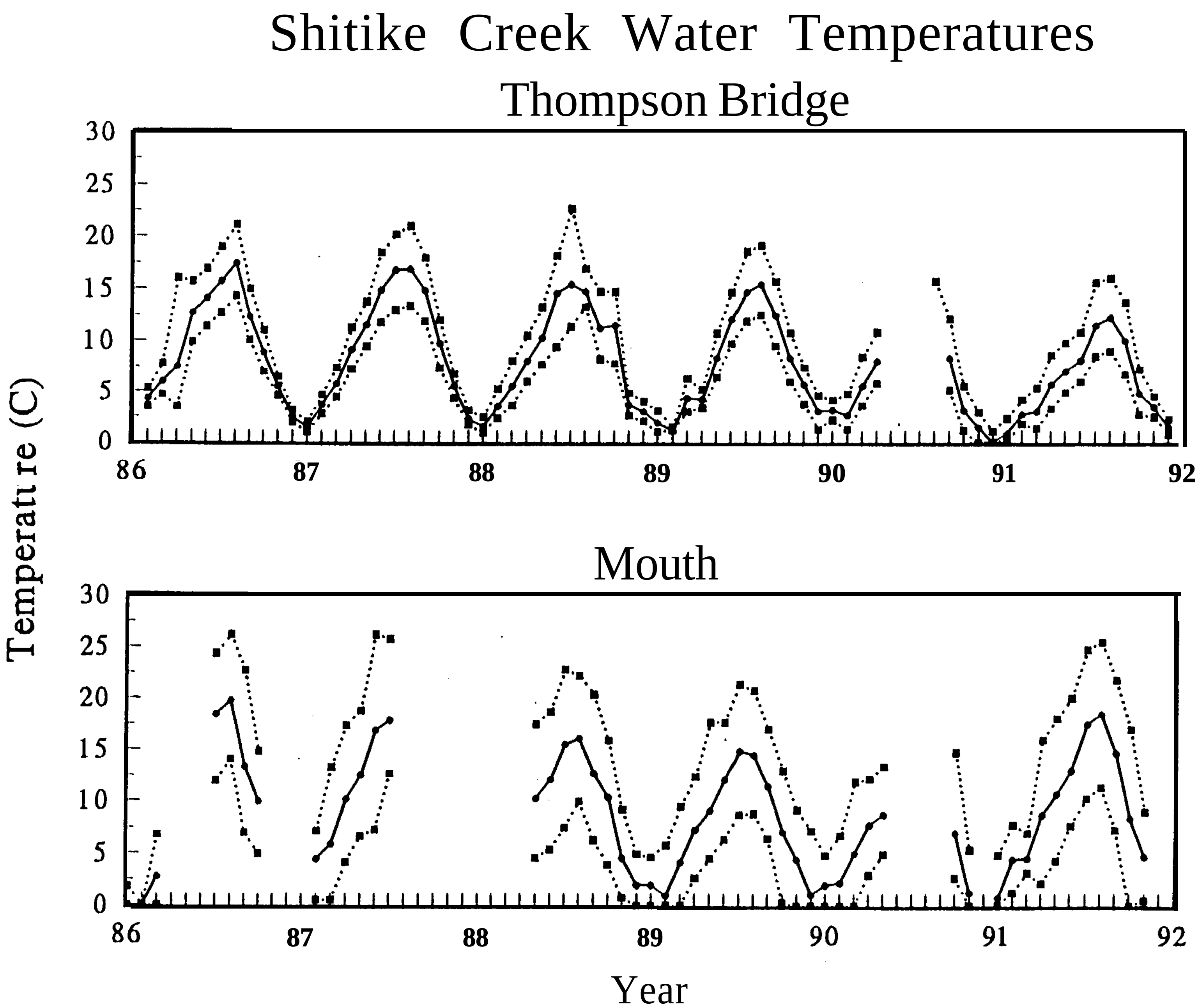
Beaver Creek Water Temperatures



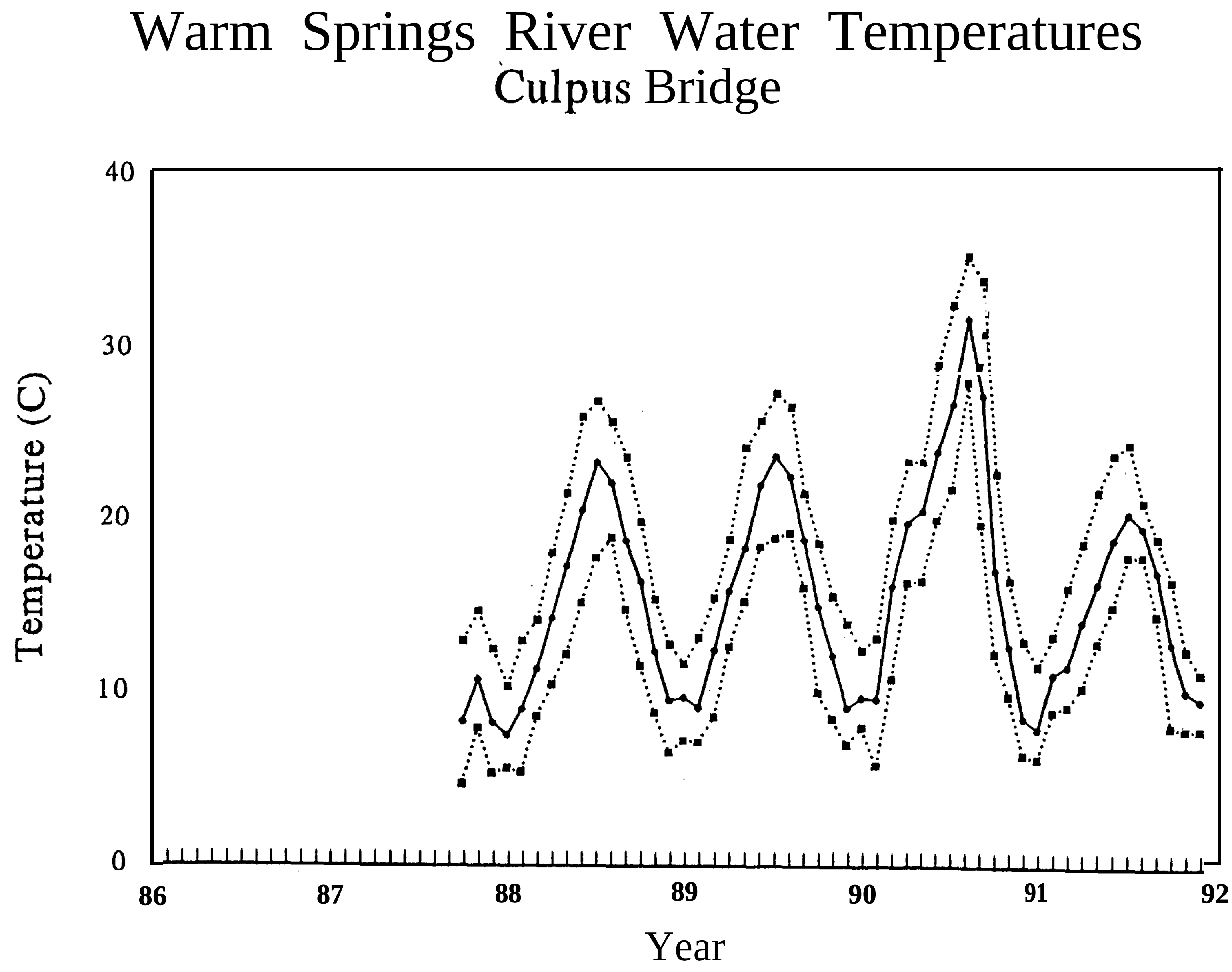
Appendix A2. Mean minimum, maximum, and average water temperatures between 1986 and 1992 at the Dahl Pine Bridge site (Rkm 22.8), Quartz Junction site (Rkm 12.6), and near the mouth (Rkm 0.8) on Beaver Creek, a tributary of the Warm Springs River.



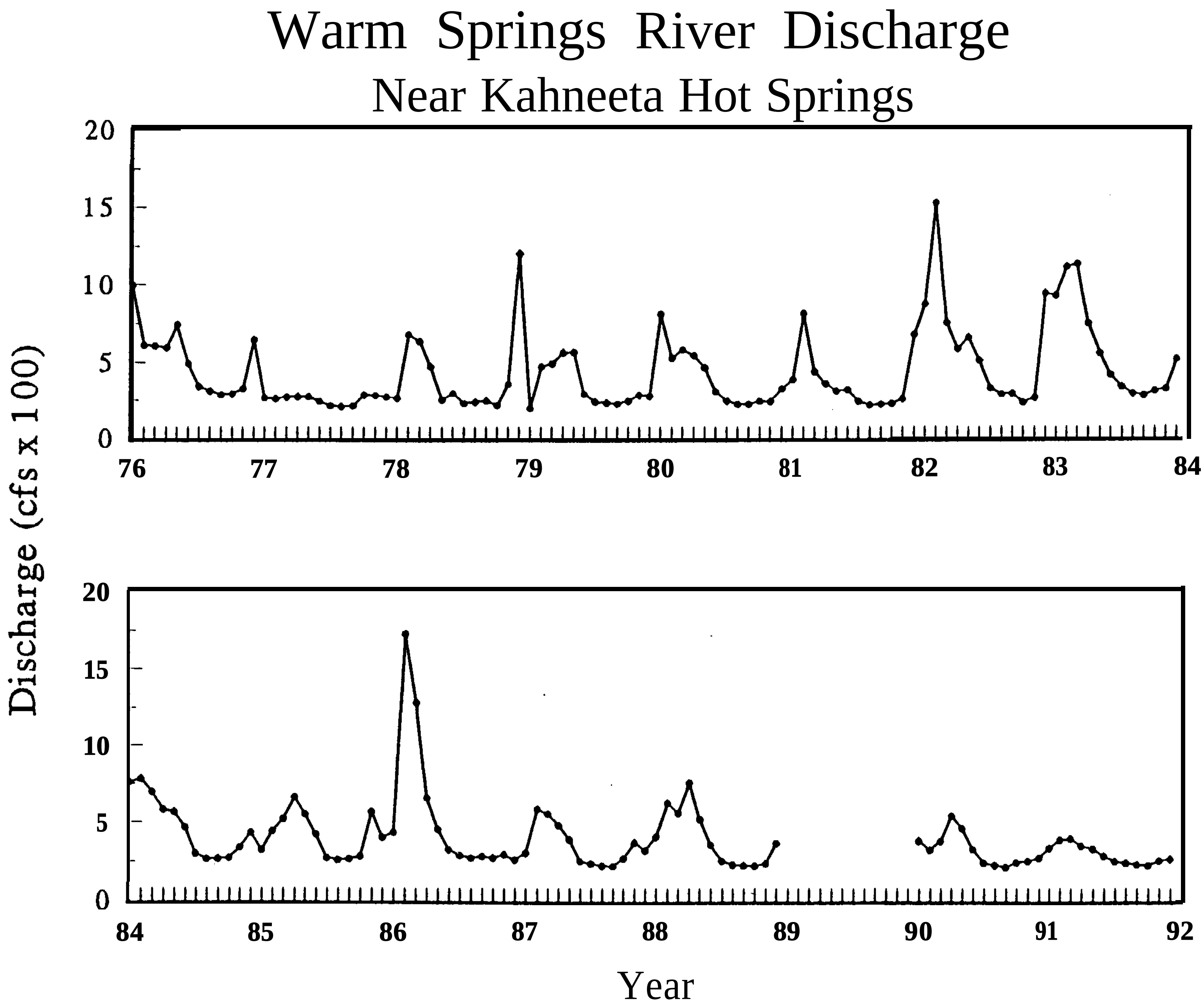
Appendix A3. Mean minimum, maximum, and average water temperatures between 1986 and 1992 at Peter's Pasture site (Rkm 24.3) and Upper Crossing site (Rkm 20.0) on Shitike Creek.



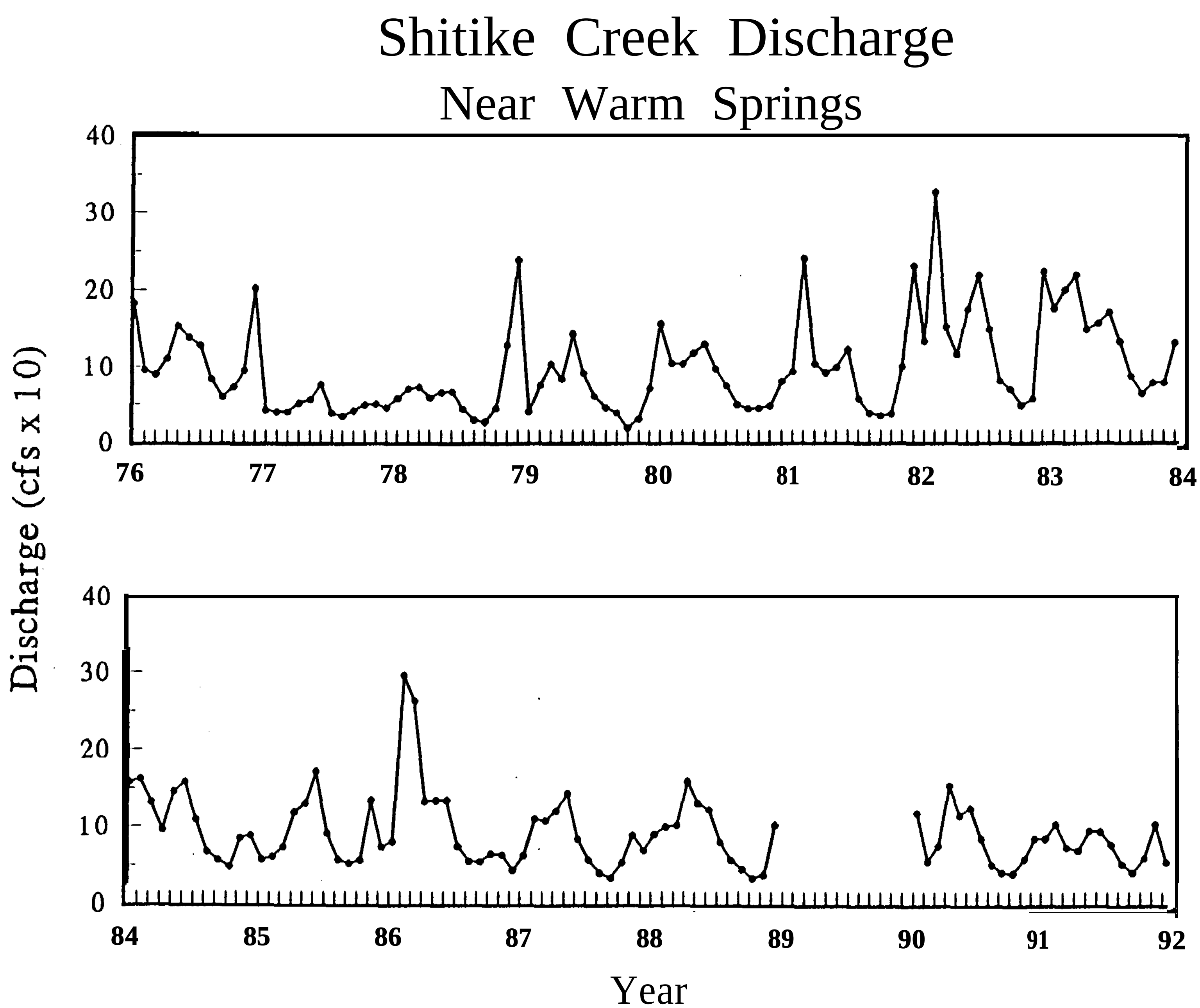
Appendix A4. Mean minimum, maximum, and average water temperatures between 1986 and 1992 at Thompson Bridge site (Rkm 7.5) and near the mouth (Rkm **0.3)** on Shitike Creek.



Appendix AS. Mean minimum, maximum, and average water temperatures between 1986 and 1992 at Culpus Bridge (Rkm 8.2) on the Warm Springs River.



Appendix A6. Mean monthly stream flows between 1976 and 1992 near Kahneeta Hot Springs (Rkm 8.2) on the Warm Springs River.



Appendix A7. kean monthly stream flows between 1976 and 1992 near the town of Warm Springs (Rkm 7.5) on Shitike Creek.

Appendix B1. Summer steelhead redd counts by index area in the Warm Springs River basin and Shitike Creek, 1982-1990.

Index Area	1982	1983	1984	1985	1986	1987	1988	1989	1990
Warm Spring River System									
Beaver Creek									
Reach D (top) to Robinson Park	--	--	--	--	--	6	0	0	0
Robinson Park to Dahl Pine	2	--	--	--	--	31	14	9	1
Dahl Pine to Canyon	3	--	--	--	1	12	11	7	6
Old Bridge to Powerline	1	--	--	--	3	5	1	0	2
Island Area	0	--	--	--	--	12	7	3	2
Mill Creek									
B-241 Road Bridge Area	--	--	--	2	0	2	0	0	0
Old Mill to Strawberry Falls	--	--	--	0	4	7	10	1	0
Strawberry Falls to Potters Pond	3	--	--	--	3	2	12	2	2
Potters Pond to Boulder Confluence	10	--	--	--	2	5	8	2	4
Warm Springs River									
Bunchgrass to Schoolie	13	--	--	--	--	--	--	--	--
Schoolie to HeHe	6	--	--	--	--	--	--	--	--
HeHe to McKinley Arthur Place	0	--	--	--	--	--	--	--	--
WSNFH to Culpus Bridge	5	--	--	--	--	--	--	--	--
TOTALS FOR WARM SPRINGS RIVER SYSTEM	43	--	--	2	13	82	63	24	17
Shitike Creek									
Peters Pasture Area	--	--	--	--	0	2	2	1	0
Upper Xing to Bennett Place	12	2	4	19	6	7	9	4	11
Bennet Place to Headworks	1	4	13	7	2	3	9	3	4
Headworks to Thompson Bridge (USGS)	22	*	*	*	3	9	7	0	1
Thompson Bridge to Community Center	21	8*	13*	17*	*	S	13	0	1
Community Center to Mouth	8	1	9	10	31*	28	12	4	0
TOTAL	64	15	39	53	42	54	52	12	17

*Combined Index Areas

Appendix B2. Spring chinook redd counts by index areas in the Warm Springs River basin and Shilike Creek, 1982- 199 1.

Index Area	RKM	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Warm Springs River Basin												
Beaver Creek												
Reach D to Robinson Park"	2.4	--	--	--	--	1	0	4	0	1	0	0
Robinson Park to Dahl Pine	7	15	59	91	42	38	46	38	36	35	24	4
Dahl Pine lo Canyon	2.7	23	24	7	17	13	27	24	46	55	15	16
Old Bridge lo Powerline	1.4	26	12	12	14	8	11	11	13	25	11	5
Powerline to Island [a]	9.6	--	--	18	13	26	14	5	3	32	8	7
Island Area	0.8	8	9	18	8	7	3	I	2	15	7	4
Mill Creek												
B-241 road brdige area [a,b]	2.7	15	3	16	17	0	0	0	0	0	0	--
Old Mill to Slawbeny Falls [a]	2.9	--	--	0	1	7	2	3	0	6	1	0
Strawberry Falls lo Pollers Pond	4.2	11	7	5	5	19	12	7	4	9	1	0
Potters Pond to Boulder Creek	3	14	15	9	10	6	9	19	23	49	8	15
Warm Springs River												
Bunchgrass to Schoolie	6.4	140	112	93	123	120	143	106	80	70	48	29
Schoolie to HeHe	10.6	133	135	97	90	129	142	119	119	145	80	48
He-He to Mckinley Arthur Place	3	36	40	21	23	43	40	41	60	50	33	22
McKinley Arthur lo Badger Creek'	2.9	--	17	28	14	0	29	18	21	43	6	II
WSNFH to Culpus Bridge	8	12	5	14	21	11	6	58	12	4	4	2
TOTAL FOR WARM SPRINGS BASIN		433	438	429	398	428	484	401	415	547	246	163

Appendix B2. Concluded

Index Area	RKM	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Adults arriving at WSNFH		2303	1878	1981	2172	1808	2181	2009	3744	3178	1356	
Jacks arriving at WSNFH		67	34	301	62	240	306	394	191	163	105	--
TOTAL:		2370	1912	2282	2234	2048	2487	2403	3935	3341	1461	--
Adults sent upstream		1587	1251	1322	1264	1211	1550	1259	1254	1701	777	973
Jacks sent upstream		46	34	164	56	55	86	69	65	66	40	20
TOTAL:		1633	1285	1486	7320	1266	1636	1328	1319	1767	817	993
Redds in area above WSNFH		421	433	415	377	417	478	396	407	535	242	161
Total fish per redd		3.9	3	3.6	3.5	3	3.4	3.4	3.2	3.3	3.4	--
Adult fish redd		3.8	2.9	3.2	3.4	2.9	3.2	3.2	3.1	3.2	3.2	--
SHITIKE CREEK												
Peters Pasture [a]	1.1	--	--	--	--	--	0	0	0	0	0	0
Powerline to Upper Xing [a]	3.2	--	_	_	_	_	_	_	3	5	1	0
Upper Xing to Bennett Place [b]	4.5	--	2	10	3	4	0	11	5	3	11	2
Bennett Place to Headworks	2.7	--	4	6	4	2	1	4	5	1	0	1
Headworks to USGS Station	3	9	6	2	10	6	0	10	3	11	6	2
USGS Station to Community Center	3.2	7	2	0	3	3	6	2	1	5	2	0
Community Center to Mouth	3.2	0	1	3	2	2	6	1	0	0	2	7
TOTAL:		16	15	23	24	20	13	28	17	25	22	12

[a] Historically a non-index area

[b] Adult chinook released at B-24 1 bridge (1982-1985)

1982 - 47 adult spring chinook: 23 females, 23 males; 9 wild, 38 hatchery
1983 - 10 adult spring chinook: 3 females, 7 males, all wild
1984 - 40 adult spring chinook: 20 females, 20 males; 24 wild, 16 hatchery
1985 - 42 adult speing chinook: 21 females, 21 males, 26 wild, 16 hatchery

Appendix B3. Spring chinook redd counts in historical index areas in the Warm Springs River basin, 1969-1991.

Year	Warm Springs River Below WSNFH	Warm Springs River Above WSNFH	Beaver Creek	Mill Creek	Total	Total Above WSNF
1969	No survey	205	39	20		264
1970	No survey	119	41	12	--	172
1971	No survey	152	15	6		173
1972	No survey	75	12	0	--	87
1973	No survey	396	154	34	--	584
1974	No survey	172	31	13	--	216
1975	No survey	560	162	86	--	808
1976	No survey	834	161	71	--	1066
1977	201	390	73	35	699	498
1978	8	620	119	49	796	788
1979	2	253	97	7	359	357
1980	3	86	22	6	117	114
1981	10	131	9	7	157	147
1982	12	309	72	25[a]	418	406
1983	5	287	104	22[b]	418	413
1984	14	211	128	14[c] [d]	367	353
1985	21	236	81	15”	353	332
1986	11	292	66	25	394	383
1987	6	325	87	21	439	433
1988	5	266	74	26	371	366
1989	8	259	97	27	391	383
1990	12	265	130	58	465	453
1991	4	161	57	9	231	227
1992	2	99	29	15	145	143

Adult chinook released at B-241 Bridge (a thru d), (Non-Historical index area)

[a] 47 adult spring chinook: 23 females, 24 males; 9 wild, 38 hatchery

[b] 10 adult spring chinook: 3 females, 7 males; all wild

[c] 40 adult speing chinook: 20 females, 20 males; 24 wild, 16 hatchery

[d] 42 adult spring chinook: 2 I females, 2 I males, 26 wild, 16 hatchery

‘Strawberry Falls passage

Appendix B4. Spring chinook brood year redd counts and out-migration estimates for the Warm Springs River basin, 19'75 to 1991.

Brood Year	Adult	Redds	Adult/Redd	Total No. Redds In WSR Basin	No. Fall Out-migrants	No. Spring Out-migrants	Total Number Out-migrants
1975	N/A	N/A	N/A	808	25,795	43,250	69,043
1976	N/A	N/A	N/A	1,066	47,041	26,043	73,084
1977	1505	498	3.0	699	25,125	25,204	50,329
1978	1808	788	2.4	796	74,727	57,216	131943
1979	906	357	2.5	359	24,930	25,628	50,558
1980	651	114	5.7	117	20,579	14,656	35,235
1981	1014	147	6.9	157	29,238	14,647	43,885
1982	1587	421	3.8	433	67,719	30,594	98,313
1983	1251	433	2.9	438	89,396	31,101	120497
1984	1322	415	3.2	429	61,970	34,827	96,797
1985	1264	377	3.4	398	35,991	38,335	74,326
1986	1211	417	2.9	428	47,125	35,651	82,716
1987	1550	478	3.2	484	59,195	27,508	86,703
1988	1259	396	3.2	401	56,007	40,365	96,372
1989	1254	407	3.1	415	42,720	33,154	75874
1990	1701	535	3.2	547	51,340	61,334	112674
1991	777	242	3.2	246	N/A	N/A	WA

Appendix B4. Densities (number/m’) and biomasses (g/m*) of salmonids in Mill Creek, 1986- 1990.

	Chinook salmon		Rainbow/steelhead		Brook trout		Bull trout		Total Salmonids	
Year	Density	Biomass	Density	Biomass	Density	Biomass	Density	Biomass	Density	Biomass
					Potters Pond					
1986	0.020	0.140	0.251	1.558	0.000	0.000	0.000	0.000	0.271	1.698
1987	0.055	0.197	0.276	0.551	0.000	0.000	0.000	0.000	0.331	0.748
1988	0.015	0.047	0.153	0.442	0.000	0.000	0.000	0.000	0.168	0.489
1989	0.010	0.044	0.243	1.300	0.000	0.000	0.000	0.000	0.253	1.344
1990	0.004	0.015	0.165	0.735	0.000	0.000	0.000	0.000	0.169	0.750
					Below Strawberry Falls					
1986	0.003	0.029	0.115	0.496	0.000	0.000	0.000	0.000	0.118	0.525
1987	0.115	0.420	0.066	0.443	0.000	0.000	0.000	0.000	0.181	0.863
1988	0.037	0.122	0.068	0.197	0.000	0.000	0.000	0.000	0.105	0.319
1989	0.036	0.191	0.107	0.422	0.000	0.000	0.000	0.000	0.143	0.613
1990	0.006	0.031	0.073	0.880	0.000	0.000	0.000	0.000	0.073	0.880
					Above Strawberry Falls					
1986	0.016	0.211	0.093	0.568	0.002	0.040	0.000	0.000	0.111	0.813
1987	0.086	0.257	0.104	0.582	0.002	0.084	0.000	0.000	0.192	0.923
1988	0.008	0.026	0.053	0.158	0.005	0.120	0.000	0.000	0.066	0.304
1989	0.081	0.315	0.151	0.400	0.003	0.131	0.000	0.000	0.232	0.846
1990	0.001	0.015	0.211	0.620	0.012	0.493	0.000	0.000	0.223	1.113
					B-241 Road					
1986	0.005	0.082	0.005	0.054	0.067	2.213	0.000	0.000	0.076	2.348
1987	0.000	0.000	0.001	0.004	0.006	0.099	0.000	0.000	0.007	0.103
1988	---	---	---	---	---	---	---	---	---	---
1989	---		---	---	---	---		---	---	---
1990	---		---					---	---	---

Appendix B5. Densities (number/m*) and biomasses (g/m*) of salmonids in Shitike Creek, 1986- 1990.

	Chinook salmon		Rainbow/steelhead		Brook trout		Bull trout		Total Salmonids	
Year	Density	Biomass	Density	Biomass	Density	Biomass	Density	Biomass	Density	Biomass
					Headworks					
1986	0.001	0.010	0.177	1.490	0.000	0.000	0.000	0.000	0.179	1.500
1987	0.003	0.013	0.126	0.477	0.000	0.000	0.000	0.000	0.129	0.490
1988	0.007	0.045	0.135	0.813	0.000	0.000	0.000	0.000	0.142	0.850
1989	0.005	0.040	0.327	0.888	0.000	0.000	0.000	0.000	0.332	0.928
1990	0.050	0.320	0.336	1.594	0.000	0.000	0.000	0.000	0.386	1.914
					Upper Crossing					
1986	0.000	0.000	0.249	1.332	0.000	0.000	0.001	0.083	0.250	1.415
1987	0.041	0.206	0.068	0.662	0.000	0.000	0.001	0.057	0.110	0.925
1988	0.024	0.145	0.109	0.401	0.000	0.000	0.002	0.126	0.135	0.672
1989	0.030	0.197	0.237	0.792	0.000	0.000	0.005	0.067	0.267	0.989
1990	0.022	0.146	0.220	1.258	0.000	0.000	0.004	0.100	0.242	1.404

Appendix B6. Densities (number/m*) and biomasses (g/m²) of salmonids in Beaver Creek, 1986- 1990.

Year	Chinook salmon		Rainbow/steelhead		Brook trout		Bull trout		Total Salmonids	
	Density	Bomass	Density	Biomass	Density	Biomass	Density	Biomass	Density	Biomass
					Lower Island					
1986	0.002	0.009	0.024	0.133	0.000	0.000	0.000	0.000	0.026	0.142
1987	0.002	0.009	0.04 1	0.246	0.000	0.000	0.000	0.000	0.043	0.255
1988	0.000	0.000	0.062	0.062	0.000	0.000	0.000	0.0000	0.062	0.062
1989	0.020	0.136	0.188	0.28 1	0.000	0.000	0.000	0.000	0.209	1.417
1990	0.018	0.059	0.035	0.172	0.000	0.000	0.000	0.000	0.053	0.23 1
					Reach A Test					
1986	0.160	0.511	0.098	0.137	0.000	0.000	0.000	0.000	0.257	0.647
1987	0.161	0.612	0.070	0.655	0.000	0.000	0.000	0.000	0.23 1	1.267
1988	0.122	0.329	0.019	---	0.000	0.000	0.000	0.000	0.141	---
1989	0.214	0.751	0.107	1.051	0.000	0.000	0.000	0.000	0.321	1.802
1990	0.276	0.46 1	0.021	0.076	0.000	0.000	0.000	0.000	0.297	0.537
					Reach B Test					
1986	0.005	0.014	0.276	2.621	0.000	0.000	0.000	0.000	0.221	2.621
1987	0.345	1.520	0.303	3.540	0.000	0.000	0.000	0.000	0.648	5.060
1988	0.057	0.203	0.125	1.265	0.000	0.000	0.000	0.000	0.182	1.468
1989	0.232	1.147	0.150	1.540	0.000	0.000	0.000	0.000	0.382	2.687
1990	0.000	0.000	0.120	1 .000	0.000	0.000	0.000	0.000	0.120	1 .000
					Reach B Control					
1986	0.000	0.000	0.222	1.657	0.000	0.000	0.000	0.000	0.222	1.657
1987	0.201	0.923	0.293	2.106	0.000	0.000	0.000	0.000	0.494	3.029
1988	0.108	0.400	0.207	0.930	0.000	0.000	0.000	0.000	0.315	1.330
1989	0.132	0.626	0.274	0.852	0.000	0.000	0.000	0.000	0.406	I.478
1990	0.000	0.000	0.120	1.000	0.000	0.000	0.000	0.000	0.120	1 .000

Appendix B7. Summary of habitat parameters measured in the Potters Pond on Mill Creek.

Habitat parameters	Year				
	1986	1987	1988	1989	1990
Site length (m)	89.00	90.40	89.60	89.60	89.60
Surface area (m^2)	856.00	788.00	818.00	819.00	795.00
Water volume (m’)	196.90	149.70	157.20	179.40	160.90
Stream width (m)	10.10	9.20	9.40	9.80	9.50
Stream depth (m)	0.23	0.19	0.19	0.22	0.20
Bottom substrate (%)	6.30	6.50	6.70	6.30	6.20
Organic cover	0.00	0.00	0.00	0.00	0.00
<2 mm	0.00	0.00	1.30	0.00	0.00
2 - 5 mm	0.00	0.00	0.00	4.00	0.00
5 - 25 mm	1.30	1.30	2.70	6.70	6.70
25 - 50 mm	14.70	14.70	9.30	9.30	17.30
50 - 100 mm	38.70	34.70	18.70	24.00	26.70
100 - 250 mm	38.70	36.00	46.70	42.70	48.00
> 250 mm	6.60	13.30	21.30	13.30	1.30
Pool (m^2)	183.00	69.00	356.00	394.00	307.00
Riffle (m^2)	660.00	719.00	462.00	425.00	488.00
Backwater (m^2)	13.00	0.00	0.00	0.00	0.00
Side channel (m^2)	0.00	0.00	0.00	0.00	0.00
Usable pool (%)	4.40	8.80	19.60	23.70	18.90
Site mean cover (%)	1.30	1.30	5.50	3.00	2.60
Logs, boulders, below water	3.40	3.10	2.60	6.00	3.10
Logs, boulders above water	30.50	3.90	49.70	39.10	33.70
Overhanging vegetation 5.3 m	8.70	5.50	40.40	17.50	47.80
Aquatic vegetation	0.00	0.00	3.20	3.60	I.90
Undercut banks	13.50	4.70	1.60	0.00	3.10
Depth with surface turbulence	43.90	86.20	2.50	33.80	10.60

Appendix B8. Summary of habitat parameters measured downstream from Strawberry Falls on Mill Creek.

Habitat parameters	Year				
	1986	1987	1988	1989	1990
Site length (m)	67.00	65.70	65.70	65.70	65.70
Surface area (m^2)	659.00	653.00	649.00	645.00	643.00
Water volume (m^3)	197.70	177.50	174.30	180.50	172.00
Stream width (m)	9.80	9.90	9.90	9.80	9.80
Stream depth (m)	0.30	0.27	0.27	0.28	0.27
Bottom substrate (%)	6.10	---	---	---	6.60
Organic cover	1.30	---	---	---	0.00
<2 mm	0.00	---	---	---	1.30
2 - 5 mm	1.30	---	---	---	0.00
5 - 25 mm	12.00	---	---	---	6.70
25 - 50 mm	14.70	---	---	---	13.30
50 - 100 mm	25.30	---	---	---	10.70
100 - 250 mm	26.70	---	---	---	41.30
> 250 mm	18.70	---	---	---	26.70
Pool (m^2)	81.00	---	271.00	232.00	219.00
Riffle (m^2)	578.00	---	378.00	402.00	424.00
Backwater (m^2)	0.00	---	0.00	11.00	0.00
Side channel (m^2)	0.00	---	0.00	0.00	0.00
Usable pool (%)	9.70	---	30.70	27.40	19.00
Site mean cover (%)	5.50	---	---	---	4.40
Logs, boulders, below water	54.00	---	---	---	1.40
Logs, boulders above water	3.90	---	---	---	3.20
Overhanging vegetation 5.3 m	15.80	---	---	---	11.90
Aquatic vegetation	0.70	---	---	---	2.80
Undercut banks	17.90	---	---	---	23.30
Depth with surface turbulence	7.70	---	---	---	57.20

Appendix B9. Summary of habitat parameters measured upstream from Strawberry Falls on Mill Creek.

Habitat parameters	Year				
	1986	1987	1988	1989	1990
Site length (m)	121.00	116.40	116.40	116.40	116.40
Surface area (m^2)	1042.00	1087.00	1032.00	1000.00	1033.00
Water volume (m’)	250.10	206.60	217.20	247.30	233.00
Stream width (m)	8.80	9.30	9.00	8.80	8.90
Stream depth (m)	0.24	0.19	0.21	0.25	0.23
Bottom substrate (%)	6.50	---	---	---	6.30
Organic cover	0.00	---	---	---	0.00
<2 mm	1.30	---	---	--e	0.00
2 - 5 mm	1.30	---	---	---	0.00
5 - 25 mm	4.00	mm-	---	---	8.00
25 - 50mm	10.70	---	---	---	14.70
50 - 100 mm	24.00	---	---	a--	18.70
100 - 250 mm	41.40	---	---	---	53.30
> 250 mm	17.30	---	---	---	5.30
Pool (m^2)	96.00	---	373.00	247.00	460.00
Riffle (m^2)	933.00	---	611.00	703.00	573.00
Backwater (m^2)	13.00	---	48.00	0.00	0.00
Side channel (m^2)	0.00	---	0.00	0.00	0.00
Usable pool (%)	5.90	-a-	16.10	19.90	25.20
Site mean cover (%)	5.00	-m-	---	---	7.70
Logs, boulders, below water	5.80	---	---	---	12.10
Logs, boulders above water	24.90	---	---	---	17.40
Overhanging vegetation 5.3 m	21.30	---	---	---	36.50
Aquatic vegetation	37.10	---	---	---	6.20
Undercut banks	6.30	---	---	---	25.10
Depth with surface turbulence	4.60	---	---	---	2.70

Appendix B 10. Summary of habitat parameters measured in the Lower Island site on Beaver Creek.

Habitat parameters	Year				
	1986	1987	1988	1989	1990
Site length (m)	41.00	43.60	46.40	46.40	46.40
Surface area (m^2)	663.00	635.00	697.00	786.00	734.00
Water volume (m')	152.50	146.00	159.00	155.10	137.00
Stream width (m)	16.04	14.60	15.10	16.40	15.60
Stream depth (m)	0.23	0.23	0.23	0.20	0.19
Bottom substrate (%)	4.20	4.00	4.50	3.80	3.90
Organic cover	0.00	4.00	6.70	0.00	2.70
<2 mm	9.30	9.30	4.00	4.00	4.00
2 - 5 mm	12.00	16.00	4.00	38.70	17.30
5 - 25 mm	33.40	32.00	25.30	37.30	53.30
25 - 50 mm	40.00	28.00	44.00	16.00	17.30
50 - 100 mm	5.30	10.70	13.30	4.00	5.30
100 - 250 mm	0.00	0.00	2.70	0.00	0.00
> 250 mm	0.00	0.00	0.00	0.00	0.00
Pool (m^2)	95.00	169.00	250.00	284.00	390.00
Riffle (m^2)	559.00	446.00	438.00	502.00	341.00
Backwater (m^2)	9.00	20.00	9.00	0.00	3.00
Side channel (m^2)	0.00	0.00	0.00	0.00	0.00
Usable pool (%)	9.20	10.00	28.80	21.90	22.30
Site mean cover (%)	2.95	4.82	7.64	3.31	5.60
Logs, boulders, below water	0.50	2.20	0.10	11.20	1.80
Logs, boulders above water	0.00	0.00	1.40	2.90	7.20
Overhanging vegetation 5.3 m	65.00	16.10	86.80	18.80	52.50
Aquatic vegetation	17.90	18.60	0.80	42.80	30.70
Undercut banks	4.10	6.50	0.00	16.60	4.80
Depth with surface turbulence	12.50	56.50	10.90	7.70	2.90

Appendix B 11. Summary of habitat parameters measured in Reach A Test site on Beaver Creek.

Habitat parameters	Year				
	1986	1987	1988	1989	1990
Site length (m)	48.30	48.30	48.30	48.30	48.30
Surface area (m”)	338.00	416.00	378.00	374.00	376.00
Water volume (m^3)	54.10	99.90	89.00	79.40	92.80
Stream width (m)	7.01	7.80	7.80	7.70	7.80
Stream depth (m)	0.16	0.24	0.24	0.21	0.25
Bottom substrate (%)	5.10	4.00	4.50	3.80	3.90
Organic cover	2.70	4.00	6.70	0.00	2.70
<2 mm	1.30	9.30	4.00	4.00	4.00
2 - 5 mm	5.30	16.00	4.00	38.70	17.30
5 - 25 mm	22.70	32.00	25.30	37.30	53.30
25 - 50 mm	21.30	28.00	44.00	16.00	17.30
50 - 100 mm	36.00	10.70	13.30	4.00	5.30
100 - 250 mm	10.70	0.00	2.70	0.00	0.00
> 250 mm	0.00	0.00	0.00	0.00	0.00
Pool (m^2)	36.00	305.00	351.00	362.00	295.00
Riffle (m^2)	284.00	111.00	27.00	11.00	81.00
Backwater (m^2)	18.00	0.00	0.00	0.00	0.00
Side channel (m^2)	0.00	0.00	0.00	0.00	0.00
Usable pool (%)	2.90	58.80	84.30	73.40	65.50
Site mean cover (%)	0.22	4.82	7.64	9.38	5.60
Logs, boulders, below water	37.40	2.20	0.10	39.40	1.80
Logs, boulders above water	0.00	0.00	1.40	0.00	7.20
Overhanging vegetation 5.3 m	9.30	16.10	86.80	40.90	52.50
Aquatic vegetation	12.00	18.60	0.80	5.00	30.70
Undercut banks	17.30	6.50	0.00	13.80	4.80
Depth with surface turbulence	24.00	56.50	10.90	0.90	2.90

Appendix B 12. Summary of habitat parameters measured in Reach B Test site on Beaver Creek.

Habitat parameters	Year				
	1986	1987	1988	1989	1990
Site length (m)	49.50	49.50	49.50	49.50	49.50
Surface area (m^2)	403.00	400.00	407.00	401.00	402.00
Water volume (m’)	68.50	52.00	64.20	56.90	60.80
Stream width (m)	8.14	8.10	8.20	8.10	8.10
Stream depth (m)	0.17	0.13	0.16	0.14	0.15
Bottom substrate (%)	5.50	6.00	6.10	6.00	6.20
Organic cover	1.30	1.30	0.00	0.00	0.00
<2 mm	1.30	2.70	1.30	1.30	2.70
2 - 5 mm	4.00	1.30	6.70	4.00	1.30
5 - 25 mm	14.80	5.30	4.00	9.30	4.00
25 - 50 mm	25.30	20.00	10.70	12.00	14.70
50 - 100 mm	25.30	30.70	28.00	29.40	21.30
100 - 250 mm	25.30	36.00	46.70	44.00	50.70
> 250 mm	2.70	4.00	2.70	0.00	5.30
Pool (m^2)	20.00	162.00	125.00	138.00	121.00
Riffle (m^2)	383.00	238.00	282.00	262.00	281.00
Backwater (m^2)	0.00	0.00	0.00	0.00	0.00
Side channel (m^2)	0.00	0.00	0.00	0.00	0.00
Usable pool (%)	2.30	11.30	8.50	10.80	11.60
Site mean cover (%)	8.51	5.54	2.28	10.47	5.05
Logs, boulders, below water	0.00	19.00	19.20	2.60	1.40
Logs, boulders above water	0.00	20.40	11.80	6.10	16.20
Overhanging vegetation 5.3 m	49.50	44.20	54.70	76.20	75.80
Aquatic vegetation	12.30	0.00	0.00	4.60	0.00
Undercut banks	38.20	16.10	14.40	10.00	6.50
Depth with surface turbulence	0.00	0.00	0.00	0.50	0.00

Appendix B 13. Summary of habitat parameters measured in Reach B Control site on Beaver Creek.

Habitat parameters	Year				
	1986	1987	1988	1989	1990
Site length (m)	48.30	48.30	48.30	48.30	48.30
Surface area (m^2)	316.00	294.00	3 14.00	303.00	309.00
Water volume (m’)	53.70	50.00	50.80	44.30	53.30
Stream width (m)	6.60	6.10	6.60	6.40	6.40
Stream depth (m)	0.17	0.17	0.16	0.15	0.17
Bottom substrate (%)	6.00	---	---	---	6.10
Organic cover	0.00	---	---	---	0.00
<2 mm	1.30	me-	---	---	0.00
2 - 5 mm	4.00	---	---	---	0.00
5 - 25 mm	10.70	---	---	---	16.00
25 -50mm	13.30	---	---	---	10.70
50 - 100 mm	26.70	---	---	---	21.30
100 - 250 mm	40.00	---	---	---	49.30
> 250 mm	4.00	---	---	---	2.70
Pool (m^2)	71.00	90.00	137.00	149.00	126.00
Riffle (m^2)	224.00	201.00	170.00	154.00	183.00
Backwater (m^2)	21.00	3.00	7.00	0.00	0.00
Side channel (m^2)	0.00	0.00	0.00	0.00	0.00
Usable pool (%)	5.10	7.40	22.50	22.50	13.80
Site mean cover (%)	2.90	---	---	6.08	3.38
Logs, boulders, below water	38.20	---	---	3.10	5.60
Logs, boulders above water	13.70	---	---	8.20	9.20
Overhanging vegetation 5.3 m	15.00	---	---	80.80	32.80
Aquatic vegetation	0.00	mm-	---	0.00	0.00
Undercut banks	13.40	-__	---	3.00	33.70
Depth with turbulence	19.70	---	---	4.90	18.60

Appendix B14. Summary of habitat parameters measured in the Headworks site on Shitike Creek.

Habitat parameters	Year				
	1986	1987	1988	1989	1990
Site length (m)	50.00	50.00	50.00	50.00	50.00
Surface area (m^2)	739.00	757.00	750.00	759.00	759.00
Water volume (m')	184.80	206.00	155.00	184.70	210.10
Stream width (m)	15.20	15.40	15.40	15.60	15.50
Stream depth (m)	0.25	0.23	0.22	0.24	0.28
Bottom substrate (%)	6.10	---	---	---	6.40
Organic cover	0.00	-a-	mm-	---	0.00
<2 mm	2.70	--e	-__	me-	0.00
2 - 5 mm	0.00	---	---	--_	0.00
5 - 25 mm	10.70	---	---	---	5.30
25 - 50 mm	16.00	---	---	---	14.70
50 - 100 mm	26.60	---	---	---	25.30
100 - 250 mm	32.00	---	---	---	41.30
> 250 mm	12.00	---	---	---	13.30
Pool (m^2)	330.00	270.00	588.00	274.00	377.00
Riffle (m^2)	380.00	483.00	124.00	485.00	382.00
Backwater (m^2)	29.00	4.00	38.00	0.00	0.00
Side channel (m^2)	0.00	0.00	0.00	0.00	0.00
Usable pool (%)	29.30	30.50	66.50	27.90	41.60
Site mean cover (%)	1.70	---	mm-	---	2.40
Logs, boulders, below water	28.10	---	-__	---	21.30
Logs, boulders above water	18.70	---	---	---	19.20
Overhanging vegetation 5.3 m	7.00	---	---	---	27.20
Aquatic vegetation	0.00	---	---	---	0.00
Undercut banks	3.30	---	---	---	17.90
Depth with surface turbulence	42.90	---	---	---	14.00

Appendix B 15. Summary of habitat parameters measured in the Upper Crossing site on Shitike Creek.

Habitat parameters	Year				
	1986	1987	1988	1989	1990
Site length (m)	63.00	57.80	57.60	57.60	57.60
Surface area (m^2)	893.00	825.00	847.00	837.00	838.00
Water volume (m')	3 12.60	237.60	231.60	243.30	250.80
Streamwidth	13.80	13.90	14.40	14.20	14.10
Stream depth (m)	0.35	0.29	0.27	0.29	0.30
Bottom substrate (%)	6.80	---	---	---	6.60
Organic cover	0.00	---	---	---	0.00
<2 mm	0.00	---	---	---	1.30
2 - 5 mm	2.70	---	---	---	0.00
5 - 25 mm	1.30	---	---	---	5.30
25 - 50 mm	1.30	---	---	---	8.00
50 - 100 mm	30.70	---	---	---	27.00
100 - 250 mm	33.30	---	--	---	30.70
> 250 mm	30.70	---	---	---	26.70
Pool (m^2)	319.00	316.00	376.00	353.00	391.00
Riffle (m^2)	490.00	509.00	448.00	485.00	447.00
Backwater (m^2)	84.00	0.00	23.00	0.00	0.00
Side channel (m^2)	0.00	0.00	0.00	0.00	0.00
Usable pool (%)	23.60	26.70	30.90	29.10	32.50
Site mean cover (%)	3.80	---	---	---	17.90
Logs, boulders, below water	14.80	---	---	---	0.70
Logs, boulders above water	16.20	---	---	---	2.00
Overhanging vegetation 5.3 m	0.40	---	---	---	29.10
Aquatic vegetation	0.10	---	---	---	0.00
Undercut banks	0.00	---	---	---	0.40
Depth with surface turbulence	68.50	---	---	---	67.80

Appendix C 1. Summary of ANOVA tests of changes in fish populations and habitat variables among Potter's Pond (PP), below Strawberry Falls @SF), and above Strawberry Falls (aSF) sites on Mill Creek, Oregon. Probability values less than 0.05 are considered significant.

	Mean score					
Dependent variables	PP	bSF	aSF	F-value	Prob	Power
Chinook density	2.1	3.9	3.8	0.39	0.68	0.09
Chinook biomass	a.9	15.9	16.5	0.53	0.60	0.12
Chinook mean weight	4.4	5.4	7.8	0.98	0.40	0.18
S teelhead density	21.8	8.6	12.2	9.59	0.00	0.94
S teelhead biomass	91.7	48.8	46.6	2.90	0.09	0.46
Steelhead mean weight	4.2	5.9	4.1	2.90	0.09	0.46
Salmonid density	23.8	12.4	16.5	4.24	0.04	0.62
Salmonid biomass	100.6	64.0	79.9	1.28	0.31	0.22
Volume (m^3)	168.8	180.4	230.8	19.78	0.00	0.99
Depth (cm)	20.6	27.8	22.4	19.50	0.00	0.99
Pool (m^2)	261.8	200.8	294.0	0.54	0.60	0.12
Riffle (m^2)	550.8	445.5	704.9	4.00	0.05	0.57
Backwater (m^2)	2.6	2.8	15.3	1.24	0.33	0.21
Usable pool (%)	15.1	21.7	16.8	0.70	0.52	0.14

Appendix C2. Summary of significant Pearson correlations between fish populations and habitat variables, and years (1986-1990) and habitat variables in the above Strawberry Falls site on Mill Creek, Oregon.

Population/time variables	Habitat variables	Correlation coefficient
Chinook biomass	Pool	0.75
Steelhead density	Backwater	-0.85
Steelhead biomass	Backwater	-0.82
Steelhead mean weight	Pool	-0.79
	Riffle	0.91
	Usable pool	-0.88
Brook trout density	Pool	0.86
	Usable pool	0.77
Brook trout biomass	Pool	0.80
	Usable pool	0.82
Brook trout mean weight	Pool	0.80
	Riffle	-0.92
	Usable Pool	0.90
Salmonid density	Backwater	-0.89

Appendix C2. Concluded.

Population/time variables	Habitat variables	Correlation coefficients
Salmonid biomass	Backwater	-0.94
Year	Pool	0.84
	Riffle	-0.a7
	Usable pool	0.99

Appendix C3. Summary of significant Pearson correlations between fish populations and habitat variables, and years (1986-1990) and habitat variables in the below Strawberry Falls site on Mill Creek, Oregon.

Population/time variables	Habitat variables	Correlation coefficient
Chinook density	Pool	0.75
	Riffle	-0.76
	Usable pool	0.93
Chinook biomass	Backwater	0.83
	Usable pool	0.80
Chinook mean weight	Depth	0.96
	Pool	-0.98
	Riffle	0.97
	Usable pool	-0.91
Steelhead density	Depth	0.89
Salmonid density	Backwater	0.76
Year	Area	-0.98
	Volume	-0.75
	Riffle	-0.76

Appendix C4. Summary of significant Pearson correlations between fish populations and habitat variables, and years (1986-1990) and habitat variables in the Potter's Pond site on Mill Creek, Oregon.

Population/time variables	Habitat variables	Correlation coefficient
Chinook density	Large cobble	-0.83
	Pool	-0.86
	Riffle	0.82
	Log/boulder above water	0.86
	Surface turbulence	0.89
Chinook biomass	Small gravel	-0.82
	Small cobble	0.78
	Large cobble	-0.95
	Pool	-0.93
	Riffle	0.95
	Usable pool	-0.84
	Log/boulder above water	-0.82
	Overhanging vegetation	-0.84
	Aquatic vegetation	-0.83
	Surface turbulence	0.91
Chinook mean weight	Depth	0.90
	Backwater	0.95
	Undercut banks	0.85

Appendix C4. Continued.

Population/time variables	Habitat variables	Correlation coefficient
S teelhead density	Large cobble	-0.94
	Mean cover	-0.78
	Overhanging vegetation	-0.97
	Surface turbulence	0.91
S teelhead biomass	Depth	0.99
Steelhead mean weight	Depth	0.94
Salmonid density	Large cobble	-0.97
	Pool	-0.75
	Riffle	0.76
	Mean cover	-0.75
	Log/boulder above water	-0.82
	Overhanging vegetation	-0.95
	Surface turbulence	0.97
Salmonid biomass	Depth	0.97
	Backwater	0.78
Year	Small gravel	0.93
	Large cobble	0.78

Appendix C4. Concluded.

Population/time variables	Habitat variables	Correlation coefficients
Year	Riffle	-0.77
	Usable pool	0.86
	Overhanging vegetation	0.75
	Undercut banks	-0.76

Appendix C5. Statistical results of time series trend analyses of numbers of redds of spring chinook salmon in index reaches in the Warm Springs Basin and Shitike Creek, Oregon.

Index Reach	Slope (b)	t-value (b=O)	Prob (b=O)	Autocorrelation Lag (yrs)	Autocorrelation r
			Beaver Creek		
Reach D - Robinson Park	-0.21	-0.75	0.49	1	-0.52
Robinson Park - Dahl Pine	-2.22	-0.97	0.36	2	-0.54
Dahl Pine - Canyon	2.27	1.48	0.18	--	--
Old Bridge - Powerline	-0.27	-0.39	0.71	--	--
Powerline - Island	-0.63	-0.38	0.72	3	-0.49
Island Area	-0.44	-0.71	0.50	--	
			Mill Creek		
B-241 Road Bridge	-1.74	-2.72	0.03	2	-0.47
Old Mill - Strawberry Falls	0.14	0.32	0.76	3	-0.48
Strawberry Falls - Potter's Pond	-0.50	-0.88	0.41	--	--
Potter's Pond - Boulder Creek	1.72	1.27	0.24	--	--
			Warm Springs River		
Bunchgrass - Schoolie	-7.36	-2.99	0.02	3	-0.51
Schoolie - He-He	-1.19	-0.46	0.66	--	--
He-He - Mckinley Arthur Place	1.75	1.46	0.18	2	-0.49

Appendix C5. Concluded.

Index Reach	Slope (b)	t-value (b=O)	Prob (b=O)	Autocorrelation Lag (yrs)	Autocorrelation r
			Warm Springs River		
McKinley Arthur - Badger Creek	0.55	0.31	0.76	4	-0.45
WSNFH - Culpus Bridge	0.10	0.05	0.96	--	--
			Shitike Creek		
Powerline - Upper Xing	-1.30	-1.64	0.24	1	
Upper Xing - Bennett Place	0.43	0.79	0.46	--	--
Bennett Place - Headworks	-0.45	-1.97	0.09	2	-0.69
Headworks - USGS Station	0.04	0.10	0.93	1	-0.54
USGS Station - Community Center	-0.12	-0.45	0.67	--	--
Community Center - Mouth	-0.02	-0.09	0.93	--	--

Appendix C6. Summary of ANOVA tests of differences in fish population and habitat variables among the Lower Island (LI), Reach A-Test (A-T), Reach B-Test (B-T), and Reach B-Control (B-C) sites on Beaver Creek, Oregon. Probability values less than 0.05 are considered significant.

	Mean score						
Dependent variable	LI	A-T	B-T	B-C	F	Prob	Power
Chinook density	0.8	18.7	12.8	8.8	3.20	0.05	0.62
Chinook biomass	4.3	53.3	57.7	38.9	1.70	0.21	0.35
Chinook mean weight	4.3	2.9	3.1	2.6	0.61	0.62	0.15
S teelhead density	7.0	6.3	19.5	22.3	7.45	0.00	0.95
S teelhead biomass	37.9	47.9	199.3	130.9	5.64	0.01	0.87
Steelhead mean weight	4.8	6.0	11.3	6.1	6.24	0.01	0.90
Salmonid density	15.6	24.9	31.1	31.1	1.07	0.39	0.24
Salmonid biomass	42.1	106.3	256.7	169.9	4.25	0.02	0.75
Volume	149.9	83.0	60.5	50.4	89.87	0.00	1.00
Depth	21.6	22.0	15.0	16.4	12.39	0.00	0.99
Substrate	4.1	4.3	5.9	--	36.44	0.00	1.00
Organic cover	2.7	3.2	0.5	--	2.11	0.16	0.35
Sand	6.1	4.5	1.9	--	3.96	0.04	0.60
Pea gravel	17.6	16.3	3.5	--	2.50	0.12	0.41
Small gravel	36.3	34.1	7.5	--	13.84	0.00	0.99
Large gravel	29.1	25.3	16.5	--	1.87	0.20	0.31
Small cobble	7.7	13.9	26.9	--	7.30	0.01	0.86
Large cobble	0.5	2.7	40.5	--	61.04	0.00	1.00

Appendix C6. Concluded.

Dependent variable	Mean score				F	Prob	Power
	LI	A-T	B-T	B-C			
Boulder	0.0	0.0	2.9	--	11.19	0.00	0.97
Pool	237.6	269.8	113.2	114.6	3.87	0.03	0.71
Riffle	457.2	102.8	289.2	186.4	20.90	0.00	0.99
Backwater	8.2	3.6	0.0	6.2	1.25	0.32	0.27
Usable pool	18.4	56.9	8.9	14.3	8.28	0.00	0.97
Mean cover	4.9	5.5	6.4	4.1	0.48	0.70	0.12
Log/bldr below water	3.2	16.2	8.4	15.6	0.86	0.49	0.19
Log/bldr above water	2.3	1.7	10.9	10.4	4.46	0.02	0.76
Overhanging vegetation	47.8	41.1	60.1	42.9	0.45	0.72	0.12
Aquatic vegetation	22.2	13.4	3.4	0.0	3.67	0.04	0.67
Undercut banks	6.4	8.5	17.0	16.7	1.32	0.31	0.28
Surface turbulence	18.1	19.0	0.1	14.4	1.30	0.31	0.28

Appendix C7. Summary of significant Pearson correlations between fish populations **and** habitat variable, and years (1986-1990) and habitat variables in the Reach B-Control site on Beaver Creek, Oregon.

Population/time variables	Habitat variables	Con-elation coefficients
S teelhead biomass	Pool	**-0.87**
	Riffle	0.78
	Usable pool	-0.86
Steelhead mean weight	Depth	0.97
	Riffle	0.76
	Usable pool	-0.81
Year	Pool	0.81
	Riffle	-0.75
	Backwater	-0.81

Appendix C8. Summary of significant Pearson correlations between fish populations and habitat variables, and years (1986-1990) and habitat variables in the Reach B-Test site on Beaver Creek, Oregon.

Population/time variables	Habitat variables	Correlation coefficients
Chinook density	Depth	-0.88
	Small cobble	0.84
Chinook biomass	Depth	-0.88
	Small cobble	0.83
Chinook mean weight	Small cobble	0.97
	Boulder	-0.75
Steelhead density	Organic cover	0.98
	Large gravel	0.86
	Large cobble	-0.87
	Overhanging vegetation	-0.78
Steelhead biomass	Organic cover	0.93
	Large cobble	-0.77
	Overhanging vegetation	-0.79
Steelhead mean weight	Large gravel	0.79
Salmonid density	Depth	-0.79

Appendix C8. Concluded.

Population/ time variables	Habitat variables	Correlation coefficients
Salmonid density	Small cobble	0.80
Year	Substrate	0.82
	Organic cover	-0.87
	Large gravel	-0.76
	Large cobble	0.92
	Overhanging vegetation	0.89
	Undercut banks	-0.88

Appendix C9. Summary of significant Pearson correlations between fish populations and habitat variables, and years (1986- 1990) and habitat variables in the Reach A-Test site on Beaver Creek, Oregon.

Population/time variables	Habitat variables	Correlation coefficient
Chinook density	Small gravel	0.94
	Large gravel	-0.78
Chinook biomass	Organic cover	-0.84
	Pea gravel	0.85
Chinook mean weight	Log/boulder above water	-0.94
S teelhead density	Log/boulder below water	0.88
	Undercut banks	0.91
Steelhead biomass	Pea gravel	0.83
Steelhead mean weight	Pea gravel	0.75
	Pool	0.81
	Riffle	-0.75
	Mean cover	0.77
Salmonid density	Organic cover	-0.96
	Pea gravel	0.75
	Large gravel	-0.98

Appendix C9. Concluded.

Population/time variables	Habitat variables	Correlation coefficient
Salmonid biomass	Pea gravel	0.83
Year	Substrate.	-0.76
	Small gravel	0.87
	Small cobble	-0.83

Appendix C10. Summary of two-sample randomization tests that compare mean densities, biomasses, and weights of fish populations before (1986-1987) and after (1989-1990) the addition of juniper rip-rap in the Lower Island site on Beaver Creek, Oregon. Probabilities less than 0.05 are considered significant.

Population variable	Number of randomizations	Mean difference	Variance ratio (F)	Prob
Chinook density	5000	-1.700	0.000	0.17
Chinook biomass	5000	-8.850	0.000	0.17
Chinook mean weight	5000	0.745	0.022	0.67
Steelhead density	5000	-7.900	0.012	0.34
Steelhead biomass	5000	-53.700	0.010	0.34
Steelhead mean weight	5000	-0.075	0.066	0.51
Salmonid density	5000	-9.650	0.012	0.17
Salmonid biomass	5000	-62.500	0.009	0.34

Appendix C 11. Summary of significant Pearson correlations between fish populations and habitat variables, and years (1986-1990) and habitat variables in the Lower Island site on Beaver Creek, Oregon.

Population/time variable	Habitat variable	Correlation coefficient
Chinook density	Depth	-0.96
	Substrate	-0.81
	Pea gravel	0.80
	Small gravel	0.77
	Large gravel	-0.91
	Backwater	-0.78
	Log/boulder above water	0.78
	Aquatic vegetation	0.90
Chinook biomass	Depth	-0.76
	Substrate	-0.76
	Pea gravel	0.95
	Large gravel	-0.81
	Backwater	-0.75
	Log/boulder below water	0.93
	Aquatic vegetation	0.90
	Undercut banks	0.90
Chinook mean weight	Organic cover	-0.86
	Large cobble	-0.88

Appendix C 11. Continued.

Population/time variable	Habitat variable	Correlation coefficient
Chinook mean weight	Mean cover	-0.96
	Overhanging vegetation	-0.76
Steelhead density	Pea gravel	0.84
	Log/boulder below water	0.95
	Undercut banks	0.85
Steelhead biomass	Pea gravel	0.95
	Log/boulder below water	0.99
	Aquatic vegetation	0.79
	Undercut banks	0.96
Steelhead mean weight	Substrate	-0.87
	Organic cover	-0.82
	Pea gravel	0.76
	Large cobble	-0.95
	Mean cover	-0.88
	Overhanging vegetation	-0.85
	Aquatic vegetation	0.82
	Undercut banks	0.77

Appendix C 11. Concluded.

Population/time variables	Habitat variables	Conrelation coefficient
Salmonid density	. Overhanging vegetation	-0.81
	Surface turbulence	0.88
Salmonid biomass	Pea gravel	0.96
	Log/boulder below water	0.99
	Aquatic vegetation	0.80
	Undercut banks	0.96
Year	Area	0.78
	Depth	-0.89
	Sand	-0.87
	Pool	0.99
	Log/boulder above water	0.91

Appendix C12. Summary of ANOVA tests of changes in habitat variables from 1988 through 1990 in the four bioengineering sites on lower Shitike Creek, Oregon. Probability values less than 0.05 are considered significant.

Habitat variables	Mean scores 1988	1989	1990	F-ratio	Prob	Power
Volume (m^3)	343.4	333.4	317.1	0.20	0.82	0.07
Depth (cm)	29.5	29.3	29.7	0.01	0.95	0.05
Substrate (%)	6.3	5.8	6.5	3.77	0.06	0.53
Organic cover (%)	1.3	0.0	0.7	0.98	0.41	0.17
Sand (%)	0.0	2.7	0.6	0.80	0.47	0.15
Pea gravel (%)	0.7	0.6	1.0	0.11	0.89	0.06
Small gravel (%)	4.4	9.7	3.0	2.39	0.15	0.36
Large gravel (%)	14.3	23.4	15.7	2.57	0.13	0.38
Small cobble (%)	27.0	31.0	26.0	0.44	0.65	0.10
Large cobble (%)	41.7	27.3	42.0	2.16	0.17	0.33
Boulder (%)	10.7	5.4	7.9	1.37	0.30	0.22
Pool (m^2)	386.8	459.8	474.5	0.23	0.80	0.08
Riffle (m^2)	637.5	604.5	531.2	0.42	0.67	0.10
Backwater (m^2)	46.5	2.3	1.5	7.98	0.01	0.86
Side channel (m^2)	98.3	66.5	55.5	0.28	0.76	0.08
Usable pool (%)	62.2	26.9	32.2	0.56	0.59	0.12
Mean cover (%)	2.4	2.4	3.1	0.59	0.57	0.12
Log/bldr below water (%)	37.8	16.5	5.7	11.87	0.00	0.96
Log/bldr above water (%)	3.1	18.8	33.4	2.32	0.15	0.35
Overhang vegetation (%)	30.6	33.3	38.0	0.12	0.89	0.06

Appendix C 12. Concluded.

Habitat variables	Mean score 1988	1989	1990	F-ratio	Prob	Power
Aquatic vegetation (%)	0.6	0.6	1.5	0.51	0.62	0.11
Undercut banks (%)	15.5	13.1	5.6	0.40	0.68	0.10
Surface turbulence (%)	11.0	15.4	15.9	0.18	0.84	0.07

Appendix C13. Significant Pearson correlations for habitat variables and time (1988-1990) in the four bioengineering sites on lower Shitike Creek, Oregon.

Habitat site	Habitat variable	Correlation coefficient
#1	Volume	0.99
	Depth	0.93
	Pea gravel	-0.87
	Small gravel	0.87
	Large gravel	0.99
	Small cobble	-0.98
	Boulder	0.87
	Pool	0.90
	Riffle	-0.97
	Backwater	-0.79
	Side channel	-0.87
	Usable pool	0.96
	Mean cover	0.95
	Log/boulder below water	-0.94
	Overhanging vegetation	0.88
	Undercut banks	-0.89
	Surface turbulence	0.80
#2	Volume .	-0.97
	Substrate	0.87
	Organic cover	-0.87

Appendix C 13. Continued.

Habitat site	Habitat variable	Correlation coefficient
#2	Sand	0.87
	Pea gravel	0.87
	Small gravel	0.87
	Boulder	-0.99
	Pool	-0.87
	Backwater	-0.87
	Usable pool	-0.92
	Mean cover	-0.98
	Log/boulder below water	-0.98
	Log/boulder above water	0.93
	Overhanging vegetation	-0.89
#3	Volume	-0.99
	Depth	-0.87
	Organic cover	0.87
	Sand	0.86
	Pea gravel	0.87
	Small cobble	0.78
	Pool	0.87
	Riffle	-0.93
	Backwater	-0.87
	Side channel	-0.97

Appendix C 13. Concluded.

Habitat site	Habitat variables	Correlation coefficient
#3	Usable pool	0.88
	Log/boulder below water	-0.98
	Log/boulder above water	0.85
#4	Volume	-0.89
	Depth	-0.87
	Organic cover	-0.87
	Small cobble	0.98
	Backwater	-0.91
	Side channel	-0.84
	Usable pool	-0.86
	Log/boulder below water	-0.90
	Overhanging vegetation	0.99
	Aquatic vegetation	0.87
	Undercut banks	0.83

Appendix C14. Summary of t-test results of differences in fish populations and habitat variables between the headworks and upper crossing sites on Shitike Creek Oregon. Probability values less than 0.05 are considered significant.

Dependent variable	Mean score		t-value	Prob	Power
	Headworks	Upper Xing			
Chinook density	1.3	2.3	-0.89	0.40	1.00
Chinook biomass	8.6	13.9	-0.76	0.47	1.00
Chinook mean weight	6.6	4.9	1.26	0.24	0.21
S teelhead density	22.0	17.7	0.74	0.48	1.00
S teelhead biomass	105.2	88.9	0.59	0.57	1.00
Steelhead mean weight	5.1	5.6	-0.30	0.77	0.06
Salmonid density	23.4	20.1	0.53	0.61	1.00
Salmonid biomass	113.6	108.1	0.19	0.85	1.00
Volume	188.1	255.2	-3.79	0.01	0.97
Depth	24.4	30.0	-3.31	0.01	1.00
Pool	367.8	351.0	0.28	0.79	0.06
Riffle	370.8	475.8	-1.57	0.19	0.35
Backwater	14.2	21.4	-0.39	0.70	0.07
Usable pool	39.2	28.6	1.43	0.21	0.30

Appendix C15. Summary of significant Pearson correlations between fish populations and habitat variables, and years (1986-1990) and habitat variables in the Headworks site on Shitike Creek, Oregon.

Population/time variable	Habitat variable	Correlation coefficient
Chinook density	Depth	0.83
Chinook biomass	Depth	0.84
Steelhead biomass	Depth	0.84
Steelhead mean weight	Backwater	0.78
Year	Area	0.78

Appendix C16. Summary of significant Pearson correlations between fish populations and habitat variables, and years (1986-1990) and habitat variables in the Upper Crossing site on Shitike Creek, Oregon.

Population/time variable	Habitat variable	Correlation coefficient
Chinook density	Volume	-0.88
	Depth	-0.79
	Backwater	-0.89
Chinook biomass	Volume	-0.92
	Depth	-0.85
	Backwater	-0.96
Chinook mean weight	Volume	-0.92
	Depth	-0.88
	Backwater	-0.93
	Usable pool	0.89
S teelhead biomass	Volume	0.77
	Depth	0.84
Bull trout biomass	Riffle	-0.89
Bull trout mean weight	Backwater	0.89
	Usable pool .	-0.75

Appendix C 16. Concluded.

Population/ time variable	Habitat variable	Correlation coefficient
Salmonid biomass	Depth	0.81
Year	Pool	0.86
	Backwater	-0.73
	Usable pool	0.91

Appendix C17. Correlation coefficients of mean monthly flows and numbers of fall, spring, and total out-migrants from the Warm Springs River basin from 1975 through 1991. There were no significant ($P < 0.05$) associations.

Year	Month	Migration time: Fall	Migration time: Spring	Total migrants
Brood Yr	Oct	-0.002	-0.155	-0.011
	Nov	0.090	0.165	0.141
	Dec	0.481	0.188	0.433
Brood Yr + 1	Jan	-0.114	-0.209	-0.169
	Feb	-0.215	-0.274	-0.270
	Mar	0.019	0.021	0.023
	Apr	0.367	0.260	0.379
	May	0.212	0.324	0.288
	Jun	0.117	-0.121	0.040
	Jul	0.060	0.003	0.047
	Aug	0.013	0.105	0.051
	Sep	-0.039	-0.040	-0.046
	Oct	0.327	0.317	0.373
	Nov		0.169	
	Dec		-0.503	
Brood Yr + 2	Jan		-0.202	
	Feb		-0.446	
	Mar		-0.336	
	Apr		-0.329	