AQUATIC ECOSYSTEM RESTORATION PROJECT

QUARTZ CREEK
WILLAMETTE NATIONAL FOREST

Five-Year Report

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ABSTRACT

A stream restoration project was initiated at Quartz Creek in 1988 to study the changes in the geomorphic and biological attributes associated with the installation of log accumulations. The stream reach was intensively studied for one year before log installation and each year thereafter for five years. Changes in channel structure include the increase in pool habitat by 11% and a increase in side-channel habitat by 17%. Recruitment of woody debris by the installed accumulations was faster than expected. In five years, the rehabilitation reach at Quartz Creek developed the amounts and sizes of debris that would be expected in a stream flowing through old-growth forests in this basin. Retention of potential food resources, as measured by leaves, has approximately tripled. Channel bedform, measured at monumented cross-sections, changed at 34 of the 48 structures with 17 exhibiting downcutting and 17 exhibiting deposition. Nineteen of the 48 installed structures have shifted or moved downstream over the five-year period. Differences in the degree of cabling (full, partial, and none) applied to the structures had no apparent effect on persistence of structures. For wood that moved, non-cabled pieces moved greater distances downstream than cabled pieces. Trout populations within the rehabilitation site have been variable with an average increase of 12% greater than the populations in 1988. Trout populations in areas above and below the rehabilitation reach and two reference streams in the McKenzie River basin are compared to populations in the project site.

INTRODUCTION

Protection of watersheds and the enhancement of degraded rivers and streams are primary concerns to fisheries and land management agencies in the Pacific Northwest. Stream and riparian degradation over the past century makes restoration of these areas critical for the recovery of anadromous salmonids, aquatic communities, and ecological functions. Effective habitat restoration projects must consider and explicitly address long-term geomorphic, hydraulic, and biological processes.

Numerous stream restoration projects have been implemented in the Willamette National Forest in the past decade. Early goals of stream habitat restoration have been to develop methodologies and observe responses in stream channels and fish populations. Information on mechanisms by which stream channels and aquatic communities respond to stream restoration in this region is extremely scarce. Miles of streams have been modified by resource agencies, but responses of fish populations or physical habitat to restoration efforts are rarely documented. Effectiveness of a stream habitat restoration project is impossible to discern with no information on pre-installation conditions or continued monitoring of future changes.

In 1986, the Blue River District Ranger and the Supervisors Office of the Willamette National Forest realized that long-term evaluation of the effectiveness of habitat restoration practices was needed. The long-term ecological research team at Oregon State University (Stream Team) cooperated in the design and monitoring of a stream restoration project. A project was initiated to study changes in the geomorphic, hydraulic, and biological attributes associated with the installation of log accumulations for stream habitat restoration.

Project Objectives

- reestablish natural volumes of woody debris,
- provide complex woody debris accumulations for salmonid habitat,
- increase availability of floodplain and off-channel refuges,
- reestablish a more diverse, stepped channel profile,
- increase the residence time of water, nutrients, and food resources,
- increase fish habitat diversity.

The project was designed to introduce and recruit large woody debris to restore the size classes and volumes that occur in undisturbed streams of similar size and gradient in the McKenzie River drainage. Larger size classes of wood (generally greater than 5 m in length and 0.50 m in diameter) were placed in the stream to create a matrix of large stable wood that would trap smaller material. This large wood was expected to create the channel structure and debris accumulations found in old-growth forest streams by forming a "backbone" to retain sediment and smaller wood.

Preliminary searches for reaches suitable for restoration were conducted in 1987 by personnel from the Forest Service, Oregon Department of Fish and Wildlife, and the Department of Fisheries and Wildlife at Oregon State University. Quartz Creek, a fourth-order stream in the Blue River District of the Willamette National Forest, was selected as the site for the habitat restoration project based on:

- relatively low elevation (2000 ft),
- representative geomorphology,
- existence of resident trout populations,
- extensive timber harvest in the basin,
- low amounts of woody debris in the stream,
- degree of habitat degradation,
- ease of access.

Geomorphic and biological features of Quartz Creek prior to project installation were measured by the Stream Team of Oregon State University from May to September 1988. Stream hydraulics and characteristics were examined by various fisheries biologists, geomorphologists, hydrologists, and forest technicians to determine the most appropriate designs and locations for habitat modifications. In particular, we acknowledge the recommendations and assistance of Steve Eubanks (BRD), Cal Joyner (LRD), Del Skeesick (WNF), Rick Cope (LRD), Ward Fong (BRD), Linda Ashkenas (OSU), Bob Beschta (OSU), Gary Lamberti (OSU), Art McKee (OSU), Fred Swanson (PNW), Gordon Grant (PNW), and Jim Sedell (PNW). BRD - Blue River Ranger District, LRD - Lowell Ranger District, WNF - Willamette National Forest, PNW - Pacific Northwest Forest Experiment Station, OSU - Oregon State University.

Project implementation was scheduled for August 1988, but fire danger delayed installation until September. Structures were installed by a private contractor under the supervision of Forest Service personnel and OSU researchers. Immediate effects from installed log accumulations were measured in October and November until high stream discharges curtailed field studies. Channel structure, woody debris, and fish populations were monitored each year from 1989 to 1993 to determine changes after winter flows had an opportunity to alter channel structure and woody debris accumulations.

PROJECT SITE DESCRIPTION

Quartz Creek is a 4th-order stream as defined by Strahler (1957) with a total drainage area of 27,000 acres. The lower nine miles of the stream flow through private forest land (Rosboro Lumber Company) while the upper reaches of the watershed are public lands managed by the U.S. Forest Service. The habitat restoration site was located just upstream of the National Forest boundary approximately nine miles from the confluence with the McKenzie River. At the habitat restoration site, Quartz Creek is a 3rd-order stream with a drainage area of 8,500 acres.

Habitat structure was modified within a 1,100-m reach of Quartz Creek (Fig. 1). Lower and upper sections of the project reach are located in a 400-yr old-growth forest. The middle section of the project site was clearcut down to the stream banks in 1975. The reach has an average slope of 4% with a streambed composed predominantly of small and large boulders. Long cascades with channel gradients of more than 8% are numerous within the 1,100-m reach. Relatively low amounts of wood debris are present in the channel due to past disturbances and salvage logging operations.

Forest Service Road 2618 runs parallel to the stream. Small access roads were temporarily constructed from the main road to deliver materials to the stream. These roads were closed after installation of structures and replanted immediately with grass.

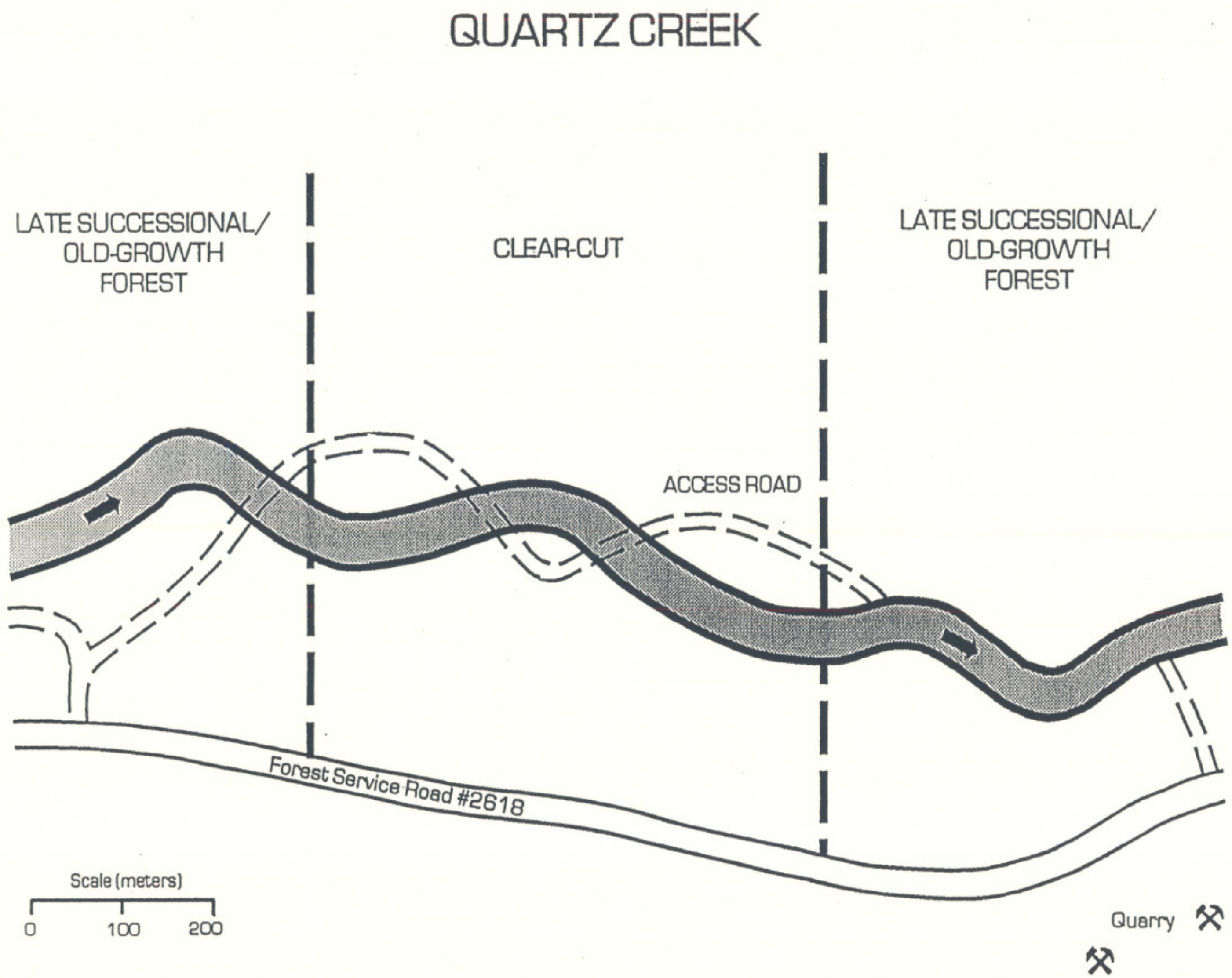

Fig. 1. Map of restoration site at Quartz Creek.

METHODS

The 1,100-m reach of Quartz Creek was mapped in detail prior to log introduction (Appendix A). Locations of all existing woody debris and all boulders over 0.5 m in diameter were recorded. Boundaries of geomorphic surfaces (e.g., wetted channel, active channel, and floodplains) were indicated on the maps. Locations of all large trees (by species), snags, small debris accumulations, undercut banks, and areas of bedrock outcrops along the stream channel also were recorded.

The 1,100-m habitat restoration site was divided into discrete habitat units following the procedures developed by Hankin and Reeves (1988). Width and depth at three transects, length, maximum depth, slope, and percent bedrock were measured for each habitat unit. The number of boulders in each channel unit were counted and placed into two size classes (0.5-2.0 m and >2.0 m).

Monumented photographic stations were established through the 1,100-m project site. Photographic stations were installed at 20-m intervals along the channel margins and marked with a white PVC stake. Photographs were taken upstream and downstream of each station from both the stream margin and a point in the center of the channel. Compass bearing, time of day, exposure settings, camera and lens type, film type for each exposure were recorded so that duplication of each photograph would be possible at future dates (Appendix B). Additional photographs were taken of all locations where habitat restoration structures were to be constructed.

Three time-lapse cameras were installed at Quartz Creek in December 1988. Exposure intervals of 15 minutes were set initially on the Super-8 movie cameras at Quartz Creek to document long-term changes in the stream bed. Exposure intervals were lengthened to 30 minutes in August 1991 to allow for longer intervals between changing film. These cameras are currently being maintained to visually record long-term changes at Quartz Creek.

Channel hydraulics were measured using the florescent dye tracer rhodamine WT. A dye solution was injected into the stream at a constant rate until concentrations of dye were uniform throughout the stream reach. Dye injection was then terminated and the gradual decrease in dye amounts at a downstream (fluorometer) sampling station was recorded. Relative hydraulic retention can be calculated from the rate at which the dye concentration increases during dye addition and decreases after termination of dye addition.

Particulate retention was measured by adding known numbers of presoaked, neutrally buoyant ginkgo leaves (*Ginkgo biloba*). This procedure was used by Speaker (1985) in other streams in the Pacific Northwest. A total of 4,000 ginkgo leaves were released at the top of each reach. A seine was placed 50 m downstream, and all leaves captured in the seine during a 2-hr interval were counted. A retention coefficient was calculated using the number of leaves added initially and the number recovered in the seine after 2 hr:

$$L_d = L_o \cdot e^{-kd}$$

L_d = Percent of leaves in transport at distance d from release point
L_o = Percent of leaves released (100%)
k = Retention coefficient
d = Distance from release point (m)

The project site was divided into six release reaches with distinct geomorphic characteristics (Table 1). Locations of dye and leaf introductions and fluorometer sampling sites in these six reaches were located on site maps so that retention measurements can be duplicated successive years.

Table 1. Characteristics of reference 50-m reaches used to measure leaf retention in Quartz Creek. Reach location refers to distance along monumented baseline in meters; downstream boundary is designated as 0 meters. Structure numbers are specific accumulations located in reaches where retention was measured.

Reach Type	Reach Location	Structure Number	Accumulations	Forest
Site 1	165 - 215	9	Deflector	Old growth
		10	V-Deflector	
		11	Sill logs	
		12	Lateral deflector	
Site 2	300 - 350	18	Lateral deflector	Old growth
		19	Full-channel jam	
Site 3	405 - 455	24	Upstream V	Clearcut
		25	Upstream V	
		26	Upstream V	
Site 4	580 - 630	35	V-Deflector	Clearcut
		36	Parallel bank log	
Site 5	765 - 815	42	Upstream V	Clearcut
Site 6	995 - 1045	50	Full-channel jam	Old growth

All woody debris ≥1.0 m in length and ≥10 cm in diameter was measured for length and diameter (minimum and maximum). Volume of each piece was calculated using the formula for a frustum of a paraboloid:

$$V = \frac{3.1416(D_1^2 + D_2^2) \cdot L}{8}$$

V = Volume (m^3)
D_1 and D_2 = Diameters at each end (m)
L = Length (m)

Each piece was tagged with numbered aluminum tags and location in the channel was recorded (Appendix C).

Channel cross-sections around log accumulations were not established until after project completion because of possible disturbance by the excavator (cross-sections illustrated in Appendix D). A minimum of one cross-section was established through each structure, and two or three transects were installed at more complex log accumulations, such as upstream V-shaped accumulations and full jams. Metal fence posts were placed above the active channel to permanently monument cross-section end points for future use and subsequent measurements. Notches in the metal posts were used to mark level reference lines for each transect.

Aquatic insects were collected for the Willamette National Forest before and after log installation in 1988. Collections of invertebrates have continued each summer since 1988. Samples were collected with a modified Hess sampler (25-cm diameter, 250-um mesh size) in riffles with a gravel/cobble substrate. A total of nine samples were taken on each date; three from the lower old-growth area, three from the clearcut area and three from the upper old-growth area. All samples were placed in whirl-pack containers and preserved with 95% ethanol. Invertebrate samples were transferred to the Willamette National Forest and are not described in this report.

In 1988 and 1989, fish abundance and distribution were determined by the snorkeling method (Hankin and Reeves 1988). Each channel unit was inventoried for fish by one diver and reinventoried by a second diver approximately 30 minutes later. Species, size, and habitat location were recorded for each fish observed. The restoration reach and adjacent reference reaches were snorkeled for direct fish observation in August in 1990-1993, and diver estimates were calibrated by population estimation by electroshocking (Armour et al. 1983).

RESULTS

Characteristics Prior to Project Installation

Forty-two individual habitat units were identified within the study site. Before structure installation, cascades were the dominant channel unit type comprising over 46% of the study area (Table 2). Other relatively high gradient habitat units, rapids and riffles, made up 24% and 14% of the reach respectively. Pools, an important habitat for fish, comprised only 10% of the entire reach. Side-channels, important habitat for fry rearing accounted for only 6% of the stream channel.

Table 2. Channel unit distribution before and after wood installation at Quartz Creek restoration site in 1988.

Unit Type	Pre-Installation #	Pre-Installation Percent of Length	Post-Installation #	Post-Installation Percent of Length
Pool	7	10	11	16
Riffle	8	14	8	15
Rapid	10	24	10	23
Cascade	15	46	15	40
Side-Channel	3	6	3	6

Prior to the structure installation, 212 pieces of wood were found in the 1,100-m reach. This amount is relatively low compared to natural amounts in similar streams in the McKenzie River drainage. Mack Creek, a third-order stream in the H.J. Andrews Experimental Forest, has over 1,666 pieces of woody debris in a 1,000-m reach. Volume of all existing wood at Quartz Creek was 0.040 m^3 per m^2 of stream channel while the volume of wood at Mack Creek was 0.795 m^3 per m^2 of stream channel. Areas above and below the restoration site contained higher amounts of woody debris, but all three reaches of Quartz Creek had similar amounts of woody debris after log installation in 1988 (Fig. 2).

Of the 212 pieces of pre-existing wood, only 70 pieces had >25% of their volume within the active channel. A large portion of the pieces of woody debris was located on the active channel terrace or perched above the active channel. These pieces of wood had little or no effect upon the stream and provided little or no habitat for fish.

The fish community at Quartz Creek habitat restoration site includes cutthroat trout (*Oncorhynchus clarki*), rainbow and steelhead trout (*O. mykiss*), and Paiute sculpins (*Cottus beldingi*). Cutthroat trout are the dominant salmonid in the system, making up 90% of total fish numbers. One adult steelhead was observed in a pool (Pool-25) located in the upper clearcut reach in August of 1988 and 1989. Bull trout (*Salvelinus confluentus*) were observed in lower Quartz Creek near the confluence with the McKenzie River, but none were found in the habitat restoration site.

Before structure installation, trout densities averaged 66 fish/100 m of stream in the restoration reach. Densities of 50-150 fish/100 m have been recorded for similar streams in the H. J. Andrews Experimental Forest (Lookout Creek and Mack Creek). Pool habitats held the greatest densities of fish (111 fish/100 m), while the lowest density of trout occurred in cascade habitats (59 fish/100 m). Riffles and rapids were intermediate in density with 75 fish/100 m and 69 fish/100 m, respectively.

Size frequency distribution of fish in 1988 exhibited reduced proportions of fry and older fish and was dominated by 4 to 5 inch fish (Fig. 3). Rainbow trout in the system were slightly larger in size than the cutthroat. The largest individuals observed, other than the one steelhead, were several 11 inch

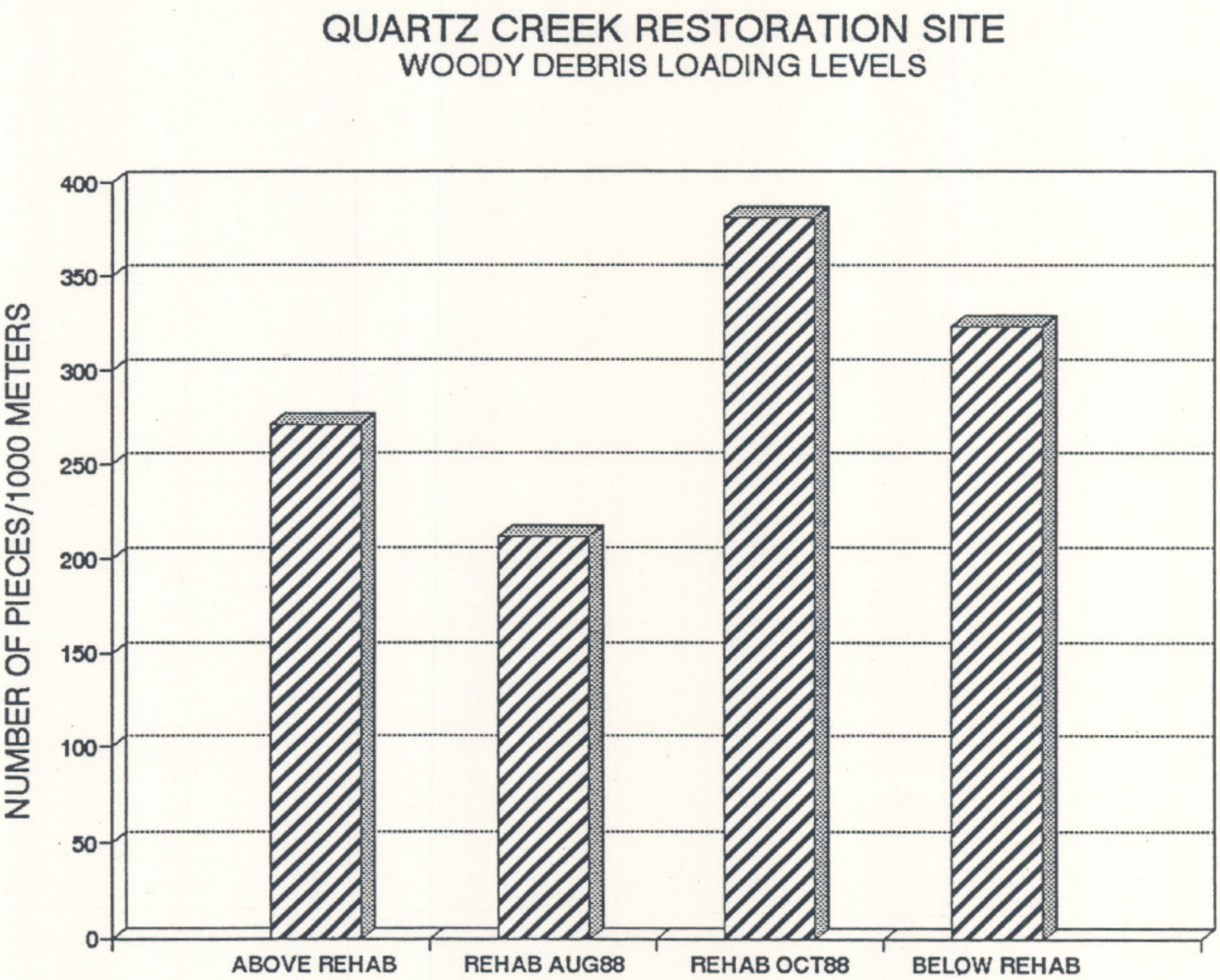

Fig. 2. Levels of woody debris in the above restoration site, restoration site before and after structure installation, and the below restoration site at Quartz Creek.

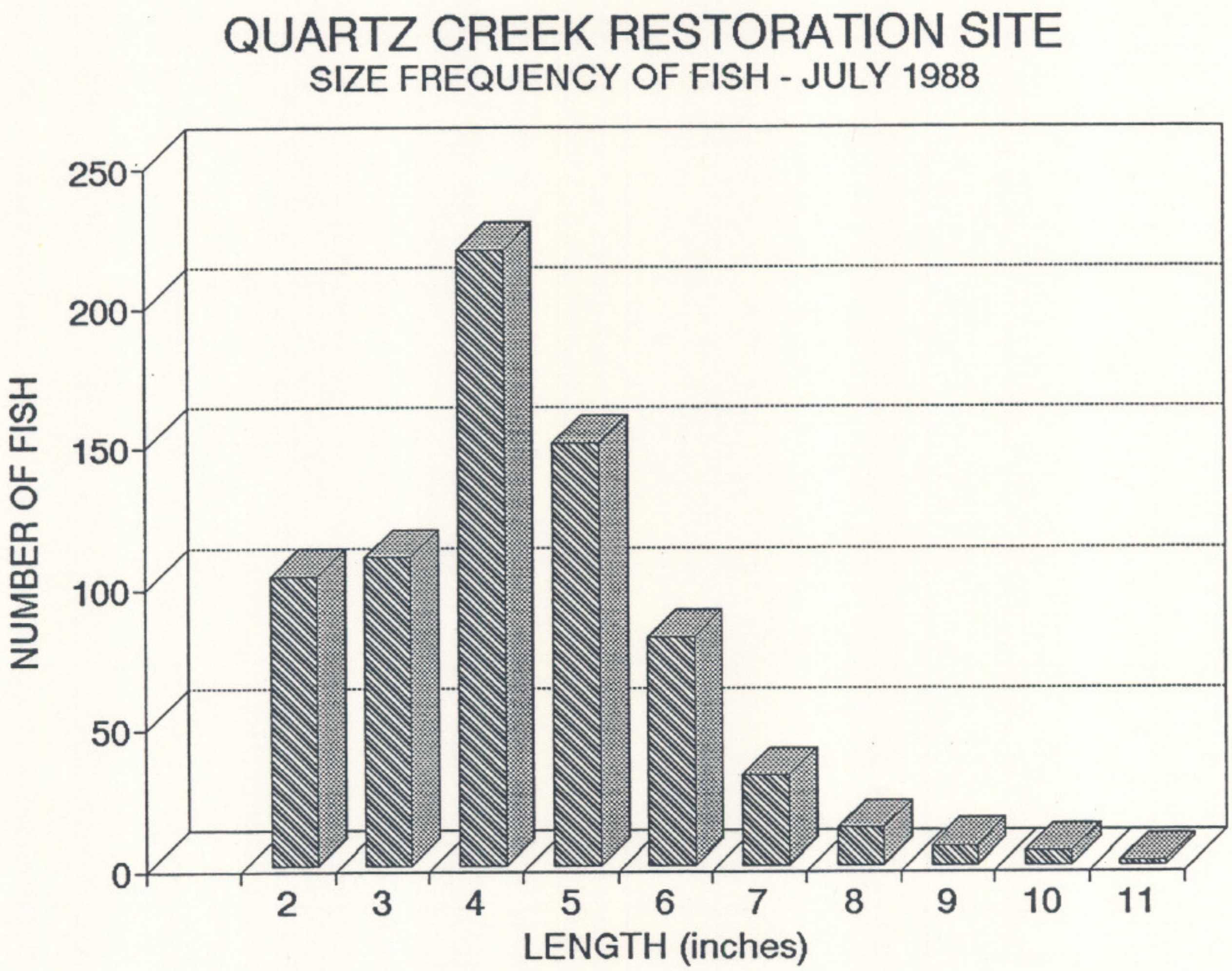

Fig. 3. Size distribution of trout in Quartz Creek restoration site, July 1988.

rainbow trout usually in deep pools associated with cover. The most numerous trout were in the 4-5 inch class corresponding to 1+ year age class.

Project Installation

Log and boulder accumulations were installed in October of 1988. Trees were felled in a section of old-growth forest (non-riparian) less than a half mile from the project site and transported by a D-8 caterpillar to locations along the stream. Boulders used to stabilize log accumulations were obtained from the immediate channel area. Twenty-five root-wads from an adjacent quarry were also used in structure construction.

A track-driven hydraulic excavator prepared the streambed for log introductions and placed individual logs in position. A "trash rack" was installed below the project site to minimize possible downstream movement of logs and potential risks to bridges lower in the system.

The species of trees used for log accumulations consisted of western red cedar (*Thuja plicata*), Douglas-fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), and bigleaf maple (*Acer macrophyllum*). Cedar logs (n = 105) were used extensively because of their slow decomposition rate, but when very large diameter logs were required, Douglas-fir logs were used (n = 77). Western hemlock (n = 3) and big leaf maple (n = 1) were rarely used because of their faster decomposition rates.

Installation of Woody Debris Accumulations

A total of 48 log accumulations were installed in Quartz Creek using 186 pieces of wood. The volume of wood installed was 0.089 m^3 of wood per m^2 of stream channel. Two additional sites were modified by boulder placement alone. Various types of log accumulations and degrees of cabling were used to evaluate the effectiveness and longevity of different types of debris installations. Seven types of log accumulations, some designed to resemble natural debris accumulations, were used in the project:

- Full-channel debris dams
- Lateral deflectors
- Lateral V-shaped deflectors
- Upstream V-shaped accumulations
- Sill logs
- Cover logs
- Parallel bank logs

Three degrees of cabling (full cable, partial cable, and no cable) were applied to each type of structure in the project reach (Table 3).

Table 3. Number of log accumulations of different types and cabling used in Quartz Creek in October 1988.

Structure	Full Cable	Partial Cable	No Cable
Full-channel debris dam	1	1	1
Lateral deflector	4	4	1
Lateral V-shaped deflector	3	3	2
Sill log	2	0	0
Upstream V-shaped accumulation	2	2	2
Cover log	2	4	2
Parallel bank log	3	0	2
Road log	2	0	5

Full-channel debris dams consisted of accumulations of wood that spanned the entire bankfull channel. Lateral deflectors were small accumulations anchored on one bank and extending into the wetted channel. A lateral V-shaped deflector was similar to a lateral deflector but included a downstream log intersecting at the point of the V. A sill log spanned the channel and lay directly on the surface of the streambed, creating a sill. An upstream V-shaped accumulation was two or more logs that spanned the channel and intersected at a point upstream of their base. Cover logs were generally small accumulations of logs placed in pools to create overhead cover for fish. Parallel bank logs were single logs placed on the edge of the wetted channel against the bank to create small amounts of lateral cover at low flow. Road logs were placed at the intersection of the temporary skid roads and the active stream channel to prevent encroachment of the stream onto the roadbed.

Location and position of each structure were added to the existing maps of Quartz Creek (Appendix E). Changes in channel geomorphology and movements of boulders and pre-existing wood by the excavator were also recorded on the existing project maps.

A large increase in the amount of woody debris within the active channel was achieved with the addition of the 48 log accumulations (Table 4; Fig. 4 and 5).

Table 4. Woody debris characteristics at Quartz Creek before and after structure installation.

Characteristic	Prior to Project	Installed by Project	After Project
Accumulations	2	48	50
Full Channel Debris dams	0	3	3
Total Pieces of Debris	212	186	398
Logs in Channel (>25%)	70	131	201
Logs ≥10 m long and 75 cm wide	6	49	55
Logs ≥6 m long and 60 cm wide	23	94	117

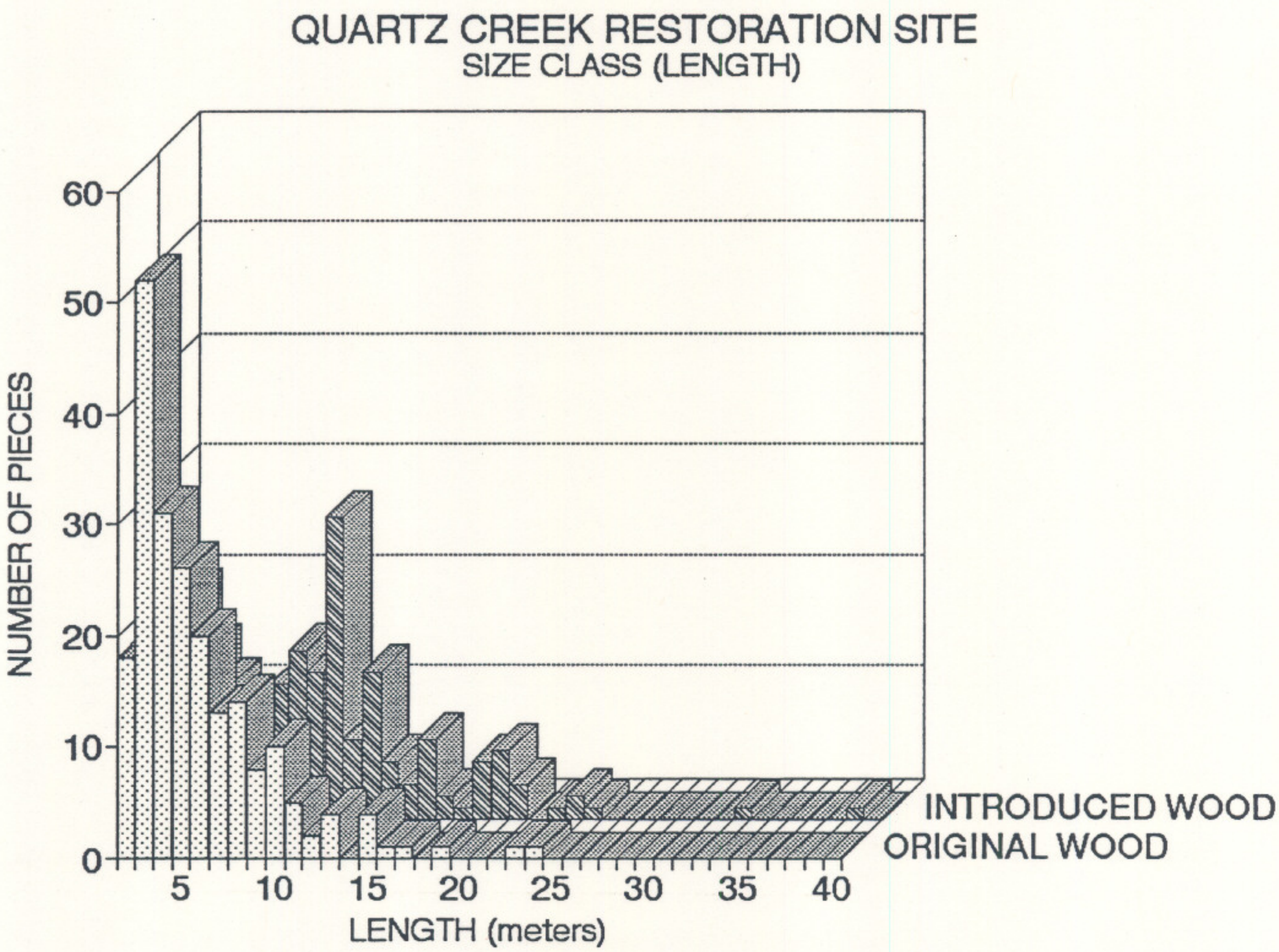

Fig. 4. Size class distribution (length) of original woody debris and introduced woody debris at Quartz Creek restoration site.

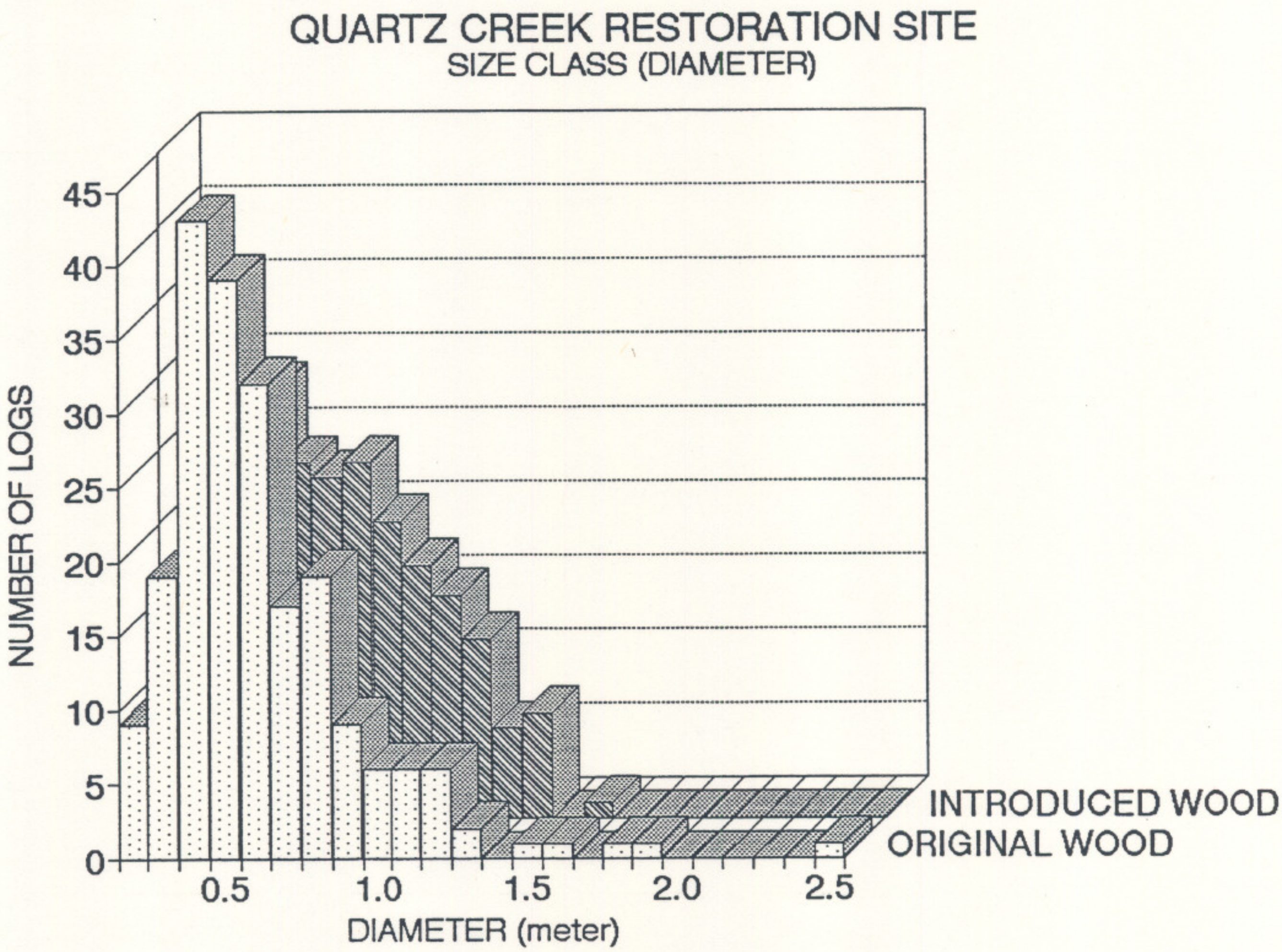

Fig. 5. Size class distribution (diameter) of original woody debris and introduced woody debris at Quartz Creek restoration site.

Several photographic stations were destroyed by machinery and required careful replacement. A complete set of photographs was retaken from each photopoint station. Photographs were taken of each specific structure site to document changes in substrate composition and channel hydraulics. All photographs are 35-mm slides and have been labeled and archived at Oregon State University.

Immediate changes in channel unit composition were recorded when the 1,100-m reach was reinventoried for habitat unit composition. Four additional pool habitat units were created in units that previously were cascades. Proportion of pool length over the entire reach increased from 10% to 16%, and length of stream in cascade habitat units decreased from 46% to 40%. Areas that originally were long, high velocity cascades were modified to develop a stair-stepped longitudinal profile. Habitat unit lengths of riffles, rapids, and side channels remained relatively unchanged.

Few complete habitat units changed significantly, but smaller sub-unit changes in the stream channel were numerous. Pool or backwater sub-units were created immediately upstream or downstream from most of the new log accumulations.

Late installation of logs in 1988 because of fire danger minimized the time available to remeasure channel composition and fish abundance before high stream flows. Substantial increases in discharge in November terminated the fish survey and retention studies. Higher discharges in late fall prevented comparison with data collected at low discharges prior to log introduction.

Project Costs

Operational costs of structure installation at Quartz Creek totaled $29,570. Total costs include 1) equipment charges for the track-mounted excavator and D-8 tractor ($21,700), 2) supplies for the cabling of the structures ($4,050), and 3) labor charges for the project leader/coordinator, tree fallers, and cabling crew ($9,580). The value of timber used in the structures was not included in the operational costs. Market value of the timber used to construct the structures in 1988 was estimated at $50,000. Note that an equivalent value of logs had been removed from the stream by past practices. Total operational costs and value of logs for the restoration project were approximately $80,000. Monitoring of the restoration site by Oregon State University was budgeted at between $11,000 and $13,000 annually. Total costs for monitoring the effectiveness of restoration for the implementation year and subsequent five years were approximately $70,000.

Responses After Project Installation (1989-1993)

The Quartz Creek habitat restoration site was resurveyed each summer from 1989 to 1993. All geomorphic and biological parameters were remeasured in the same manner as in the pre-introduction data collection. Photographs were taken from all monumented photopoints. Time-lapse camera systems have been maintained throughout the period. Influences of high water discharges on three types of log accumulations have been recorded, and one camera photographed the formation of an over-flow channel during a flood. Though quantitative measurements are difficult to derive from these time-lapse films and photopoint photographs, valuable subjective information on relative movement of large woody debris has been obtained.

Starting in 1989, we surveyed additional distances of 400 m below and 1500 m above the 1,100-m habitat restoration site with the Hankin-Reeves stream survey methodology. Channel unit composition within the restoration site was similar to the structure of channels above and below the restored reach (Table 5).

Length of stream in pool habitat increased from 10% before structure installation to 21% by 1993. Quality of pool habitat also increased with a mean maximum depth of 0.76 m before structure installation to 0.88 m in 1992 (lowest observed summer low flow) and 1.04 m in 1993 (highest observed summer low flow; see Table 7).

Length of stream in side-channel habitat changed significantly over the 5 year period. Before structure installation the restoration site had 6% of its length in side-channels but in 1993, 23% of the total length of stream channel was side-channel habitat. Side channels were more narrow than the main channel, thus areal extent of side channels did not change as greatly. Side channel accounted for 161 m^2 in 1988 (2.0% of total wetted channel) and 589 m^2 in 1993 (6.2% of total wetted channel).

Behavior of Woody Debris Accumulations

A flood in 1989 provided the first major "test" of the integrity of the log accumulations. The recurrence interval for this flood was estimated to be approximately five years. Viewing film from the time-lapse camera systems and inspections of the log accumulations showed that the flow was capable of moving numerous pieces of large woody debris. Based on time-lapse photography, peak height of the water during this flood was estimated to be 10-12 feet above winter base flow.

Table 5. Total length of channel units in meters for the below restoration reach, restoration reach, and above restoration reach at Quartz Creek from 1988 through 1993. Total length is the sum of main channel and side channel lengths. Percentage of total wetted channel length for each habitat unit type is included in parentheses.

BELOW RESTORATION REACH

Channel Unit	1988	(%)	1989	(%)	1990	(%)	1991	(%)	1992	(%)	1993	(%)
Pool	N/A	N/A	40	(10)	76	(17)	76	(17)	64	(13)	84	(16)
Glide	N/A	N/A	0	(0)	23	(5)	23	(5)	32	(6)	17	(3)
Riffle	N/A	N/A	57	(15)	46	(11)	46	(11)	115	(22)	129	(25)
Rapid	N/A	N/A	130	(33)	227	(52)	227	(52)	229	(44)	251	(48)
Cascade	N/A	N/A	162	(41)	27	(6)	27	(6)	30	(6)	0	(0)
SC	N/A	N/A	0	(0)	35	(8)	35	(8)	43	(8)	41	(8)
Step	N/A	N/A	2	(1)	3	(1)	3	(1)	3	(1)	4	(<1)
Total			391		437		437		516		526	

RESTORATION REACH

Channel Unit	1988	(%)	1989	(%)	1990	(%)	1991	(%)	1992	(%)	1993	(%)
Pool	116	(10)	170	(17)	222	(18)	251	(19)	251	(19)	280	(21)
Glide	0	(0)	0	(0)	0	(0)	17	(1)	16	(1)	17	(1)
Riffle	157	(14)	98	(10)	183	(15)	242	(19)	193	(14)	201	(15)
Rapid	264	(24)	426	(42)	314	(26)	300	(23)	297	(22)	329	(24)
Cascade	509	(46)	289	(28)	275	(23)	224	(17)	246	(19)	197	(14)
SC	69	(6)	25	(2)	212	(17)	254	(19)	307	(23)	315	(23)
Step	0	(0)	13	(1)	8	(1)	20	(2)	24	(2)	30	(2)
Total	1,115		1,021		1,214		1,308		1,334		1,369	

ABOVE RESTORATION REACH

Channel Unit	1988	%	1989	%	1990	%	1991	%	1992	%	1993	%
Pool	N/A	N/A	264	(17)	258	(18)	258	(18)	258	(18)	220	(13)
Glide	N/A	N/A	0	(0)	0	(0)	0	(0)	0	(0)	39	(2)
Riffle	N/A	N/A	65	(5)	84	(6)	84	(6)	84	(6)	127	(8)
Rapid	N/A	N/A	459	(30)	181	(13)	181	(13)	181	(13)	294	(18)
Cascade	N/A	N/A	725	(47)	900	(62)	900	(62)	900	(62)	965	(58)
SC	N/A	N/A	0	(0)	10	(1)	10	(1)	10	(1)	21	(1)
Step	N/A	N/A	15	(1)	7	(0)	7	(0)	7	(0)	9	(<1)
Total			1,538		1,440		1,440		1,440		1675	

Only 21 of the 186 pieces of wood originally installed (11.8%) have been transported out of the restoration reach. Of the 48 instream log accumulations installed in Quartz Creek, 21 log accumulations "moved" during the high winter discharges. Operationally, we defined "movement" of an accumulation as transport of pieces within a structure one meter or greater downstream. Logs used as road blocks were not included in the analyses but were reported in Table 6. The relative degree of cabling in the log accumulations did not affect tendency for structures to move. Of the 19 log accumulations that moved more than one meter, eight were completely cabled, six were partially cabled, and five were not cabled. If a distance of 10 meters or greater is used for classifying a structure as moving, only eight structures moved: two fully cabled, three partially cabled, and three non-cabled.

Distance moved downstream differed for different types of log accumulations. Of the 19 log accumulations, only six moved more than 10 meters downstream (Table 6). The average distance moved was 15 m for cabled log accumulations, 19 m for partially cabled log accumulations, and 81 m for non-cabled log accumulations.

Most of the logs that moved or shifted less than 10 meters downstream are still performing the original objectives they were designed to perform. Logs that moved downstream greater distances had less of a tendency to continue with their original objective but other desirable objectives were met. For example, many of the logs that made up the upstream "V" which moved greater than 10 meters are now acting as cover logs in pools further downstream.

Table 6. Characteristics of log accumulations that moved ≥1 meter in Quartz Creek from September 1988 through October 1993. Logs used as road blocks were not included in analyses of movement.

Structure Type and Number	Degree of Cabling	Distance Moved (m)
Full Jam (#2)	Partial	10
Lateral Deflector (#3)	Full	10
Upstream V (#5)	None	120
Parallel Bank (#6)	None	80
Pool Cover (#8)	Partial	5
Lateral Deflector (#9)	Full	5
Sill Log (#11)	Full	2
Pool Cover (#13)	None	200
Pool Cover (#20)	None	1
V Deflector (#23)	None	2
Upstream V (#24)	Partial	80
Upstream V (#25)	Full	2
Pool Cover (#29)	Full	8
V Deflector (#35)	Partial	2
Parallel Bank (#40)	Full	85
Upstream V (#42)	Partial	12
Lateral Deflector (#46)	Partial	4
Upstream V (#48)	Full	5
Full Jam (#50)	Full	5
Road Block (#28)	None	100
Road Block (#30)	None	120

Retention of Water and Particulate Material

Dye releases performed before log introductions showed that hydraulic retention was relatively low in the high gradient single channel sections of the study site. Particulate retention was lowest in the bedrock chute area opposite the quarry. Hydraulic and particulate retention were somewhat higher in those reaches that contained side-channels or in areas where some woody debris was present in the channel. In reaches where dye concentrations quickly approached a maximum asymptotic concentration, hydraulic retention was considered low. Hydraulic retention was greater when the time to reach asymptotic concentrations takes longer.

Measurements of channel hydraulics and retention were conducted each year in the same six reaches that were analyzed before structure installation (Fig. 6a-f). Though the same stock concentration of dye and rate of injection were used in all five years, asymptotic concentrations varied from year to year due to changes in stream discharge. When constant dye injection rates are used during lower stream flows, observed concentrations of dye increase. Stream discharge (Q) is calculated using the rate of injection, the concentration of dye injected, and the measured concentration of dye in the stream at asymptotic concentration at the downstream sampling site (Kilpatrick 1967). Discharges in mid-summer ranged from 3.0-12.7 ft^3/s during the 5-yr monitoring period, averaging 6.9 ft^3/s (Table 7).

Table 7. Discharge rates (ft^3/s) for Quartz Creek from 1988 to 1993.

Stream Reach	July 1988	August 1989	August 1990	August 1991	August 1992	August 1993
Site #1	7.62	7.43	5.07	7.02	3.55	11.94
Site #2	4.97	6.89	7.27	6.37	3.04	12.62
Site #3	5.42	7.74	6.82	6.93	3.30	12.71
Site #4	5.31	6.61	5.19	6.37	3.29	11.58
Site #5	5.71	6.88	4.35	6.60	3.45	12.12
Site #6	6.60	7.75	6.71	7.29	3.93	12.33
Average	5.94	7.22	5.90	6.76	3.43	12.22

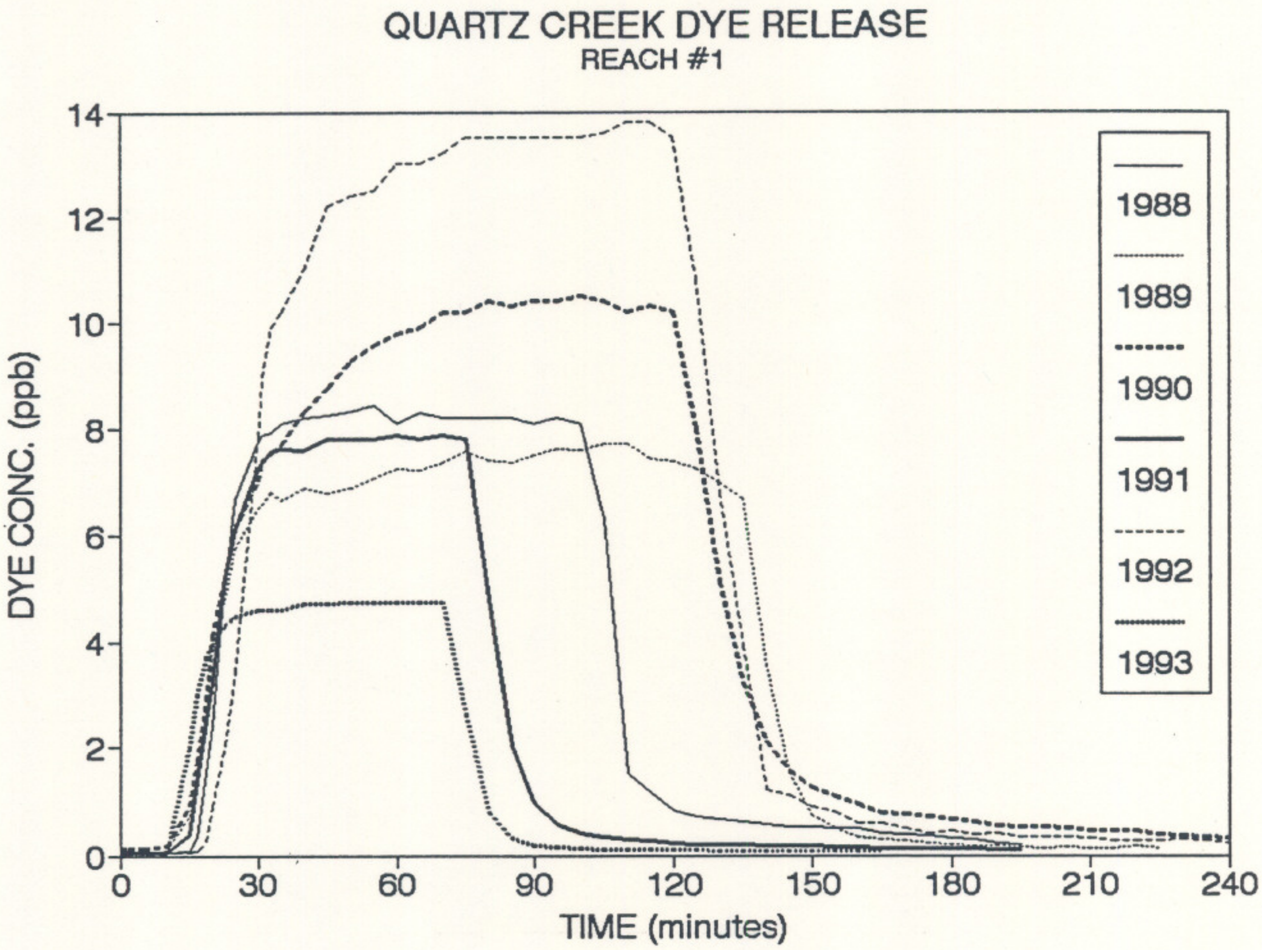

Fig. 6a. Dye release curves for release reach 1 at Quartz Creek restoration site, 1988-1993.

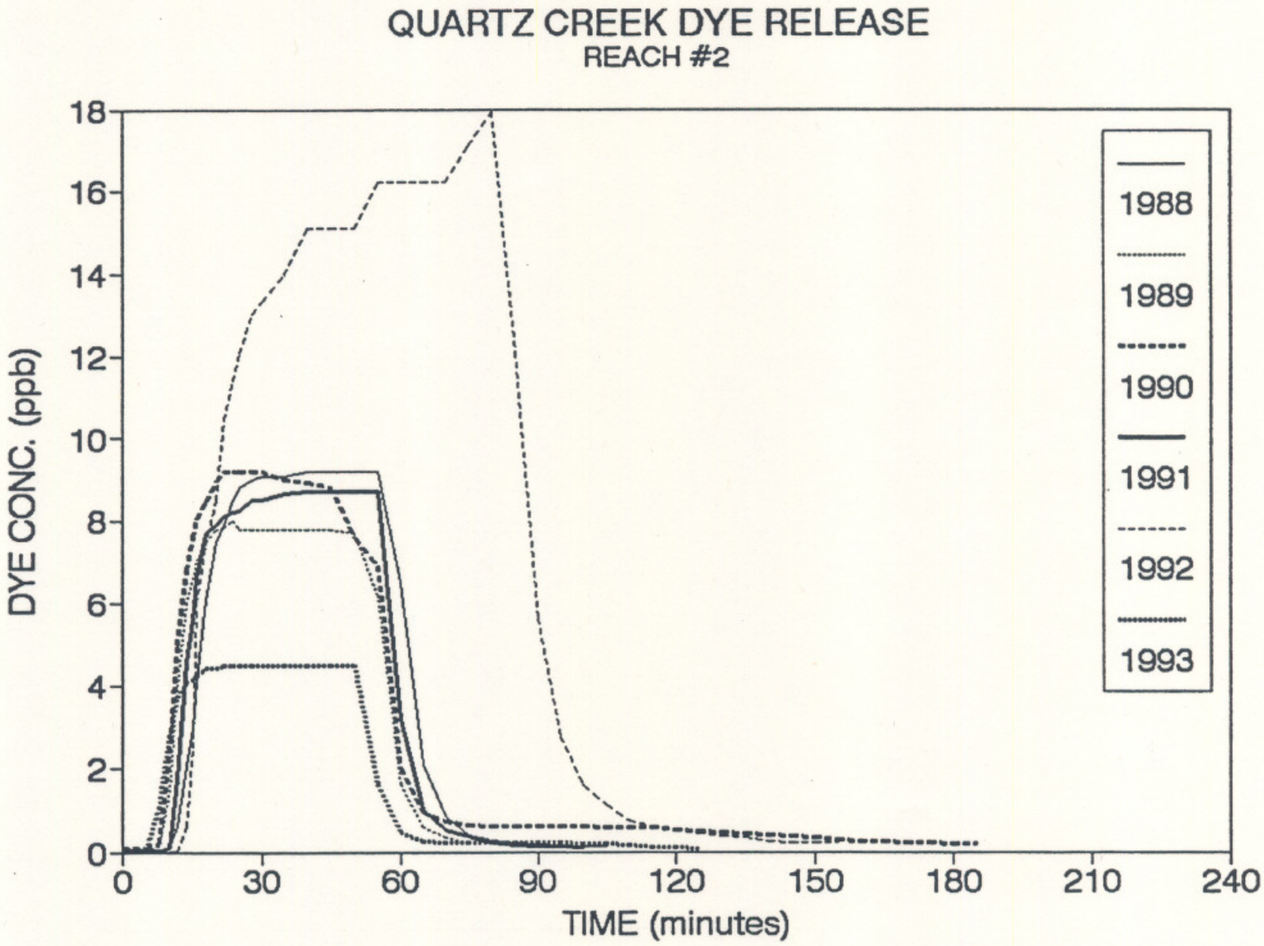

Fig. 6b. Dye release curves for release reach 2 at Quartz Creek restoration site, 1988-1993.

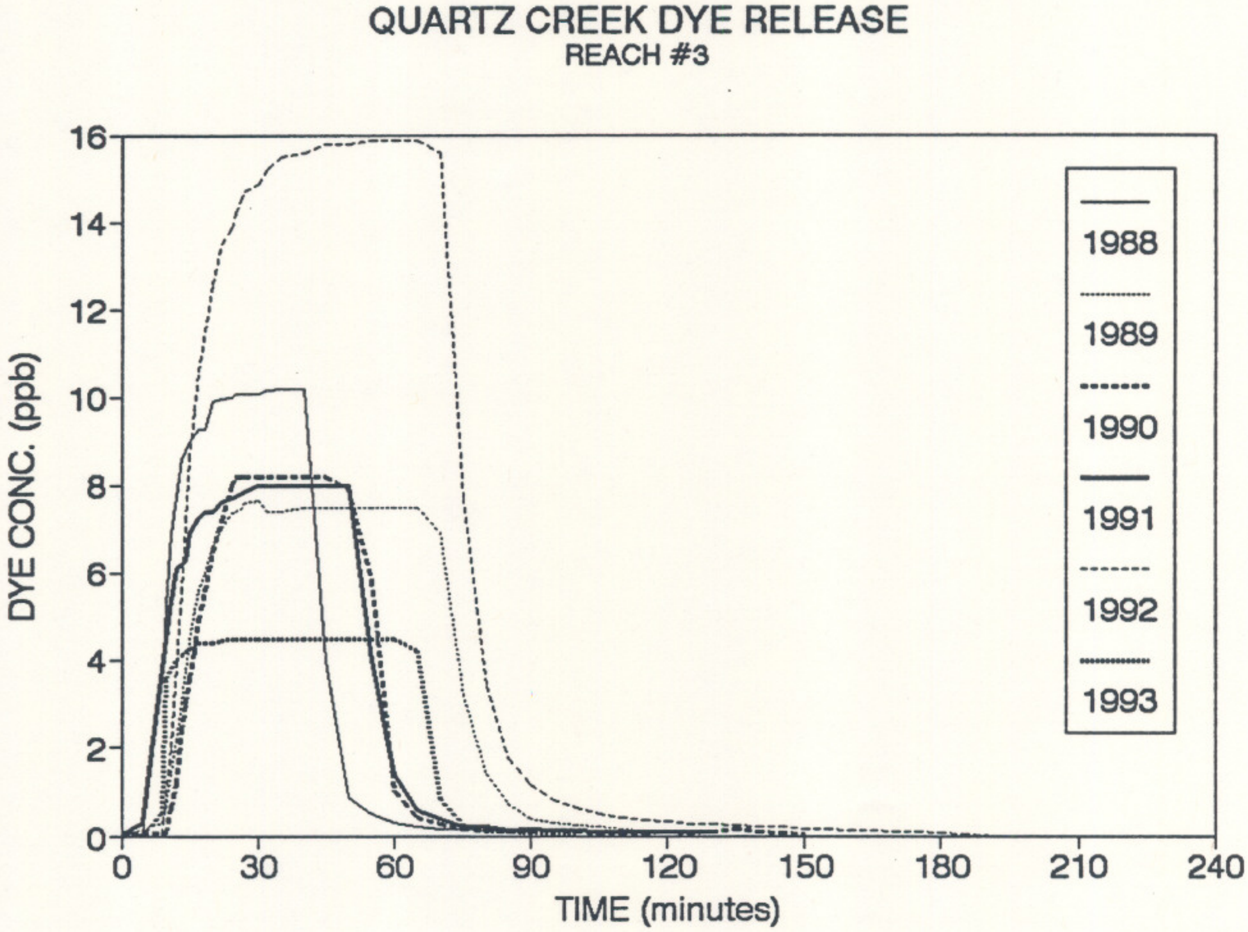

Fig. 6c. Dye release curves for release reach 3 at Quartz Creek restoration site, 1988-1993.

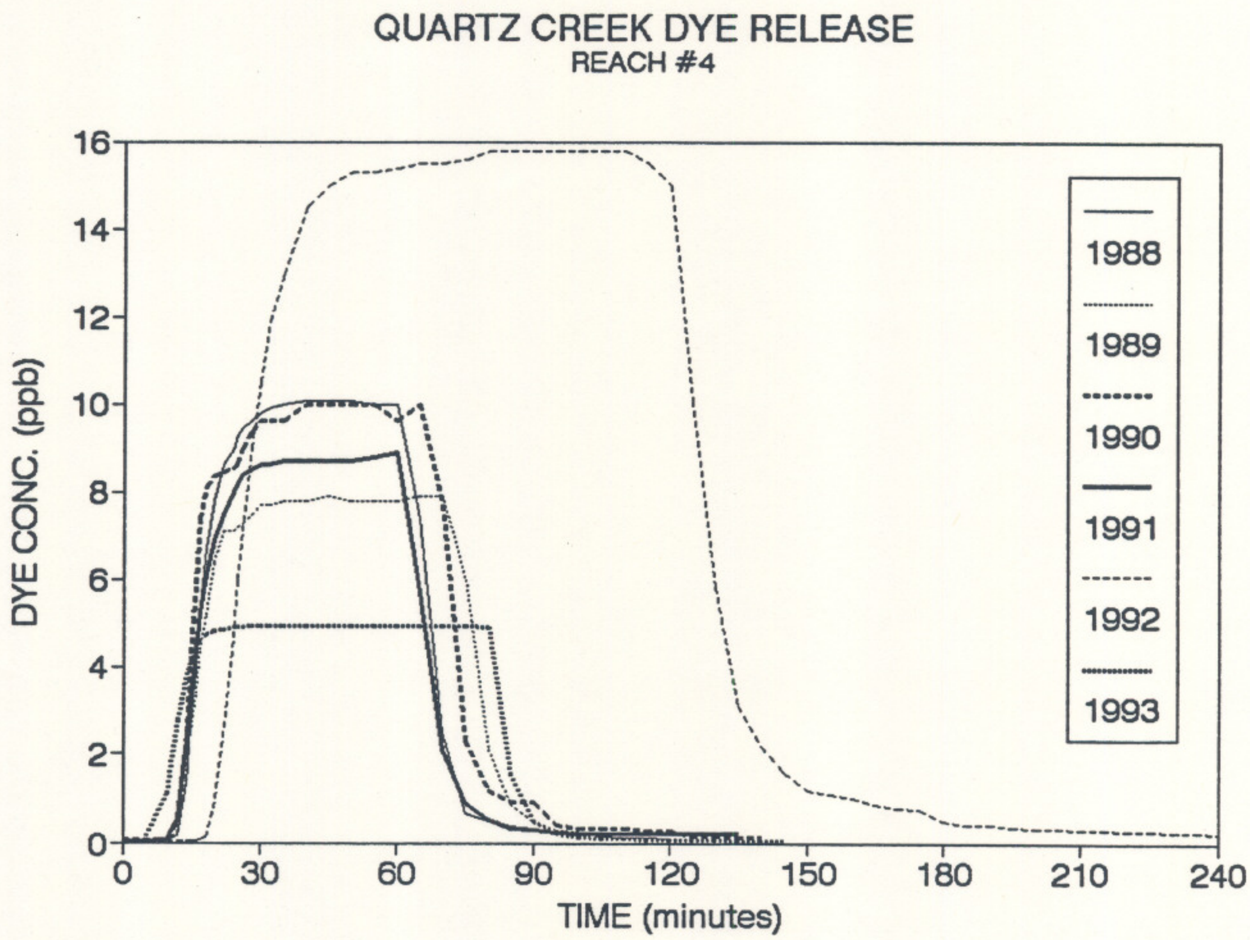

Fig. 6d. Dye release curves for release reach 4 at Quartz Creek restoration site, 1988-1993.

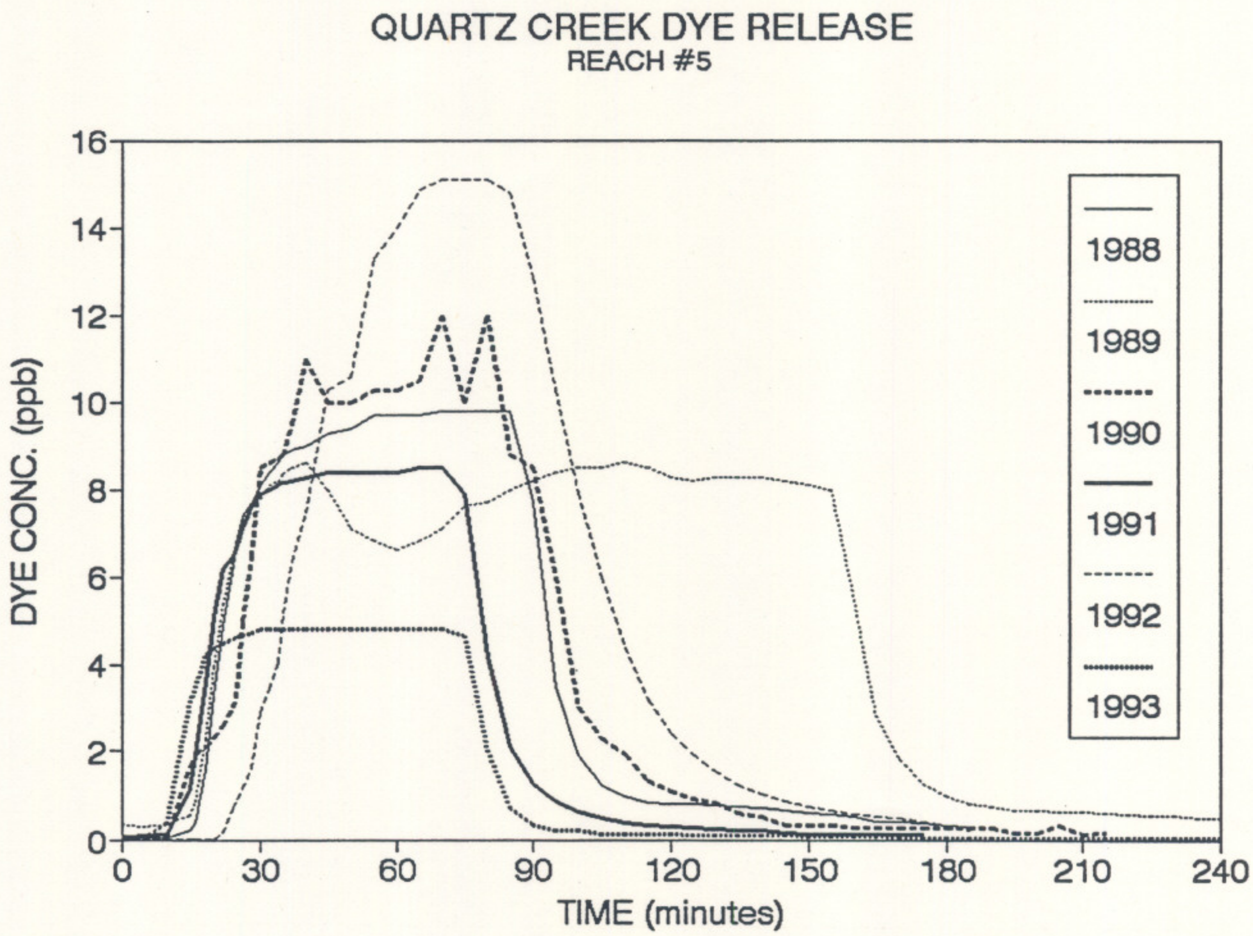

Fig. 6e. Dye release curves for release reach 5 at Quartz Creek restoration site, 1988-1993.

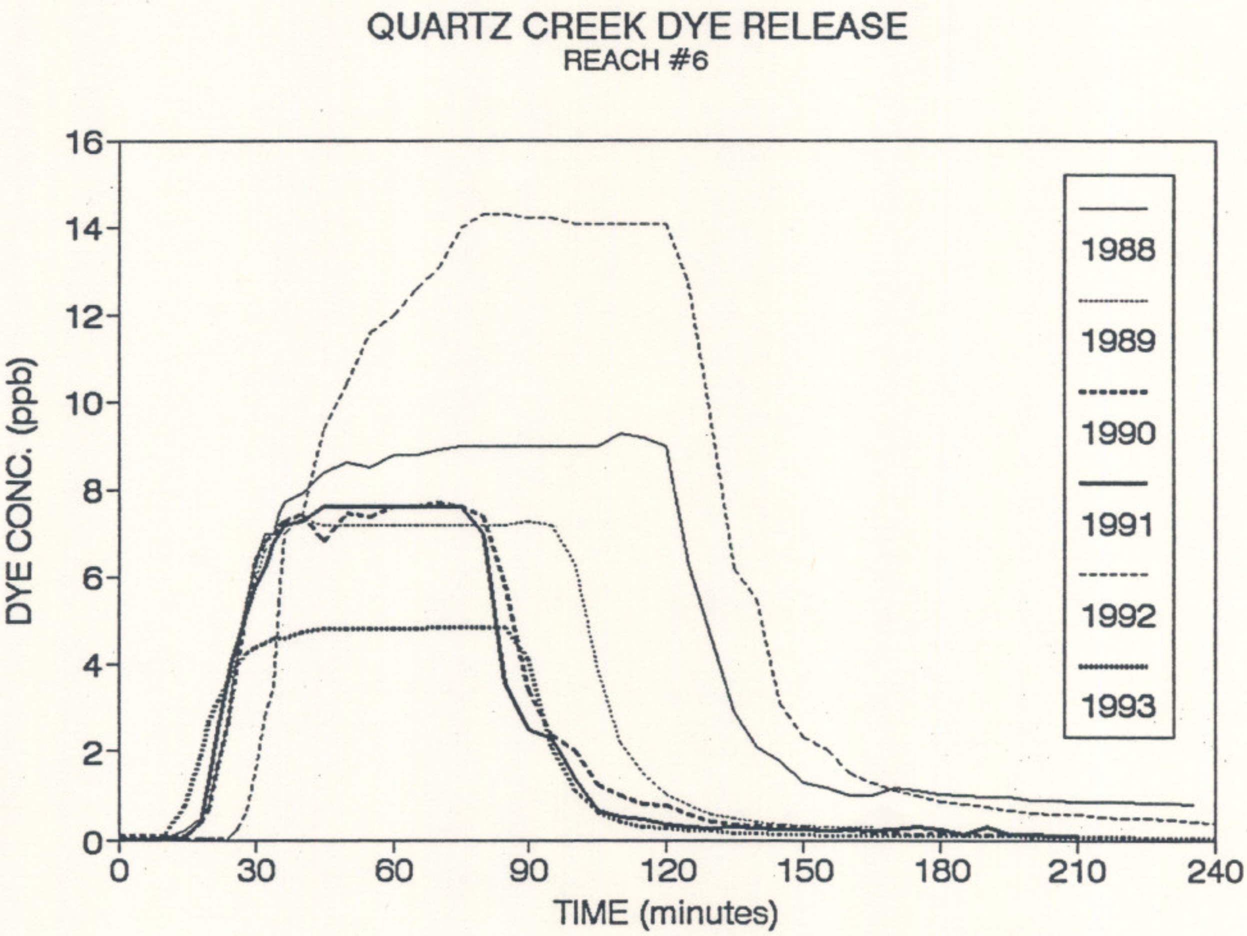

Fig. 6f. Dye release curves for release reach 6 at Quartz Creek restoration site, 1988-1993.

Table 8. Retention coefficients (k) for particulate retention releases at Quartz Creek restoration site from 1988 to 1993.

Stream Reach	1988	1989	1990	1991	1992	1993
Site #1	0.004	0.034	0.036	0.032	0.057	0.022
Site #2	0.034	0.040	0.033	0.045	0.037	0.093
Site #3	0.022	0.052	0.022	0.031	0.040	0.022
Site #4	0.018	0.022	0.008	0.025	0.138	0.012
Site #5	0.023	0.035	0.022	0.014	0.090	0.013
Site #6	0.014	0.023	0.025	0.027	0.075	0.016
Average	0.019	0.034	0.024	0.029	0.073	0.030

Particulate retention was measured each year by releasing 4,000 ginkgo leaves in the same reaches as in 1988. Particulate retention generally increased in the six reaches after the addition of the log accumulations (Table 8). Retention of particulate material is greater when the value of the retention coefficient (k) increases. The average leaf travel distance (1/k) decreased in all six reaches between 1988 and 1989 (Table 9). In 1988, the average leaf traveled approximately 83 m; but the travel distances decreased to an average of less than 40 m in the five years after restoration.

Table 9. Average leaf travel distance (1/k) in meters in reference reaches of Quartz Creek restoration site from 1988 to 1993.

Stream Reach	1988	1989	1990	1991	1992	1993
Site #1	250.0	29.4	27.8	31.6	17.6	45.5
Site #2	29.4	25.0	30.3	22.1	27.4	10.8
Site #3	45.5	19.2	45.5	32.1	25.0	45.5
Site #4	55.6	45.5	125.0	39.6	7.2	83.3
Site #5	43.5	28.6	45.5	70.4	11.1	76.9
Site #6	71.4	43.5	40.0	36.4	13.3	62.5
Mean	82.6	31.9	52.3	38.7	16.9	54.1

Recruitment of New Wood

Large woody debris (≥1.0 m in length and ≥10 cm in width) that entered the study site during high winter discharges and storm events was efficiently retained by the log accumulations (Fig. 7 and 8). By the end of the 5-yr period, addition of the original log accumulations had retained sufficient amounts of new wood to restore the size class distribution of wood in the Quartz Creek restoration site to levels observed in streams in old-growth forests in the basin. Using Mack Creek in the H.J. Andrews Experimental Forest as a reference, amounts of wood in Quartz Creek in 1993 were similar to the amounts of wood in Mack Creek (Fig. 9a-c and 10a-c).

The most efficient structure that trapped woody debris was an non-cabled full jam (Structure #19) located in the middle of the restoration site. The jam was originally constructed with 20 pieces of wood. The jam contained 39 pieces in 1989, 97 pieces in 1990, 100 pieces in 1991, 130 pieces in 1992, and 163 pieces of woody debris in 1993.

Pieces of woody debris retained in the restoration reach were more likely to become incorporated into accumulations rather than to be deposited singly. In 1989, 101 pieces of woody debris entered the restoration reach; 91 pieces (90%) were incorporated into accumulations. In 1990, 445 pieces entered the reach with 369 pieces (83%) occurring in accumulations. In 1991, 106 pieces entered the reach and 72 pieces (68%) were stored in accumulations. In 1992, 85 pieces entered the reach with 67 pieces (79%) in accumulations. In 1993, 649 pieces entered the reach and 538 pieces (83%) were found in accumulations. Many of the pieces that entered in 1993 originated from trees blown down in the restoration reach by a wind storm in March of 1993. The total volume of woody debris in 1993 in Quartz Creek was 0.213 m^3 of wood per m^2 of stream channel.

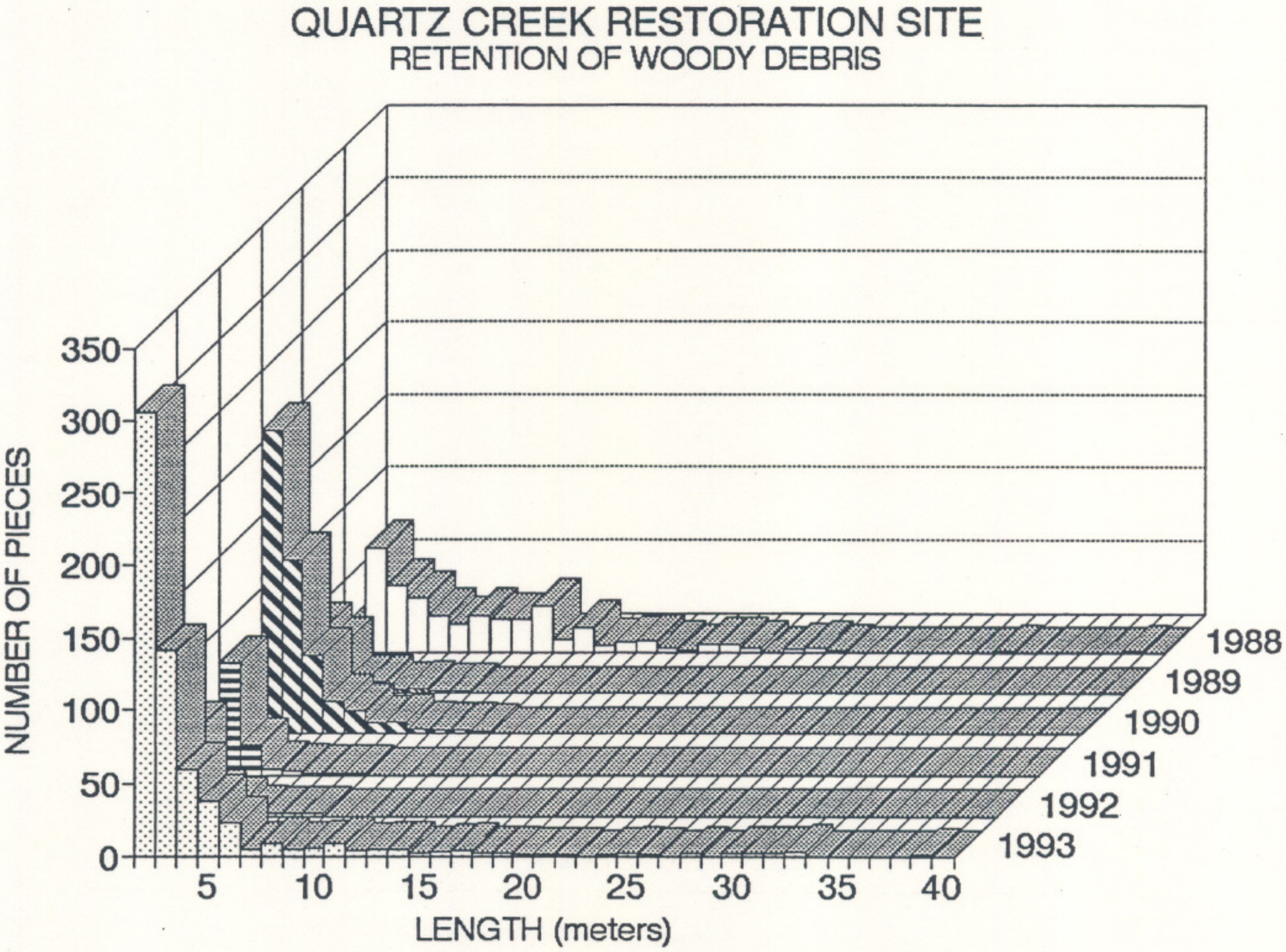

Fig. 7. Size class distribution (length) of woody debris retained in Quartz Creek restoration site, 1988-1993.

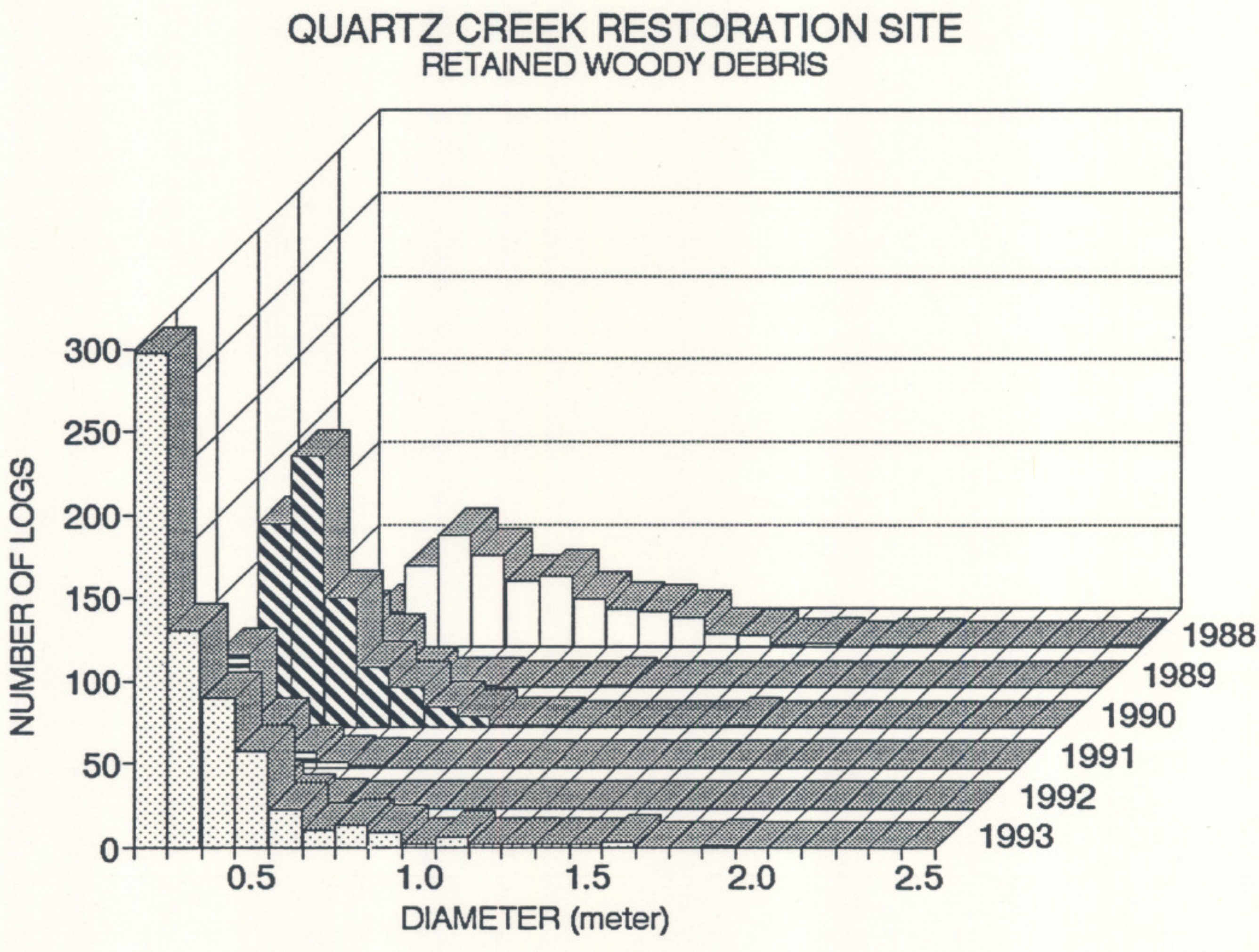

Fig. 8. Size class distribution (diameter) of woody debris retained in Quartz Creek restoration site, 1988-1993.

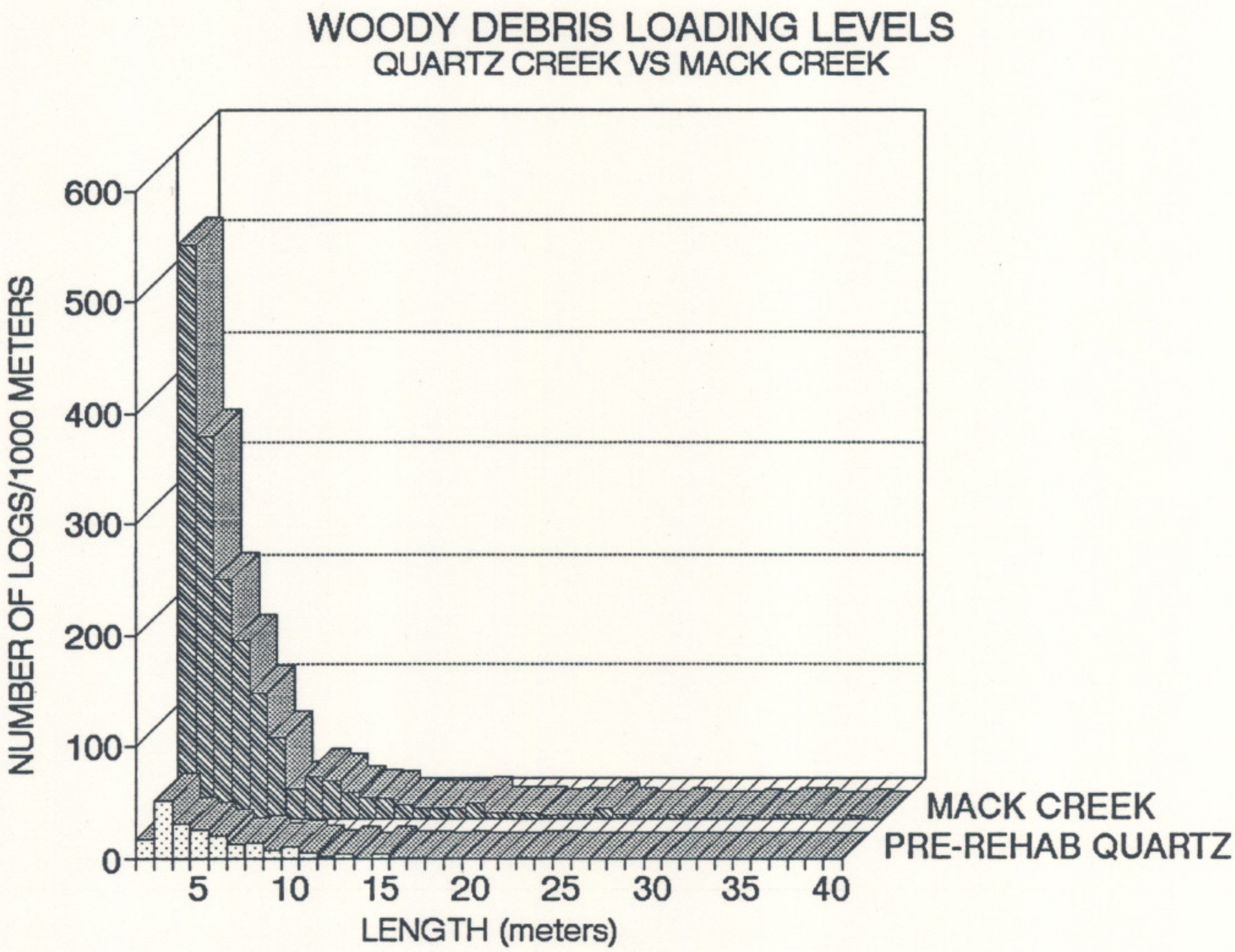

Fig. 9a. Size class distribution (length) of woody debris at Mack Creek and Quartz Creek restoration site before structure installation.

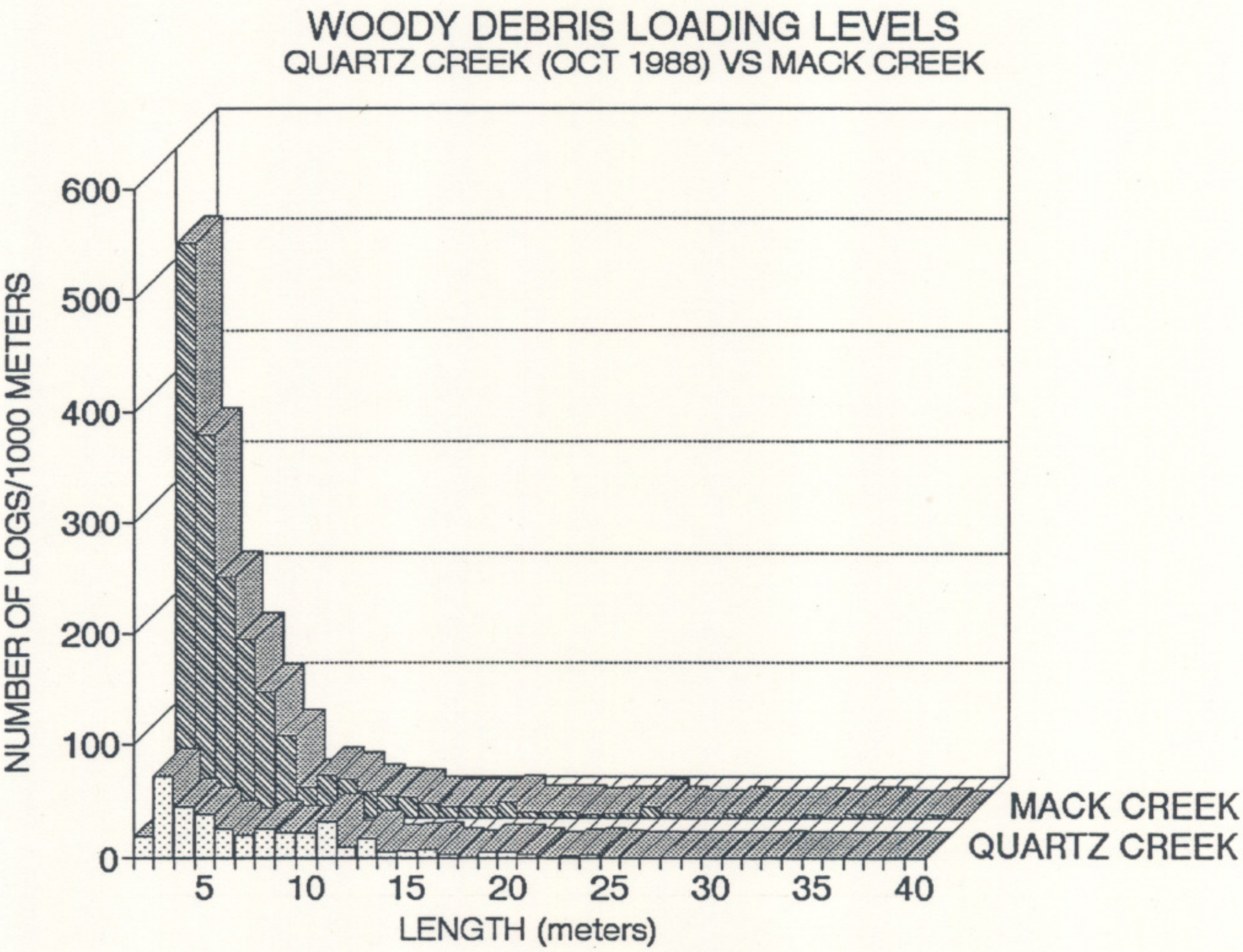

Fig. 9b. Size class distribution (length) of woody debris at Mack Creek and Quartz Creek restoration site immediately after structure installation.

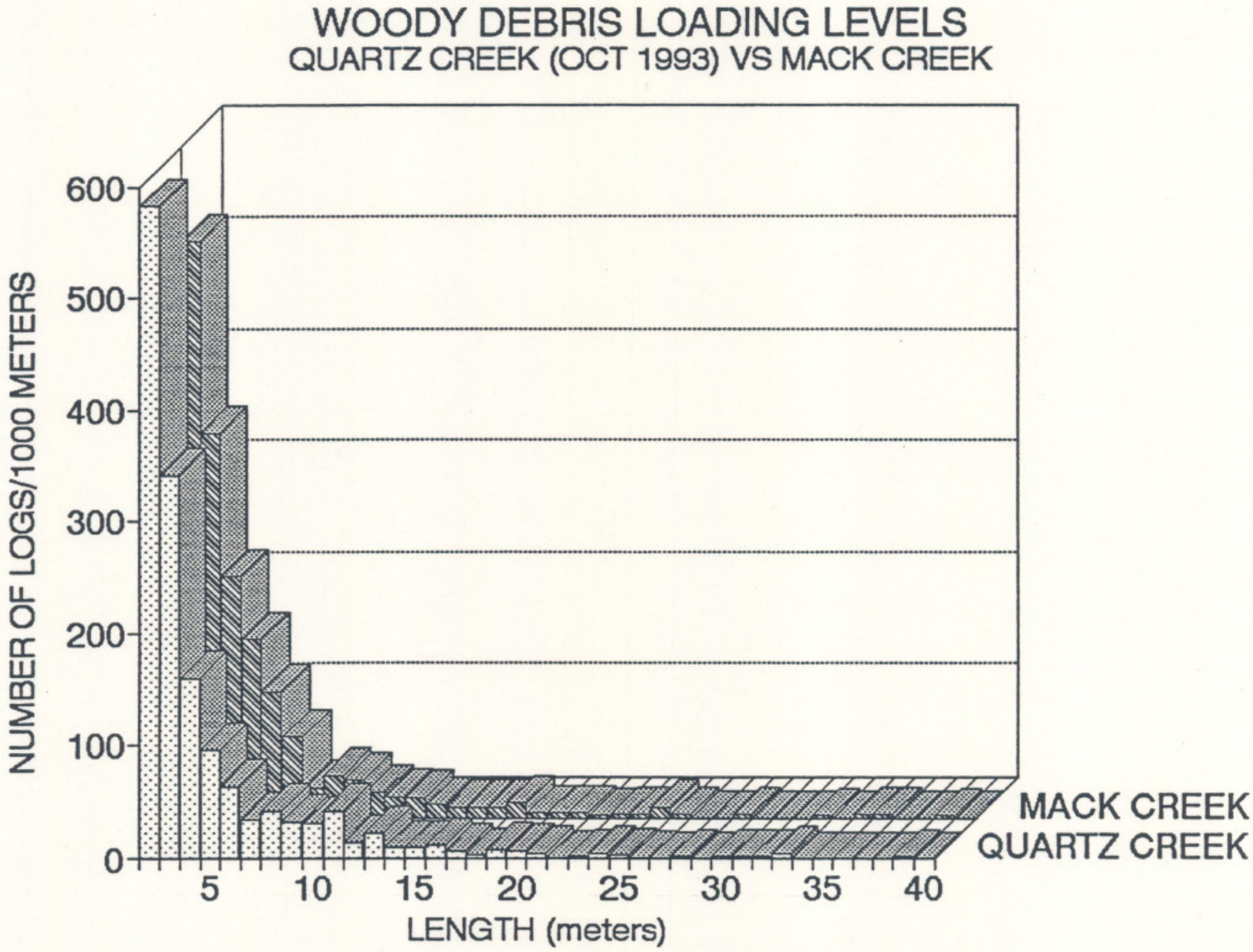

Fig. 9c. Size class distribution (length) of woody debris at Mack Creek and Quartz Creek restoration site, October 1993.

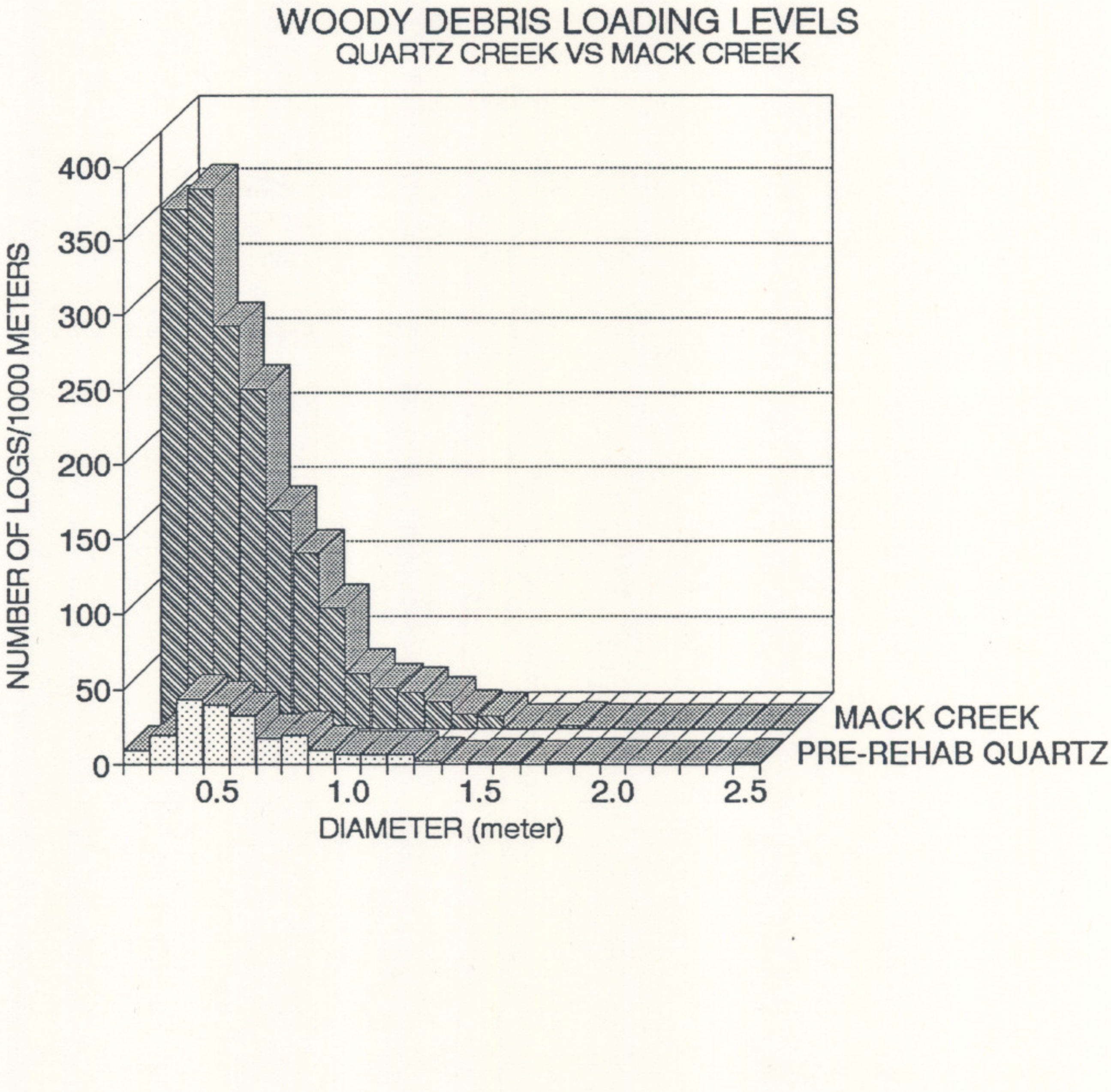

Fig. 10a. Size class distribution (diameter) of woody debris at Mack Creek and Quartz Creek restoration site before structure installation.

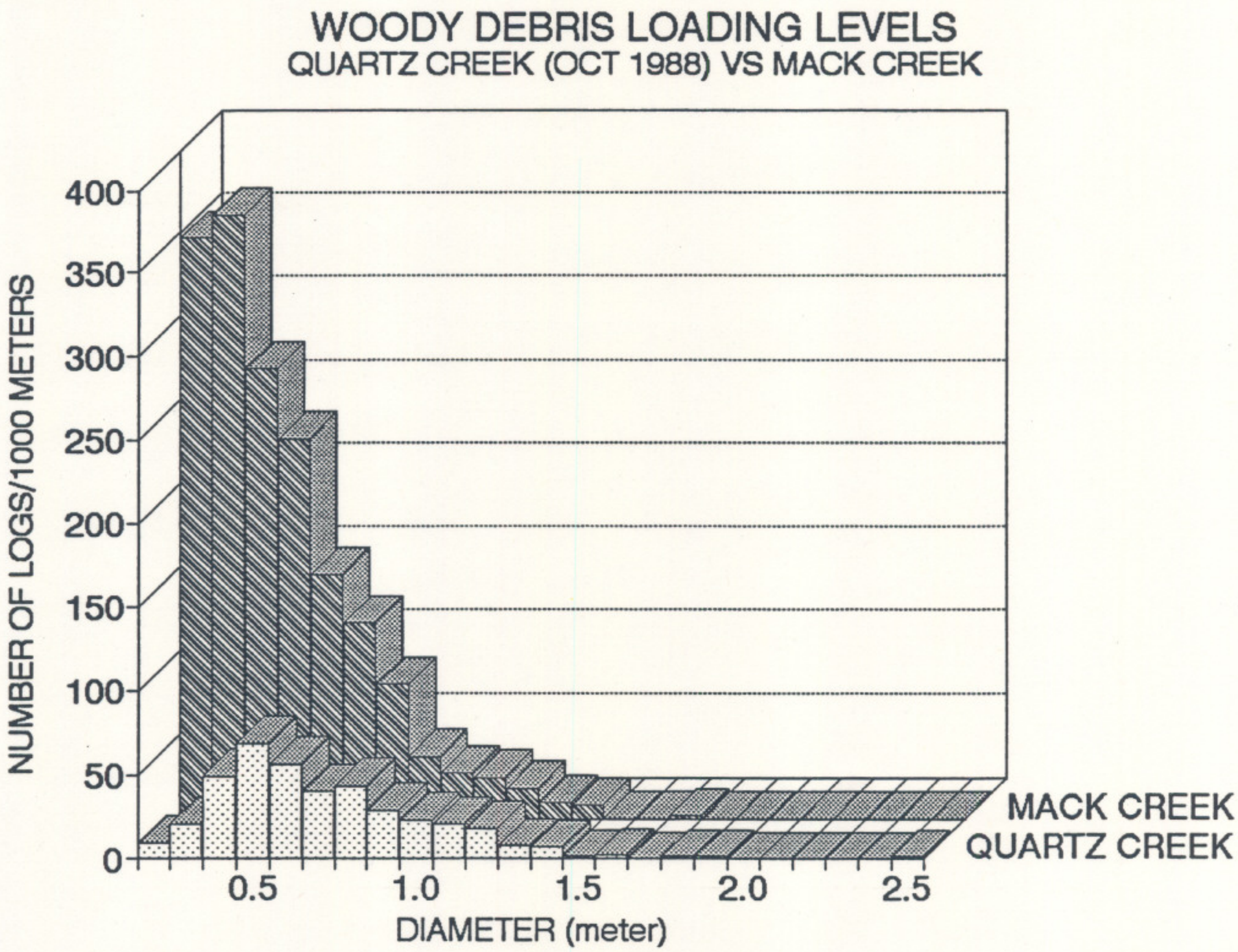

Fig. 10b. Size class distribution (diameter) of woody debris at Mack Creek and Quartz Creek restoration site immediately after structure installation.

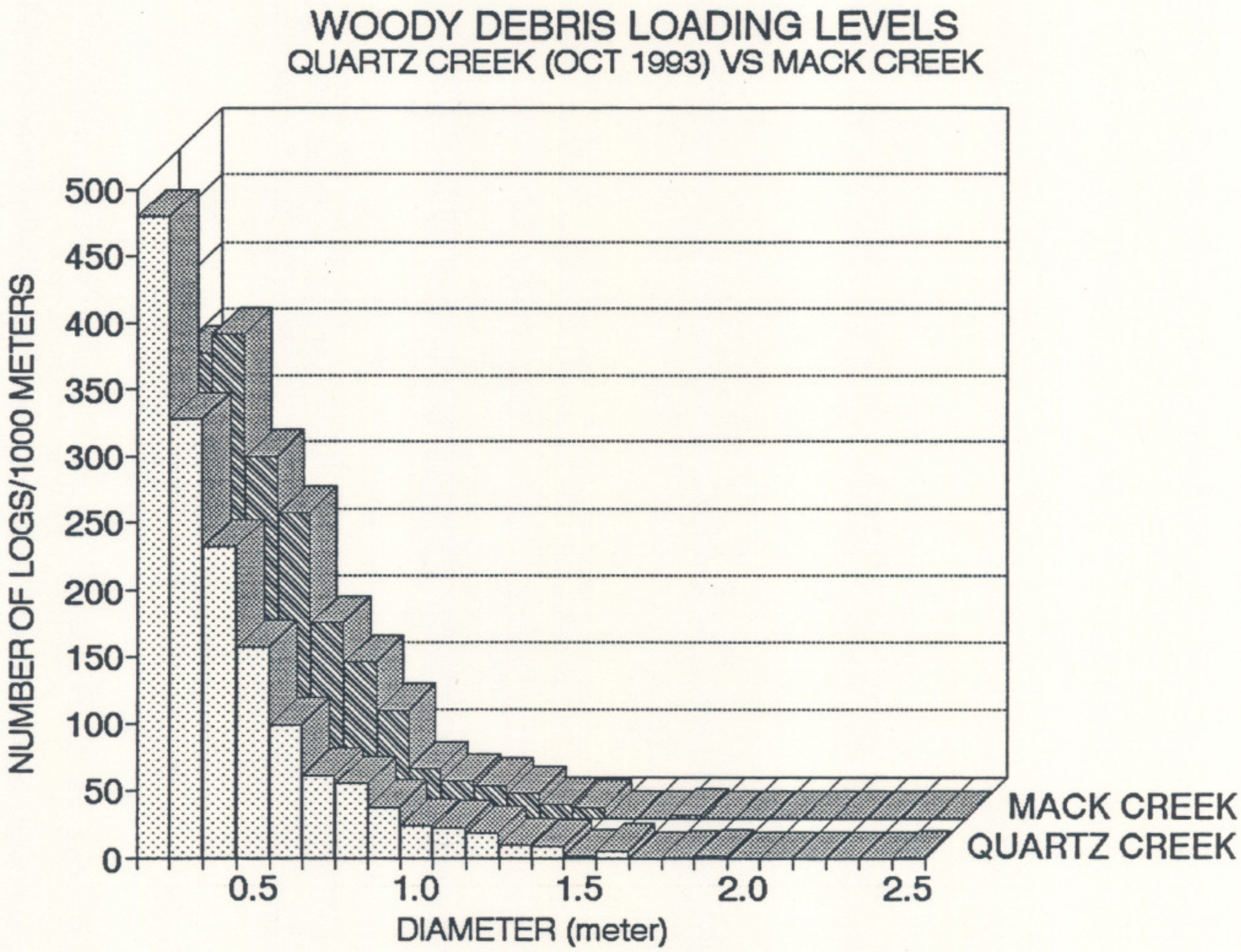

Fig. 10c. Size class distribution (diameter) of woody debris at Mack Creek and Quartz Creek restoration site, October 1993.

Change in Channel Morphology

Channel bedforms changed in 34 of the 48 monumented cross-sections, 17 exhibiting downcutting and 17 exhibiting deposition (Appendix D). Overall depth and composition of the streambed remained relatively stable, but fine gravel (smaller than the dominant cobble substrate) was deposited or scoured at several locations. Various log accumulations, such as upstream "V"s and some lateral deflectors, had deep sections scoured out below them. Sediment accumulated above the sill logs in the reach dominated by bedrock before restoration.

In the 47 channel cross-sections, depth was monitored at 1,818 individual points (Table 10). The maximum scour that occurred at any point was 2.07 m below the upper full-channel dam. The greatest amount of deposition at any monitored point was 1.98 m at a lateral V-deflector. Maximum net scour for an entire transect was 0.62 m at a lateral V-deflector, and the greatest net deposition for a transect was 0.30 m at a lateral deflector. Maximum scour of more than 1.0 m were observed at 17 transects, and maximum deposition of more than 1.0 m occurred at 10 transects. More than 10 cm was scoured (net for entire transect) at 12 transects by the end of the 5-yr period, and 13 transects experienced a net deposition of more than 10 cm. The average change in streambed height for all transects at the end of 5 yr was a degradation or scour of 0.01 m. Overall streambed height did not change substantially. However, net changes of more than 10 cm occurred at 53% of the transects, and maximum changes of more than 1.0 m were observed at 57% of the monitored transects.

Table 10. Scour and deposition of substrates at 47 cross-sections in the restoration reach at Quartz Creek. All values are in meters.

Cross Section	Maximum Scour	Maximum Deposition	Net Change	n
1-1	-1.72	0.72	-0.316	42
2-1	-0.49	0.84	-0.115	38
2-2	-1.62	0.09	-0.323	36
2-3	-0.58	0.32	-0.102	30
3-1	-1.48	0.12	-0.616	43
5-1	-0.64	0.49	0.175	41
5-2	-0.80	0.54	-0.113	43
6-1	-1.03	1.10	-0.052	40
7-1	-1.09	0.45	-0.001	43
8-1	-0.40	0.25	-0.119	41
9-1	-0.83	0.34	-0.097	37
11-1	-1.09	0.79	-0.089	34
12-1	-0.65	1.10	0.106	32
13-1	-1.54	0.36	-0.048	45
15-1	-0.63	0.91	0.159	43
17-1	-0.54	0.59	0.003	30
18-1	-0.53	0.22	-0.103	46
19-1	-0.43	0.85	0.068	42
19-2	-0.69	1.42	0.037	43
19-3	-0.23	0.75	0.291	47
20-1	-1.23	0.64	0.142	47
22-1	-0.38	0.66	0.104	43
23-1	-0.46	0.68	0.215	48
24-1	-1.66	0.43	-0.079	44
24-2	-0.55	1.47	0.052	41
25-1	-0.31	1.01	0.110	60
25-2	-1.17	1.03	-0.043	51
26-1	-1.10	1.02	-0.014	51
29-1	-1.37	1.07	0.063	29
31-1	-0.51	0.89	0.299	45
33-1	-0.45	0.49	-0.079	39
34-1	-1.07	1.98	0.172	35
35-1	-0.63	0.73	-0.013	33
37-1	-1.20	0.60	-0.056	44
38-1	-0.98	0.64	-0.145	33
39-1	-0.50	0.73	-0.071	39
40-1	-0.97	0.98	-0.072	38

Table 10. (cont.)

Cross Section	Maximum Scour	Maximum Deposition	Net Change	n
42-1	-0.63	0.52	0.014	38
42-2	-1.42	0.71	-0.111	41
46-1	-0.31	0.12	-0.031	17
47-1	-0.57	0.39	-0.075	35
48-1	-1.18	0.74	0.046	29
48-2	-0.67	0.58	0.019	14
49-1	-0.47	1.08	0.214	27
50-1	-0.43	0.73	0.204	28
50-2	-2.07	0.62	-0.282	49
50-3	-0.05	0.64	0.181	24

Changes in Trout Populations

Each year from 1989 to 1993 fish abundances and distribution were again analyzed in the 1,100-m restoration site. The 1,500 m section immediately above and the 400-m section immediately below the restoration site also were analyzed. Based on snorkel data, average fish densities before structure installation within the restoration site were 66 fish/100 m, but within one year after installation, fish densities were 86 fish/100 m (Table 11, Fig. 11). In 1990, fish densities fell in the restoration site to 59 fish/100 m, but in 1991 fish densities climbed to 127 fish/100 m. In 1992, fish densities fell in both the restoration reach and the below restoration site. In 1993, fish densities declined in all three sites.

Over the five year period fish densities were usually highest in the 400-m section below the restoration site. Densities were lowest in the section above the restoration site for the same time interval. Fish densities were highest in pool habitats in all years for all reaches (Table 12).

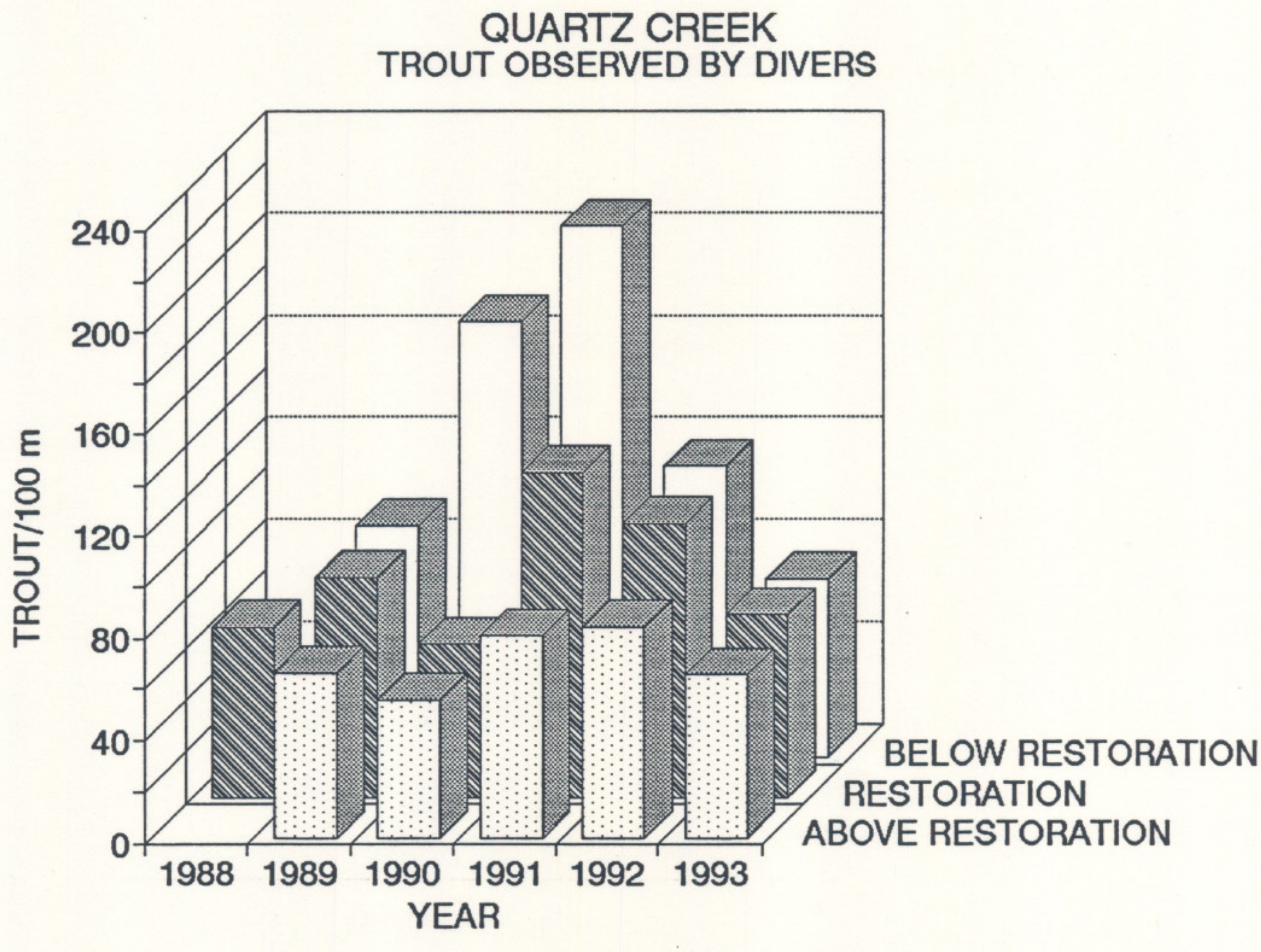

Fig. 11. Trout densities based on snorkel counts in the above restoration site, restoration site, and the below restoration site, 1988-1993.

Table 11. Number of fish/100 meters of stream (based on snorkel counts) for three sites at Quartz Creek from 1988 to 1993.

Study Site	1988	1989	1990	1991	1992	1993
Below Restoration Site	NA	90.2	170.5	208.0	113.9	69.5
Restoration Site	66.4	85.7	59.4	126.6	107.0	71.2
Above Restoration Site	NA	63.9	53.2	78.1	81.9	63.1

Size frequency distributions were developed from data on visual estimates of fish size during snorkeling observations. One year after restoration, a J-shaped size distribution was observed (Fig. 12). Large numbers of fry were observed in 1989 compared to low numbers of fry in 1988. Larger numbers of 1+ and 2+ fish were also observed in 1989. In 1990, distribution was somewhat bimodal, reflecting lower numbers of fry (Fig. 13). In 1991, there was a large year class of young fish, approximately three-fold greater than other years in the monitoring period (Fig. 14). Over 940 fry were observed in the 1,100-m restoration site. In 1992, size class distribution was similar to the J-shaped distribution of 1989 (Fig. 15). In 1993, fry numbers declined and size frequencies resembled those observed prior to restoration (Fig. 16).

Table 12. Number of fish/100 m in different habitat types observed by snorkeling at Quartz Creek from 1988 through 1993.

BELOW RESTORATION REACH

Channel Unit Type	1988	1989	1990	1991	1992	1993
Pool	N/A	64.3	294.3	329.8	232.1	144.0
Glide	N/A		261.5	130.4	31.7	83.3
Riffle	N/A		113.3	143.6	85.0	74.8
Rapid	N/A	114.3	135.5	238.5	112.6	40.2
Cascade	N/A	69.2	56.3	48.2	71.0	
Side-Channel	N/A					4.9
Step	N/A					

RESTORATION REACH

Channel Unit Type	1988	1989	1990	1991	1992	1993
Pool	111.2	177.0	121.4	208.5	157.9	96.9
Glide				126.5	73.6	40.7
Riffle	75.2	99.0	63.5	167.2	123.9	72.4
Rapid	68.9	83.0	50.0	135.8	89.5	65.4
Cascade	59.1	53.0	57.6	98.2	65.1	53.3
Side-Channel	14.5	20.0	8.6	27.0		
Step		19.0	26.7	57.1		20.0

ABOVE RESTORATION REACH

Channel Unit Type	1988	1989	1990	1991	1992	1993
Pool	N/A	172.0	111.0	111.6	121.7	127.6
Glide	N/A		33.3	66.7	58.3	37.9
Riffle	N/A		73.3	135.7	90.5	30.7
Rapid	N/A	89.0	25.6	84.4	82.2	71.4
Cascade	N/A	64.0	41.0	62.8	69.6	51.6
Side-Channel	N/A		10.0	30.0		33.3
Step	N/A					22.7

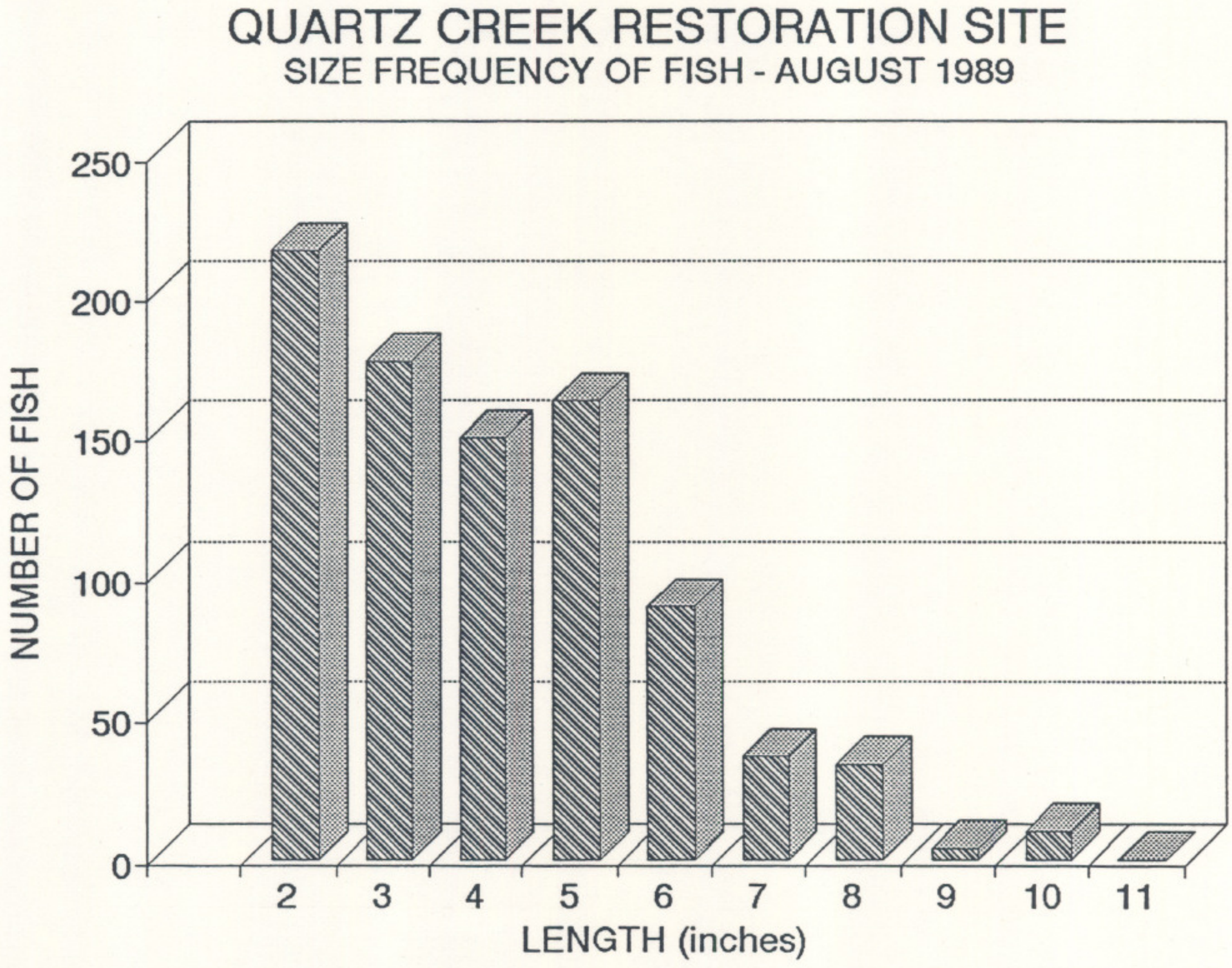

Fig. 12. Size frequency distribution of trout in Quartz Creek restoration site based on diver observations, August 1989.

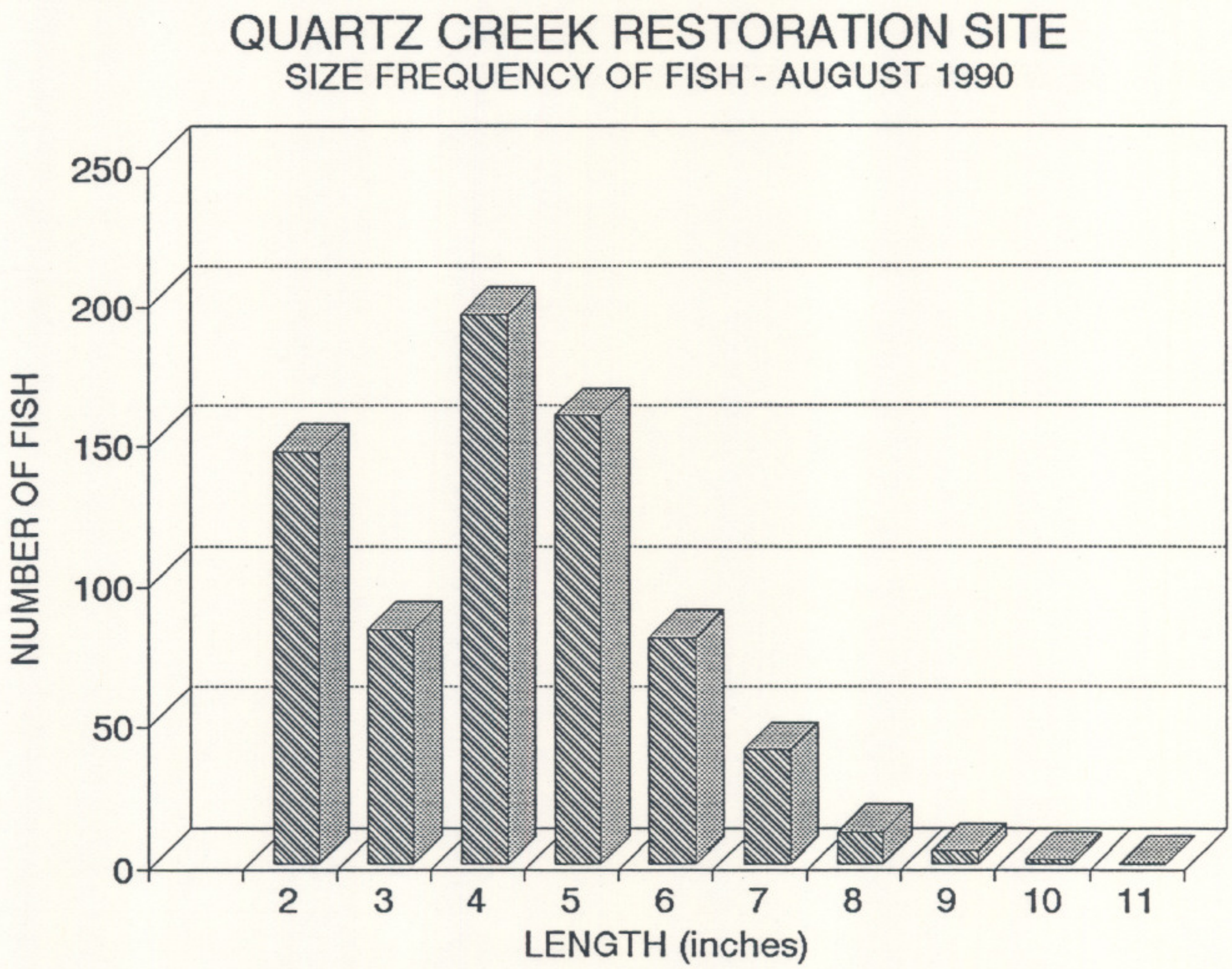

Fig. 13. Size frequency distribution of trout in Quartz Creek restoration site based on diver observations, August 1990.

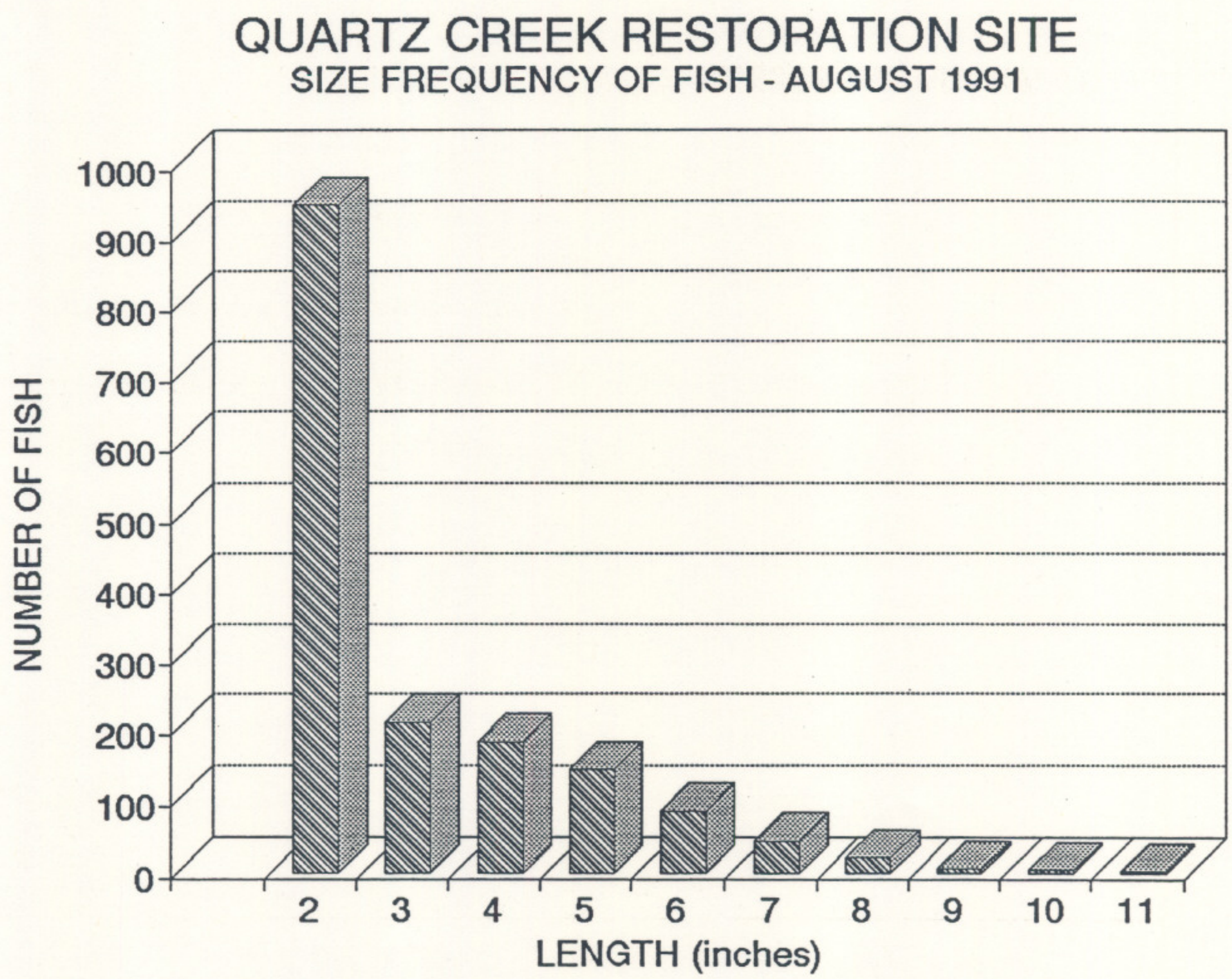

Fig. 14. Size frequency distribution of trout in Quartz Creek restoration site based on diver observations, August 1991.

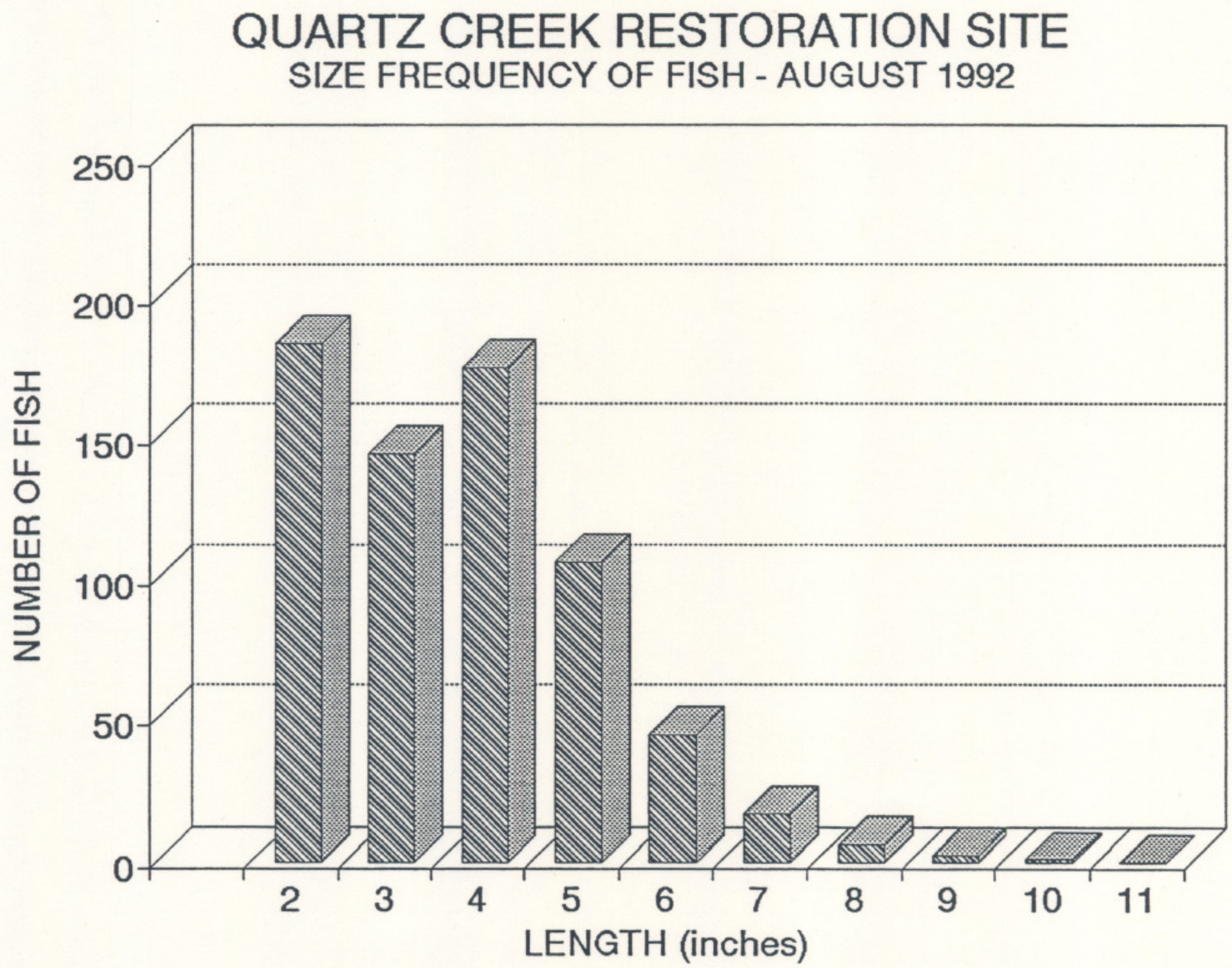

Fig. 15. Size frequency distribution of trout in Quartz Creek restoration site based on diver observations, August 1992.

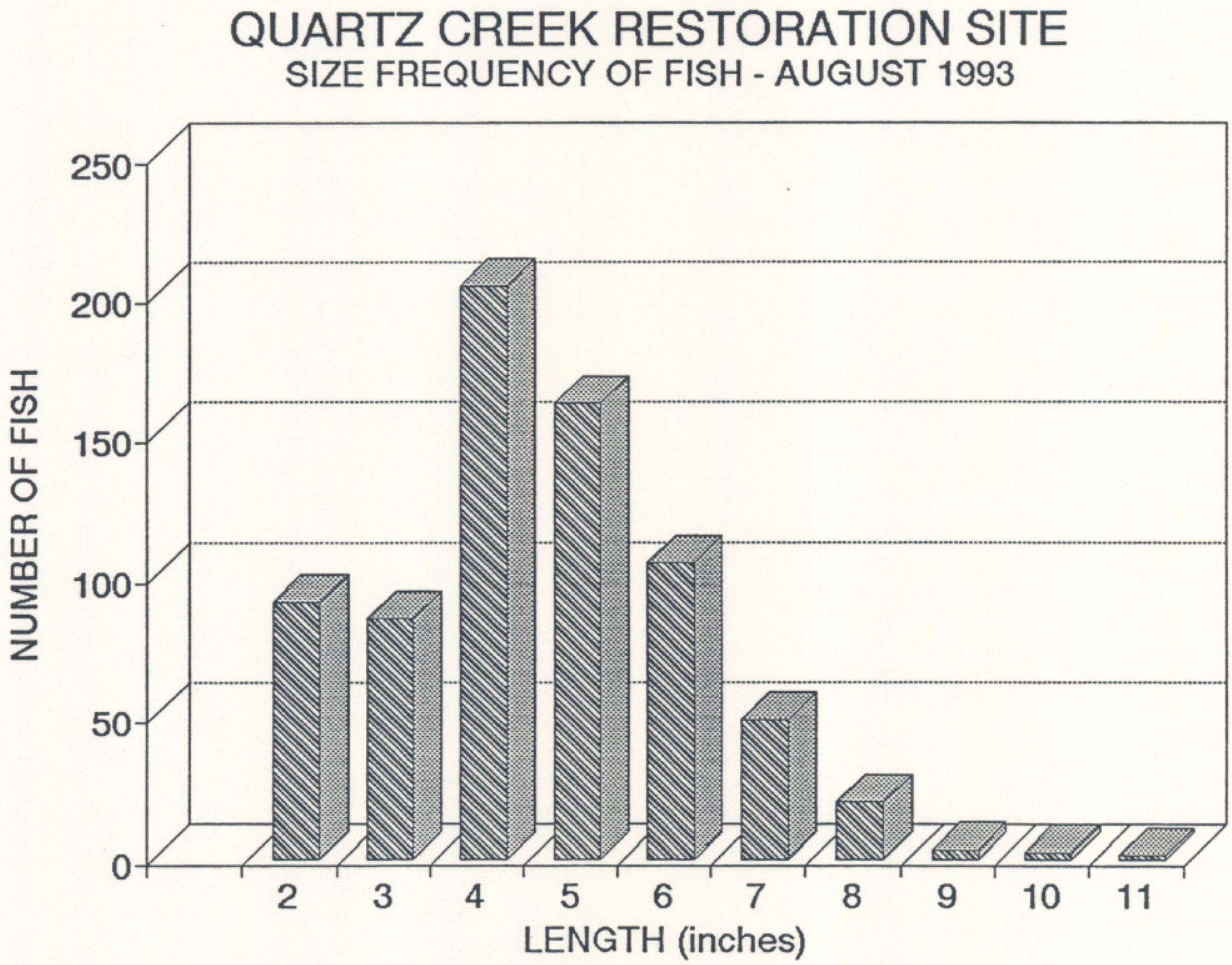

Fig. 16. Size frequency distribution of trout in Quartz Creek restoration site based on diver observations, August 1993.

The restoration site was electroshocked each year from 1990 to 1993 to validate the accuracy of snorkel counts by divers. Pass-removal method was used as the fish population estimator. Comparison of population estimates from snorkeling to those derived from electroshocking established correction factors for each habitat type for 1990-1993 (Table 13). A correction factor of <1.0 indicates that divers observed more fish than were estimated by electroshocking;

Table 13. Factors for correcting diver counts to fish populations (as determined by electrofishing estimates) for habitat types in Quartz Creek for 1990-1993.

Unit Type	1990	1991	1992	1993
Pool	3.1	1.3	1.7	1.9
Glide			2.3	2.7
Riffle	3.4	1.6	1.6	2.2
Rapid	3.2	2.6	1.8	1.8
Cascade	3.5	4.7	3.2	2.8
Side-Channel	10.0	2.0		
Step	2.5	2.5		5.7

values >1.0 indicate that electroshocking estimated more fish, and a value of 1.0 indicates that both methods estimated the exact same population. With the exception of cascades and steps, correction factors for 1991, 1992, and 1993 were lower than in 1990.

Total fish populations for the entire restoration reach were estimated by applying the correction factors to snorkel counts obtained in the three study sites. In 1991, trout populations were highest in the section immediately below the restoration site, and populations within the restoration site were only slightly greater than those upstream (Table 14, Fig. 17). In 1992, trout populations declined in all three sites, especially in the site below the restoration reach. In 1993, trout populations decreased at all three sites but the decline in the restoration site was proportionately less than in adjacent reaches (6% in the restoration reach versus 20% above and 26% below). Limited numbers of replicate years do not permit statistical analysis without future information.

Table 14. Number of fish/100 meters corrected for diver observation efficiencies for different habitat types at Quartz Creek for 1990-1993.

Study Reach	1990	1991	1992	1993
Below Restoration	519.5	489.9	186.8	149.7
Restoration Site	203.9	277.1	205.7	192.6
Above Restoration	177.7	252.4	203.2	149.5

Pool habitat types in 1990 consistently contained the highest densities of fish while side-channels had the lowest (Table 15). In 1991, fish densities were similar for all habitat types except side-channels and steps, which held less numbers of fish. In 1992, fish densities were highest in the pools but fish numbers declined in faster channel units. In 1993, fish concentrations decreased in most channel unit types but increased in the side-channels and steps.

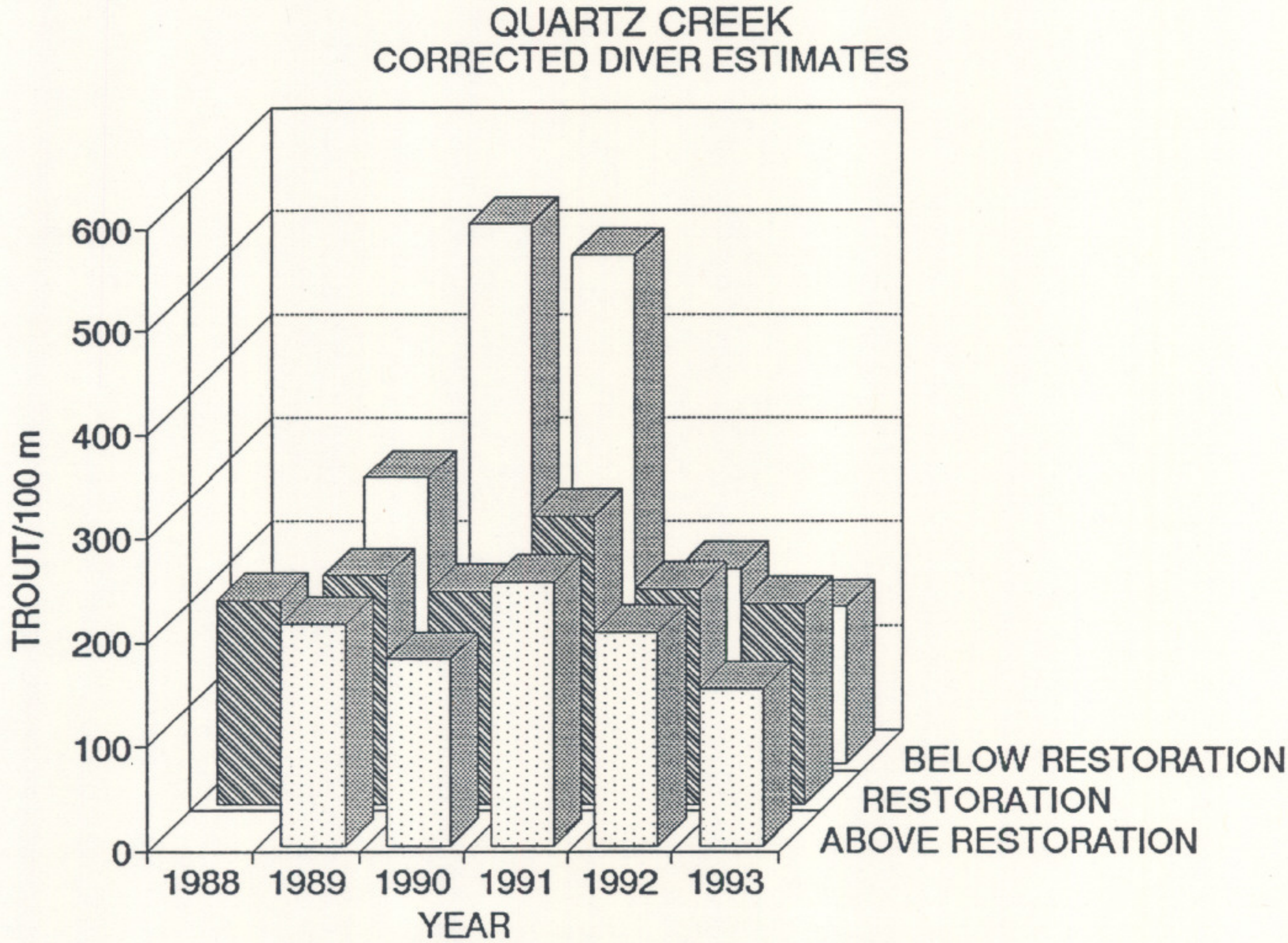

Fig. 17. Corrected diver estimates of trout densities at Quartz Creek in the above restoration site, restoration site, and below restoration site, 1988-1993.

* Values for 1988 and 1989 restoration site derived from applying mean correction values obtained in 1990-1993.

Table 15. Numbers of fish/100 meters in Quartz Creek restoration site corrected from electroshocking data for 1990-1993.

Habitat Type	1990	1991	1992	1993
Pool	251.0	244.1	300.8	194.9
Glide		223.5	171.8	110.5
Riffle	213.0	225.4	209.1	138.7
Rapid	167.0	244.2	184.4	121.6
Cascade	173.0	246.9	203.2	167.5
Side-Channel	69.0	72.4	40.0	145.9
Step	106.0	142.9	125.0	298.0

Post-Installation Technical Evaluation

In November 1988, the habitat restoration project was evaluated by 17 scientists and technical staff involved with the project. Representatives from Oregon State University, U. S. Forest Service, and Oregon Department of Fish and Wildlife participated in the evaluation.

Each structure was rated on a scale of 0-10 as to the degree to which it was anticipated to achieve its geomorphic and fishery objectives. Rating interpretations were: 0-3 = Poor (will not achieve objective), 4-6 = Fair (may achieve objective), 7-10 = Excellent (will achieve objective). The average rating of log accumulations for geomorphic objectives was 5.63, and the average rating for fish habitat objectives was 5.20. The overall restoration project rating of was 5.42.

Specific log accumulations that scored high on both the geomorphic and fisheries objectives were the full debris dams and the upstream "V" log accumulations. Structures that scored low were the cover logs (structure #37) that were installed too high above the stream channel and cover logs (structure

#49) that had too many boulders used for support and thus filled in the pool that the logs were originally intended to cover.

DISCUSSION

Most habitat restoration projects in the Pacific Northwest have been installed on relatively low gradient streams. Higher gradient streams with their tremendous potential stream power create a problem for habitat restoration. The project at Quartz Creek because of its higher gradient (4% average slope) and relatively large drainage area required careful design of structures and there placement.

Performance of Log Structures

Resource managers and restoration project designers generally want log structures to stay in place to achieve the intended goals of the project, particularly in view of the values of materials placed in the stream. In addition, they frequently are concerned about potential downstream damage by movement of logs from the restored reaches. Stream restoration projects in the Pacific Northwest commonly use steel cable and epoxy to secure log installations. While these attempts to restrict log movement are well intended, they ignore the natural dynamics of woody debris and stream channels.

Time-lapse photography of woody debris during high spring flows on Mack Creek (H.J. Andrews Experimental Forest) shows that natural debris dams rise and fall with changing stream discharge. During high discharges, these log accumulations float up and the majority of water passes underneath. On the falling limb of the hydrograph, the pieces fall back into place, and it is often difficult to discern any changes. Logs inundated by higher flows naturally tend to float, and any logs that are bound to the streambed are subjected to high flotation forces. Structures that are not cabled or partially cabled can move and adjust to the directions and intensity of the force of flowing water.

Even if the dynamics of wood accumulations is disregarded, stream channels are dynamic and change through time. Streambeds can move both vertically and laterally. Channels shift their positions across a valley floor, and channels accumulate sediments (channel aggradation) or cut down through sediments (channel degradation) over time frames of several years to several decades. Log structures that have been anchored into place by "hard engineering practices" cannot shift with the changing channel.

Specific objectives in restoration projects may require the additional security provided by cabling. Some channel locations are exposed to extreme hydraulic forces, and logs without attachment have little chance to remaining long enough to accomplish the habitat objectives. Some log accumulations, such as sill logs in narrow, constricted channels need to be down next to the stream bottom to function properly. These types of log accumulations need to be cabled securely because extreme hydraulic forces during high flows will move them to downstream areas of lower velocity.

The upstream-V log accumulations installed at Quartz Creek effectively created a step-pool profile in long cascades, but they too had to take the full force of high winter discharges because of their design. Five of the 21 log accumulations that "moved" were of this type. The "V" configuration focuses the force of the flow to the middle of the channel and quickly scours sediments. This scour can cut back under the structure and cause upstream sediment deposits to give way under the structure and change the arrangement of debris in the accumulation. In one instance a secondary or flood channel was formed during high flows around an upstream "V". Flows down these secondary channel take some pressure off log accumulations in the main channel during high water events. The structures that the highest tendency to move or shift were the upstream-V accumulations (5 of 6), followed by full jams (2 of 3), sill logs (1 of 2), and cover logs (4 of 8).

Placement of "road logs" to block off abandoned access roads that enter and leave the stream channel should be used only if flow onto the floodplain would be undesirable. During high discharge events, streams naturally leave their channel and flow out onto the surrounding floodplain. This helps dissipate the greater stream power during flood events. "Road logs" serve only to block this water from entering the floodplain and thus help maintain tremendous turbulence within the main channel. In Quartz Creek, the bed material and floodplain deposits were composed predominantly of coarse sediments (i.e., cobbles and boulders). Downstream sedimentation or extensive floodplain erosion was not a substantial risk in this project. In reaches with finer sediments, such as the sandstone sediments of the Coast Range, floodplain erosion along access roads could create greater risks and would need to be carefully considered.

The upstream-V log accumulations and some of the lateral deflectors had large amounts of potential spawning gravel deposited below them on the sides of the stream during winter discharges. Directly below the tip of the upstream-V log accumulations, deep plunge pools were scoured.

The excellent retention of large woody debris pieces by the non-cabled full debris jam(Structure #19) in the middle of the restoration site is very encouraging. The number of logs increased more than eight-fold in five years. In appropriate reach locations, these types of jams provide more natural habitat than heavily cabled "trash racks" and still effectively capture floating debris during high flows. The non-cabled full debris jam grew from 20 logs to 163 logs in five years, while the trash rack of nine logs accumulated 31 logs. Accumulations of a few large logs will not capture wood from transport as effectively and will not create complex habitats as quickly as more complex accumulation of logs.

Types and spacing of structures in a restoration project should not be designed to follow fixed patterns or uniform distributions, such as one structure every 25 m. Types of accumulations and ranges of spacings found naturally in a stream of the same size and relative location can serve as models for restoration design. Structures should be placed at locations that are geomorphologically and hydraulically appropriate. One should be cognizant however, that a structure may impose negative effects on the next structure either upstream or downstream if accumulations are placed too close together.

Distances between structures in the Quartz Creek project averaged 20 m and did not cause any appreciable hydraulic problems for neighboring structures. Some structures were located as close as five meters apart, and some were located directly across the stream from each other in areas where the wetted channel was relatively wide.

Evaluation of Log Accumulations

Land managers and researchers increasingly recognize the need for evaluation of restoration efforts. Performance of log structures commonly is based on whether a structure moves or changes it's original position. This static view of woody debris is based more on institutional performance than on ecological or geomorphic function. The ultimate goal of ecological restoration is to provide materials so that the stream system can provide its natural physical and ecological functions rather than to build a permanent and unchanging habitat structure. We recommend that agencies and researchers should begin to evaluate restoration efforts based on the degree to which the stream has recovered the desired habitat functions and the role of the introduced material in that recovery.

Nineteen of the 48 instream log accumulations have moved more than one meter since installation in 1988, but those moved logs are still performing good functions. The majority of the 19 log accumulations moved less than 10 m and the few that did move further were eventually deposited on or within existing log accumulations. We observed no major differences in the permanence of log structures regardless of the degree of cabling.

The incorporation of logs intact with root-wads into log accumulations was successfully applied to several accumulations. Whole trees with attached root-wads were easily pushed over by the excavator. This type of woody debris in the stream channel is extremely stable during high discharges. Use of trees with intact root-wads should be encouraged in future habitat restoration projects. Disruption of streambanks by pushing over trees can create complex lateral habitats in local areas, but extensive destabilization of stream banks along a larger reach should be avoided.

Incorporation of root-wads with no attached bole exhibited mixed results. Those root wads that were placed singly along the sides of the stream channel tended to roll easily during high discharges. When root-wads were incorporated into log accumulations, such as in the middle of lateral deflectors, they provided more complex lateral habitat that potentially serves as critical winter refuge for fish and salamanders.

For those structures that were fully cabled or partially cabled and still "moved", inadequate size of attached boulders was one of the factors for movement. Because all boulder material was obtained from the direct site of structure installation, large boulders were not accessible in some cases and moderate sized boulders had to be used.

There were 314 glue joints and 29 cable clamps incorporated in the 19 fully cabled and 14 partially cabled structures. Glue failure and/or bedrock fracture was responsible for 6 of the 314 joints to fail.

In future stream restoration projects that require structures to be firmly in place (e.g., sill logs), hydraulic calculations of the volume of rock needed to hold a volume of wood in position should be carefully calculated. If large sized boulders are not present on site, appropriate sized boulder material can be transported to the site but this adds substantially to project costs.

Most of the movement of structures occurred soon after installation. Since the summer of 1990, few of the installed structures have moved or shifted. This possibly suggests that as time progresses after installation, structures become somewhat more stable within the range of flows that have been experienced. In the Quartz Creek project, flows were generally low during the five year period, and high flows events were equal to or less than a 5-yr recurrence interval.

We reemphasize that movement alone should not be considered a failure of a specific log accumulation or the project as a whole. If the wood is moved by the stream and used effectively to create functional habitats in the stream, the intent of introducing wood into the channel is met. In many respects, effective redistribution of wood by the stream is a more desirable ecological response than remaining in an original fixed position.

Ecological Responses

Hydraulic and particulate retention is extremely important in stream ecosystems in that it allows aquatic organisms time to process organic matter such as detritus and leaves which enter from the riparian zone or sources upstream. These aquatic invertebrates in turn are a major source of food to the fish population.

Hydraulic retention was poor in the 1,100-m reach of Quartz Creek before log introduction. This can be largely attributed to the constrained configuration of the stream channel, relatively low amounts of woody debris, low number of deep pools, and the lack of extensive backwaters. A large storm event (e.g., recurrence interval of 15 years or greater) is needed before deep scouring below structures and backwater formation occurs. Hydraulic retention at the restoration at Quartz Creek will probably not improve until such a large storm event acts upon the system.

Quartz Creek and 12 similar sized streams in the Blue River District were sampled for leaf retention and hydraulic retention in 1982 (Speaker 1985). Quartz Creek had the poorest retention curves of all 13 streams sampled. This indicates the low level of woody debris and lack of deep pools in Quartz Creek compared to the other streams sampled.

Particulate retention increased with the addition of the log accumulations (see Table 9). Large increases in particulate retention occurred in the bedrock chute area where sill logs were installed and in the long cascade reach site where three inverted V-log accumulations were installed. We anticipate that particulate retention will increase as smaller debris continues to become entrained and incorporated into the log accumulations.

Original woody debris, installed structures, and retained woody debris within the restoration reach generally moved only short distances during high winter discharges. In 1989, 33 (8.6%) of the 385 total pieces of wood debris in the restoration reach moved a distance of 5 meters or greater. In 1990, 50 (10.4%) of the 479 total pieces moved, and in 1991, 32 (3.7%) of the 857 pieces moved. In 1992, 53 (5.6%) of the 947 total pieces moved, and in 1993, 46 (4.8%) of the 968 total pieces moved a distance of 5 meters or greater.

In contrast, movement of natural woody debris at Mack Creek averages around one percent annually for flows of less than 10-yr recurrence intervals. Rates of movement at Quartz Creek indicate that the woody debris in the restoration reach was somewhat unstable directly after structure installation. The size of the pieces that moved were usually small (1.0 - 5.0 m long), and the pieces moved relatively short distances. Most of the moving pieces eventually were incorporated into structures downstream. After five years, the amount of woody debris moving within the restoration site has declined.

The wind storm that struck the restoration site in the spring of 1993 blew down 23 large trees (>0.50 m diameter) into the active channel. These trees blew down with their root-wads intact, thus increasing the stability of the stream system. Large amounts of sediment were disturbed with the uprooting of these trees, but minimal amounts of sediment have entered the active channel from this event because most disturbance was on the terraces and upslope areas.

Short-term barriers to fish passage are possible in projects where downcutting creates elevational breaks that are higher than the jumping ability of resident or anadromous fish species. Seasonality of fish movement must be considered in assessing barriers. None of the log accumulations created barriers to fish movement during any season. Such barriers are not anticipated in the future because of the dominance of cobble and boulder as bed material in Quartz Creek. High channel roughness throughout the reach provides numerous opportunities for both upstream and downstream access for fish.

Snorkeling surveys performed each year after structure installation (with correction based on electroshocking calibration) showed a 12% increase in fish numbers in 1989, 4% increase in 1990, 41% increase in 1991, 5% increase in

1992, and 2% reduction in 1993 in the restoration study site. Estimates of trout populations for the 5-yr period after restoration averaged 12% higher than the population observed in 1988.

These population changes could be attributed to numerous factors:

- Installed structure allowed for greater over wintering survival of fish.
- Natural yearly fluctuations in trout populations can vary by over 100% (personal communication Rogers-ODFW, House-BLM). Trout populations are extremely dynamic and have a tendency to vary dramatically with yearly changes in stream hydrology.
- High discharges during the winter of 1989-1990 could have decreased overwintering survival resulting in the lower population in 1990.
- Relatively mild winter and spring flows in 1991 may have caused the very large increase in young fish in the 1991 survey.
- Deposition of spawning gravels behind numerous log accumulations allowed for high spawning success.
- Extremely low summer discharges during 1992 could account for the lower number of fish in the restoration reach in that year.
- High discharges in the spring of 1993 may have increased young-of-the-year mortality or delayed their emergence from the gravels.
- Increased retention of organic matter has resulted in an increase in the invertebrate population and resulted in more drift organisms for the fish community to feed upon.

The increase in number of fish in the reach below the restoration site is interesting. Because there is no large corresponding increase in the number of fish in the site above the restoration site, it is possible that the restoration site is acting as a source of fish production in seeding the area below. High discharges in the winter/spring of 1989-1990 may have contributed to this by moving fish from the restoration site down into the below restoration site.

The number of fry observed in the restoration site in 1988 were low in comparison to the next four years. Stream flows were extremely low in July 1988 when the pre-introduction fish snorkeling was conducted. The trout fry were still quite small and resided in very shallow lateral habitats. These shallow water areas are somewhat inaccessible to divers during the snorkel survey. In successive years, snorkel surveys were conducted in mid-August when fry were larger and occupied deeper areas within the stream. The larger size of the fry and their positions in the channel made counting much more efficient in 1989-1993.

Snorkeling and shocking surveys were also performed for the same five year period at an old-growth section of Mack Creek and at a control section at North Fork Quartz Creek (a deciduous canopied third-order stream approximately twelve miles north of the restoration site on Quartz Creek). Both of these streams contain relatively undisturbed populations of cutthroat trout. Large yearly fluctuations in trout populations occur in all three streams (Fig. 18). Trout populations were highest at both Quartz Creeks in 1991 and were also high for Mack Creek that year. Trout populations were low at both Mack Creek and N.F. Quartz Creek in 1988 and 1989 but were stable at Quartz restoration site for the same time period. In all five years, the trout population at Quartz restoration was higher than the other two streams. Trout numbers in 1992 and 1993 increase in Mack and N.F. Quartz Creeks but decrease slightly at the Quartz restoration site. Interannual variation in resident trout populations in the upper McKenzie River basin is approximately +/- 25% of mean abundances. Changes in trout numbers in Quartz Creek are well within that range of variability.

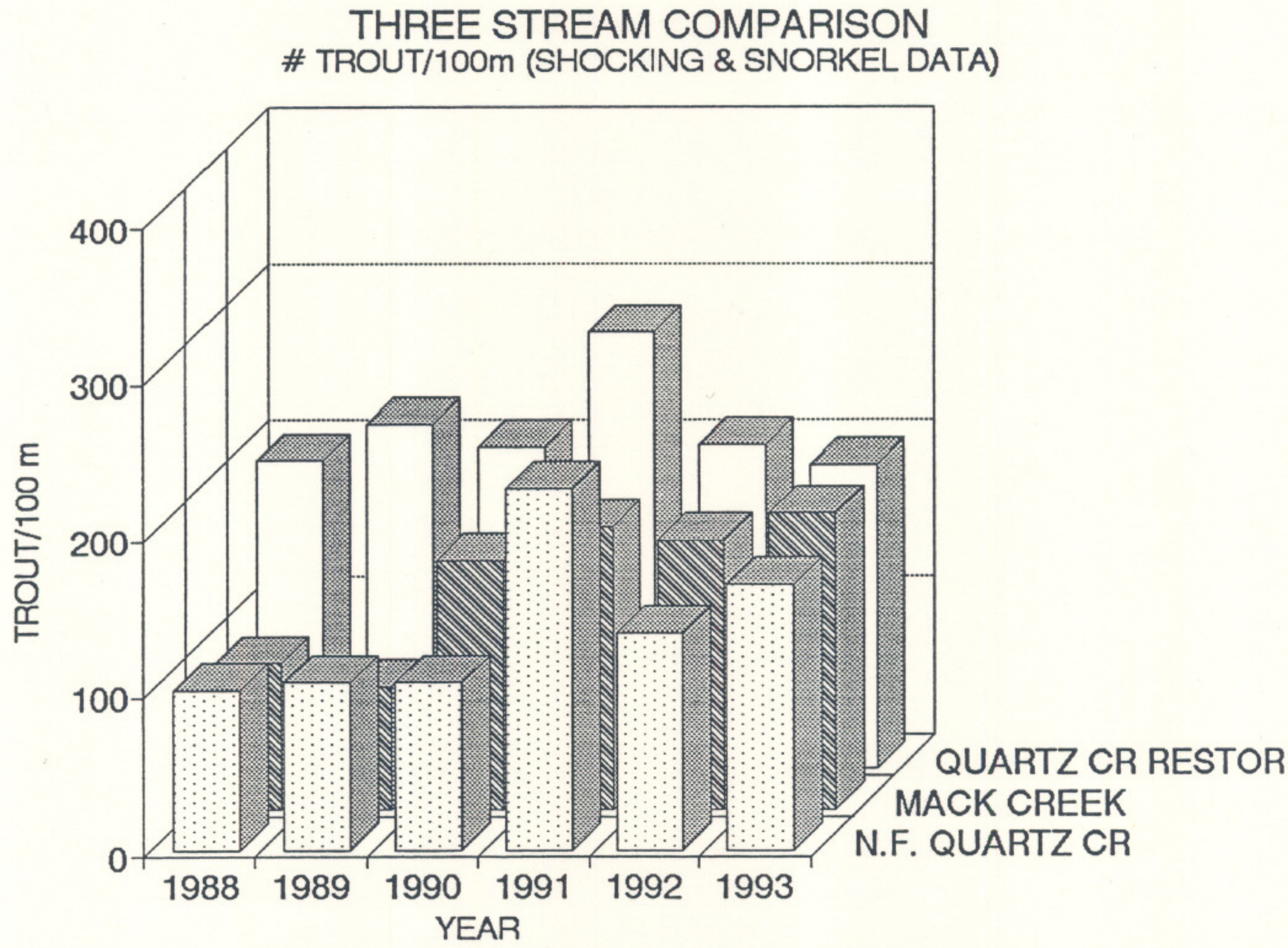

Fig. 18. Trout densities at Quartz Creek restoration site, Mack Creek, and N. F. Quartz Creek, 1988-1993.

SUMMARY

This report is the culmination of 5 years of monitoring at Quartz Creek. Detailed monitoring is scheduled to take place again at the ten year period (1998) and 20 year period (2008) after structure introduction. If a "major" reorganizational event (e.g., >25 year recurrence flood) inundates the site then a special monitoring year would be instituted. These monitoring efforts in the future should consist of all measurements taken of the biological and physical parameters in the first five years of the study.

The Department of Fisheries and Wildlife (Stream Team) at Oregon State University (104 Nash Hall, Corvallis, Oregon, 97331) is the repository of all field data, photographs from photopoints, and time-lapse movie film.

The Aquatic Ecosystem Restoration Project resulted in several major physical and biological changes in Quartz Creek in a relatively short period of time. The rapid recruitment of woody debris by the installed debris accumulations in Quartz Creek is faster than we expected. In five years, the restoration reach of Quartz Creek has nearly developed the amounts and sizes of debris that would be expected in a similarly sized stream flowing through an old-growth forest in this basin. Over the short term, the large wood installed by the project has effectively retained the smaller size classes in transport. Channel scour or deposition have been observed in association with most of the accumulation. Deepening of the local channel is the most common channel change. Almost half the accumulations have shifted a meter or more, but little of the wood has left the restoration reach. Only twenty-one of the 186 pieces (11.3%) of wood originally installed have been transported out of the restoration reach. Most of the transported pieces have been relatively small in size with a mean length of 4.1 m and a mean diameter of 0.47 m.

Retention of potential food resources (as measured by leaves) increased approximately five fold in 1992 compared to pre-introduction levels. In 1993, when stream discharge was almost three times normal flow the retention of leaves was only two times as high. It has been shown that leaf retention rates decrease with increasing stream discharge (Speaker 1985).

Trout populations within the restoration reach have increased slightly, but trout populations downstream of the reach showed large increases for two years. Existing data cannot determine the specific causes for the downstream population. The trout habitat for this reach is relatively poor with extensive runs of bedrock substrate. The downstream population may reflect natural variation in these populations or the increase may be a response to downstream seeding by fry reared in the restoration reach.

As part of the continuing effort of the Long Term Ecological Research group at Oregon State University monitoring will continue at Quartz Creek but at a severely reduced level of intensity. Habitat mapping within the restoration site will continue each year to monitor changes in the channel structure. Monitoring of the retention of large woody debris will also continue with the mapping, measuring, and tagging of all new debris within the restoration site. The three time-lapse camera systems will continue to be maintained to visually monitor any changes to the structures. Funds are not available to continue the level of monitoring for the first five years of the project, but monitoring will continue at the 10 year and 20 year period. In addition, the Willamette National Forest may call for detailed monitoring after a major flood event.

The Aquatic Ecosystem Restoration Project has accomplished many of the physical and biological objectives since 1988. Short-term changes in wood and habitat created by the project are favorable. Rapid retention of new large woody debris by the structures has been particular encouraging. The long-term effectiveness of the project still remains unanswered. Geomorphic and ecological responses to a major flood event (e.g., > 25-yr recurrence interval) will be an important test of this approach for ecosystem restoration.

LITERATURE CITED

Armour, C.L., K.P. Burnham, and W.S. Platts. 1983. Field methods and statistical analyses for monitoring small salmonid streams. U.S. Fish & Wildlife Service.

Hankin, D.G., and G.H. Reeves. 1989. Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. Can. J. Fish Aquat. Sci. 45:834-844.

Kilpatrick, F.A., W.W. Sayre, and E.V. Richardson. 1967. Flow measurements with fluorescent tracers (a discussion). J. Hydraul. Div. Amer. Soc. Civil Eng. 93: 298-308.

Speaker, R. 1985. Distribution and retention of particulate organic matter in streams in the Cascade Mountains of Oregon. M.S. Thesis, Oregon State University, Corvallis, 145 p.

Strahler, A.N. 1957. Quantitative analysis of watershed geomorphology. Am. Geophys. Union Trans. (EOS) 38:913-920.