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EFFECTS OF MOUNT ST. HELENS ERUPTION ON SALMON POPULATIONS AND HABITAT IN THE TOUTLE RIVER

by

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ABSTRACT

The eruption of Mount St. Helens on May 18, 1980 caused massive devastation of the fishery resources in the Toutle River watershed. Catastrophic changes caused by the debris avalanche, pyroclastic flows and mudflows destroyed fish populations and 218 km (77%) of the 280 km of anadromous fish habitat formerly utilized by salmonids. High concentrations of suspended sediment caused many adult spawners to avoid the Toutle River in 1980 and 1981, and instead return to the upper Cowlitz River and Kalama River. Adult salmon and steelhead that returned to the Toutle River were observed spawning in most tributaries formerly utilized before the eruption. Adult salmon spawned in unstable volcanic substrates with average concentrations of fine particles (<0.850 mm) ranging from 11.2% to 36.0% in 1981 and from 11.2% to 33.5% in 1982. Survival of eggs to hatching stage in volcanic substrate ranged from 50% to 95%. Successful reproduction observed in impacted streams was attributed to temporary groundwater upwelling.

Juvenile coho mortality ranged from 0% to 83% during the summer period and was closely associated with high water temperature ($R^2 = .80$). Water temperatures in a new tributary on the debris avalanche exceeded 25°C (considered the upper incipient level for coho) during 10 days in 1981 and 30 days in 1982. Small 3rd to 4th order tributaries without riparian vegetation would require riparian trees at least 4.2 meters tall to provide enough shade to reduce summer water temperatures to pre-eruption levels. Regenerated red alder and Douglas fir would be tall enough to provide temperature control within six and ten years, respectively.

Juvenile coho mortality during winter ranged from 62-83% in unaffected streams and 82-100% in affected streams. Mortality increased with increases

in severity of impact and was associated with channel stability, suspended sediment, and the amount of cover provided by large organic debris ($R^2 = .57$). Channel stability and suspended sediment are directly related to depth of channel inundation by mudlfow or debris avalanche. Old tributary channels buried by the adjacent river mudlfow have degraded to near pre-eruption levels and are beginning to develop channel morphology suitable for fish rearing. New channels on the South Fork Toutle mudflow are developing more slowly, but are expected to reach a stable condition before the new channels on the debris avalanche. Sediment problems and channel instability on the debris avalanche are expected to diminish in 30 to 35 years. Small 3rd and 4th order streams would require woody debris at least 25-35 cm in diameter to provide channel stability and refuge cover. Regenerating riparian trees would require 50-75 years to become large enough to provide inputs of large organic debris for tributary streams. Larger mainstem rivers will require larger trees that will not be available for an estimated 75-100 years. Therefore, the lack of instream cover provided by large organic debris will be the limiting factor for complete habitat recovery in the Toutle watershed.

Coho survival during smolt outmigration was in excess of 42% for a 46 km reach of the Toutle River. Smolt survival for the future is optimistic if suspended sediment levels are lower than 5,000 mg/l during the spring outmigration period.

Recovery of the fishery resources in the Toutle drainage is dependent on the recovery of habitat and fish stocks. Tree planting, riparian timber management, and artificial inputs of large organic debris could accelerate habitat recovery. An integrated management approach of a hatchery stock operation that complements wild stock production would make the greatest use of natural habitat and accelerate stock recovery.

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INTRODUCTION

The eruption of Mount St. Helens on May 18, 1980 caused massive devastation of the fishery resources in the Toutle River watershed. A gigantic avalanche moved down the north side of Mount St. Helens and was deposited in the upper 17 miles of the North Fork Toutle River. Mudflows moved down the North and South Forks of the Toutle River causing widespread destruction as they passed downstream through the lower Toutle and Cowlitz Rivers (Cummans 1981). Hot pyroclastic flows caused water temperatures to exceed the lethal tolerance for fish, as temperatures at the mouth of the Toutle were recorded in excess of 34°C (Rees 1980). Catastrophic changes caused by the pyroclastic flows, ash fallout and mudflows destroyed fish populations and habitat in the Toutle River and in most tributaries located within the eruption impact area.

The subsequent erosion of ash and mud deposits caused suspended sediment levels that were lethal to juvenile salmon through the summer and autumn of 1980 (Stober et al. 1981). Returning adult salmon, during autumn 1980, were observed dead and unspawned along the river banks, apparently as a result of suffocation from the high concentration of suspended sediment or from stranding in an effort to swim up the shallow braided channels in the river. The Toutle salmon hatchery, located at the mouth of the Green River, was also destroyed by mudflow and all juvenile salmon in the hatchery perished.

The destruction of salmon habitat and the loss of the Toutle hatchery will have a significant impact on commerical and sport fisheries in the Pacific Northwest. The natural production of salmon and trout in the Toutle River is estimated to provide an annual catch of 52,000 fish, and is worth more than 2.25 million dollars (computed from Tables VII-10 and VII-11, Cowlitz County Dept. of Community Development 1983). Hatchery production provided an even larger proportion of the catch (251,500 fish) and is estimated to have an annual value of more than 12 million dollars. Therefore the annual loss to the fishery is large and will become larger depending on the time required for natural habitat and fish stocks to recover.

Information concerning the effects of a volcanic eruption on the aquatic environment and the subsequent natural recovery is scarce. The best information is limited to observations of spawning salmon and fishery catch records collected by local fishery personnel during the 1912 eruption of Mount Katmai in southwestern Alaska. During the eruption of Mount Katmai, ash, 8 to 25 cm deep, was deposited on Afognek Island, which is located approximately 97 km east-southeast of Katmai Volcano (Chamberlin and Bower 1913). A survey of the principal salmon streams on the island, indicated that in the eastern portion, where the ashfall was least, mollusks, worms, and some insect larvae could be collected. However, the streams on the west side of the island where the fall of ash was heavy, were almost destitute of fish food. The streams were literally choked with sand and mud; old channels were obliterated and the water spread in a thin sheet over the meadows (Ball 1914). The eruption occurred when the sockeye salmon run was just beginning in the streams of Afognek Island. Salmon in the streams during the eruption were either killed by the heavy concentration of sediment or they were driven back downstream and into the estuary. Ball (1914) observed that many of the returning sockeye would ascend the streams a short distance, and then return to the sea, repeating these erratic movements many times. The streams in the mountainous sections remained muddy thus preventing or delaying the appearance of salmon on the spawning grounds. The behavior of the returning salmon, described by Ball, would suggest that the sockeye were capable of finding their home stream, even though it was choked with sediment, but did not enter or were delayed as a result of an avoidance response to the sediment. Follow up stream surveys in 1913 and 1914 indicated that the spawning conditions were improving but the streams were still turbid following periods of heavy rain (Bower and Aller, 1915). The impact of the Mount Katami eruption on the salmon runs and the rate of stock recovery was determined by Eicher and Rounsefell (1957), from investigation of fishery catch records. They found that the influence of the heavy ashfall was very apparent in the small catches made from 1916 to 1920 when the returning adults would come from broods subjected to the ash while in fresh water. However the runs (1921-1927) returning from the smaller numbers of spawners in 1916 to 1920 were fully as large as before the eruption. Therefore, the impact of the ashfall appears to have been short term (4-5 years), as the sockeye runs on Afognek Island recovered quickly and interestingly under the presence of a commercial fishery. Eicher and Rounsefell (1957) provide data to suggest that the rapid recovery of sockeye was due to an increased lake productivity as a result of nutrients provided from the ashfall. More recent studies concerning the effects of ashfall on lake productivity, (Dugdale and Dugdale 1961, Barsdate and Dugdale 1972, and Poe 1980) support the findings of Eicher and Rounsefell.

Other studies, documenting the effects of volcanism on fish are limited to a few short descriptions of fish kills due to ashfall from Mount Bezymyannyi (eruption 1955-56) on Kamchatka (Kurenkov 1966), and mudflows in the Kamchatka River (Tovarova 1958 and Gorshkov 1959), see reviews in Poe (1980).

Since the eruption of Mount St. Helens, several studies concerning the effects on fish have been completed. Redding and Schreck (1981) assessed the immediate physiological effects of chronic exposure to suspended volcanic ash with steelhead trout and found that volcanic ash induced physiological responses that is characteristic of sublethal stress in fishes. Based on their results, the investigators infer that exposure to volcanic ash and other types of suspended solids may significantly lower a fish's chances for survival, especially during periods when other sublethal deleterious factors, e.g., high water temperature, are imposed simultaneously. Stober et al. (1981) determined that the tolerance of juvenile coho and chinook salmon to suspended volcanic sediment was an order of magnitude lower for live-box tests conducted in the Toutle River compared to laboratory static bioassays. Apparently, additional environmental factors (i.e., temperature, velocity, and organic compounds) present in the Toutle River after the eruption, combine to lower the tolerance of salmon to volcanic sediment. Stober et al., found that lethal conditions in the Toutle River persisted through the summer following the May 18 eruption, but that survival improved by spring 1981 with the decline in suspended sediment. Brannon et al., (1981), using laboratory apparatus demonstrated that the addition of volcanic ash from Mount St. Helens to home water did not prevent home water discrimination by adult chinook, but did inhibit their upstream movement. Consequently, Brannon et al. predict that salmon returning to the Toutle River are more likely to stray or delay their migration when presented with a choice between home water containing volcanic ash and clear, non-natal water.

Information derived from the past eruptions of other volcanos is neither sufficient to provide an understanding of how fish production is impaired nor adequate to provide an estimate of recovery time. Therefore, the purpose of the present study was to: 1) determine the effects of the Mount St. Helens eruption on salmon populations and habitat in the Toutle River system; 2) identify the environmental components that are presently limiting natural production; and 3) to determine the most probable course and time frame for natural recovery.

HISTORY OF VOLCANISM AND FISHERY RESOURCES OF THE TOUTLE RIVER

The history of Mount St. Helens and the history of salmon stocks in the Toutle River help us understand how the streams and lakes were formed, and, provide a clue as to how salmon populations have recovered in the past. Mount St. Helens has been active for the past 40,000 years with intermittent activity that included numerous explosive eruptions over periods of hundreds to thousands of years, which were seperated by apparent dormant intervals ranging in length from a few hundred to about 15,000 years (Mullineaux and Crandell 1981). A brief review of the intermittent eruptive phases that have occurred during the past 4,000 years (Mullineaux and Crandell 1981) indicates the dynamic nature of the Toutle River basin. During the Smith Creek eruptive period, which began about 4,000 years ago, lahars (term refers to mudflow or debris flows that resulted from volcanic activity) extended down the North Fork Toutle River at least 50 km below Spirit Lake. Spirit Lake was probably created during this period as a result of daming of the North Fork Toutle by the fan of lahars and pyroclastic flow deposits at the base of Mount St. Helens. The Pine Creek eruptive period occurred about 300 years after the Smith Creek period (3,000-2,500 years ago) and lasted about 500 years. During this period, lahars and fluvial deposits aggraded the valley floors of both the North and South Forks of the Toutle River, and created the basin of Silver Lake by blocking a tributary valley. The next major volcanic activity occurred during the Kalama Period (300-450 years ago). It is unclear as to how far lahars extended down the Toutle Valley during this time; however, evidence of lahars are known in the Camp Baker area on the North Fork Toutle River (R. Janda, personal communication). The most recent eruptive period, prior to 1980, is the Goat Rock period which began in 1800 AD. Many minor explosive eruptions were observed by explorers from the 1830's to mid 1850's with the last eruption in 1857. Most of the eruptions during this period were small scale and lahars were limited to areas near Spirit lake. Indians in the vicinity during the 1850's reported to the Cowlitz missionaries that they observed dead salmon floating down the Toutle River after an eruption of Mount St. Helens (Harris 1976).

Salmon populations in the Toutle River were frequently disrupted by volcanic eruptions and were presumably devastated by the large lahars that were more destructive to channels and floodplains than the 1980 eruption of Mount St. Helens (Janda et al. 1981). Yet the populations must have recovered as the channels stabilized and the waters were recolonized by survivors from the tributaries, by returning adults from the ocean, and by strays from other systems. In the 1940's, less than 90 years after the Goat Rock eruptive period, salmon and steelhead runs in the Toutle were reported to have been large (Bryant 1951). Coho spawner surveys conducted on the tributaries to Spirit Lake in the 1940's recorded spawner densities that were among the highest for streams in the lower Columbia River (Allen 1982). Therefore, any impacts on salmon, as reported by the Indians from the 1850's eruptions, either must have been small or the recovery was completed by the 1940's.

Salmon stocks that inhabit the Toutle River have characteristics that vary somewhat from stocks in this vicinity. The Toutle River coho were predominately composed of a stock that returned to the river in late summer and early autumn (LeMier, 1955). In contrast, coho in the Cowlitz River return later in the season, during autumn and winter (Hager and Hopley 1981). The fall chinook stock in the Toutle River has an extended juvenile freshwater residence period that lasts as long as one year (Reimers and Loeffel 1967).

On the contrary, the generally accepted length of freshwater residence for fall chinook juveniles is usually about 90 days after yolk absorption. This extended freshwater residence of fall chinook is very similar to the general life history of spring chinook. The Toutle River, historically has had a small run of spring chinook (Bryant 1951 and W. Dammers, WDF, personal communication). Perhaps the overlapping life history pattern of the spring and fall chinook stocks creates competition that resulted in only one stock being dominant.

The wild runs of salmon and steelhead in the Toutle River have been augmented by artificial production for the past 30 years in an effort to sustain a heavy commercial and sport fishery. Prior to the eruption, the Toutle salmon hatcheries average annual production was 1.4 million coho and 3.2 million fall chinook salmon. Also, about 240,000 winter and summer steelhead smolts were released annually into the Toutle River system (Cowlitz County Dept. of Community Development 1983). The effects of these hatchery releases on the wild stocks has not been investigated. However, the sport catch of steelhead in the Toutle River had consistantly ranked among the best in the state (Schuck and Kurose 1982). On the other hand, the density of coho spawners in the upper North Fork Toutle and Spirit Lake area has been slowly declining and was at a record low level in 1979 (Allen 1982, and W. Dammers, WDF, personal communication).

STUDY DESIGN

The study was divided into two steps. First a general survey of streams previously utilized by anadromous salmonids was conducted to determine the location of survivors, and to assess the magnitude and type of impacts on fish habitat. Based on survey results, streams were grouped according to the type and intensity of impacts on habitat and by the presence of fish. Second, nine stream reaches representative of different types of effects identified in step one, were selected for intensive study (Table 1, Figure 1). Intensive studies were conducted during an 18 month period (April 1981 through October 1982) to: 1) evaluate adult spawner success, spawning habitat and embryonic survival; 2) document the physical and biological characteristics of salmonid rearing habitat; and 3) measure juvenile salmonid growth and survival. Information from three stream reaches with no volcanic effects are compared to that from six stream reaches with volcanic effects in order to provide a relative measure of the impacts on habitat and fish survival.

Table 1. Physical characteristics of the affected and unaffected study streams in the Toutle River watershed.

Stream	Type of Effect	Gradient (%)	Stream order	Elevation (m)	Low flow area (m^2)		Area of drainage basin above study reach (km^2)	Distance from mouth of Toutle (km)	Length of study reach (m)
					(81)	(82)			
Alder Cr.	No effect	.57	4	277	1356	1397	30.0	46	240
Upper Wyant Cr.	No effect	.33	4	149	1616	1707	30.3	26.5	310
Devils Cr.	No effect	1.01	3	402	1210	1410	10.6	48	300
Elk Cr. (Green R.)	Ash and tephra deposits, and scorched riparian	.56	3	481	1216	--	21.8	67	275
Upper Deer Cr.	Mudflow in old channel and partially scorched riparian	.68	4	335	1717	1215	18.4	52	300
Lower Wyant Cr.	Mudflow in old channel and sparse partially dead riparian	.46	4	143	1456	1266	31.3	26.5	300
Lower Deer Cr.	New channel on mudflow and partial riparian	.68	4	323	1459	1461	20.2	52	300
Herrington Cr.	New channel on coarse mudflow and no riparian	1.24	3	375	1277	1767	8.8	53	300
Bear Cr. N.F. Toutle R.	New channel on landslide debris-flow and no riparian	.80	3	469	787	847	7.5	54	220

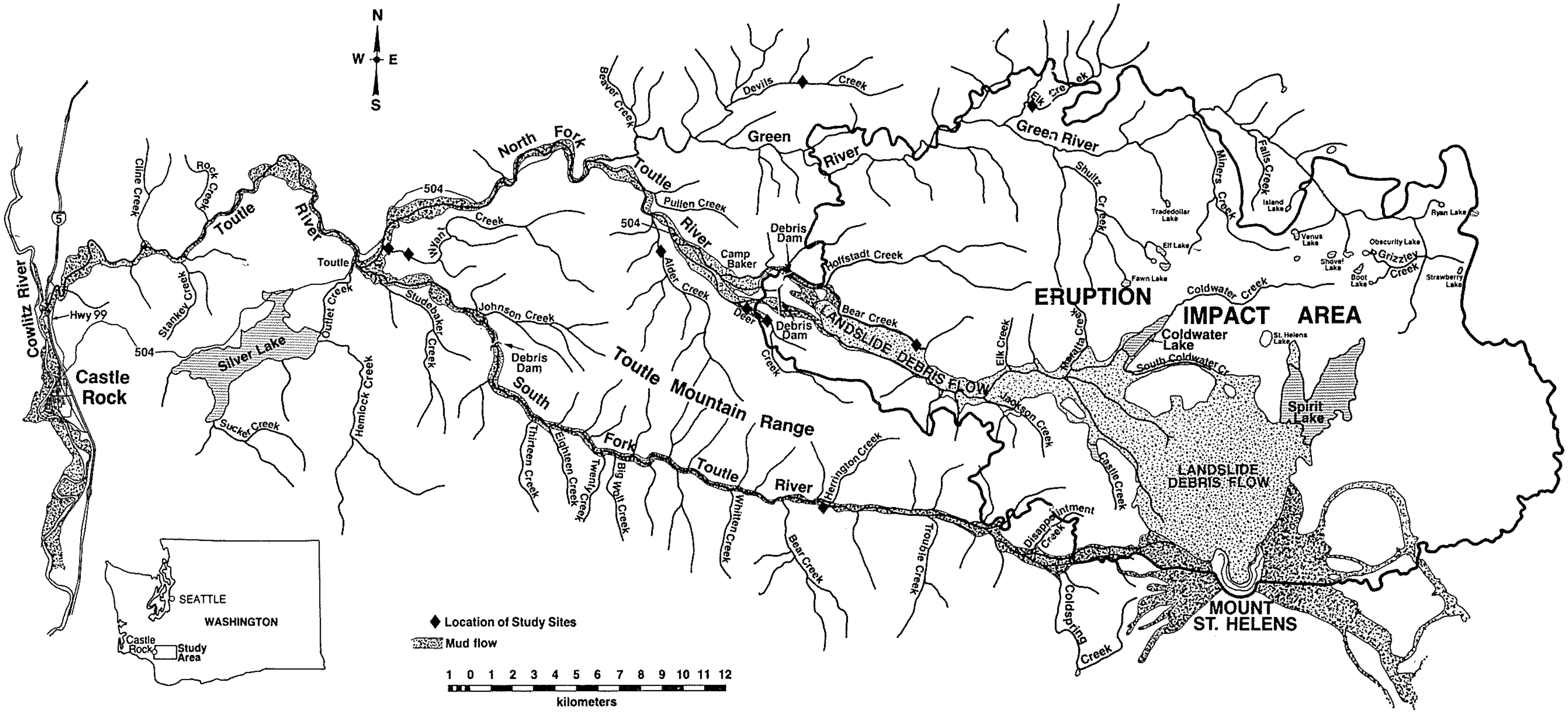

Fig. 1. Post-eruption map of Toutle River drainage showing location of study sites and areas of impact.

VOLCANIC IMPACTS ON FISH HABITAT AND SURVIVAL OF FISH

Materials and Methods

Streams formerly utilized by anadromous salmonids were surveyed by foot, rubber raft, and helicopter to determine habitat conditions and the location of fish survivors. Information on streams not visited by the research team was obtained from surveys conducted by fishery biologists from the Washington Departments of Fisheries and Game. Stream length information was either measured from post-eruption topographic maps (U.S. Geological Survey, Scale 1:24000) or obtained from data compiled by the Cowlitz County Department of Community Development (Sarah Deatherage, personal communication).

Results

The eruption of Mount St. Helens impacted 77 percent (218 kms), of the 281 kms (Table 2) of rivers and tributary streams formerly accessible to anadromous salmonids in the Toutle drainage. The effects of the eruption on fish and habitat range in "orders-of-magnitude" and are a function of distance and location in respect to the volcano (Figure 1). Streams within the drainage were separated into five general categories according to environmental similarities that include: no impact; mudflows; landslide-debris-flow; ash and tephra; and ash, tephra and wood debris. The streams that received no impact, except for a dusting of ash fallout, are all tributaries (Table 2), and are located outside the eruption impact area and above the mudflows in the river valley. Salmonids endemic to the Toutle drainage (i.e., cutthroat trout, steelhead trout, coho salmon, and chinook salmon) were observed in the unimpacted streams during 1981.

Mudflows in the South Fork Toutle, lower North Fork Toutle, mainstem Toutle and the lower reaches of adjacent tributaries impacted the greatest area (58 percent) of streams compared to other impacts (Table 3 and Appendix Table A for specific locations). During 1981, juvenile salmonids were observed in many of the mudflow impacted tributaries (e.g., lower portions of: Wyant, Deer, Johnson, and Herrington Creeks). However, it is unlikely that the fish we observed, survived the eruption in the impacted area. Rather, juveniles probably moved downstream from unimpacted areas since the eruption.

The landslide-debris-flow in the upper North Fork Toutle affected a smaller area than mudflows, but, caused the greatest damage to fish habitat (Table 3). Old channels in the upper North Fork Toutle valley were completely buried by a layer of debris ranging from 50 m to 200 m thick (Cummans 1981). The upper reaches of the new streams that developed on the debris-flow were also severely damaged by the pyroclastic flows and subsequent deposition of ash, tephra, and woody debris. Fish survivors were not found in surveys of Jackson, Castle, and Maratta Creeks. But, two juvenile cutthroat trout were discovered in October 1981, in the steep valley wall portion of upper Bear Creek. The southwesterly aspect (Figure 1) and steep valley walls of Bear Creek presumably shielded the stream from the direct force of the eruption blast. Stream surveys in the upper North Fork Toutle, within the eruption impact area, indicate that fish residing in areas accessible to anadromous passage did not survive the eruption. But, that steeper upland tributaries, utilized by resident fish, could have fish survivors.

Streams located in the Green River watershed on the outer edge of eruption impact area (Figure 1) received damage from deposition of ash, tephra

Table 2. Total length of rivers and tributary streams accessible to anadromous salmonids before the eruption of Mount St. Helens and portion of length impacted by eruption.

Period	Rivers	STREAMS Tributaries	Combine
	km	km	km
Total length before eruption	163.3	117.4	280.7
Total length impacted by eruption (%)	163.3 (100)	54.3 (46.2)	217.6 (77.5)

Table 3. Type of impacts received in rivers and tributary streams accessible to anadromous salmonids that were caused by the eruption of Mount St. Helens.

Type of Impact	Rivers km	Rivers (%)	Tribuaries km	Tribuaries (%)	Combine km	Combine (%)
Mudflow	101.3	(46.5)	24.9	(11.4)	126.2	(57.9)
Landslide Debris	24.0	(11.0)	18.6	(8.5)	42.6	(19.5)
Ash & Tephra	20.0	(9.2)	6.0	(2.8)	26.0	(12.0)
Ash, Tephra, & Woody Debris	18.0	(8.3)	4.8	(2.3)	22.8	(10.6)
Total Length Impacted	163.3	(75.0)	54.3	(25.0)	217.6	(100.0)

and woody debris (Appendix Table A). Salmonid survivors were not found in streams with heavy concentrations of tephra and woody debris (i.e., Shultz and Minors Creeks) but were observed in Elk Creek, which only received a thin layer of ash and tephra. Timber along streams located in a 1 to 2 km wide band within the perimeter of the eruption impact area did not blow down, but were defoliated and killed from the scorching heat wave caused by the eruption.

SPAWNER SUCCESS, SPAWNING HABITAT, AND EMBRYONIC SURVIVAL

Materials and Methods

Spawner Abundance and Distribution

Selected tributary streams were surveyed on foot during spring and autumn 1981 to determine the distribution, numbers, and species composition of returning adult salmonids. All redds were counted and marked with surveyors flagging in order to prevent over-counts during successive surveys.

Spawner Straying

The straying of adult spawners that originated from the Toutle Salmon Hatchery was determined through examination of coded-wire-tag recovery data supplied by the Washington State Department of Fisheries. Comparisons of 1980 and 1981 recoveries with six years of pre-eruption data were examined to determine if adult spawners exhibited any avoidance behavior or loss of homing ability as a result of the altered environment.

Success of Natural Reproduction

The success of adult spawners in producing offspring in impacted streams was determined from fry surveys conducted during spring 1982. Stream reaches where redds were known to exist during the spawning period were surveyed visually or with an electroshocker to confirm the presence of salmonid fry. Immigration was recognized as a feasible source of fry that could confuse the determination of successful natural reproduction. Therefore, natural reproduction was assumed to be successful only when abundant fry were observed in the vicinity of known redds.

Quality of Spawning Habitat

Stream bottom gravel samples were collected from typical spawning habitat areas during late summer 1981 and 1982. Samples were gathered with a modified

McNeil corer, and gravel size composition analyzed by the standard wet sieving and volumetric displacement method (Cederholm et al. 1978). Three pairs of gravel samples were collected from three consecutive spawning areas within each study site.

Embryonic Survival

A coho egg planting experiment was conducted during December and January (1981-82) to determine the survival of coho eggs from the eyed stage to emergence in mudflow substrate. Ten lots of 300 eggs were planted in artificially constructed redds in affected and unaffected study sites. Our plan was to remove eggs from one-half of the redds during the egg hatching stage to obtain an estimate of survival to hatching. The remaining redd sites were to be covered with a net prior to emergence in order to trap the emergent fry and obtain an estimate of survival to emergence. However, as a result of large winter freshets and unstable channels in the affected streams only the survival to hatching phase of the study was completed.

Artificial redds were constructed in a fashion designed to mimic the configuration of a natural redd. A depression, 25 cm deep, was excavated in the substrate by displacing material downstream with the aid of a four-pronged rake. A piece of pipe (4 inch o.d.) was placed in the hole and held in a vertical position while substrate located directly upstream was raked into the depression creating a mound surrounding the pipe. Salmon eggs were poured into the top of the pipe and allowed to settle on the bottom before burying with substrate placed into the pipe. The pipe was carefully removed and the exact location determined by measurements with bi-secting tapes secured to stakes on the stream banks. Following redd construction, the elevation of the redd surface was periodically measured with a hand level and graduated rod to determine if bed scour or deposition may have disturbed the redd.

Egg survival to the hatching stage was determined from excavation of the artificial redds after a sufficient time for incubation had passed. Excavation of the redd includes: the extraction of a gravel sample from the redd with the gravel sampler previously described. During gravel sampling a net was placed immediately downstream to catch any eggs or alevins displaced during the removal of the sampler. Contents of the sampler were carefully removed and examined for eggs and alevins. Next, a containment basket was placed over the redd area and a gasoline powered pump was used to flush all remaining eggs and alevins out of the substrate. All eggs and alevins caught in the basket and the gravel sampler were enumerated. Eggs were determined alive if they appeared transparent, were of typical color and displayed normal embryonic development. All alevins were recorded as alive since they had obviously survived through hatching.

Results

Spawner Abundance and Distribution

Returning adult salmon penetrated considerable distances up both forks of the Toutle River and the Green River in 1981 (Table 4). Adults were observed as far upstream as Elk Creek (river kilometer, RK 67) on the Green River, in Deer Creek (RK 52) on the North Fork Toutle, and a small unnamed tributary (RK 54) 1 km upstream of Herrington Creek in the South Fork Toutle. New barriers to fish migration in the Green River system were not created by the volcanic eruption. Therefore, the maximum possible penetration into the Green River drainage (Black Fall, RK 79) was determined to be unchanged. The North Fork Toutle was blocked during 1980 and 1981 at RK 54 by the debris retention structure constructed by the Army Corps of Engineers. However, fish passage

Table 4. Escapements of salmonids to tributaries of the Toutle River, 1981.

Stream	Species	Number of live/dead	Date of first observation	Date of final observation	Number of redds	Area surveyed
Alder	Spr. Chinook	4/1	9/3	9/25	22	Mouth upstream 2400 m
	Fall Chinook	1/3	10/2	10/26		
	Coho	40/3	10/2	10/26		
	Steelhead	0			2	
	Unknown	11/0	10/12	10/26	51[1]	
Deer	Spr. Chinook	113/35	8/11	9/4	91	Mouth upstream 2400 m
	Fall Chinook	0				
	Coho	3/0	9/20	10/22		
	Steelhead	6/0	4/28	9/22	1	
	Unknown	1			6	
Lower Wyant	Spr. Chinook	0				Mouth upstream 800 m
	Fall Chinook	?				
	Coho	3/5	10/25		49	
	Steelhead	2/2	3/26	5/5	39	
	Unknown	1	10/25			
Upper Wyant	Spr. Chinook	3/0				Upstream from mudflow 475 m
	Fall Chinook	0				
	Coho	0/1	11/11			
	Steelhead	0	3/21		2	
	Unknown	1	10/26		32	
Herrington	Spr. Chinook	9/2	8/17	9/4	10	Mouth upstream 1900 m
	Fall Chinook	0				
	Coho	12/1	10/29		4	
	Steelhead	0				
	Unknown	0				
Lower Devils	Spr. Chinook	0				Mouth upstream 1900 m
	Fall Chinook	0				
	Coho	6/0	10/9	10/27		
	Steelhead	0				
	Unknown	5	10/23	10/27	37	

Table 4. Escapements of salmonids to tributaries of the Toutle River, 1981 (continued).

Stream	Species	Number of live/dead	Date of first observation	Date of final observation	Number of redds	Area surveyed
Upper Devils	Spr. Chinook	0				900 m upstream of 1100 Rd. Bridge
	Fall Chinook	0				
	Coho	0				
	Steelhead	0				
	Unknown	0	10/27		4	
Elk (Green R.)	Spr. Chinook	12/5	9/4	9/29	11	Mouth upstream 1700 m
	Fall Chinook	0				
	Coho	0				
	Steelhead	0				
	Unknown	0				
Studebaker[2]	Coho	11/5	11/4		40	Mouth upstream 2400 m
Johnson[2]	Fall Chinook	0/10	11/4		3	Mouth upstream 1200 m
	Coho	20/34	11/4		64	
	Steelhead	2/0	3/24			

[1] Redds of unknown origin.

[2] WDF unpublished data.

around the dam became feasible in March 1982 after a mudflow and flood breached the dam in two places. Spawner surveys were not conducted in autumn 1982. Thus, migration of spawners upstream of the dam is unknown. The South Fork Toutle River also had a debris retention structure located at RK 33. But adult spawners were not completely blocked from migration, as some fish were able to ascend the structure and many were trapped and transported upstream by the Washington Department of Game (Schuck and Kurose 1982). The South Fork dam was removed in autumn 1982 and the subsequent penetration of spring chinook was observed as far upriver as Goat Creek (RK 64). The observations of returning adults during 1981 indicates that spawners are capable of returning to all accessible streams despite the high concentrations of suspended sediment and lack of holding areas in the river.

The abundance of spawners and subseqent redds varied greatly among the streams surveyed (Table 4). Also, the location of redds did not appear to be governed by the presence or absence of volcanic impacts. Deer Creek contained the largest number of spring chinook and the greatest number of redds undoubtedly as a result of former fry releases from the Deer Springs Rearing facility. The second largest number of redds were from steelhead observed in lower Wyant Creek and all were constructed on mudflow substrate. In contrast, significantly fewer steelhead redds were found in upper Wyant Creek despite the more favorable environment and close proximity to the lower study reach.

Spawner Straying

Salmon smolts released from the Toutle Hatchery (located on the Green River) before the eruption exhibited a great amount of straying upon their return as adults, following the eruption (Table 5). Coded wire tag data for a six year period prior to the 1980 eruption indicates that very low numbers of adults (estimate 14 fall chinook and 1 coho) strayed into

Table 5. Return location of marked Toutle Hatchery coho and fall chinook before and after eruption of Mount St. Helens. (Data compiled from Washington Department of Fisheries Progress Reports).

			LOCATION									
Species	Brood year	Recovery year	Toutle Hatchery	Toutle Sport	Cowlitz Sport & Net	Cowlitz Hatchery	Kalama	Washougal	Lewis	Grays	Skamokowa	Elokomin
					Estimated returns[1]							
F. Chinook	71	74	19									
Coho	71	74	85									
F. Chinook	72	75	5	5	1							
F. Chinook	71	75	81	81	17		4					
Coho	72	75	4867	659	225	1						
F. Chinook	71	76	113				7					
F. Chinook	72	76	50				3					
F. Chinook	73	76	2									
F. Chinook	71	77	5		1							
F. Chinook	72	77	26	2	4							
F. Chinook	73	77	40	3	6							
F. Chinook	73	78	16	3								
F. Chinook	73	79	1									
F. Chinook	76	79	8	4								
F. Chinook	77	79	1									
Coho	77	79	14	20								
					Observed Returns[2]							
F. Chinook	76	80			48	18	44	1		8		6
F. Chinook	77	80			25	18	30	1				3
F. Chinook	78	80			1		4					
Coho	77	80	14[3]		774	290	25	2	4			74
Coho	78	80				2						
F. Chinook	76	81			8	4	8		6[3]		2	
F. Chinook	77	81			74	71	47		1	6	12	2
F. Chinook	78	81			3	4	1					
Coho	78	81	19[3,4]									

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[1] Estimated returns equals the number of recovered marks expanded by some factor.

[2] Observed returns equals the actual number of marks recovered.

[3] Spawning ground recoveries.

[4] 17 captured at S.F. Toutle trap.

hatcheries other than the Toutle Hatchery. Fall chinook were recovered in the Kalama River Hatchery and coho returned to the Cowlitz River Hatchery located 38 and 48 kilometers from the mouth of the Toutle River, respectively. However, after the 1980 eruption of Mount St. Helens, considerable numbers of Toutle stock chinook and coho were observed returning to unfamilar hatcheries and spawning grounds. During 1980 and 1981, 47% and 34% of the fall chinook tag recoveries, respectively, were recovered at hatcheries located outside of the Toutle/Cowlitz River system. Fall chinook were recovered as far away as the Washougal Hatchery, 121 km up the Columbia River from the Toutle River and downriver 118 km at the Grays River Hatchery. Toutle coho demonstrated a similar degree of straying as the fall chinook, except that many more coho returned to the Cowlitz Hatchery. The data indicates a significant shift in the number of adult strays and distribution of strays following the eruption of Mount St. Helens. Returning adults were actively avoiding the Toutle River and in some cases the Cowlitz River as well. Straying fish are presumed to be responding to the harsh water quality (high temperature and high suspended sediment concentration) conditions that were present in the Toutle and lower Cowlitz Rivers.

Success of Natural Reproduction

Coho, chinook, and trout fry were observed during spring 1982 in affected stream reaches where adults had spawned previously (Table 6). The presence of fry indicates that eggs deposited into mudflow substrate were not totally lost, despite high concentrations of sand. The level of egg survival to emergence can not be determined from these observations. However, survival of coho in Studebaker and lower Wyant Creeks (mudflow streams) must have been quite high, because large populations of fry were observed in a short stream reach. Similarily, steelhead fry were very abundant in Cline Creek (mudflow

Table 6. Affected(*) and unaffected stream reaches in the Toutle drainage where salmonid fry, originating from natural production, were observed during spring 1982.

	SPECIES		
Stream	Coho	Chinook	Trout[1]
Cline Cr.*	X		X
Outlet Cr.*	X		X
Studebaker Cr.*	X		X
Johnson Cr.	X		
Herrington Cr.*			X
Lower Wyant Cr.*	X		X
Alder Cr.	X		
Deer Cr.*	X	X	X
Elk Cr.*		X	X

[1] Cutthroat trout and steelhead trout fry cannot be distinguished, thus grouped under trout.

stream) indicating that natural production was very successful in some locations.

Quality of Spawning Habitat

Fine sediment (sediment <0.850 mm) concentrations in spawning gravel are very high in the streams impacted by mudflow and avalanche deposits, but show a trend of changing after only one winter (Table 7). During 1981 the levels of fines in affected streams excluding upper Deer Creek ranged from 2 percent to 16 percent greater than the highest levels measured at an unaffected site. Streams that run across the North Fork Toutle avalanche deposit (i.e., Bear, Jackson, and upper North Fork Toutle) had higher concentrations of fines than streams that run across mudflow deposits (i.e., lower Deer and Herrington Creeks). A comparison between study sites in upper and lower Deer Creek in 1981 indicates that sediment flushing was occurring in the upper reach. Since the impacts in Deer Creek, and many other streams below the debris avalanche, were due to mudflows backing up the channel, we would expect the upper reaches to recover first. Unfortunately, Deer Creek was inundated by a mudflow from the March 1982 eruption of Mount St. Helens causing a significant increase in fine sediment observed in 1982. Other streams that had mudflows backed-up the channel have since scoured down to the old stream bed and have better gravel quality than the new streams flowing over a mudflow deposit. For example, lower Wyant, Bear (S. F. Toutle) and Trouble Creeks have a lower concentration of fines than Bear (N. F. Toutle) and Herrington Creeks.

Rates of spawning habitat recovery appear to be dependent on type of impact and location within the drainage. The Green River gravel composition contains less fines than the gravel in the North and South Forks of the Toutle River. This is presumably due to the difference between impacts caused by ash fallout (The Green) and mudflows. The middle stretch of the South fork toutle

Table 7. Spawning gravel quality as indicated by the percentage of fine sediment (<0.850 mm) in the gravel for affected and unaffected streams of the Toutle River during summer 1981 and 1982.

Stream	1981 number of samples	1981 mean percent sediment <.850 mm	1981 95% C.I.%	1982 number of samples	1982 mean percent sediment <.850 mm	1982 95% C.I.%
UNAFFECTED SITES						
Alder	8	19.4	16.9-22.0	6	16.2	11.0-21.4
Upper Wyant	6	20.6	10.4-30.8	6	19.3	14.6-23.9
Johnson				6	13.7	8.1-19.2
AFFECTED SITES						
Cline				6	33.5	27.3-39.8
Lower Wyant				6	18.3	11.6-24.9
Lower Deer	8	22.2	17.7-26.7			
Upper Deer	5	11.2	4.2-18.2	6	29.7	20.4-39.0
Bear (N.F. Toutle)	4	36.0	28.7-43.2	6	26.7	20.5-33.0
Jackson	4	29.5	19.5-39.6			
Upper N.F. Toutle 1/	4	29.1	20.7-37.5			
Middle N.F. Toutle 2/				6	25.5	20.8-30.3
Lower S.F. Toutle 3/				6	26.5	21.2-31.8
Middle S.F. Toutle 4/				6	16.0	11.4-20.7
Bear (S.F. Toutle)				6	11.2	7.9-14.6
Herrington	6	22.7	18.6-26.8	6	19.1	14.1-24.2
Trouble				6	11.4	9.2-13.6
Lower Green 5/				6	15.4	12.1-18.7
Middle Green 6/				6	15.1	10.1-20.1

[1] Approximately 4 km upstream of confluence with Coldwater Creek

[2] Approximately 1 km downstream from Kid Valley, Highway 504 bridge

[3] Near lower South Fork Toutle bridge

[4] Near Big Wolf Creek

[5] Downstream of 1000 Rd. bridge

[6] Upstream of Elk Creek

(near Big Wolf Creek) is recovering faster than the lower reach (near lower S. F. Toutle bridge). The lower reach has a lower gradient than the middle reach, thus requiring more time for flushing.

Spawning gravel quality is showing signs of improvement with time. Comparisons of intragravel sediment concentrations between years for Bear (N. F. Toutle) and Herrington Creeks shows a decrease in fines. Average concentrations of fines in Bear Creek have been reduced by 10 percent after only one winter freshet period.

Embryonic Survival

Survival of coho salmon eggs from the eyed stage to hatching for the egg plant experiment ranged from 0 to 100 percent (Table 8). Only 21 of the 70 redds initially constructed could be analyzed, as stream bed scour and channel movements altered most of the study sites. Therefore, the results from a small sample size should be viewed with caution. Nevertheless, the limited results indicate that the majority of the eggs planted had very high survival to the hatching stage. An expected relationship between survival and sediment concentration was not apparent. Upper Deer Creek and Herrington Creek had similar concentrations of fine sediment yet significantly different average survival rates (Table 9). Also a surprisingly high egg survival was measured in Bear Creek (mean = 88.7%) despite the relatively high concentration (mean = 26.1%) of fine sediment in the redd. Apparently factors other than sediment concentration were accounting for the observed egg survival. The wide variation in egg incubation time (ranging from 22 to 40 days) was suspected as having an effect. However, regression analysis indicated that no significant relationship was present. Gravel permeability and intragravel dissolved oxygen supply are more than likely causal factors. Unfortunately, these parameters were not measured in the experiment.

Table 8. Survival to hatching of planted coho salmon eggs in tributaries of the Toutle River, winter (1981-1982).

Stream	Redd No.	Days	Eggs deposited	Total recoveries	Percent recovery	Live recoveries	Percent survival	Dead recoveries	Pecent mortality
Alder	7	34	300	160	53.3	154	96.2	6	3.7
Lower Wyant	19	24	300	165	55.0	95	57.5	70	42.4
Upper Deer	11	28	300	201	67.0	193	96.0	8	3.9
	12	28	300	195	65.0	181	92.8	14	7.1
	13	28	300	146	48.6	142	97.2	4	2.7
	14	28	300	155	51.6	151	97.4	4	2.5
	15	28	300	87	29.0	80	91.9	7	8.0
Herrington	1	40	291	159	54.6	154	96.8	5	3.1
	2	40	293	249	84.9	89	35.7	160	64.2
	3	40	296	190	64.1	111	58.4	79	41.5
	4	39	296	194	65.5	4	2.0	190	97.9
	5	39	296	148	50.0	0	0	148	50.0
	6	39	299	226	75.5	61	26.9	165	73.0
	7	36	293	220	75.0	186	85.5	34	15.4
	8	36	297	138	46.4	48	34.7	90	65.2
	9	36	293	246	83.9	189	76.8	57	23.1
	10	36	296	241	81.4	209	86.7	32	13.2
Bear	1	27	300	130	43.3	120	92.3	10	7.6
	5	27	300	219	73.0	203	92.6	16	7.3
	9	22	300	45	15.0	45	100.0	0	0
	10	22	300	113	37.6	79	69.9	34	30.0

Table 9. Survival to hatching of planted coho salmon eggs and concentration of sediment in artificial redds in affected(*) and unaffected tributaries of the Toutle River during winter 1981-82.

		Sediment Concentration		Egg survival	
Stream	Number of samples	Mean percent <.850 mm	95 percent C.I. (%)	mean (%)	95 percent C.I. (%)
Alder	1	16.5	--	96.2	--
Lower Wyant*	1	--	--	57.5	--
Upper Dear*	5	14.6	8.6-20.5	95.1	91.9-98.3
Herrington*	10	14.2	10.0-18.5	50.3	24.9-75.7
Bear*	4	26.1	17.0-35.1	88.7	68.0-100

SALMONID REARING HABITAT

Materials and Methods

Channel Morphology

Longitudinal profiles of the stream thalweg and cross-sectional profiles of the stream channel were constructed from ground survey measurements collected during the summer low-flow period in 1981 and 1982. Measurements were made with a theodolite and electronic distance meter to an accuracy of ± 1 cm. Field measurements (polar coordinates) were converted to rectangular coordinates and the data were plotted to scale with a graphics plotter at the University of Washington, Academic Computer Center.

Reference stakes were placed at each study site in 1981 in order to allow measurements repeated in 1982 to be collected at the same location. However, winter freshets destroyed reference stakes at four study sites causing some alteration in the locations of 1982 measurements. Some of the cross-sectional transects in Lower Wyant, Upper Deer and Bear Creeks could not be located exactly and are referenced as approximate for 1982. The Lower Deer Creek study site was altered significantly in 1982 as a result of mudflows and flooding caused by the March 19, 1982 eruption of Mount St. Helens. Consequently, the 1982 study site had to be relocated 150 meters downstream of the 1981 study site.

Physical Habitat Inventory

Fish habitat in streams is composed of a combination of physical parameters that include water depth, water velocity, substrate size composition, and cover structures (e.g., embedded logs and overhanging brush).

Habitat parameters were inventoried for each study reach during the summer low flow period in 1981 and 1982. Habitat parameters of depth, velocity, and substrate size were estimated from a transect measurement technique and cover structures were measured directly.

Cross-channel transects used for measurement of depth, velocity, and substrate, were placed at 5 m - 10 m intervals along the study reach. The interval distance chosen depended upon habitat complexity. Hence, a stream with frequent shifts in depth, velocity, or substrate would be inventoried with short transect intervals, and a stream with little diversity in habitat parameters was inventoried with longer transect intervals. Parameter measurements were collected at 1.0 meter intervals along each transect, with the first measurement taken at 0.5 meters from the waters edge. Water depth and velocity (at 0.6 of depth) were measured with a standard graduated wading rod and a Marsh McBirney Model 201 velocity meter, respectively. Substrate size composition was estimated by a subjective ranking procedure at each depth-velocity measurement point. The dominant size substrate, in an imaginary cell that has an area of 1.0 meter wide by one-half the distance to the next transect upstream and one-half the distance to the next transect downstream, was visually estimated to be in one of the following size categories:

Substrate Size Category	Size (mm)
1. silt, sand, ash	<2
2. pea gravel	2-20
3. cobble	20-100
4. rock	100-300
5. small boulder	300-900
6. large boulder	>900
7. bedrock	
8. organic detritus	

Habitat parameter values collected for each cell along a transect are assumed representative of the water depth, average velocity, and dominate substrate for the total area of stream encompassed by each imaginary cell. Therefore, the data for an entire study reach or any subreach, defined by a beginning and ending transect, are summarized by combining cell areas for cells that have values for each parameter within a specified value range. The data summary provides a table of stream surface areas for a set of specified water depths, water velocity, and substrate size categories.

Fish cover structures, consisting of logs embedded in the stream bottom, brush hanging over the water surface, undercut banks, debris matrices (assemblages of large and small debris), and exposed logs were measured with a graduated rod, and surface areal coverage for each cover type was computed.

Water Temperature

Water temperature was monitored continuously during the summer months at 7 of the 9 study sites with recording-type thermometers. Equipment limitations prevented temperature monitoring at the upper Deer Creek and upper Wyant Creek study sites. However, periodic spot temperature measurements at the unmonitored sites indicated that water temperatures averaged 1°C and 1-2°C lower than temperatures in lower Deer Creek and lower Wyant Creek, respectively. Equipment malfunctions have caused some data gaps that are indicated in the statistical summary of the results section. Daily maximum temperatures are expressed as a cumulative temperature frequency curve that is plotted in a manner similar to a stream flow duration curve utilized by hydrologists (Stalnaker and Arnette 1976). The cumulative temperature frequency curve indicates the percentage of days during the summer that water exceeded a specified temperature. Maximum daily temperatures, for streams with periods of missing data, were estimated from linear regression equations developed with streams that had a continuous data record.

Fish Food Supply

Macroinvertebrate drift samples were collected from each study stream on four separate dates during summer 1981 with a modified high speed plankton sampler. The sampler consists of a plexiglass tube, 15 cm diameter by 50 cm long, with a 10 cm diameter opening at the mouth and a 250 micron mesh net attached to the opposite end. The sampler was deployed in the stream thalweg below the water surface and operated for a 24 hour period. Total water volume filtered through the sampler is computed from the product of the mouth area and average water velocity measured at the month of the sampler.

Macroinvertebrate samples, stored in 70% ethyl alcohol and rose bengal stain solution, were enumerated and identified under a 7x-30x variable power disecting scope. Organism abundance was expressed as daily drift density (number of organisms/volume of water filtered in 24 hours).

Results

Channel Morphology

Channel morphology in tributary streams affected by the eruption of Mount St. Helens range from negligible to significantly different than the morphometry found in unaffected streams in the Toutle drainage. Stream channel topography in unaffected streams is characterized by frequent, long, deep pools (>0.5 m deep) alternating with shorter, shallow riffle areas (Alder and upper Wyant Creeks, Figure 2). Channel width to depth ratio is low (range 5-8), as cross-sectional profiles exhibit a narrow and deep form (Figures 3

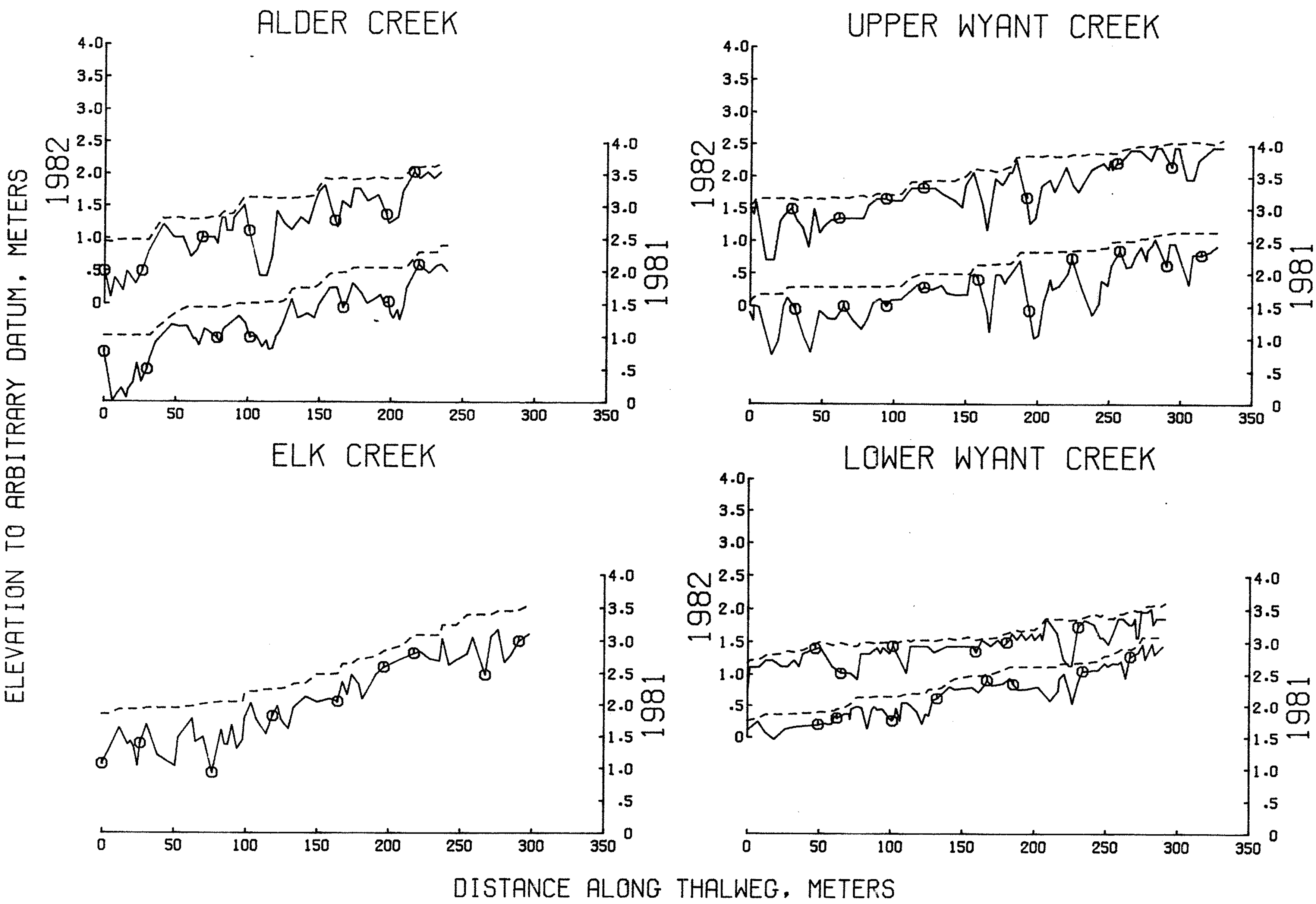

Figure 2. Longitudinal profiles of stream thalweg for Upper Wyant, Lower Wyant, Alder and Elk Creeks during summer low flow period in 1981 and 1982. Circles denote approximate location of channel cross-sections. Dashed line is water surface.

and 4). The processes of erosion and deposition are evident over time. Nevertheless, pool number and shape has remained constant and channel banks are stable. The presence of riparian vegetation and associated root matrix provides a cohesiveness to stream banks that resists erosion and channel widening.

The Elk Creek watershed, located on the northern fringe of the eruption impact area (Figure 1), received from 3 cm to 10 cm of air-fall ash and tephra deposition (Waitt and Dzurisin 1981). Hill slope erosion following the eruption caused ash deposits to accumulate on point bars and in pools of Elk Creek. Morphometric surveys conducted in 1981 indicated that stream bottom topography and cross-section profiles (Figures 2 and 5) were very similar to conditions observed in Alder Creek and upper Wyant Creek. Channel banks were relatively stable as a result of a dense growth of brush and shrubs that had recovered from the scorching heat wave. Hence, the effects of the eruption on channel morphology in Elk Creek are concluded to be insignificant from a fishery habitat viewpoint. The channel survey was not repeated in 1982, as conditions were observed to be similar to that measured in 1981.

The lower reach of Wyant Creek was inundated by mudflow deposits that range from 3 m to 5 m deep in the lower North Fork Toutle River (Janda et al. 1981). In November 1980, lower Wyant Creek was observed flowing over the surface of the mudflow and through a patch of dead alder and accumulations of woody debris. The stream channel was very shallow (<20 cm deep) and poorly defined. But, by summer 1981, the channel had become incised into the mudflow and had developed a shallow profile with alternating pool and riffle reaches (Figures 2 and 6). Continued channel degradation has caused significant increases in width and depth by summer 1982. The channel has degraded approximately 3 meters below the mudflow surface with root wads of streamside

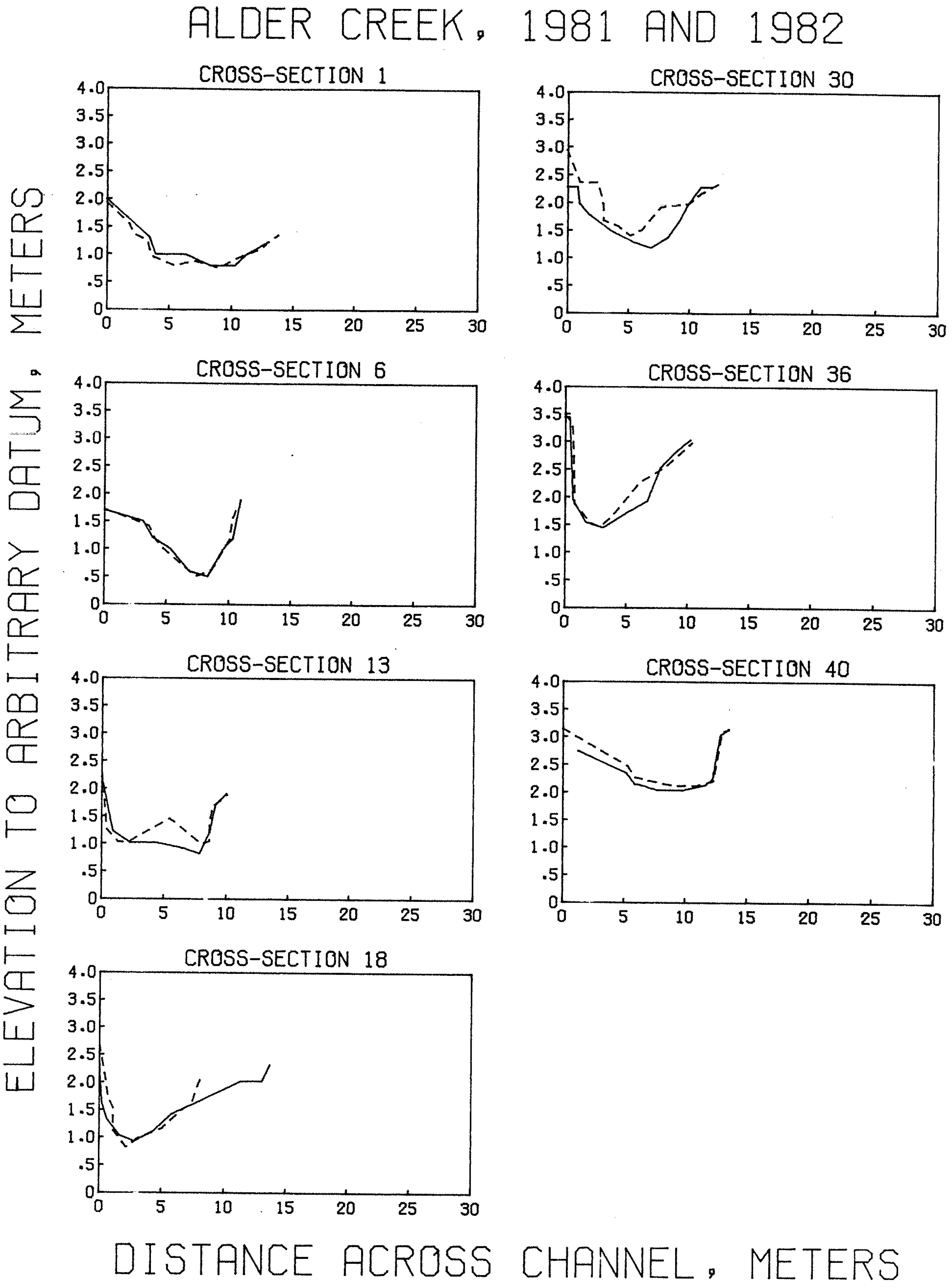

Figure 3. Cross-sectional profiles for Alder Creek during summer 1981 (dashed line) and 1982 (solid line).

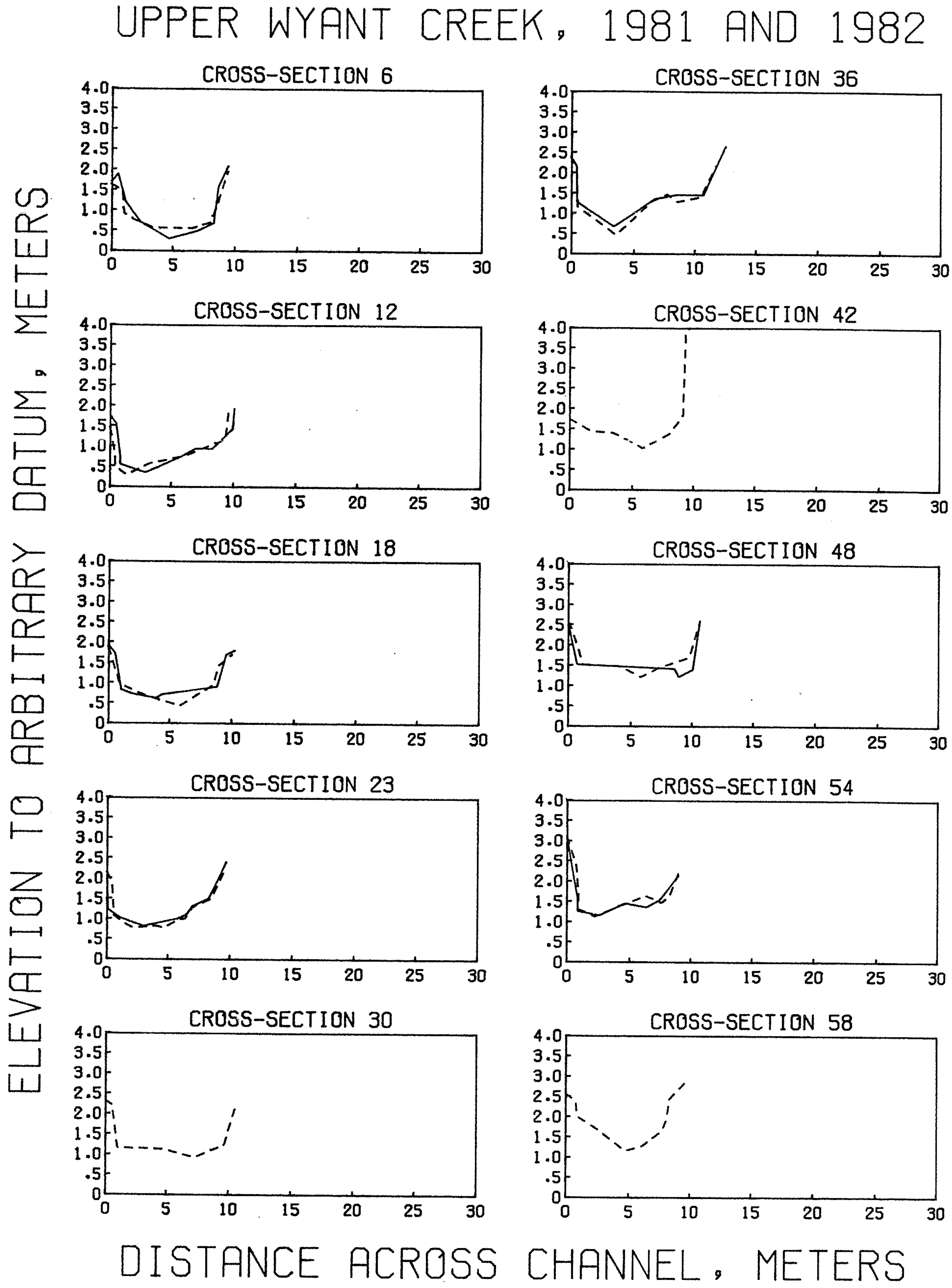

Figure 4. Cross-sectional profiles for Upper Wyant Creek during summer 1981 (dashed line) and 1982 (solid line).

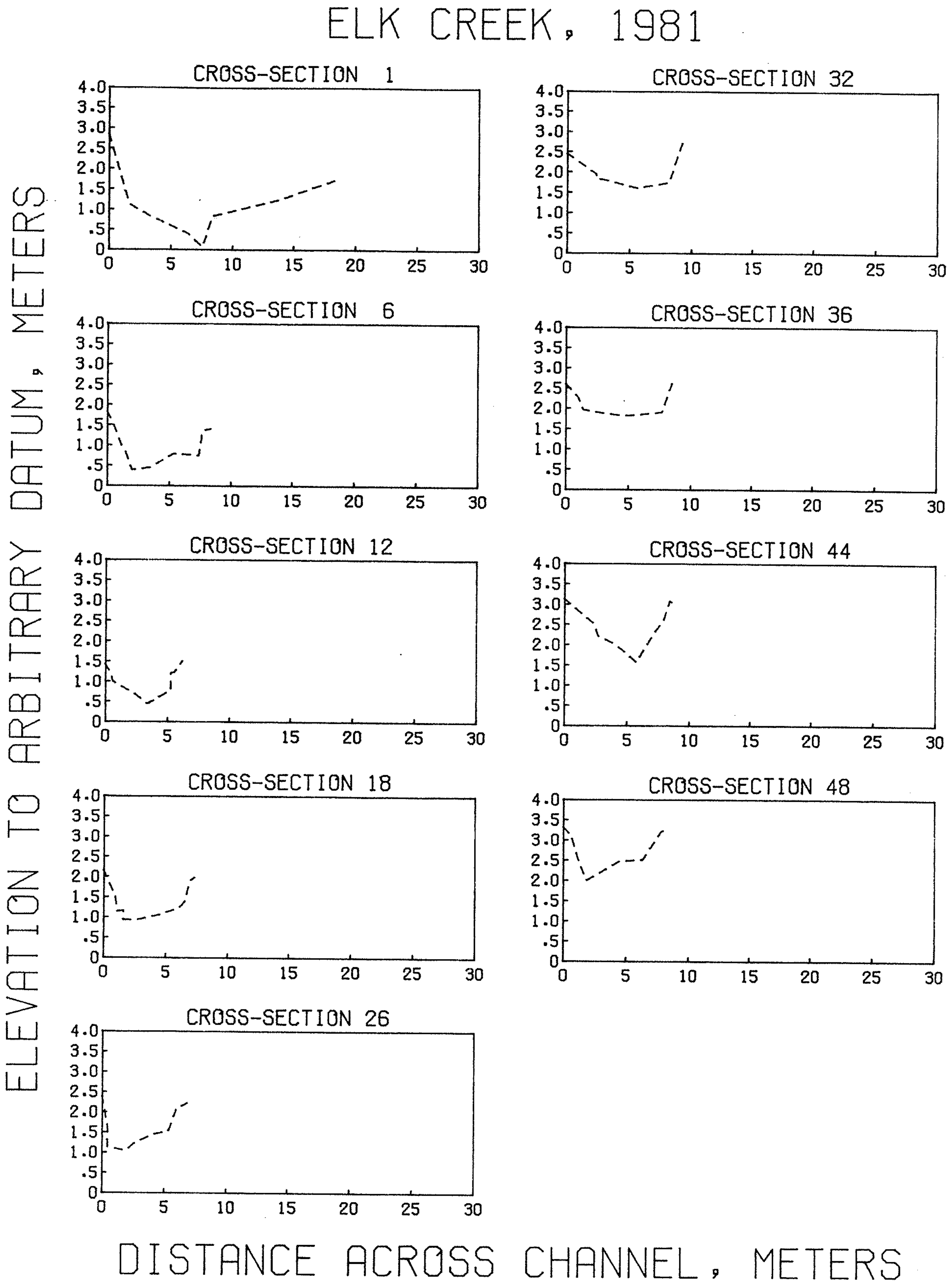

Figure 5. Cross-sectional profiles for Elk Creek during summer 1981.

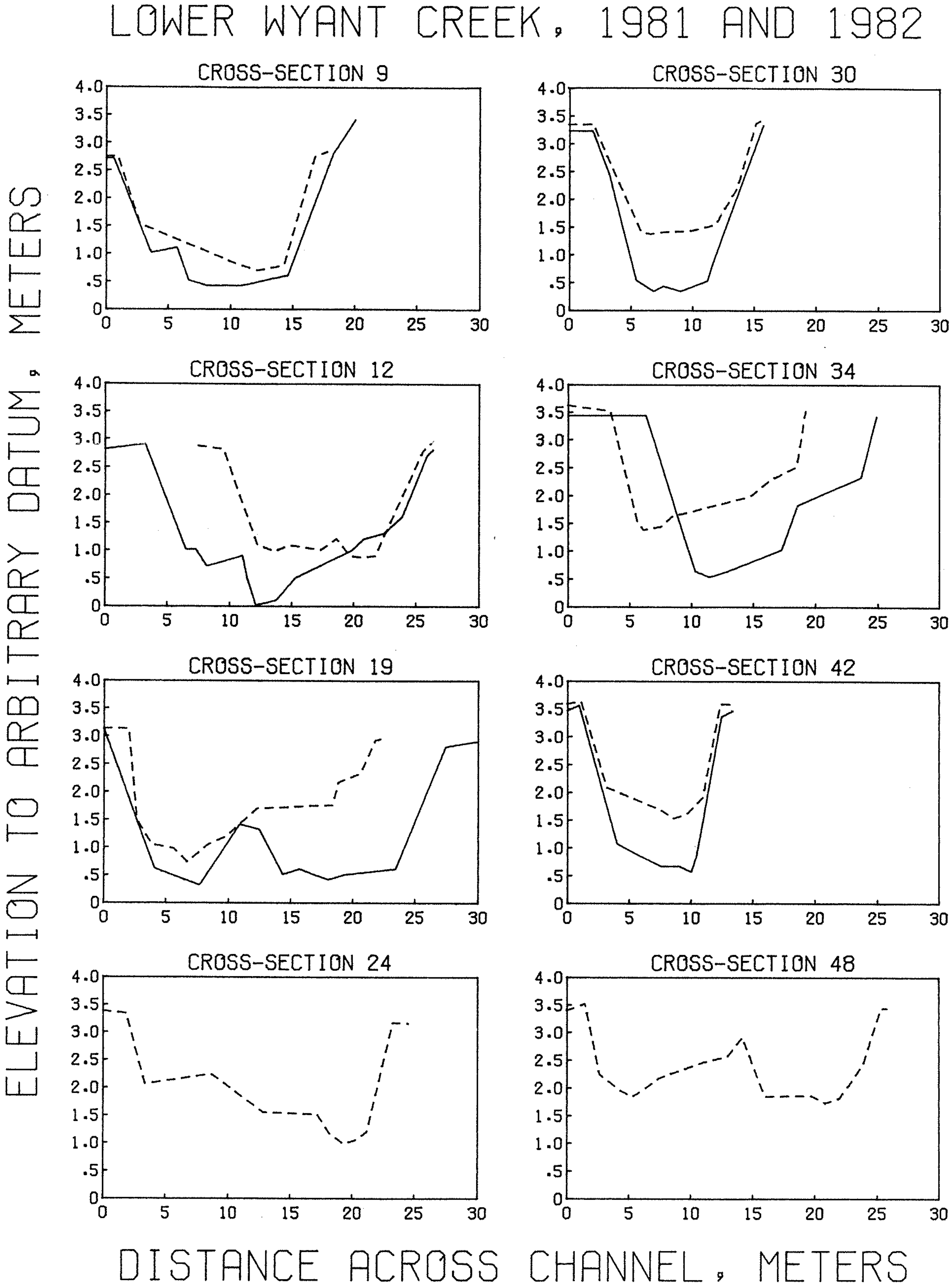

Figure 6. Cross-sectional profiles for lower Wyant Creek during summer 1981 (dashed line) and 1982 (solid line).

residual woody debris becoming exposed. Consequently, the rate of channel degradation is likely to decrease and further large decreases in channel elevation are not expected. The development of several pools ($\geq$0.5 m deep) in 1982 (Figure 2) indicates that bottom topography is beginning to recover in lower Wyant Creek and has started to resemble conditions in the unaffected reach of upper Wyant Creek.

Deer Creek was buried by mudflow deposits that range in depth from less than 1 meter in the upper study site to greater than 2 meters in the lower study site. Mudflows in the lower 500 meters of Deer Creek obliterated the old channel causing the stream to establish a new channel on the mudflow deposits. The lower Deer Creek study site, surveyed during 1981, was located at the junction of the new channel with the old channel and shows the contrasting states of recovery (Figures 1 and 7). The old portion of the channel (upper 150 meters) had recovered a pool and riffle topography. Whereas, the new portion of the channel was shallow and uniform in shape. The old channel banks and riparian vegetation had maintained a narrow cross-sectional profile (cross-sections 36 to 54, Figure 8) in contrast to a broad shallow profile (cross-sections 1 to 24) in the new portion of lower Deer Creek. Channel topography in upper Deer Creek, in 1981 had characteristics similar to an unaffected stream (Figures 7 and 9) indicating that much of the mudflow material had been scoured out of the stream.

Mudflows from the March 19, 1982 eruption of Mount St. Helens breached the North Fork Toutle debris dam (Figure 1) on the South end, causing the river to overflow into upper Deer Creek. Subsequent freshets removed the new mudflow deposits, but destroyed old channel topography in the entire reach accessible to anadromous salmonids. In 1982, channel shape in upper and lower Deer Creek were similar to each other (Figures 7, 10, 11) and both resembled

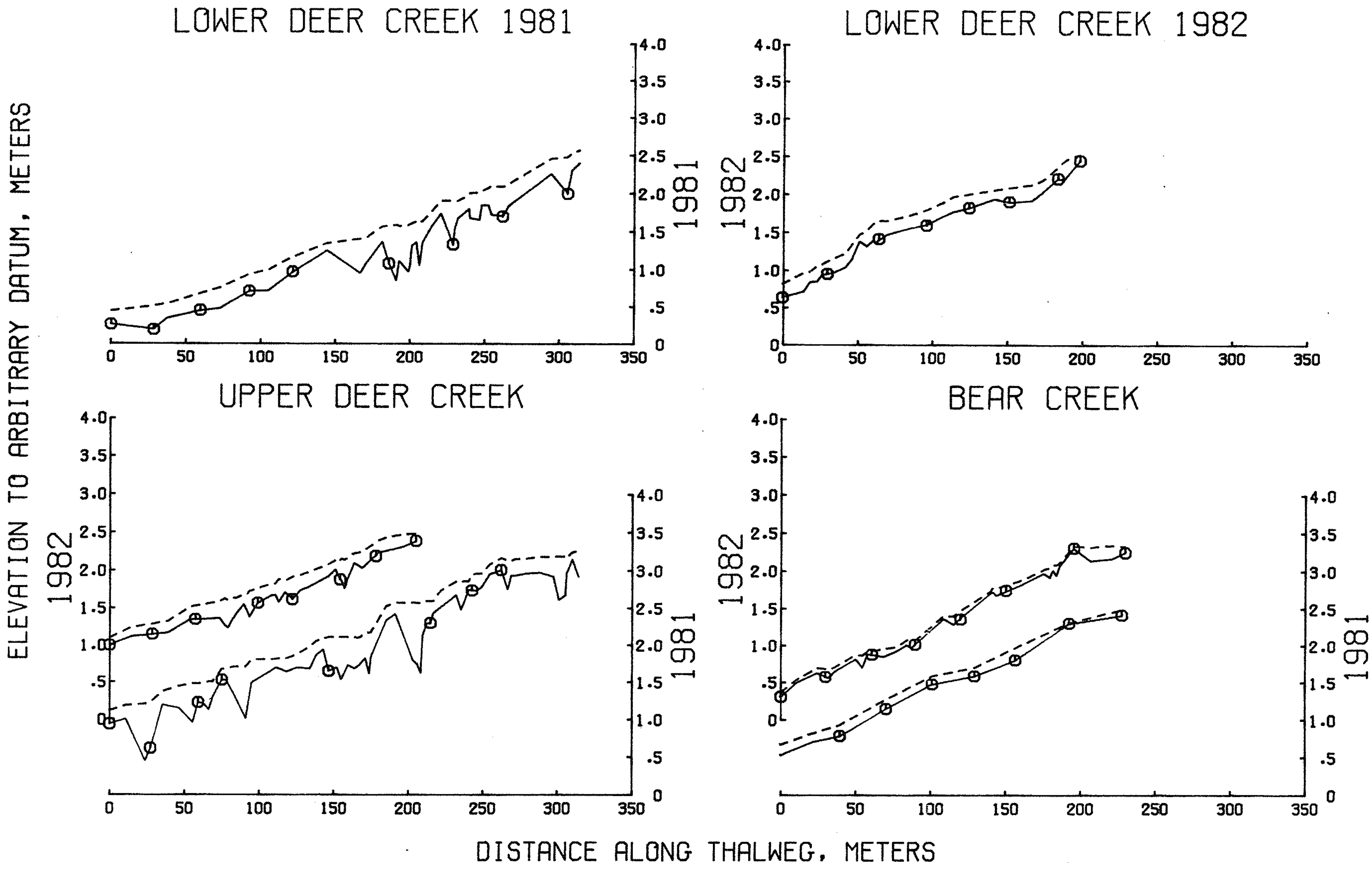

Figure 7. Longitudinal profiles of stream thalweg for Lower Dear, Upper Deer, and Bear Creeks during summer low flow period in 1981 and 1982. Circles denote approximate location of channel cross-sections. Dashed line is water surface.

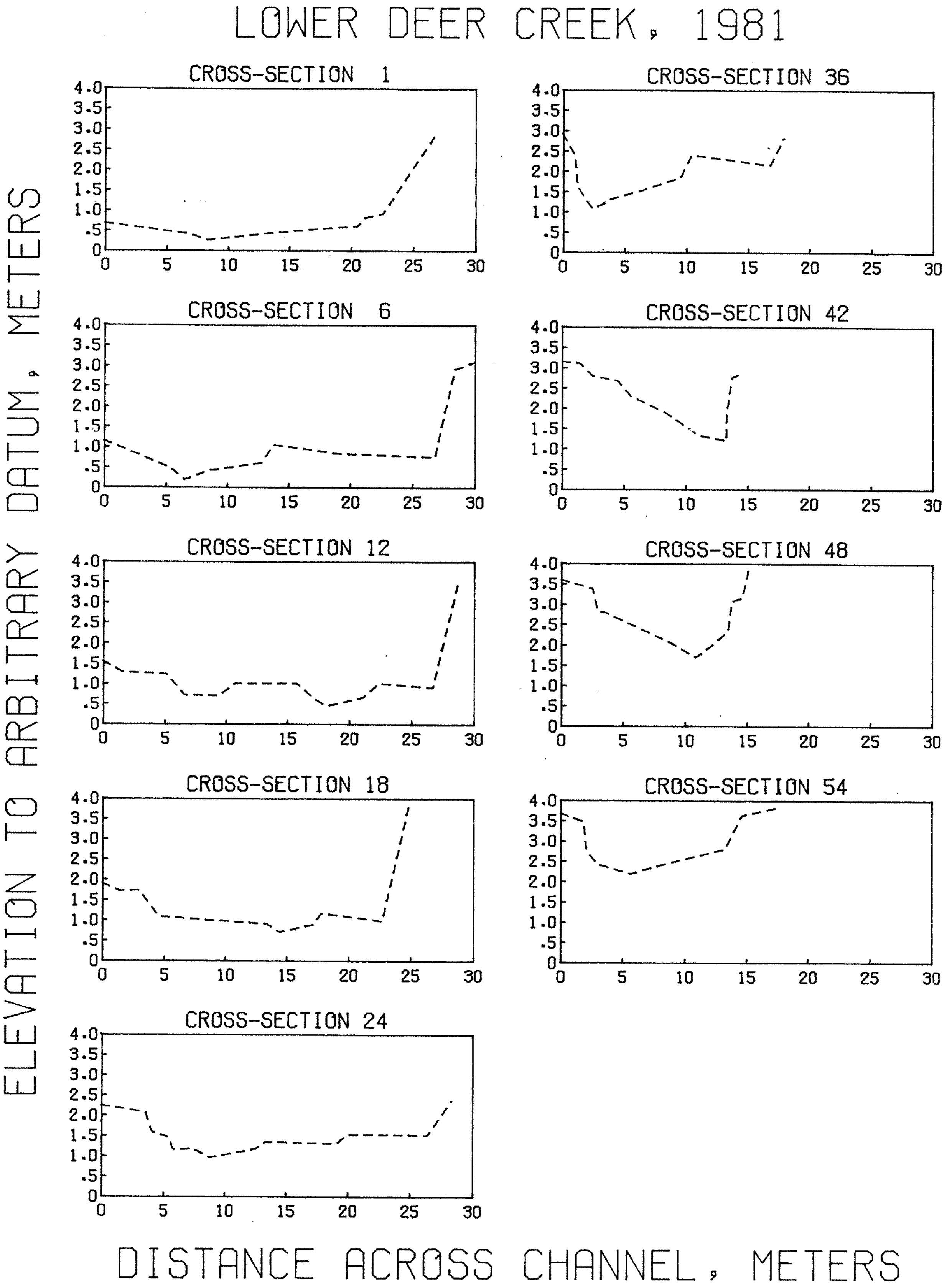

Figure 8. Cross-sectional profiles for Lower Deer Creek during summer 1981.

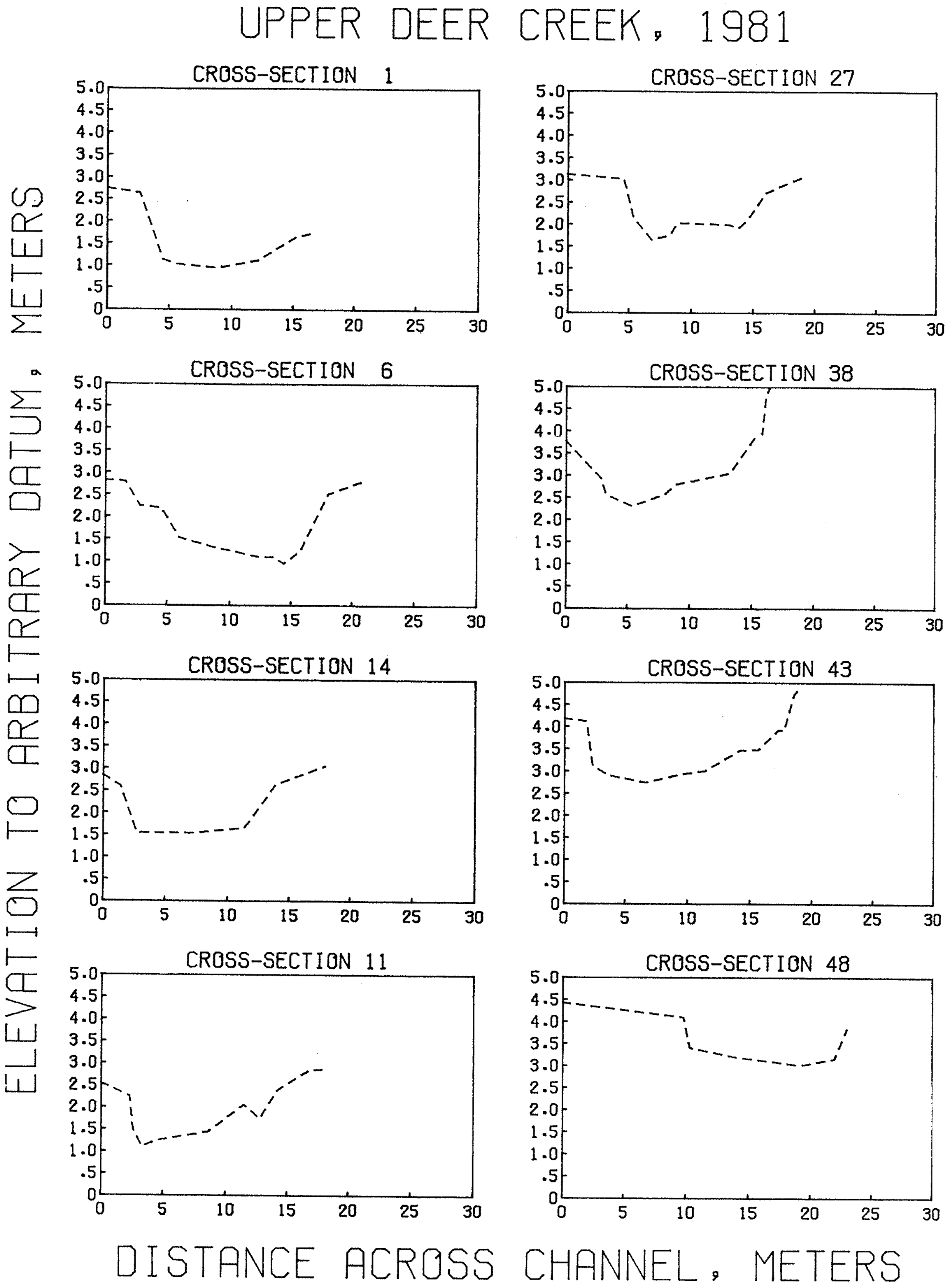

Figure 9. Cross-sectional profiles for Upper Deer Creek during summer 1981.

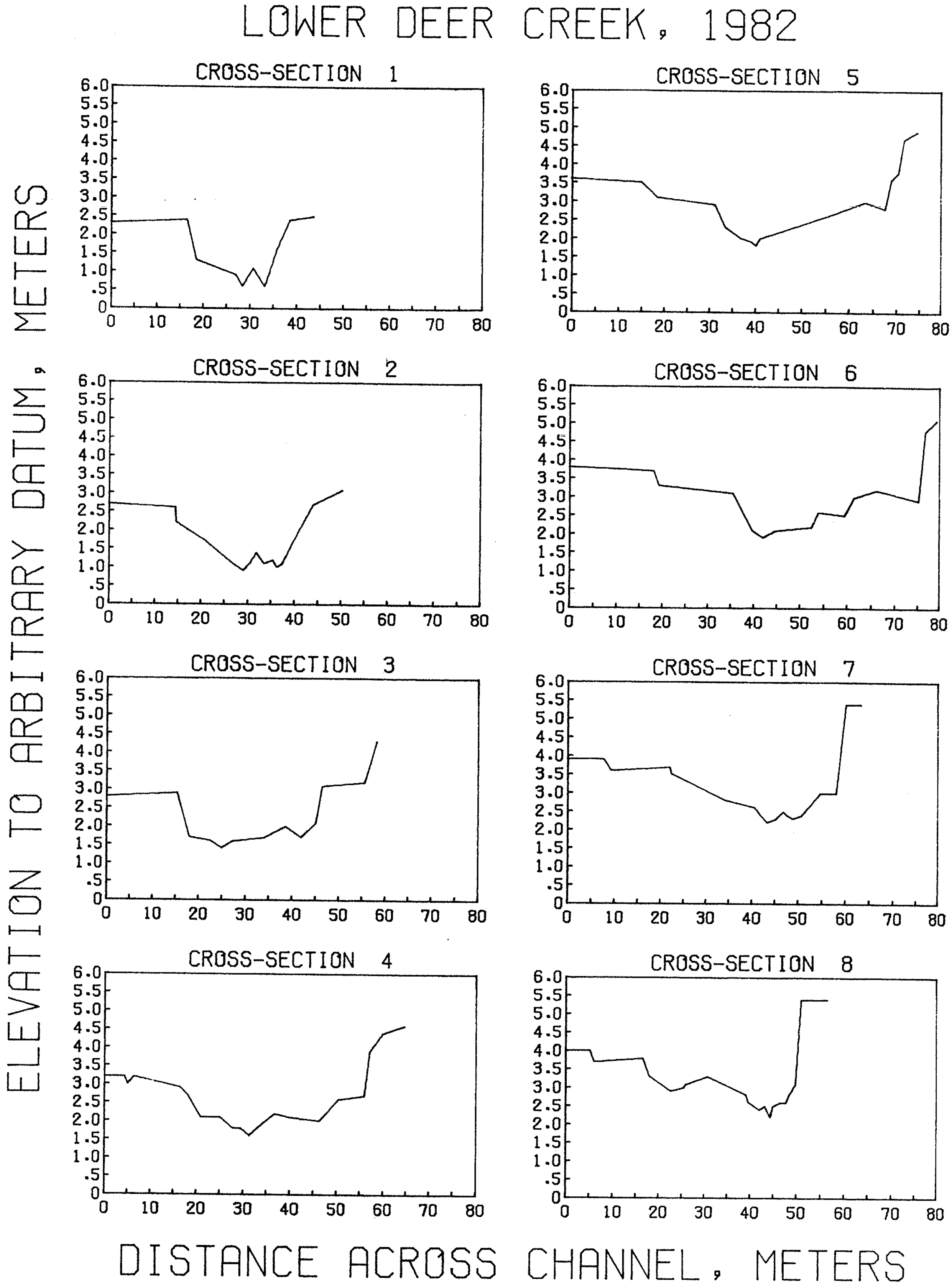

Figure 10. Cross-sectional profiles for Lower Deer Creek during summer 1982.

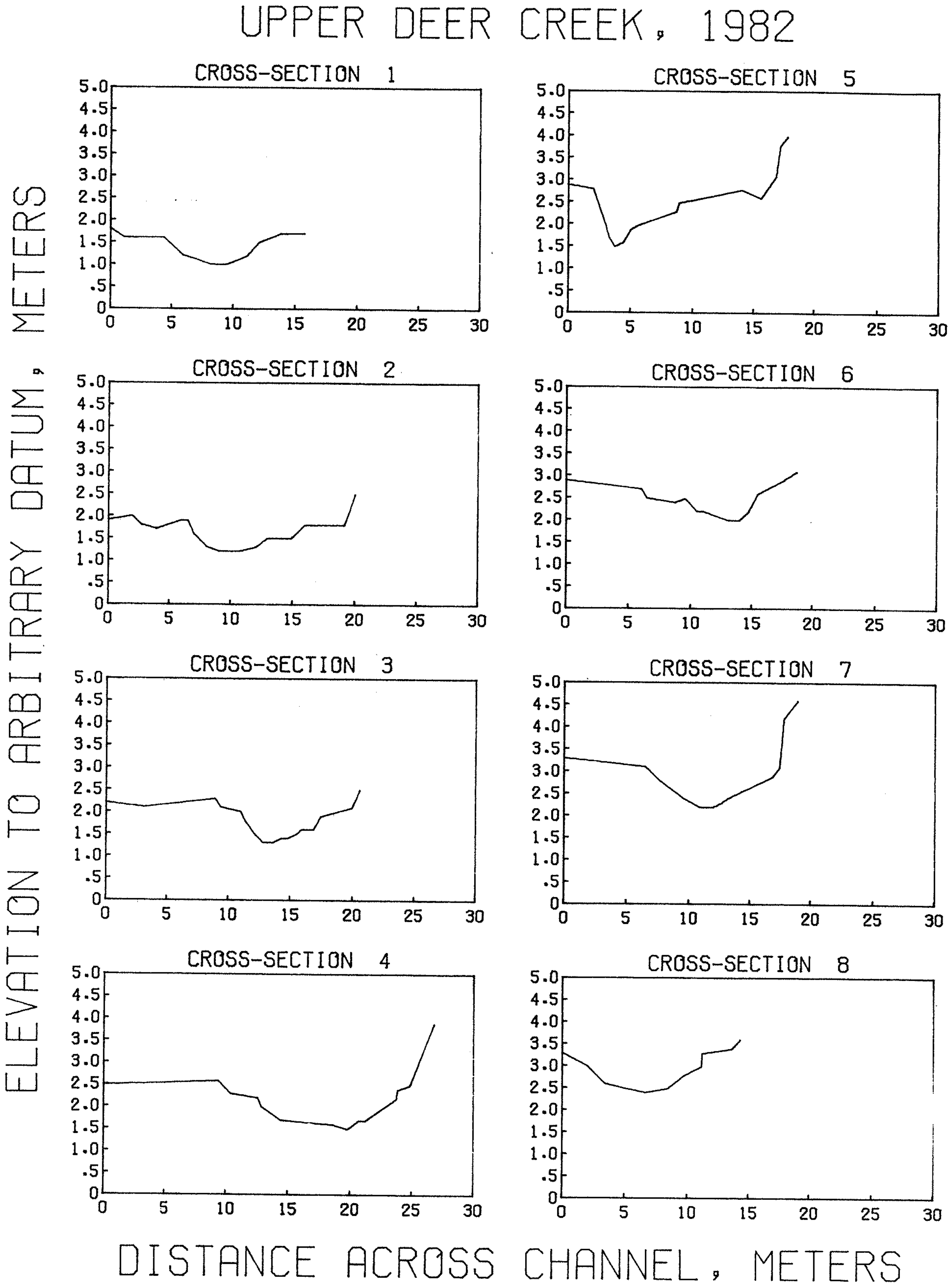

Figure 11. Cross-sectional profiles for Upper Deer Creek during summer 1982.

conditions present in the new portion of lower Deer Creek during 1981. The loss of riparian vegetation coupled with channel widening is expected to slow the rate of habitat recovery.

Bear Creek, a new channel stream developing on the landslide debris flow (Figure 1) represents the most severe impact on streams caused by the eruption of Mount St. Helens. Debris deposition is so thick that channel degradation is unlikely to recover the former stream channel. Stream bed and banks are composed of unconsolidated materials that are easily eroded and results in unstable channel conditions. Pools were non-existent in 1981 and are weakly developed in 1982 (Figure 7). Lateral migration of the channel has increased channel width (cross-sections 1 to 25, Figure 12) and has caused the formation of a secondary overflow channel.

The debris-flow and mudflows in the upper North Fork and South Fork Toutle valleys caused many streams, that formerly flowed from the valley wall directly into the river, to bend at the junction with the mudflow and flow down valley, parallel to the river (Figure 1). These parallel tributaries are termed new terrace streams because of their location on the mudflow deposits that form new terraces along the river. Harrington Creek, located in the South fork Toutle drainage, is an example of a new terrace tributary that is rapidly developing a complex channel morphology (Figures 13 and 14). Between 1981 and 1982, pool depth and the number of pools have increased greatly as channel topography is beginning to resemble that of Devils Creek (Figures 13 and 15) an unaffected tributary of similar gradient and drainage area (Table 1). However, channel formation in Herrington Creek may be disrupted by headward erosion that has caused an increased gradient in the lower 100 meters of the study section (Figure 13). Channel development must begin again, unless boulders in the mudflow deposits provide a check point and prevent further erosion.

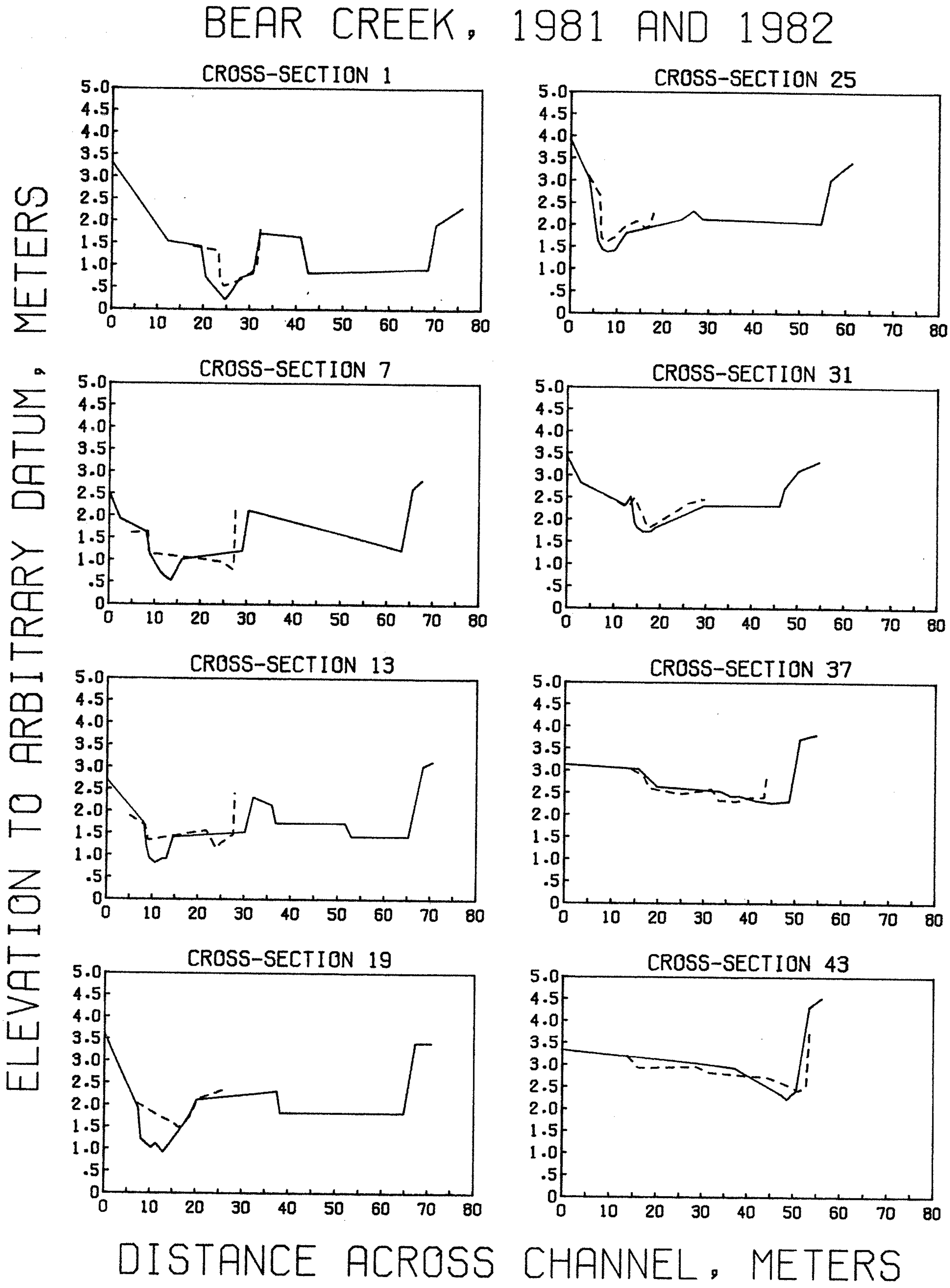

Figure 12. Cross-sectional profiles for Bear Creek during summer 1981 (dashed line) and 1982 (solid line).

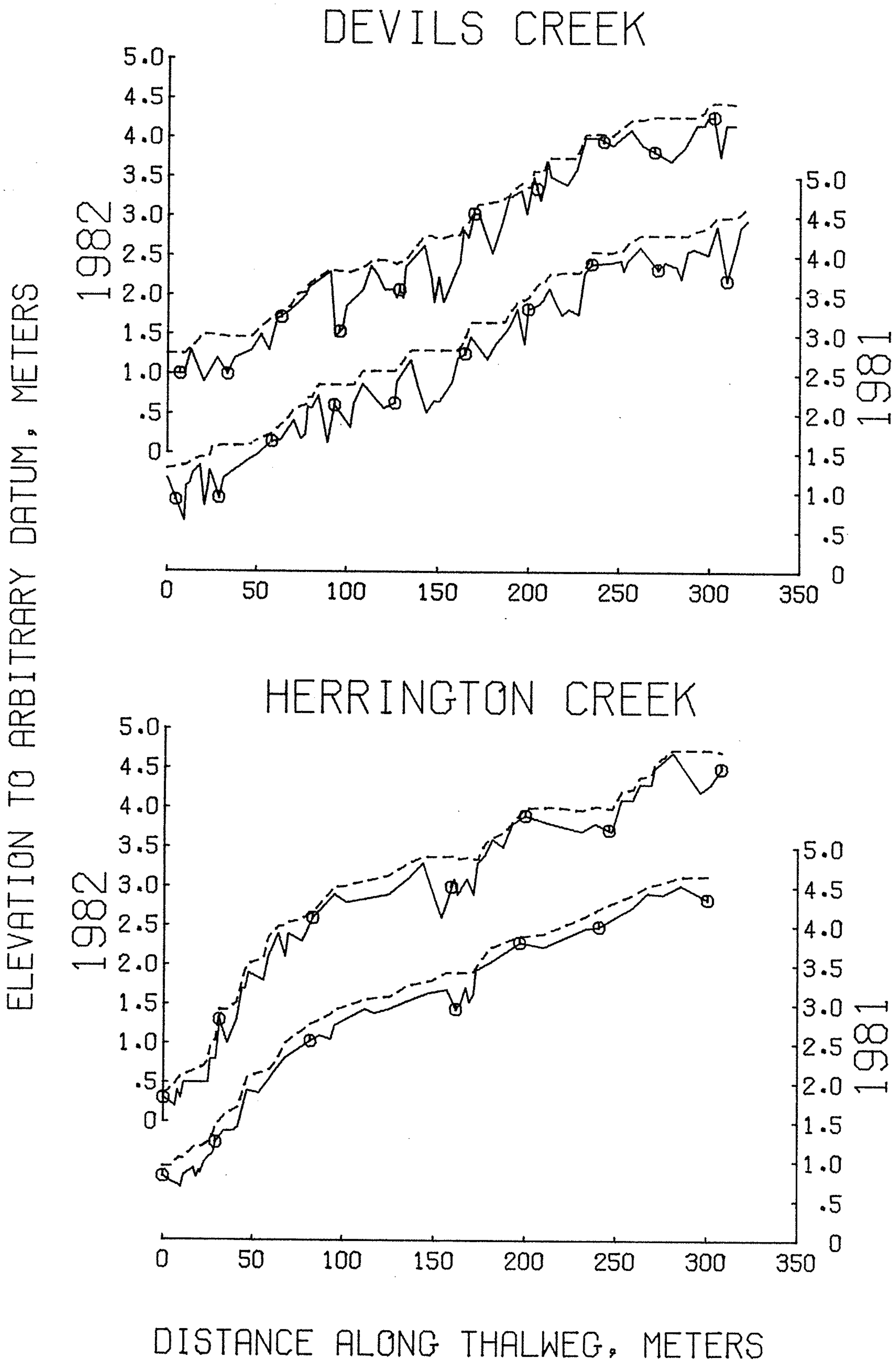

Figure 13. Longitudinal profiles of stream thalweg for Devils and Herrington Creeks during summer low flow period in 1981 and 1982. Circles denote approximate locations of channel cross-sections. Dashed line is water surface.

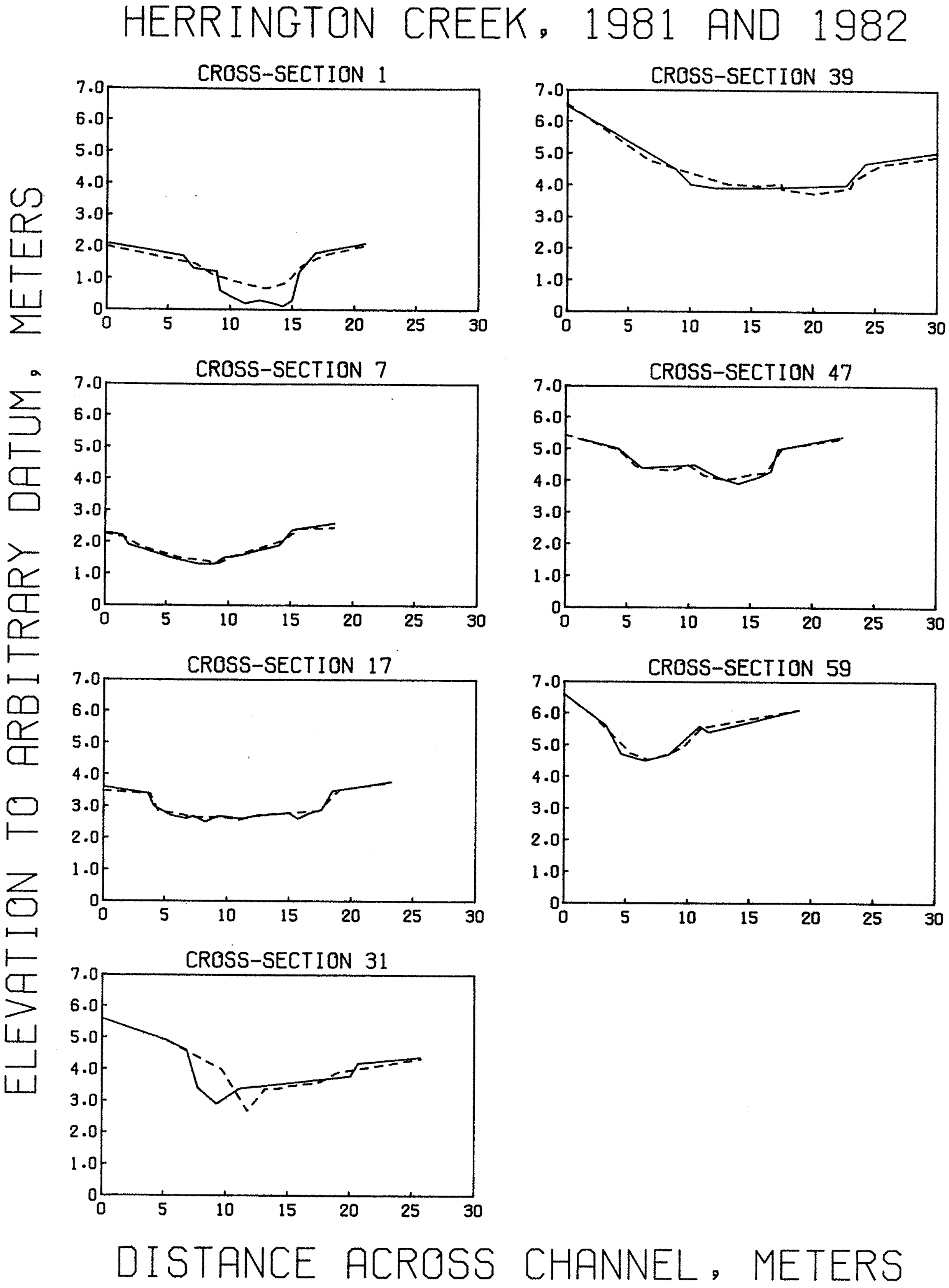

Figure 14. Cross-sectional profiles for Herrington Creek during summer 1981 (dashed line) and 1982 (solid line).

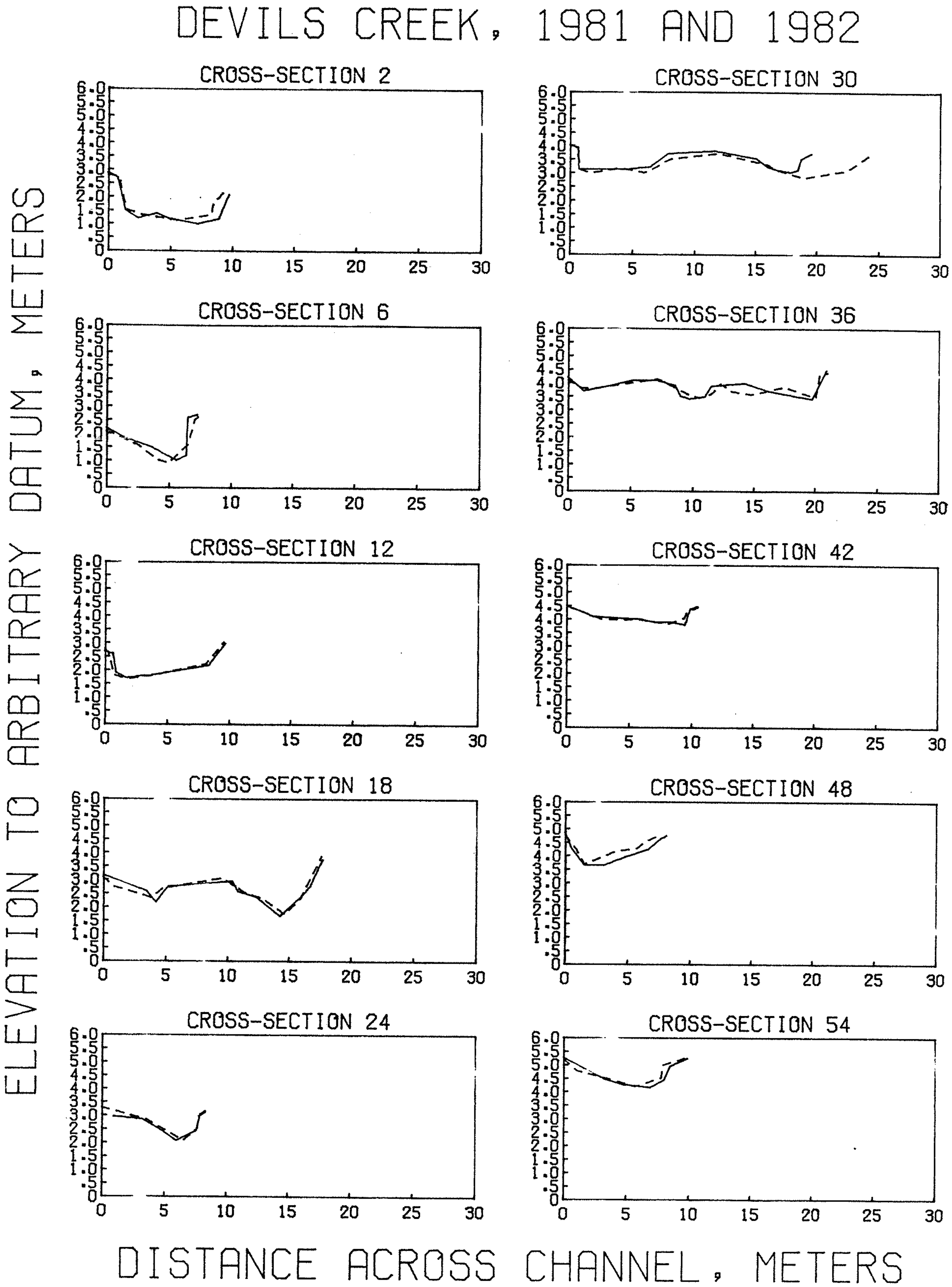

Figure 15. Cross-sectional profiles for Devils Creek during summer 1981 (dashed line) and 1982 (solid line).

Physical Habitat Inventory

The range of physical habitat parameters observed in streams affected by the eruption of Mount St. Helens are significantly different from conditions observed in unaffected streams. Water depths less than ten centimeters, occur in 40% to 50% of the water surface area in old channels buried by mudlfows (i.e., upper and lower Deer, and lower Wyant Creeks, Figure 16) and from 63% to 99% of area for new chanels on the mudflow or debris flow (i.e., Herrington and Bear Creeks). The old channels buried by mudflow had some moderately deep water (20 cm - 60 cm), but not as much as occurs in the unaffected streams. Comparison of water depth distribution between years indicates a small increase in area of water greater than 60 centimeters deep for lower Wyant Creek and a decrease of deeper water areas for lower Deer Creek and upper Deer Creek. The improvements in lower Wyant Creek can be attributed to channel degradation while the loss of deeper water in both Deer Creek study sites is a result of the March 1982 mudflow. Surprisingly, very few changes in water depth have occurred in Herrington and Bear Creeks by 1982, even though longitudinal profiles of these streams (Figures 7 and 13) indicate pool development. Perhaps the transect interval of 10 meters used during the habitat inventory was not sufficient to detect the few pools indicated by the longitudinal profiles.

Comparisons of water velocity distributions (Figure 17) between streams are not as clearly indicative of volcanic impacts as is water depth. It was expected that streams with few pools and shallow depth profiles would have a relatively greater area with higher water velocities. Yet, Bear Creek, which does not have pools deeper than 20 centimeters had a high proportion of the stream area with velocities less than 15 cm/s. On the other hand, a comparison of water velocities between years for an impacted stream does show

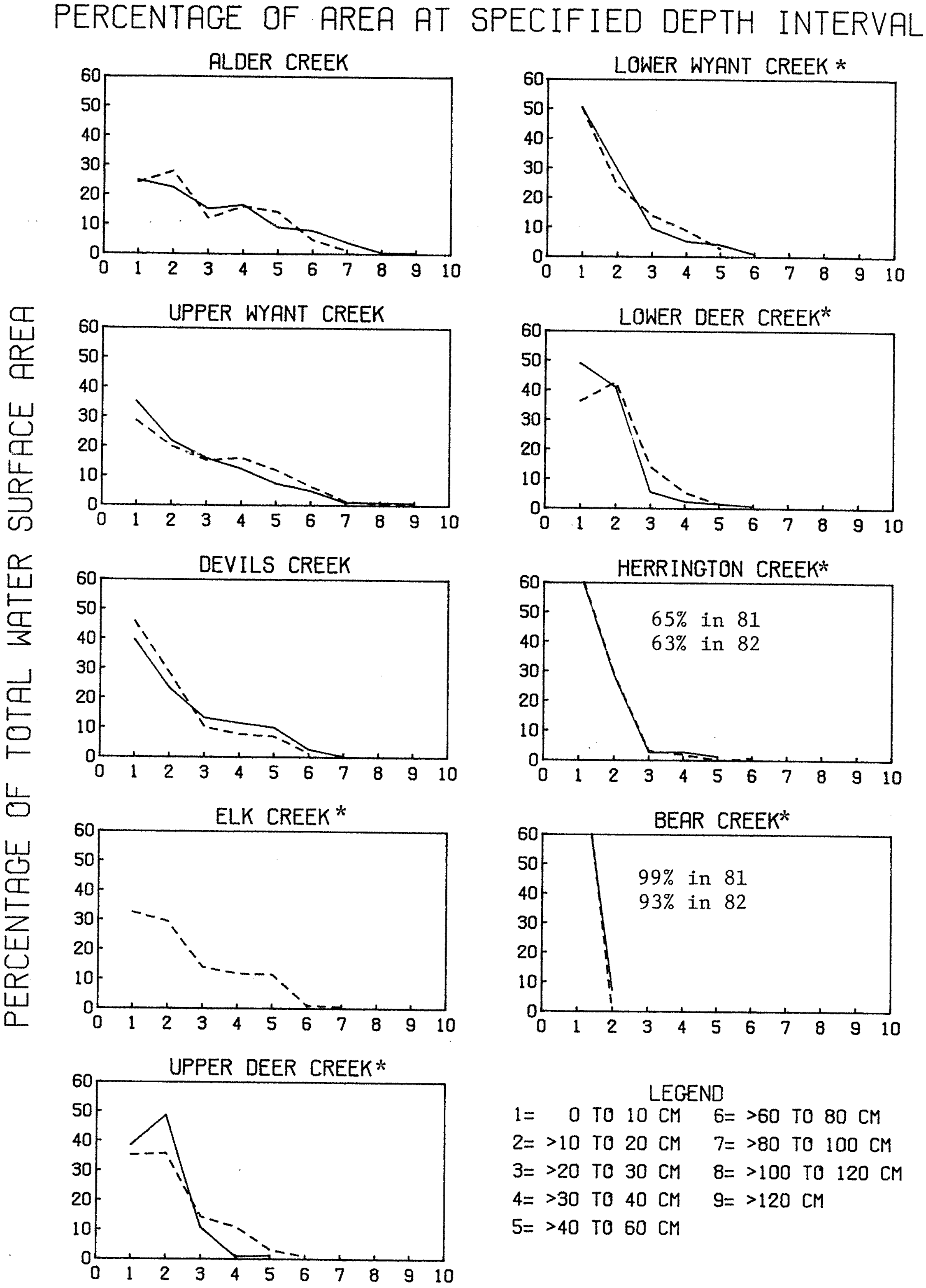

Figure 16. Percentage of total water surface area at specified depth interval for affected (*) and unaffected tributary streams of the Toutle River during summer low flow in 1981 (dashed line and 1982 (solid line).

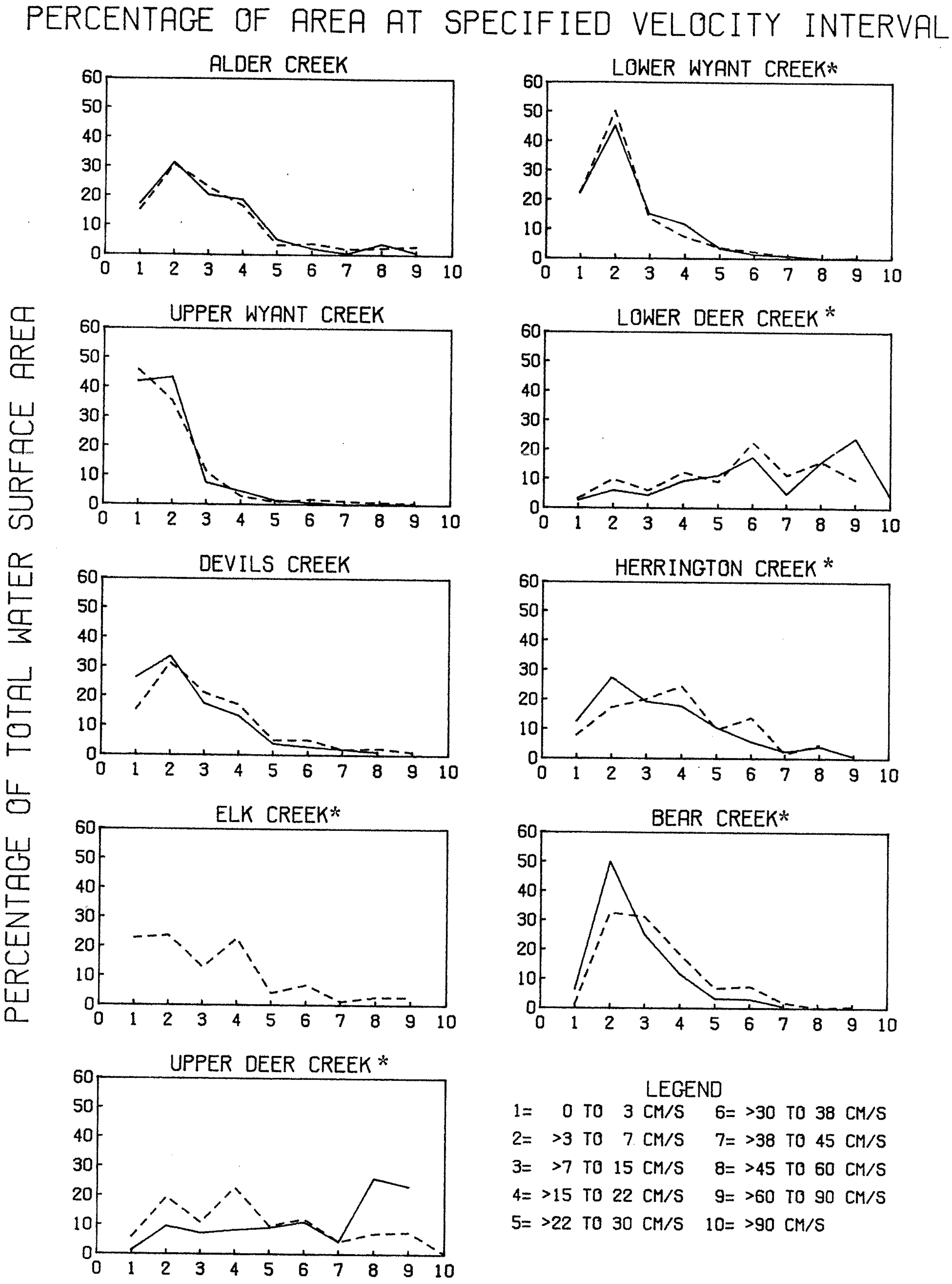

Figure 17. Percentage of total water surface area at specified velocity interval for affected (*) and unaffected tributary streams of the Toutle River during summer low flow in 1981 (dashed line) and 1982 (solid line).

the effects of pool recovery or loss. In 1982, Herrington and Bear Creeks had more low velocity area than in 1981 as a result of pool development. Likewise, both Deer Creeks had less low velocity areas and more high velocity areas in 1982, as a result of the March mudflow that destroyed pool topography (Figure 17).

Stream substrate size composition is indicative of the impacts caused by mudflows and airfall ash (Figure 18). Elk Creek, which was affected by ash, the mudflow streams (lower Wyant Creek and Herrington Creek) and Bear Creek, located on the debris flow, had substrate that was predominantely composed of materials less than 20 mm in 1981. While in 1982, these same streams show a shift toward larger cobble size material indicating a rapid recovery when compared to the unaffected streams (i.e., Alder Creek and Devils Creek). The debris flow is composed of 20 percent cobble size and larger size material (Cowlitz County Dept. Community Development, 1983, page IV-12). Therefore, as the tributary channels are degraded, as shown in the channel morophology section, we can expect the larger sized materials to drop out and form a new stream bed. However, recent inundation of stream channels from the March 1982 mudflow reversed the recovery process in both Deer Creeks (Figure 18). Note that the high proportion of fine substrate measured in upper Wyant Creek is not typical of the other unaffected streams, the difference is presumably as a result of logging and land development activities upstream of our study area.

The presence of instream or streamside cover structures in affected streams depended upon the type and severity of impact. Impacts from ash and a shallow mudlfow deposit in Elk Creek and upper Deer Creek, respectively, had a minor effect on fish cover structures (Figure 19) observed in 1981. Streamside brush that was damaged by the heat wave was recovering and instream structures were as abundant as that in the unaffected study streams. Cover

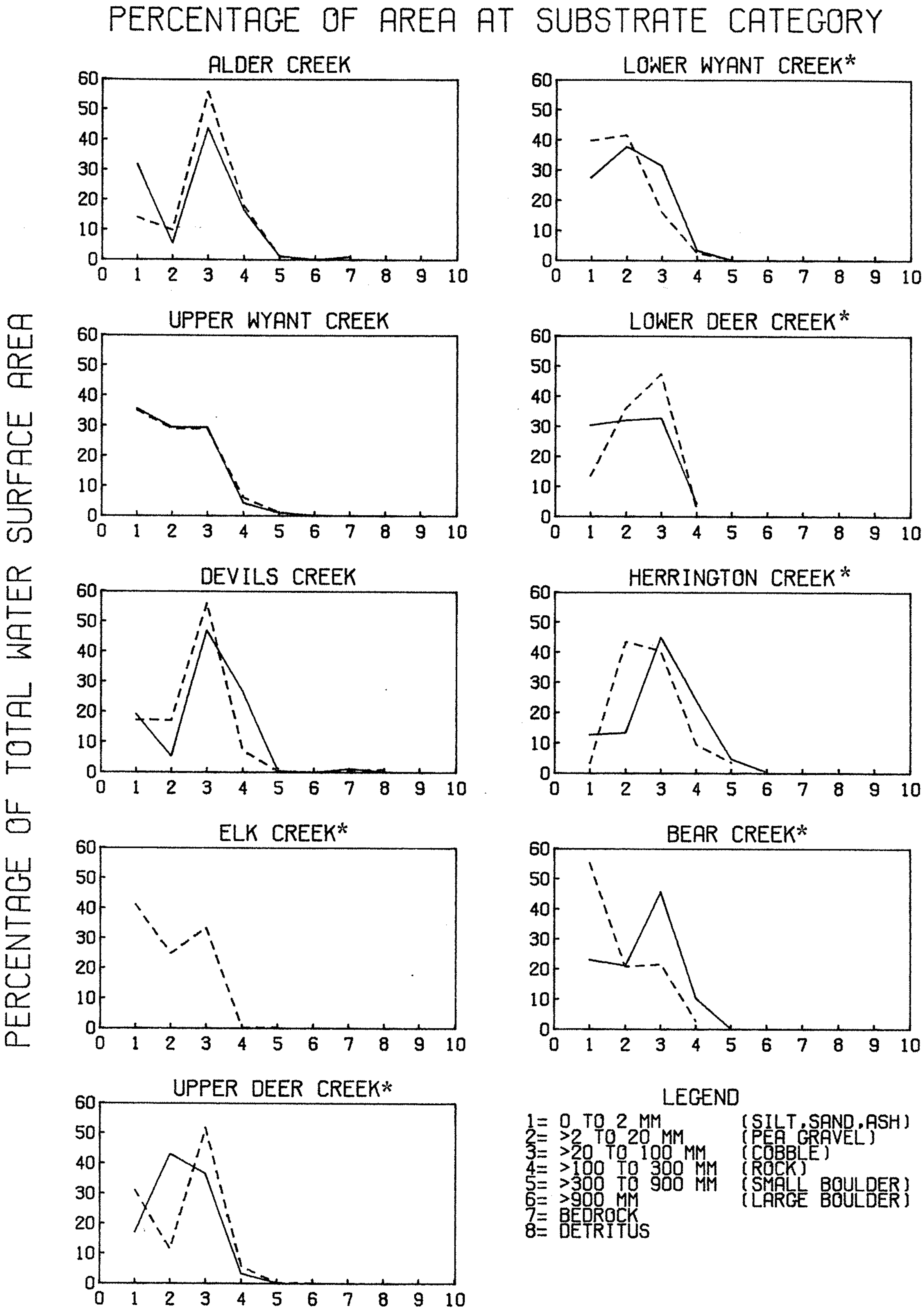

Figure 18. Percentage of total water surface area at specified substrate size category for affected (*) and unaffected tributary streams of the Toutle River during summer low flow in 1981 (dashed line) and 1982 (solid line).

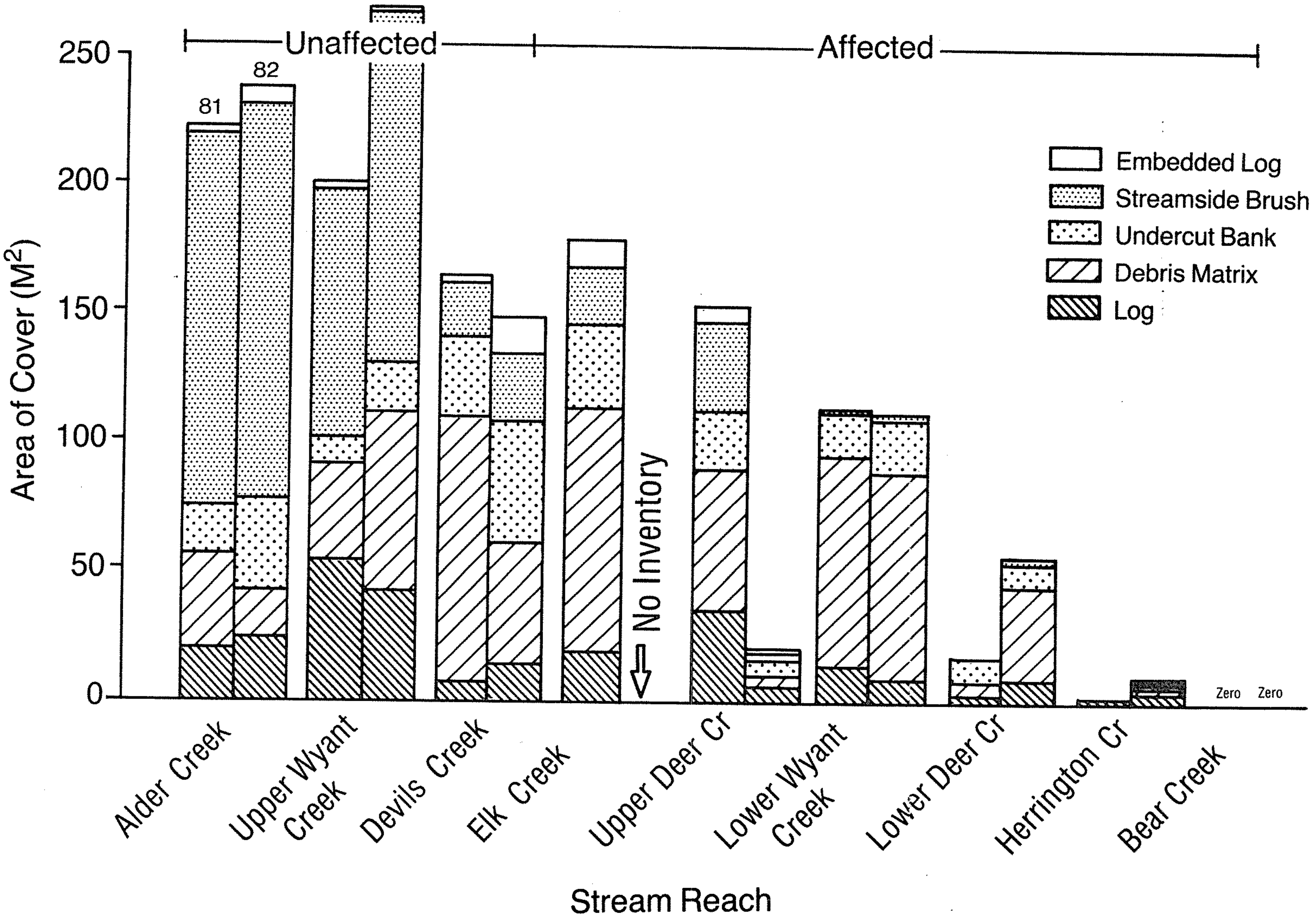

Figure 19. Total area (m^2) of fish cover and relative composition of cover items in the study reaches of affected and unaffected tributary streams of the Toutle River during 1981 and 1982.

structures were also moderately abundant in lower Wyant Creek. But, this material consists primarily of residual woody debris and from recruitment of new material from dying alders along the channel. Lower Deer Creek retained a small amount of cover items in 1981 and recruited additional material by 1982. The March mudflow and subsequent flooding in 1982 flushed debris downstream from upper Deer Creek resulting in some debris being deposited in the lower study section. Cover structures were sparse or non-existant in the new channel streams (i.e., Herrington Creek and Bear Creek) and is expected to remain meager for a long time.

Water Temperature

Water temperatures recorded in the impacted tributary streams was very high and in most cases was directly related to the absence of riparian vegetation. Bear Creek, located entirely in the blast zone, had no vegetative canopy and had the highest temperature (Table 10), and the greatest number of days where temperature exceeded 25°C (Figures 20 and 21), the upper incipient limit for juvenile coho salmon (Brett 1952). Temperature levels in Elk, Deer and Herrington Creeks are due to a combination of perturbations caused by logging and the volcanic blast, and the temperatures in Alder Creek and lower Wyant Creek reflect the effects of devegation as a result of timber harvesting upstream of the study sites. The mean temperature is lower in Deer Creek than all the other streams except Devils Creek (Table 10) because cool water from Deer Springs buffers the effects of canopy devegetation. Devils Creek is the only stream that has the entire channel enclosed by a vegetative canopy. Therefore, the temperature regime for Devils Creek represents the natural background levels expected for streams in the Toutle drainage. Comparisons of maximum daily temperatures between streams (Figures 20 and 21) indicate that

Table 10. Water temperature statistics (°C) for affected (*) and unaffected study streams in the Toutle River watershed for summer 1981 and 1982.

Stream year	JUNE			JULY			AUGUST			SEPTEMBER (1st week only)		
	Range	Mean	Maximum diel fluctuation	Range	Mean	Maximum diel fluctuation	Range	Mean	Maximum diel fluctuation	Range	Mean	Maximum diel fluctuation
Alder												
1981	9-16	12.0	5.8	10-20	14.7	5.3	11-22	15.6	5.0	12-18	14.9	4.5
1982	11-22	15.5	5.6	11-21	15.4	6.1	11-18	14.5	7.7	13-18	15.6	5.0
Devils												
1981	6-16	11.9	9.4	11-16	13.1[1]	3.0	11-17	13.5	2.7	9-14	11.4	3.3
1982	9-16	12.3	3.9	10-15	12.1	2.8	11-15	12.5	2.2	12-14	12.9	1.6
Elk*												
1981	9-19	12.5	6.3	13-23	16.8[2]	7.8	13-26	17.7	8.3	12-20	15.4	7.5
1982[3]	---	---	---	---	---	---	---	---	---	---	---	---
Lower Wyant*												
1981	11-19	13.8[4]	4.0	9-20	14.2	6.0	11-25	16.8[5]	10.5	---	---	---
1982	10-23	14.4	10.0	13-25	16.7	11.5	12-22	15.6[6]	7.0	---	---[7]	---
Lower Deer*												
1981	8-17	11.2	7.2	8-20	13.2	9.2	9-22	13.9	9.2	9-17	12.1	7.2
1982	7-20	12.2	8.0	10-20	13.1	8.5	9-20	13.2	8.0	10-19	13.2	7.5
Herrington*												
1981	6-20	10.2	11.4	8-25	14.6	11.1	12-26	16.4	12.0	8-19	12.7	10.5
1982	---	---[8]	---	8-26	15.0[8]	15.6	9-26	14.9	14.4	10-25	16.6	14.4
Bear*												
1981	8-21	12.0	12.0	9-26	15.3	15.0	11-26	17.0	14.0	11-22	15.6	11.0
1982	9-27	15.2	15.0	9-28	15.7	16.1	9-29	16.6	16.1	12-27	16.6	13.9

[1] Data for 7/5 through 7/22 is missing

[2] Data for 7/1 through 7/22 is missing

[3] Temperature was not monitored in 1982

[4] Data for 6/1 through 6/17 is missing

[5] Data for 8/11 through 8/31 is missing

[6] Data for 8/20 through 8/31 is missing

[7] Data for 9/1 through 9/7 is missing

[8] Data for 6/1 through 7/12 is missing

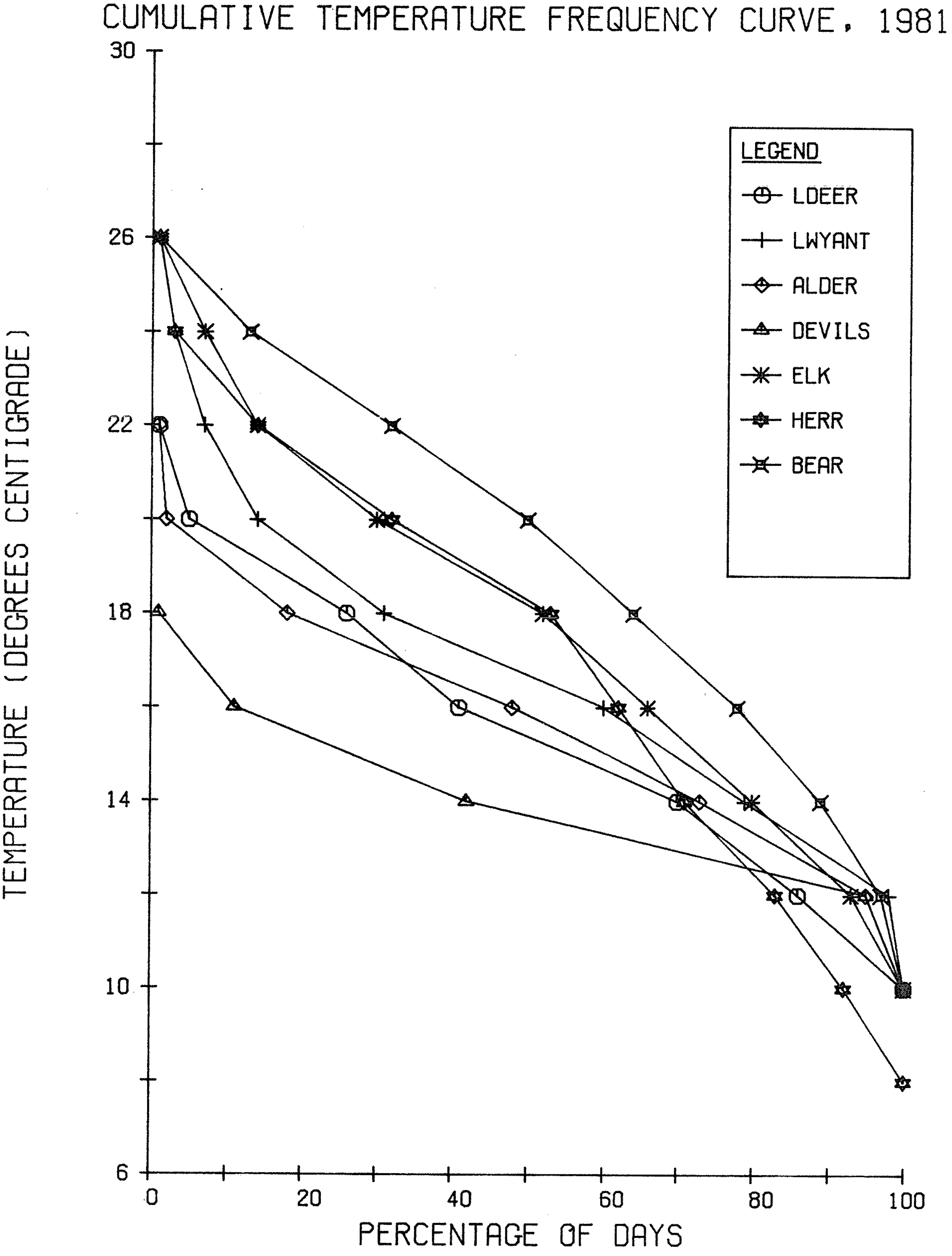

Figure 20. Cumulative temperature frequency curve for affected (*) and unaffected study streams in the Toutle watershed during summer (June 1st through September 7th) 1981. Plot indicates percentage of days water temperature exceeded any given temperature level.

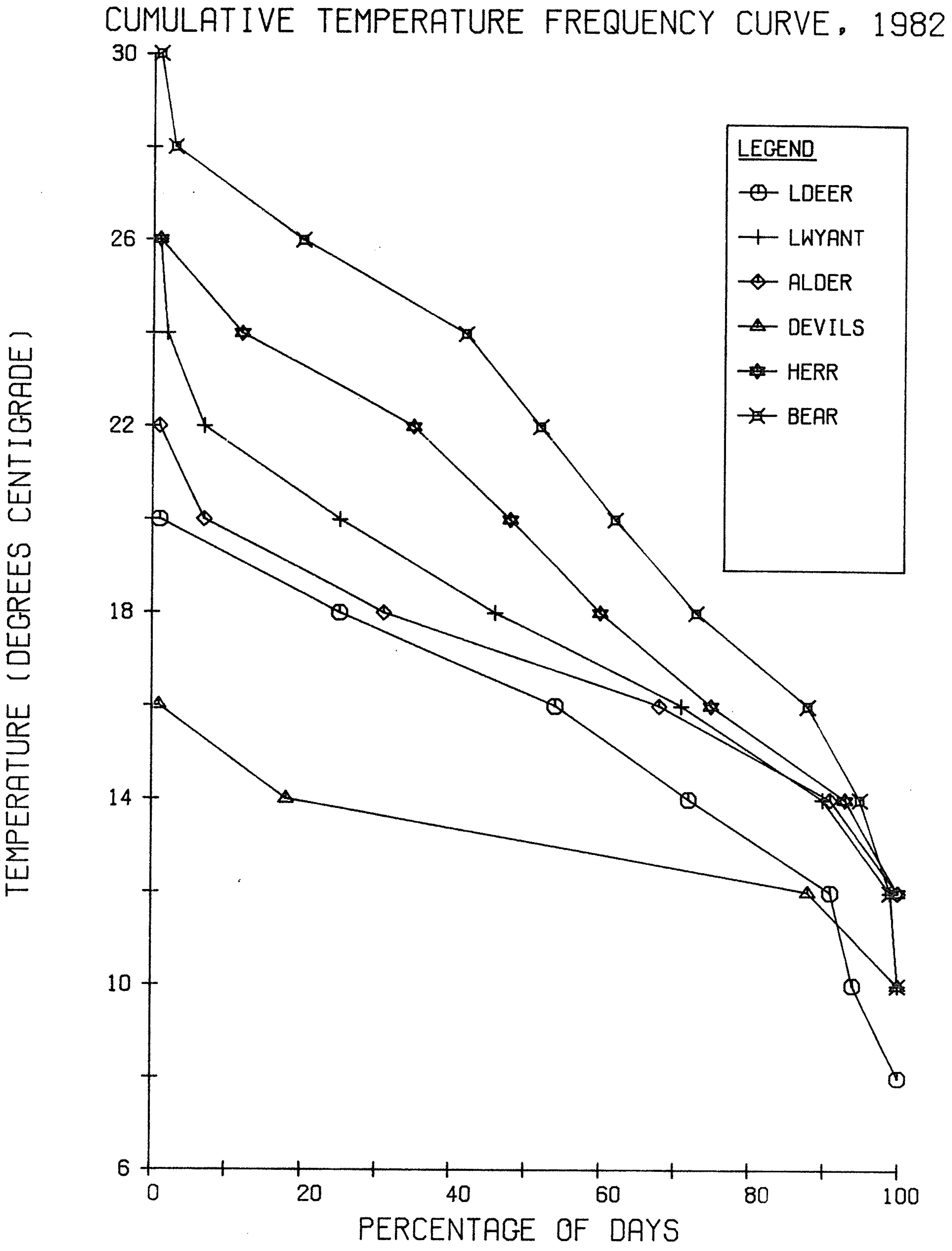

Figure 21. Cumulative temperature frequency curve for affected (*) and unaffected study streams in the Toutle watershed during summer (June 1st through September 7th) 1982. Plot indicates percentage of days water temperature exceeded any given temperature level.

all the study streams, including Alder Creek, exceed the natural background temperature levels most of the time during the summer. High water temperatures are expected to continue for a long time in the new channel streams (i.e., Herrington Creek and Bear Creek), as riparian vegetation regeneration is just beginning.

Fish Food Supply

Macroinvertebrate drift samples collected during summer 1981 indicated that food organisms were present in all impacted study streams (Figure 22). There was considerable variability in densities between sampling dates in both affected and unaffected streams. However, all of the affected sites had lower densities of organisms than did the unaffected streams on the May 22 and October 22 sample dates. In July, densities were lower at Elk, upper Deer, and Bear Creeks, and in September only upper Deer Creek had densities lower than the lowest density for the unaffected streams.

Taxonomic composition of drift samples collected in May and July (Figure 23) indicate that community structure is less diverse in the more severely impacted streams. Lower Wyant, lower Deer, Herrington and Bear Creeks had more than 50% of the potential food supply composed of chironomidae larvae. One exception, was the high abundance of Collembola that occurred in Bear Creek during May. Moderately impacted streams (i.e., Elk Creek and upper Wyant Creek) did not appear to be different in taxonomic composition from the unaffected study streams.

The results show that the fish food supply in the affected streams is relatively low, but that the difference between the affected and unaffected streams is not very large. Also the magnitude of impact on the stream environment does not appear to have much effect on the relative recovery rate

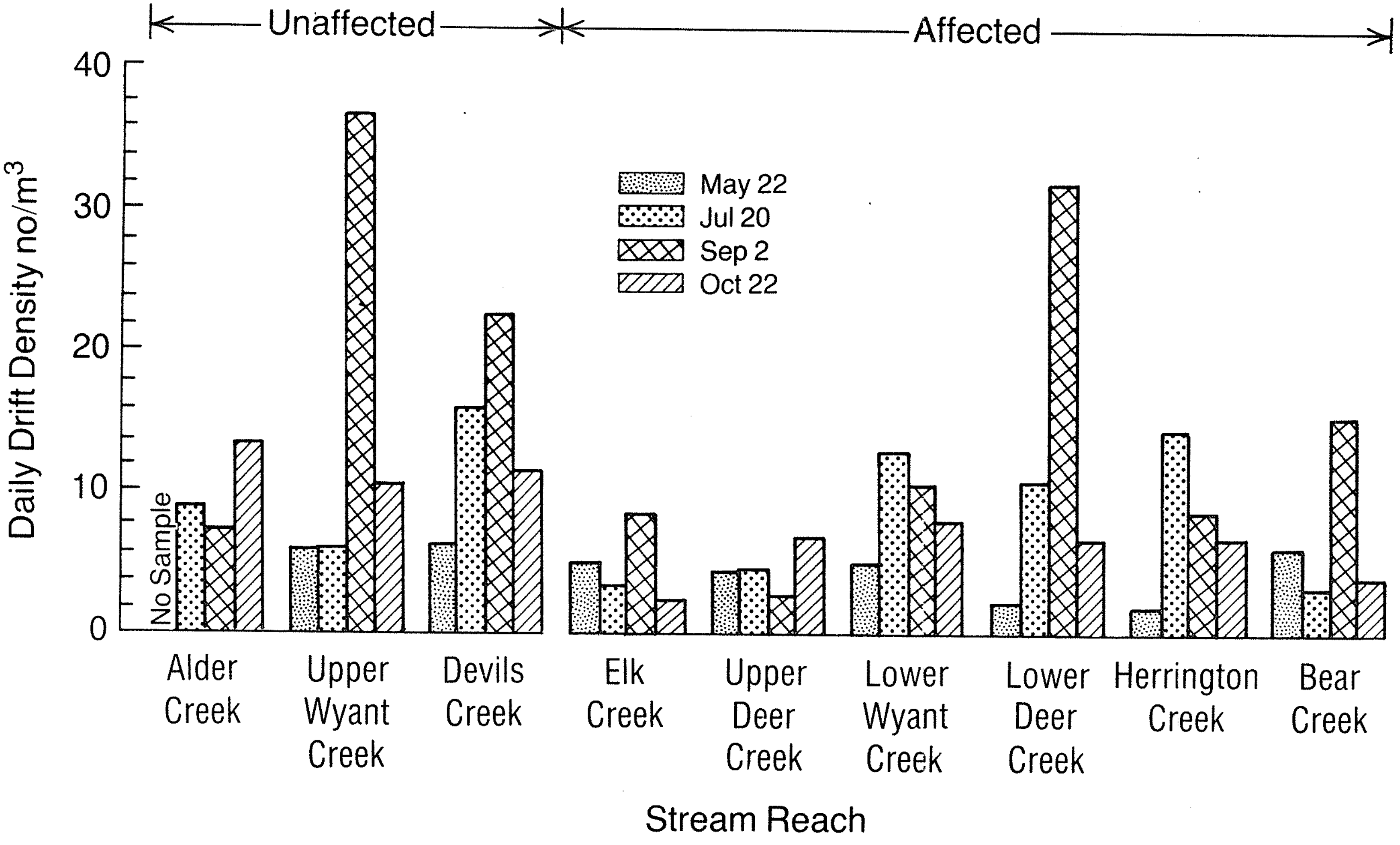

Fig. 22. Daily macroinvertebrate drift density (No/m^3) in affected and unaffected study streams of the Toutle River during 1981.

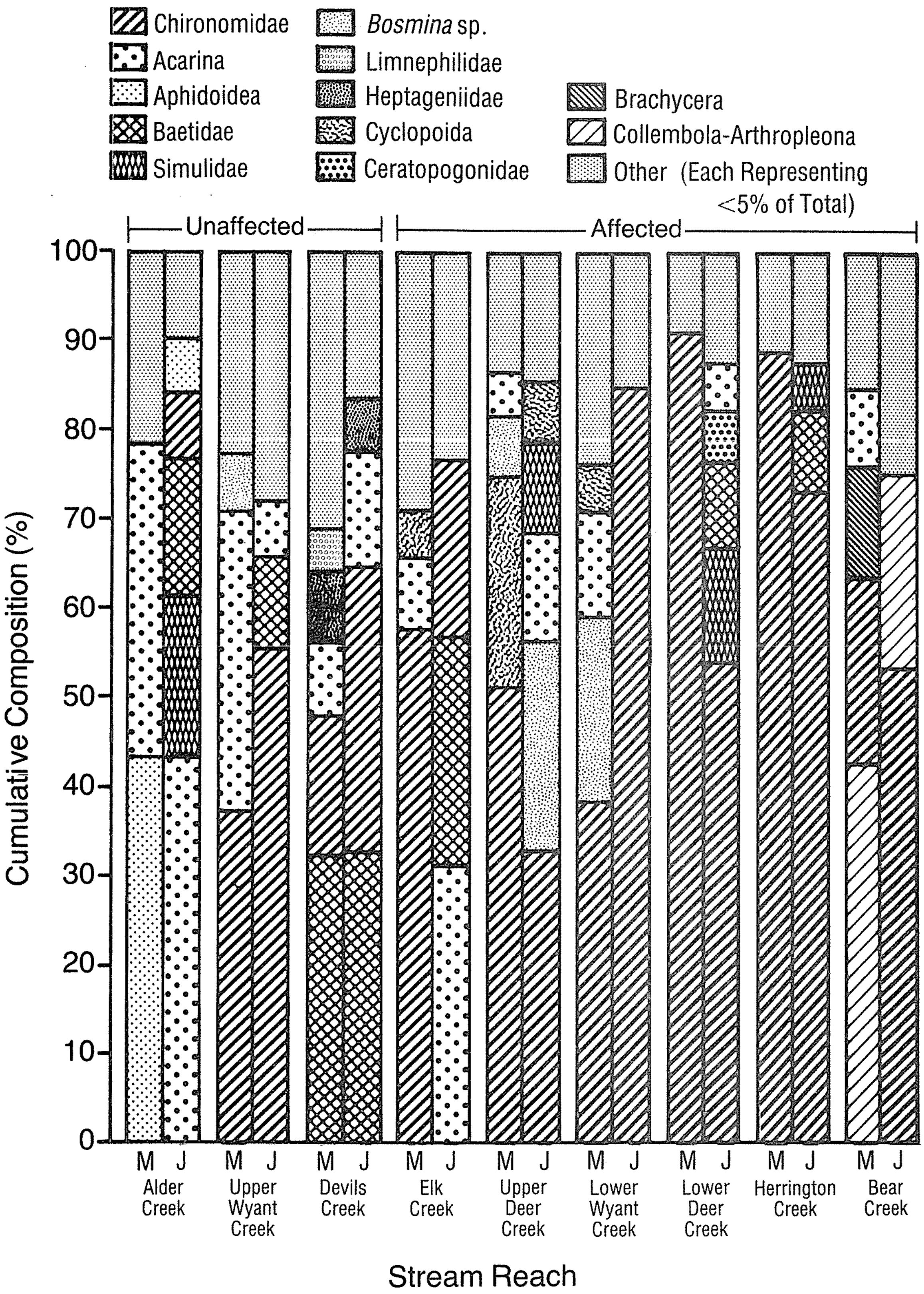

Figure 23. Macroinvertebrate drift taxonomic composition for affected and unaffected study streams of the Toutle River during May and June 1981.

in organism abundance. Presumably the survivors or primary invader types find the unstable streams suitable for colonization and are taking advantage of an area where few conpetitors can survive.

JUVENILE SALMONID GROWTH AND SURVIVAL

Materials and Methods

Fish Stocking

The streams selected for intensive study were surveyed with electrofishing gear in April 1981 to determine the relative abundance and species composition of the fish populations. Most of the streams did not contain coho and the trout populations were very small (Table 11). In order to evaluate the impacts of the altered habitat conditions on growth and survival of juvenile salmonids the streams need to be seeded to maximum capacity. Since most of the fish population was initially destroyed during the eruption and only small numbers of adult spawners were observed in autumn 1980 the surviving populations were assumed to be below carrying capacity. Therefore, the introduction of cultured fish was necessary to artificially seed all of the study reaches. Coho salmon were chosen for planting because they require only one year of freshwater residence before smolting and surplus fry were readily available. Other salmonid species (i.e., steelhead and cutthrout trout) were not planted because of the complexity this would have added to the study design. Consequently, only coho responses to habitat impacts can be evaluated in this study. Observations of steelhead trout and cutthroat trout are included in the study results, but only for the purpose of documenting their distribution and relative abundance.

Coho fry were scatter planted within each study reach during May 1981 and 1982. Fry, approximately 2 months old, were obtained from the Washington Department of Fisheries Cowlitz River Salmon Hatchery and planted at a density of 10 fish per m^2 of pool area. Mean lengths and weights of planted fish were not statistically different between streams at the time of introduction

Table 11. Pre-fish planting population assessment in affected (*) and unaffected study streams of the Toutle River basin, March 20-27, 1981.

Stream	Distance surveyed (m)	Fish captured
Alder	100	1 coho (smolt), 11 steelhead
Upper Wyant	75	7 coho (fry), 1 steelhead
Devils	75	11 cutthroat, 3 steelhead
Elk*	125	12 cutthroat, 59 steelhead
Upper Deer*	100	2 cutthroat, 8 steelhead
Lower Wyant*	100	4 coho (fry), 4 steelhead
Lower Deer*	350	1 cutthroat, 1 steelhead
Herrington*	300	1 cutthroat, 19 steelhead

(Appendix Table B).

Population Statistics

Population censuses were conducted in July and September 1981, and March and September 1982. Fish were captured with electrofishing gear and population estimates were computed for the entire study reach and for distinctive habitat sub-units within each study reach. Population estimates were computed for all streams except Bear Creek using the Chapman modification of the Peterson mark-and-recapture method (Chapman 1951). The variance associated with the estimate was based on a normal or binomial distribution as described by Seber (1973, p. 62-64). The lack of instream cover in Bear Creek caused fish to move to the end of the study reach, and concentrate at the stop nets during a population census. Consequently, marked fish were not randomly distributed within the population and the mark-and-recapture estimate was determined to be inaccurate. Therefore, the Leslie removal method (Ricker 1975, p. 150-153) was employed to estimate population size for Bear Creek. Routine length and weight data were collected at the time of capture for the computation of biomass and growth statistics. Also, all fish captured in September 1981 and March 9,1982 were cold branded with dry ice and acetone, in order to facilitate survival estimates after winter and during the spring smolt outmigration.

Smolt Survival Study

The survival of coho smolts during the downstream migration in the Toutle River was computed from marked fish release and recapture experiments. Several experiments were conducted where known numbers of marked smolts were released into Alder Creek located 46 km from the mouth of the Toutle River.

Fish were recaptured in a large fyke net at the old Highway 99 bridge (Figure 1), located approximately 1.5 km above the confluence of the Toutle and Cowlitz Rivers. The fyke net consisted of: a 40 ft. long net with a mouth opening of 4 ft. deep by 12 ft. wide, and a 6 ft. long torpedo shaped live tank attached to the cod end of the net. During experiments the net was fished continously except for periodic removal at two-hour intervals for the purpose of emptying captured fish from the live tank. Floating debris presented a considerable problem and frequently ripped the net resulting in fishing gaps of up to several hours while the net was being repaired.

Fyke net efficiency was tested on several occasions by the recapture of marked fish that were released approximately 1.5 km upstream of the net. Efficiency calculations are based on the assumptions that no mortality occurred between the release site and the net, and that the distribution of the fish within the stream would be representative of the distribution of fish migrating from Alder Creek. Therefore the percentage of the test fish caught, represents the fraction of the total number of fish migrating past the bridge that would be captured during a release-recapture experiment. For example:

$$\frac{\text{1000 efficiency fish released}}{\text{100 captured}} = \text{10\% efficiency}$$

$$\frac{\text{200 Alder Creek fish captured}}{\text{10\% efficiency}} = \text{2000 Alder Creek fish reaching the bridge}$$

In addition to the smolt release experiment, all wild salmonids captured in the fyke net were enumerated, weighed, and measured. Non-salmonids were also enumerated and all live fish were returned to the river.

Results

Population Abundance and Density

Juvenile coho population densities measured during the summer low flow period (Table 12) do not clearly reflect the habitat impacts caused by the volcanic eruption. Streams with large differences in channel morphology, instream cover, and temperature regime were found to have similar population densities (e.g., Alder and Bear Creeks in 1981, and upper Wyant and lower Deer Creeks in 1982). Further, some of the more severely impacted streams (i.e., Bear Creek and lower Wyant Creek) had higher population densities than the unaffected streams. The large population variation that exists within affected and unaffected stream groups indicates that factors other than habitat are probably accounting for the population densities observed at summer low flow. For example, a family of mergansers were observed in Herrington Creek for a period during summer in 1981 and 1982. In contrast, predators were never observed in Bear Creek which is similar to Herrington Creek in channel morphology but Bear Creek is located within the blast zone. Another factor affecting coho is the presence or absence of steelhead trout and cutthroat trout that are competing for similar resources. Finally, a freshet in early June 1981 (Figure 24) may have caused the large difference in densities observed between 1981 and 1982 in all the study streams except Deer Creek.

Population comparisons between years within Deer Creek do show the effects of habitat impacts on carrying capacity. Habitat in the upper section of Deer Creek was destroyed by the March 19, 1982 mudflow, while habitat in the lower section improved slightly from the deposition of large woody debris. Consequently, the density of coho in the upper section decreased in comparison to 1981. Whereas, the density of coho in the lower section increased with the

Table 12. Juvenile coho density and biomass with 95% confidence intervals during the September low flow period for affected(*) and unaffected study streams of the Toutle River for 1981 and 1982.

Stream	1981		1982	
	Density (95% C.I.)	Biomass (95% C.I.)	Density (95% C.I.)	Biomass (95% C.I.)
	fish/m^2	g/m^2	fish/m^2	g/m^2
Alder	.40 (.36-.43)	2.47 (1.04-3.90)	...[2]	...
Upper Wyant	.22 (.18-.26)	.71 (.22-1.20)	.25 (.22-.28)	.97 (.04-1.89)
Devils	.20 (.16-.24)	1.24 (.58-1.90)	...	...
Elk*	.40 (.36-.44)	2.28 (1.03-3.52)	...	...
Upper Deer*	.46 (.38-.54)	3.29 (1.42-5.15)	.16 (.12-.20)	1.50 (.33-2.68)
Lower Wyant*	.08 (.05-.12)	.64 (.47-.69)	1.60 (1.53-1.67)	4.96 (4.04-5.88)
Lower Deer*	.10 (.08-.16)	1.10 (.63-1.30)	.24 (.22-.26)	1.65 (.59-2.71)
Herrington*	.01 (.006-.02)	.06 (.04-.08)	.01 (.01-.03)	.06 (.01-.09)
Bear*	.40 [1]	1.66 [1]	1.54 (1.07-3.46)	4.60 (3.21-10.37)

[1] All fish were captured, no confidence limits computed.

[2] No census

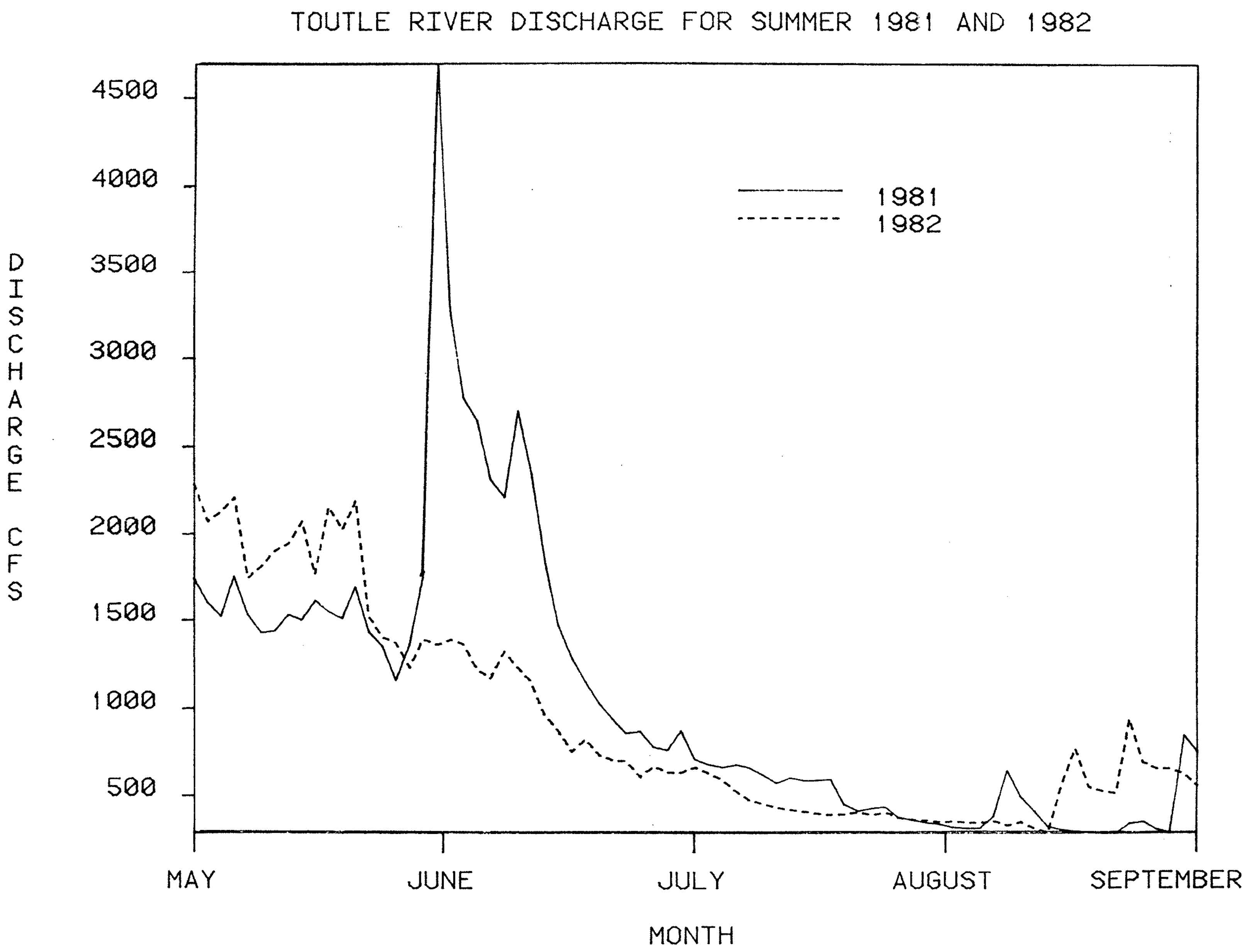

Figure 24. Mean daily discharge (cfs) of the Toutle River at Highway 99 bridge, May through September 1981 and 1982.

increase in cover.

Changes in the 1981 coho population with time (Table 13) indicates that September population abundance does not necessarily determine the number of fish remaining after the winter months. Instead, the number of fish remaining in the study sections in March 1982 is indicative of habitat conditions. All the unaffected streams had high numbers of pre-smolts regardless of the pre-winter population. Whereas, all of the affected streams except Elk Creek had very low populations of pre-smolts in March. Elk Creek channel morphology and quantity of cover was similar to that in the unaffected streams. Therefore, the data suggests that low overwinter survival in the other affected streams is probably due to the lack of pools, absences of cover, and channel instability associated with the mudflow. Distinctions in population response to old channels with mudflows vs. new channels developing on the mudflow or debris avalanche is not evident at this time.

Correlation between population abundance in March and habitat parameters measured in September support the foregone observations. Assuming habitat measured in September is indicative of conditions that exist in March. A regression analysis indicates that total area of available cover accounts for 62% ($R^2 = .62$) of the population variability. Further, areas of stream with water depths of 40-60 cm (i.e., pools) have a R^2 of .58 ($P \leq .05$), but when water depth and cover are combined in the regression, the R^2 is not improved. Water depths of 40-60 cm in combination with water velocity of 7-22 cm/s does improve the R^2 to .70 ($P \leq .05$) indicating that deep slack water areas are important determinants of population abundance.

Steelhead and Cutthroat Abundance and Survival

Steelhead and cutthroat trout population abundance and density vary

Table 13. Juvenile coho population estimates with 95% confidence intervals for affected(*) and unaffected study streams of the Toutle River watershed, June, 1981 to September, 1982.

Stream	June 81	September 81	March 82	September 82
Alder	540(447-603)	543(492-594)	207(106-463)	2/
Upper Wyant	781(656-906)	359(294-424)	62(46-94)	429(383-474)
Devils	248(197-299)	243(193-294)	88(63-140)	2/
Elk*	765(657-874)	491(444-538)	86(59-151)	2/
Upper Deer*	953(829-1078)	791(646-936)	1/	195(147-243)
Lower Wyant*	204(162-366)	112(80-173)	3(2-6)	2027(1942-2112)
Lower Deer*	233(163-366)	156(115-228)	8(6-19)	357(325-388)
Herrington*	64(38-124)	11(8-23)	0	26(19-48)
Bear*	2/	312 3/	30(25-55)	1301(907-2929)

1/ Eruption of March 19, 1982 destroyed study section, no estimate

2/ No census

3/ Removal method employed

All fish captured, variance = 0

greatly within affected and unaffected study streams (Tables 14 and 15). Low population abundance in affected streams may be due to habitat degradation. However, the variable recruitment of fry for all study stream results in population variation that obscures the effects of volcanic impacts. Nevertheless, high densities of trout fry in upper Deer and lower Wyant Creeks in 1981, and Herrington Creek in 1982 does indicate that adults successfully spawned in these streams and that large numbers of fry were able to survive through the summer.

Overwinter survival of trout fry was very low in all impacted streams except Elk Creek. An analysis of length frequency histograms (Figures 25-28) indicates that yearling and older individuals represent a small proportion of the population. For example, steelhead fry in lower Wyant Creek were very abundant in 1981 (Figure 25), yet very few yearlings were observed in 1982 (Figure 26). Similarly, Herrington Creek was dominated by older trout in 1981 (Figure 27), but few large individuals remained in 1982 (Figure 28). One exception to this trend, is the concentration of older cutthroat trout (age 2+) in lower Wyant Creek in 1982 (Figure 28), that appear to indicate high overwinter survival. Since few yearling cutthroat were present in lower Wyant Creek in 1981 (length 85-130, Figure 27), the older individuals observed in 1982 are presumed to be immigrants.

Growth

Growth of juvenile coho from May 1981 to March 1982 is highly variable and does not appear to be related to habitat impacts (Figure 29). But, pre-smolt fish size is less variable and does appear to be influenced by the extent and type of habitat alteration. Fry that were of equal size in May, exhibited different growth rates during the summer and resulted in a wide

Table 14. Population estimates with 95% confidence intervals and population densities for steelhead trout in affected(*) and unaffected tributaries of the Toutle River during September 1981 and 1982 - all age groups combined.

	1981		1982	
Stream	Number (95% C.I.)	Density fish/m^2	Number (95% C.I.)	Density fish/m^2
Alder	172 (131-212)	.13	--[1]	--
Upper Wyant	6 (4-12)	.004	2 [2]	.001
Devils	7 (4-16)	.005	--	--
Elk*	62 (47-96)	.05	--	--
Upper Deer*	602 (281-1427)	.34	0	0
Lower Wyant*	918 (834-1002)	.91	51 (30-106)	.04
Lower Deer*	90 (54-175)	.06	0	0
Herrington*	13 (0)	.01	206 (175-238)	.12
Bear*	0	0	0	0

[1] No census

[2] No fish marked and only 2 caught on recapture run, so variance cannot be computed.

Table 15. Population estimates with 95% confidence intervals and population densities for cutthroat trout in affected(*) and unaffected tributaries of the Toutle River during September 1981 and 1982 - all age groups combined.

Stream	1981 Number (95% C.I.)	1981 Density fish/m^2	1982 Number (95% C.I.)	1982 Density fish/m^2
Alder	97 (84-110)	.07	---[1/]	--
Upper Wyant	39 (22-89)	.02	29 (19-54)	.02
Devils	115 (81-182)	.09	--	--
Elk*	39 (29-58)	.03	--	--
Upper Deer*	341 (247-496)	.20	9 (6-18)	.007
Lower Wyant*	52 (33-92)	.04	24 (14-55)	.02
Lower Deer*	106 (76-161)	.07	15 (10-35)	.01
Herrington*	35 (28-57)	.03	4 (4-8)	.002
Bear*	0	0	0	0

[1/] No census

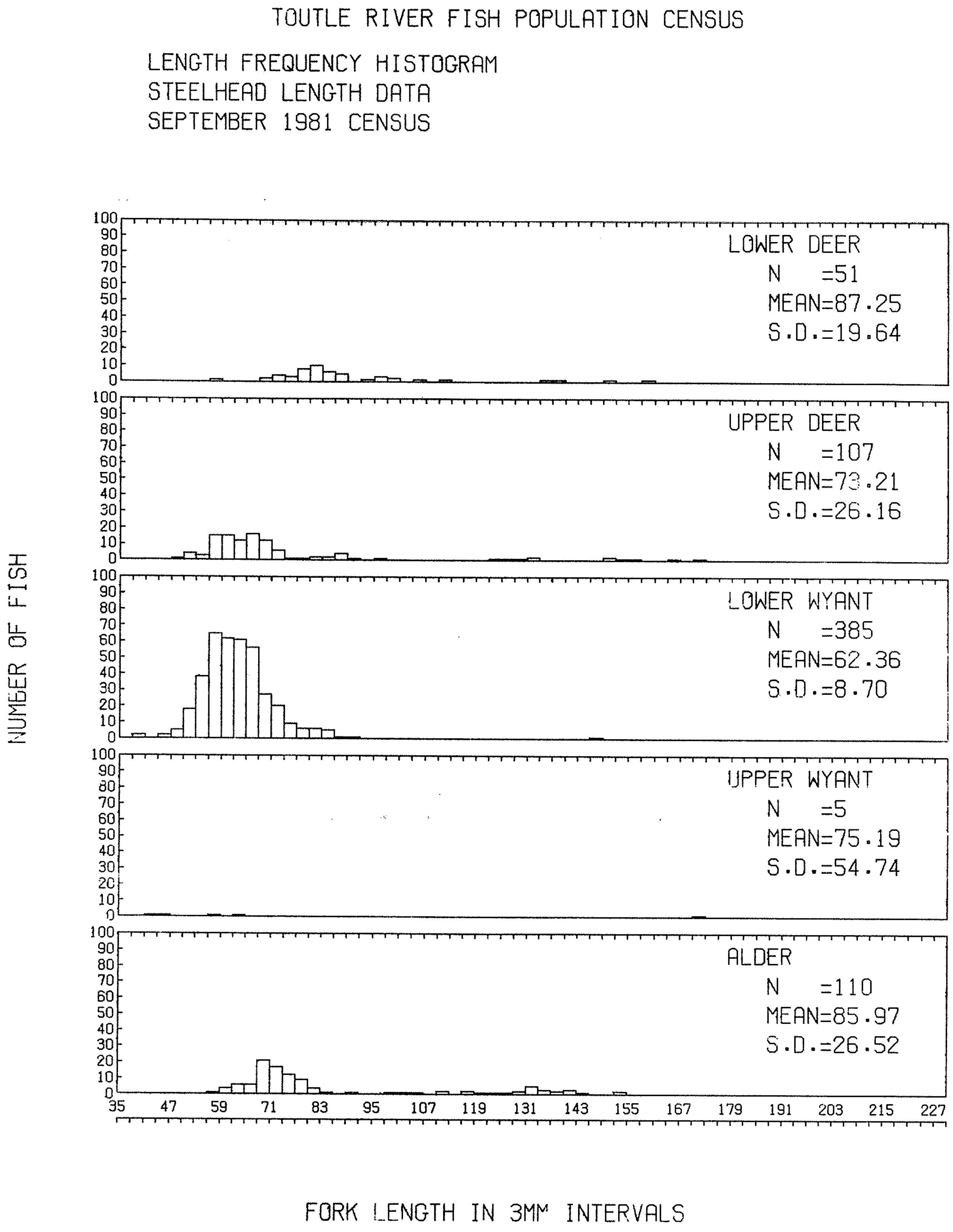

Figure 25. Length frequency histograms for steelhead trout in affected (*) and unaffected tributaries of the Toutle River during September 1981.

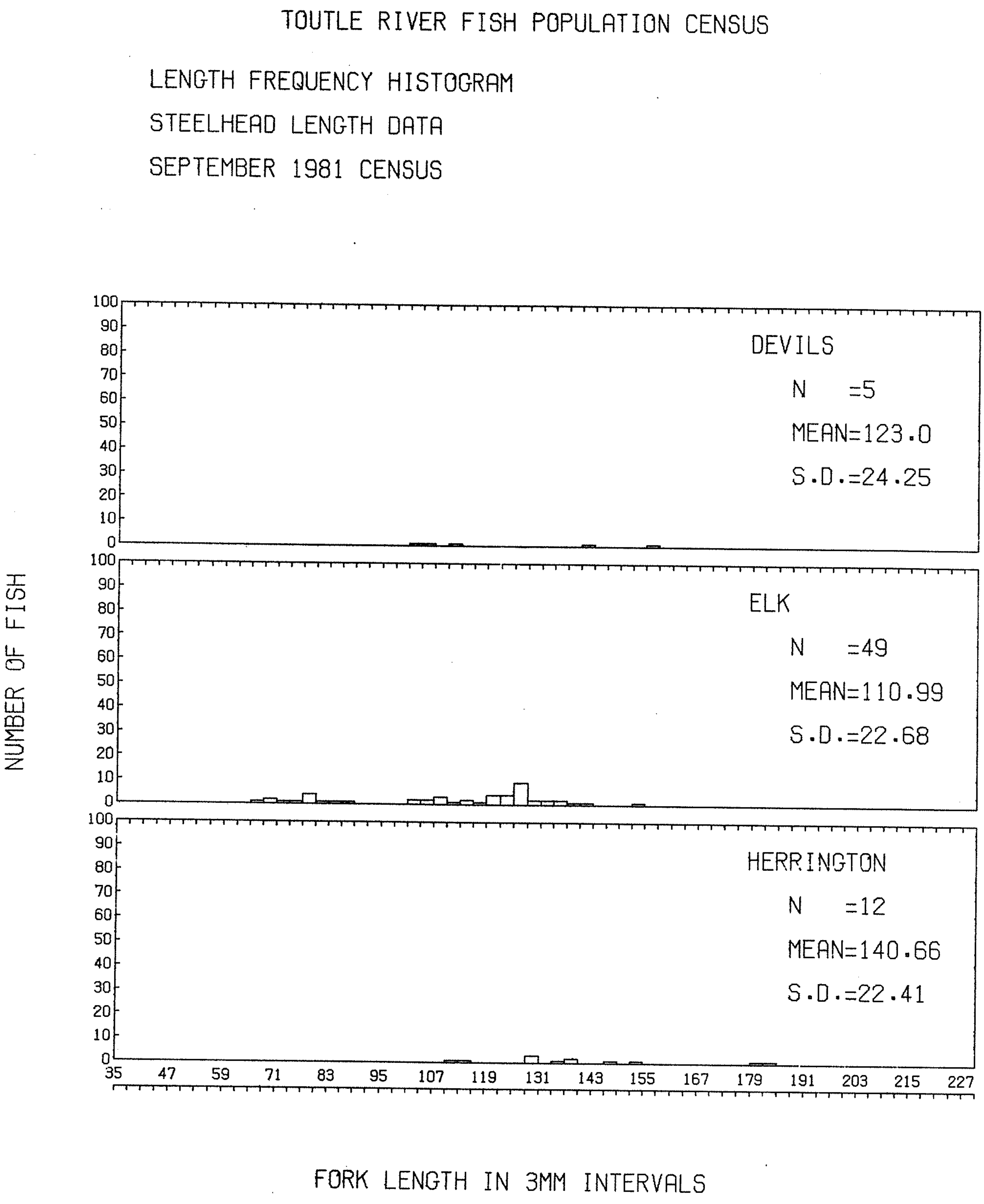

Figure 25 (continued). Length frequency histograms for steelhead trout in affected (*) and unaffected tributaries of the Toutle River during September 1981.

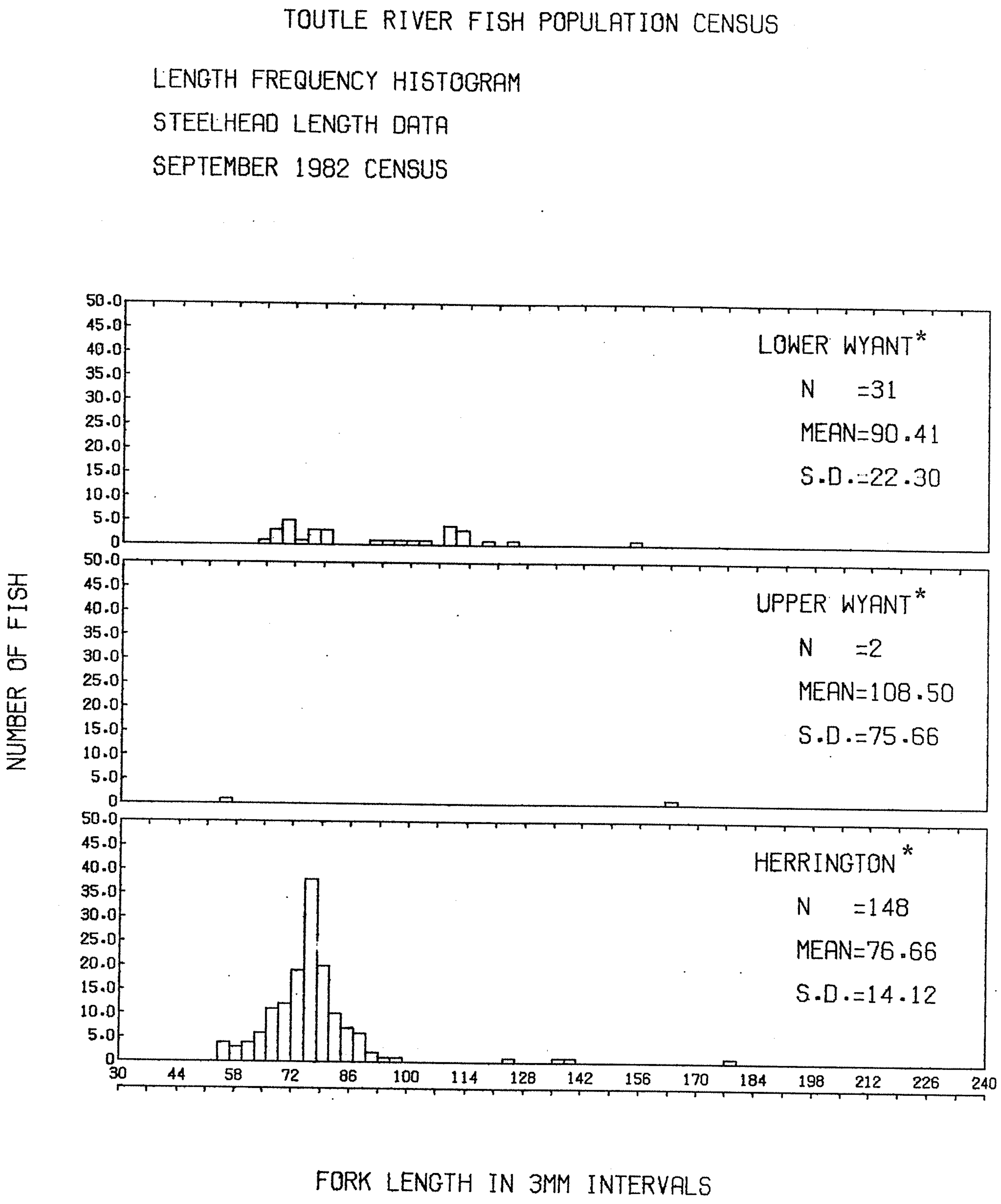

Figure 26. Length frequency histograms for steelhead trout in affected (*) tributaries of the Toutle River during September 1982.

TOUTLE RIVER FISH POPULATION CENSUS

LENGTH FREQUENCY HISTOGRAM
CUTTHROAT LENGTH DATA
SEPTEMBER 1981 CENSUS

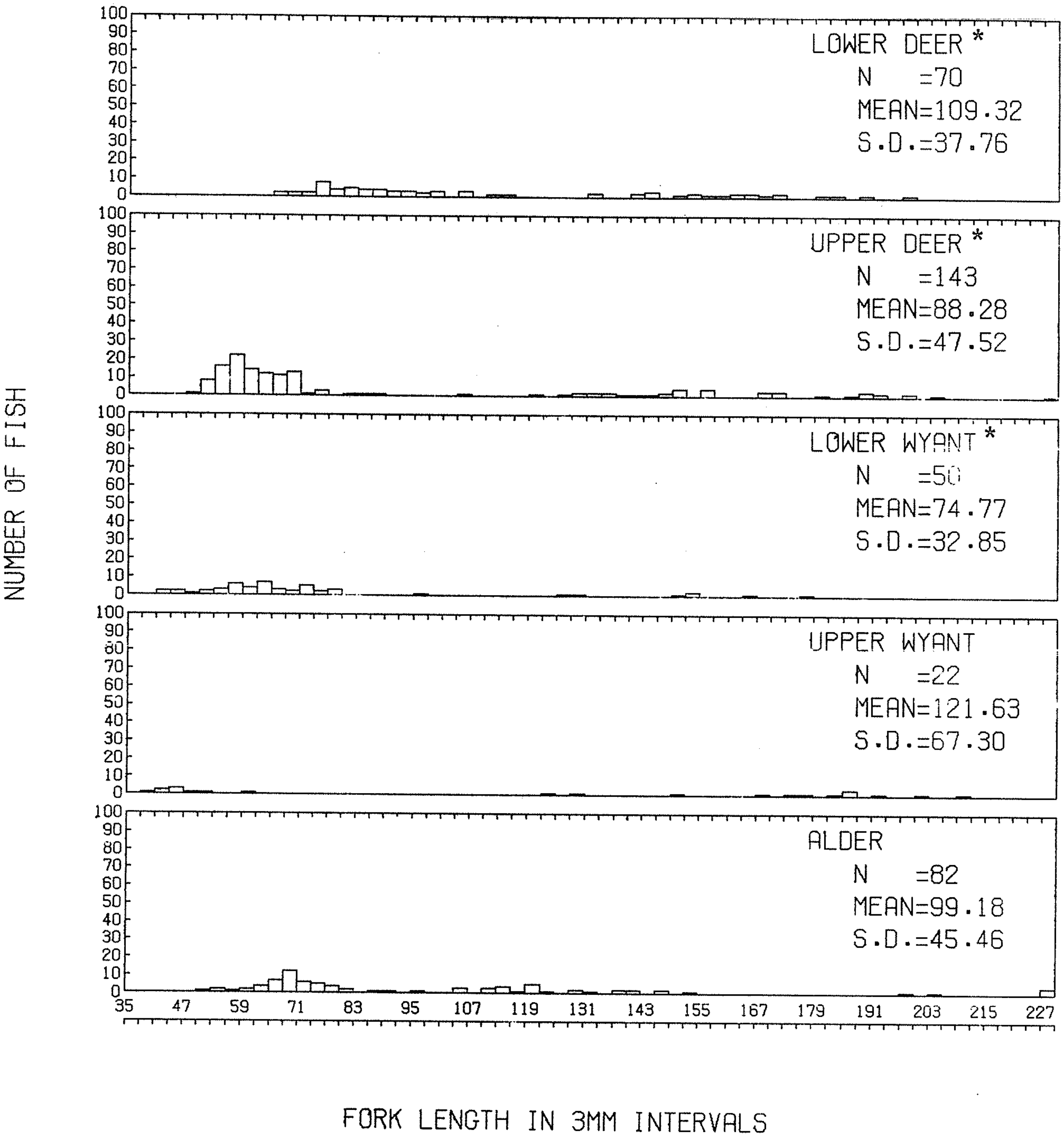

Figure 27. Length frequency histograms for cutthroat trout in affected (*) and unaffected tributaries of the Toutle River during September 1981.

TOUTLE RIVER FISH POPULATION CENSUS

LENGTH FREQUENCY HISTOGRAM
CUTTHROAT LENGTH DATA
SEPTEMBER 1981 CENSUS

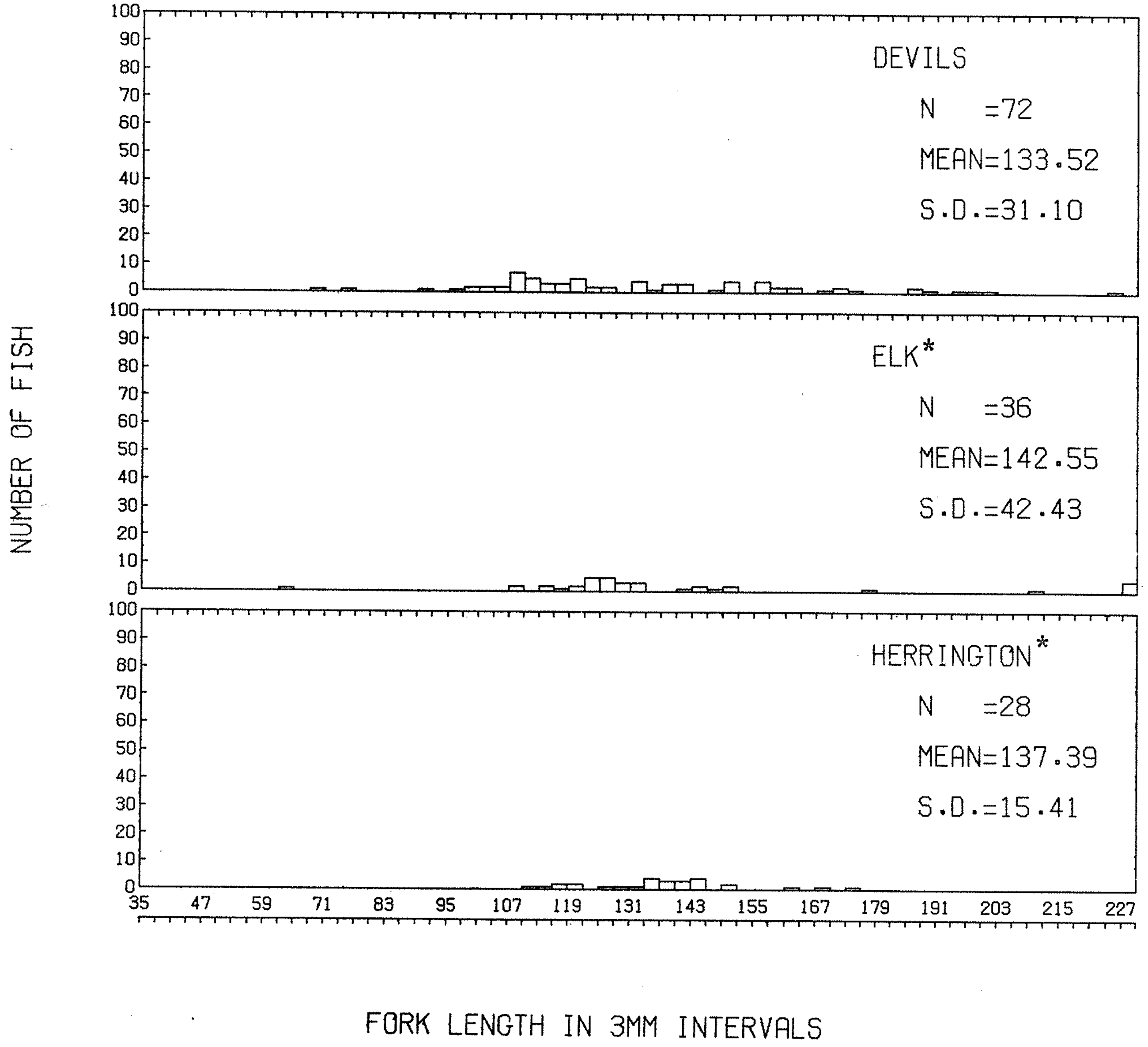

Figure 27 (continued). Length frequency histograms for cutthroat trout in affected (*) and unaffected tributaries of the Toutle River during September 1981.

TOUTLE RIVER FISH POPULATION CENSUS

LENGTH FREQUENCY HISTOGRAM
CUTTHROAT LENGTH DATA
SEPTEMBER 1982 CENSUS

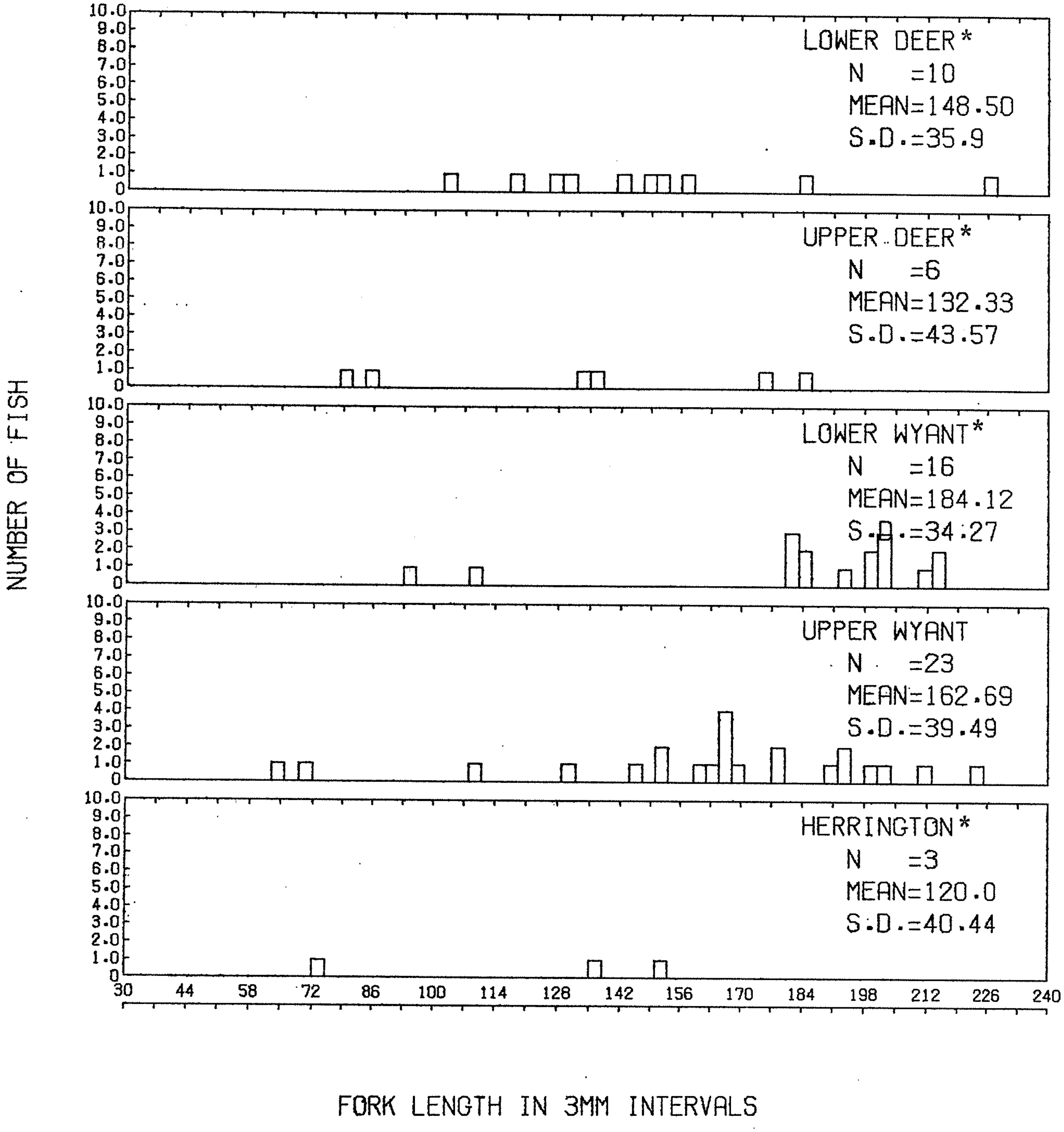

Figure 28. Length frequency histograms for cutthroat trout in affected (*) and unaffected tributaries of the Toutle River during September 1982.

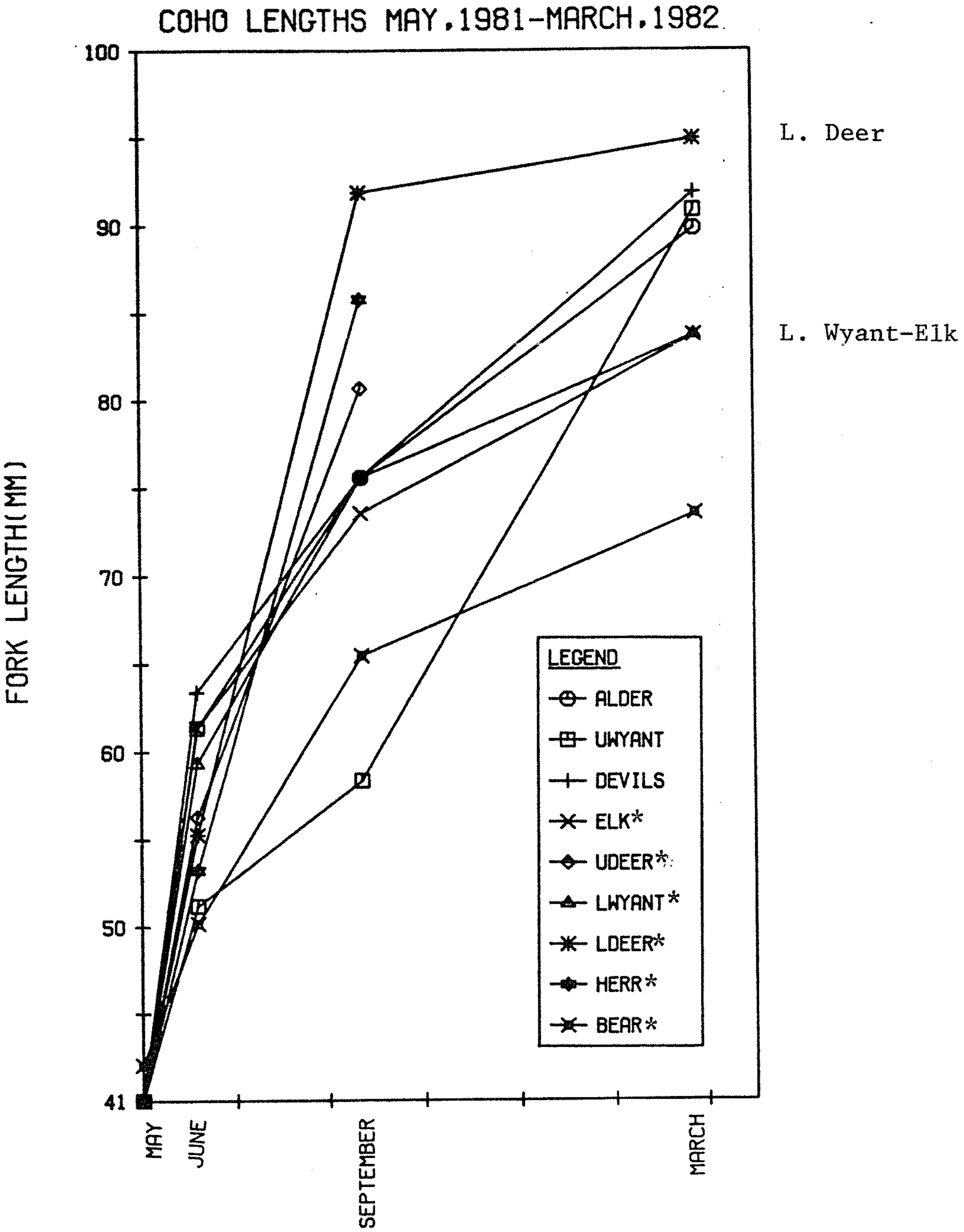

Figure 29. Mean fork length (mm) of juvenile coho salmon captured in study streams of the Toutle River June 1981-March 1982. Values for May, 1981 were the mean length of fry when planted. * indicates affected streams.

varation of sizes that ranged from 66 to 92 mm by September (Figure 29 and Appendix Table B). Coho in three streams impacted by mudflows (i.e., lower Deer, Herrington, and upper Deer) had mean lengths significantly ($p \leq .05$) greater than fish in the unaffected streams. Whereas fish lengths in the other affected streams fell within the mean range of variability observed in the unaffected streams. The large variations between streams for fish density, water temperature and food supply were thought to account for the variation in fish size. However, Pearson correlation analysis examining density dependent growth yielded no significant results. The observation in upper Deer Creek which had the highest density of fish and the third largest fish size, obscured any relationship. Correlations between growth rate and mean maximum temperature or maximum diel temperature fluctuation also were not significant. Similarily, no relationsihp was found between growth and insect abundance. However, multiple regression of summer growth rate with total area of cover and mean maximum water temperature in August was found to be significant ($p \leq .05$, $R^2 = .55$). Apparently, the interaction of space (or availability of suitable feeding stations) with temperature is important, but no single factor dominates, especially in light of between stream differences in density and possibly food supply.

In March, mean lengths of pre-smolts within the unaffected streams averaged 91 mm and were significantly different ($p \leq .05$) from the mean lengths of pre-smolts in the affected streams (Figure 29). Habitat impacts have caused a reduction in growth of fish in lower Wyant, Elk, and Bear Creeks regardless of population density. Presumably, high water temperature and lack of cover are the primary factors causing a lower growth rate. Note Bear Creek coho had the lowest growth rate, the highest water temperature, and a complete absence of cover in 1981. On the contrary, growth of fish in lower Deer Creek was greater than growth of fish in the unaffected streams despite significant habitat degradation. Lower water temperature in combination with low population density are the most probable factors that would account for the growth difference compared to the other affected streams. Unfortunately winter growth data is not available for Herrington Creek, as no fish survived, nor is data available for upper Deer Creek, as the population was not censused before the March 19, 1982 mudflow. Growth data for the 1982 year class of coho is not available. However, fish mean length in September ranged from 62 mm to 98 mm (Appendix Table B) indicating a wide variation in fish size similar to that observed in September 1981.

Mortality

Mortality in this study includes the loss of fish due to volitional or non-volitional movements of fish out of the study reach, as well as, losses due to death. During the summer period coho mortality ranged from 0% to 83% (Table 16). The observed 0% mortality is probably biased as a result of immigration, nevertheless the actual mortality is assumbed to be low. Fish in the unaffected streams excluding upper Wyant Creek had very low mortality compared to that measured in the affected streams. Therefore, mortality indicates that habitat alterations caused by the volcano are having an impact on population survival during the summer. Further examination of causal factors indicates that high water temperatures are escalating population mortality. Oversummer mortality was highly correlated ($R^2 = .80$, $p \leq .05$) with the maximum diel temperature fluctuation measured during August (Figure 30) and moderately correlated ($R^2 = .44$, $p \leq .05$) with the maximum monthly mean temperature. Thus, the loss of shade, as a result of volcanic impacts on riparian vegetation, is causing significant effects on the suitability of

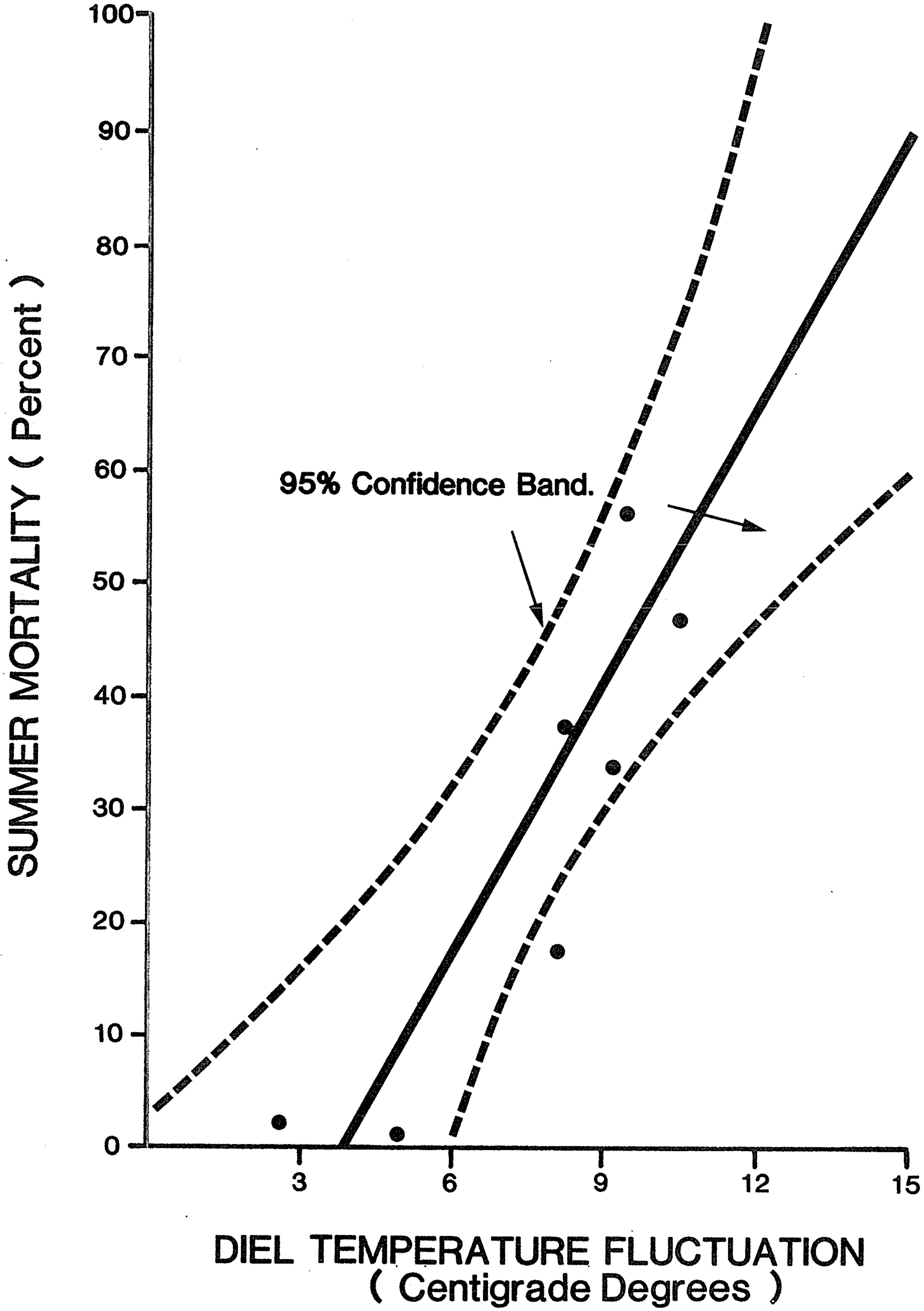

Figure 30. Regression of coho summer mortality with the maximum diel temperature fluctuations encountered in August 1981. Mortality was calculated from June-September, 1981.

summer rearing habitat. The effects of devegetation are apparent as far away from the volcano as Elk Creek (26 kms), where, the scorching heat wave killed all riparian vegetation. Higher mortalities in lower Wyant Creek and Herrington Creek are indicative of the higher water temperatures that are a result of the shallow mudflow channels and the complete absence of shade. Fish in both Deer Creek study sections are only moderately affected by the loss of riparian vegetation because of the cooling effect Deer Springs has on water temperature. On the other hand, upper Wyant Creek has a dense vegetative canopy, yet fish experienced a high summer mortality because the water temperature has been elevated by forest harvesting activities upstream of the study reach.

Mortality of coho between September and March increased among affected streams with the increase in severity of impact (Table 16). Winter mortality ranged from 62% to 83% in the unaffected streams and 82% to 100% in the affected streams. Unstable channel morphology, high suspended sediment levels and lack of cover structures in the mudflow channels are associated with the highest levels of mortality during winter. Whereas, Elk Creek, which had channel morphology and cover conditions similar to the unaffected streams also had a lower overwinter mortality. Correlation analysis with channel morphology was not attempted because of the difficulty of reducing the data to a usable statistical parameter, and suspended sediment data was not collected. But, regression analysis with cover indicated that winter mortality is significantly related to the area of cover ($R^2 = .57$, $p \leq .05$) in the study streams (Figure 31).

Population Stability

The interpretation of population abundance and mortality results can be

Table 16. Mortality estimates for juvenile coho salmon in affected (*) and unaffected Toutle River tributaries, 1981.

Stream	Oversummer mortality (%) (June-September)	Overwinter mortality (%) (September-Winter)
Alder	0	62
Upper Wyant	54	83
Devils	2	64
Upper Deer*	17	NA
Elk*	36	82
Lower Wyant*	45	97
Lower Deer*	33	95
Herrington*	83	100
Bear*	NA	90

NA - Data not available. No estimate made in Bear Creek in June. No estimate possible in Upper Deer Creek in March due to mudflow of March 19, 1982.

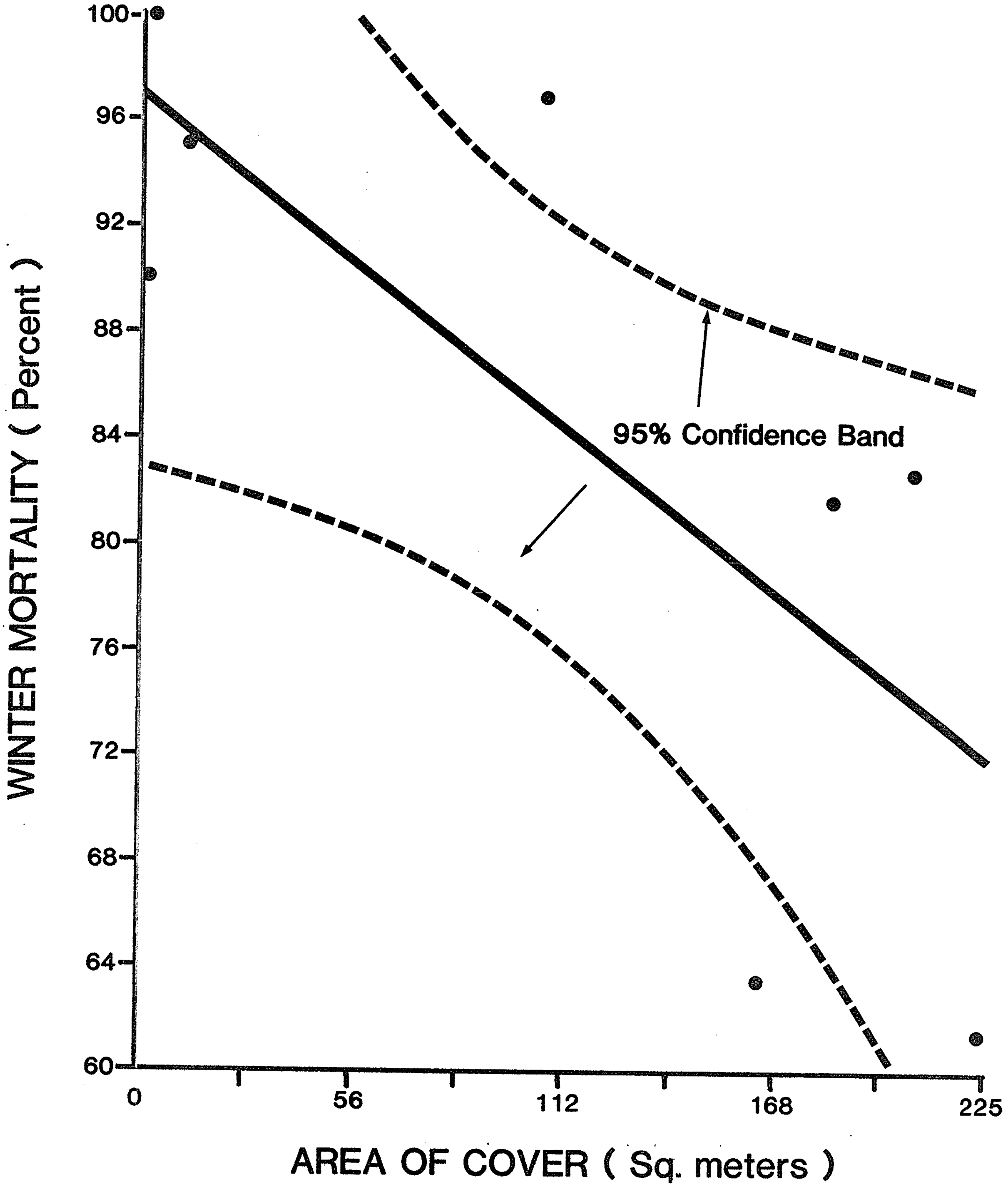

Figure 31. Regression of coho overwinter mortality with area of cover for tributaries of the Toutle River. Mortality calculated for September 1981 to March 1982.

misleading because of fish immigration into and emigration from the study sites between sample periods. The greatest potential for error occurrs during winter when frequent freshets can displace fish observed in September from a study reach. Then, new individuals from another reach may replace the original residents before the March population census. Thus, it is possible that the spring census data could incorrectly indicate little or no change in population abundance or mortality. In order to verify the data trends stated, the number of fish recaptured in March that were branded in the previous September were analyzed.

The recovery of branded fish during March indicates that the unaffected streams and Elk Creek retained more September fish than the more severely impacted stream (Table 17). Those streams with the largest March populations contain the greatest fraction of coho that were branded in September (R^2 = .85, $p \leq .05$). Furthermore, a large percentage of the pre-smolts present in March in the unaffected streams and Elk Creek were coho that resided in the study reach throughout the winter (Table 18). Whereas, few of the presmolts produced in the impacted streams except lower Deer Creek result from summer populations. Instead most of the coho in these streams were composed of immigrants. Thus, the coho population present in March is not entirely composed of September residents. But the abundance of September residents present in March parallels the trend in total population abundance indicating our interpretation of population results is correct. Similarily the overwinter mortality of September residents (Table 18) is greater than for the total population (Table 16), but the trends between affected and unaffected streams are similar.

A strong relationship is also found between habitat characteristics and population stability, measured as a fraction of the September brands present

Table 17. Number of brands applied to coho salmon in September 1981, and recaptured in March 1982, for affected (*) and unaffected tributaries of the Toutle River.

Stream	Brands applied September 1981	Brands recaptured March 1982 1st pass	Capture Efficiency	Total[1] September brands recaptured (expanded)	Fraction[2] September brands recaptured (expanded)
Alder	397	14	.17	82	.21
Upper Wyant	230	8	.51	16	.07
Devils	144	9	.36	25	.17
Elk*	353	7	.27	26	.07
Upper Deer*	Data not available due to March 19, 1982 mudflow				
Lower Wyant*	84	0		0	.00
Lower Deer*	99	2	.41	5	.05
Herrington	8	0		0	.00
Bear*	311	1	.83	1	.003

[1] Total September brands recaptured (expanded) = $\frac{\text{number of brands caught in 1st pass}}{\text{capture efficiency}}$

[2] Fraction of September brands recaptured (expanded) = $\frac{\text{total September brands recaptured (expanded)}}{\text{brands applied in September}}$

Table 18. Contribution of September 1981 residents to the March 1982 population, number of immigrants, and overwinter mortality for affected(*) and unaffected tributaries of the Toutle River.

Stream	Presmolts produced [1] by September residents	March population estimate	Percent of March estimate comprised of September residents	Number of immigrants	Percent over-winter mortality of September residents
Alder	114	207	55	93	79
Upper Wyant	25	62	40	37	93
Devils	41	88	47	47	83
Elk*	34	86	39	52	93
Upper Deer*	Data not available due to mudflow of March 19, 1982				
Lower Wyant*	0	3	0	3	100
Lower Deer*	8	8	100	0	95
Herrington*	0	0	0	0	100
Bear*	1	30	3	29	99+

[1] Presmolts produced by September residents = fraction of September brands recaptured (expanded) x September population estimate.

in March. A significant relationship ($R = .73$, $P \leq .05$) was found between total area of cover and population stability. Further, the greatest fraction of September brands occurs in the unaffected streams. It appears that population stability is governed to a large extent by the presence of deep pools and cover habitat that function as refuge areas during winter freshets. The mudflow streams have little refuge habitat, cannot support many fish overwinter, and are not very attractive areas for immigrants.

Smolt Survival Study

Attempts to capture marked smolts in the fyke net located at the highway 99 bridge proved to be near impossible. Large concentrations of floating debris caused frequent breakdowns that resulted in poor data for two of three experiments. The most successful experiment involved the release of 4,000 marked coho smolts into Alder Creek on May 18, 1982. The fyke net was operated from May 20th through May 25th before a major breakdown occurred that terminated the experiment. The fyke net was not fished on May 18 or 19 because catches from previous experiments indicated that the smolts would not migrate immediately after their release. During the experiment 1,000 smolts were released upstream of the fyke net to test capture efficiency. The subsequent catch of 135 fish resulted in a capture efficiency of 13.5%.

During the period the fyke net was fishing, 195 coho were captured of the 4,000 test fish released from Alder Creek (46 km upstream). However, the fyke net could not be fished continuously, as periodic tearing of the net from entangled debris created periods when the operation was stopped for repairs. Therefore, in order to account for periods longer than one-half hour that the net was inoperable an estimate of the numbers of fish missed was calculated. The number of fish missed was assumed to be equal to:the average of the number of smolts captured in the preceding and subsequent two hour sample periods, multiplied by the fraction of a sample period that the net was not fishing. Expansion of the raw data to include periods of equipment breakdown results in a total estimated catch of 225 smolts during the sample period (Table 19). Based on a catch efficiency of 13.5%, it was estimated that 1,667 smolts or 42% of the coho released reached the mouth of the Toutle River. Since the experiment was terminated before all marked fish had dispersed and the daily catch had not declined, it is suspected that survival during outmigration was much greater than 42%.

Information on suspended sediment from the U.S. Geological Survey shows that coho migrated through waters in the North Fork Toutle and Mainstem Toutle with suspended sediment concentrations that averaged 5,000 mg/l (Table 20). Physical examination of captured fish indicated that the typical buildup of mucus on fish gills as a result of irritation from sediment was not apparent. Given the river discharge levels observed during the experiment, fish could migrate from Alder Creek to Highway 99 bridge in less than nine hours if fish traveled with the river flow. Therefore, fish probably moved quickly through the river when migrating and minimized their exposure time to high suspended sediment levels.

A summary of all fish captured in the fyke net during May 20-25 indicates that wild coho, steelhead and cutthroat smolts were migrating from the Toutle River (Table 21). The coho smolts are progeny of adults that returned to the Toutle River in autumn 1980 subsequent to the May 18th eruption. Therefore natural reproduction in the Toutle drainage is occurring since the eruption, but the low numbers of smolts indicates that either adult escapement is low or juvenile survival is low, or both. The presence of non-salmonid species (i.e., peamouth, bluegill, yellow bullhead, and yellow perch) is probably due

Table 19. Catch of marked coho smolts in fyke net operated during May 20 to May 25, 1982 in the Toutle River at Highway 99 bridge.

Time	5/20	5/21	5/22	5/23	5/24	5/25	Total (raw/expanded value)
AM							
12:00- 2:00		1	5*	1	36	12	50/55
2:00- 4:00		5	5*	1	10*	1*	6/22
4:00- 6:00		7	7	0	7	3	24/24
6:00- 8:00		2*	7*	0	13	1	14/23
8:00-10:00		2	7	6	2	0*	17/17
10:00-12:00		5	**	6	1	0*	12/12
PM							
12:00- 2:00		3	3	2	1		10/10
2:00- 4:00		5	3	1	6		15/15
4:00- 6:00		1	2	9			12/12
6:00- 8:00		6	1	0	7		14/14
8:00-10:00	2	**	3	**	5		10/10
10:00-12:00	0*	4	**	6	1		11/11
Total (raw/ expanded value)	2	39/41	26/43	32/32	79/89	17/18	195/225

*Indicates expanded value. See text for explanations of expansion.

**Time of sets are not precise. If set ended closer to an odd hour, no catch was tallied for nearest even hour period.

Table 20. Mean river discharge and mean suspended sediment concentration in the Toutle River at Kid Valley and at Highway 99 Bridge during May 1982.[1]

	Kid Valley		Highway 99 Bridge	
Date	Discharge (cfs)	Susp. Sed. (mg/l)	Discharge (cfs)	Susp. Sed. (mg/l)
May 20	1160	5428	1760	3998
21	1330	5569	1920	4629
22	1500	5679	2190	5581
23	1390	4796	2070	4652
24	1340	4190	2020	4584
25	1390	4263	2410	6608
Mean	1352	4987	2062	5008

[1] Information computed from provisional data, U.S. Geological Survey.

to fish moving out of Silver Lake through Outlet Creek (Figure 1) which is located 14.5 km upstream from the Highway 99 Bridge.

Table 21. Summary statistics for fish captured in fyke net operated during May 20 to May 25, 1982 in the Toutle River at Highway 99 bridge.

Species	Total number captured	Mean length (mm)		Standard deviation	Mean weight (g)		Standard deviation
Wild coho	88	118	(86)[1]	16.0	18.9	(80)[1]	7.9
Test coho	195	129	(100)	26.8			
Efficiency coho	135						
Steelhead kelts	2	750	(2)	0			
Wild steelhead *Salmo gairdneri*	59	165	(56)	24.9	44.1	(48)	18.7
Hatchery steelhead	1280						
Wild cutthroat *Salmo clarki*	36	172	(36)	16.6	45.7	(32)	13.0
Peamouth *Mylocheilus caurinus*	226	189	(182)	33.9	169.6	(43)	69.7
Bluegill *Lepomis machrochirus*	20	172	(20)	10.4	137.1	(17)	23.8
Yellow bullhead *Ictalurus natalis*	1	275	(1)				
Pacific lamprey *Entosphenus tridentatus*	8						
Yellow perch *Perca flavescens*	1	73	(1)				

[1] Number of fish measured or weighed.

DISCUSSION

Adult Migration

Following the eruption of Mount St. Helens many adult salmon destined for the Toutle River did not return to their natal stream. Significant numbers of fall chinook and coho returned to other Columbia River tributaries and the Cowlitz Hatchery located upstream from the confluence of the Cowlitz River with the Toutle River. Factors that could account for the observed straying include: a loss of the homing cue in the Toutle River water, damage to olfactory sensory epithelium from exposure to high concentrations of suspended sediment, or an avoidance to harsh water quality conditions. Our study was not designed to examine this question but our observations are helpful in providing an explanation. Water quality characteristics that salmon use for a homing cue apparently remained discernable after the eruption. In 1981, hundreds of spring chinook were observed returning to Deer Creek where they were released as fry. Toutle coho were also observed at the South Fork Toutle trap operated by the Washington Department of Game (Shuck and Kurose 1982). Therefore, as a result of these observations we concluded that homing was not altered by the loss of a homing cue in the Toutle River. Histological examination of olfactory sensory epithelium was not performed, thus it is unknown if sediment caused any damage to sensory capabilities. Laboratory studies conducted by Brannon et al. (1981) showed that the sensory epithelium was not damaged in chinook exposed to a sluary of volcanic ash (650 mg/l) for one week. Sediment concentrations in the Toutle River were often an order of magnitude greater and migration periods were probably greater than one week. Thus, it is probable that adults received damage to sensory organs. But if a fishes sensory capabilities were damaged while the fish was in the Toutle River, it is unlikely that the impared individual would leave because it could no longer detect the difference between suitable or unsuitable water.

The most likely cause for fish straying is fish avoidance in response to the high suspended sediment concentrations in the Toutle and lower Cowlitz Rivers. Brannon et al. (1981) demonstrated in laboratory experiments that adult chinook had a reduced preference for home water containing 350 mg/l of suspended volcanic ash compared to an alternative choice of clear non-home water. In addition, Brannon et al. found that the presence of volcanic ash in the water reduced the proportion of fish moving upstream, to make a choice from 78% to 57%. Thus, fish may delay their migration. Given these results, it is not surprising to find large numbers of Toutle River fish straying to other streams. The average daily concentration of suspended sediment at the mouth of the Toutle River ranged from 3300 mg/l to 75,000 mg/l and 300 mg/l to 33,000 mg/l during the fall migration period (September-November) in 1980 and 1981, respectively (U.S. Geological Survey, provisional data). Sediment concentrations in the Cowlitz River were lower (600-18,000 mg/l in 1980 and 28-8,700 mg/l in 1981 at Castle Rock) than the Toutle River, yet, remained high enough to cause fish straying. The high sediment concentrations in the South Fork Toutle River were also considered to be a primary factor causing a delay in the timing of fish migrations observed by Shuck and Kurose (1982).

The implication of fish straying and delays in fish migration can be significant to recovery of salmon populations in the Toutle River. After the eruption of Mount St. Helens, habitat damage in the Toutle drainage has reduced reproductive efficiency of the system. Consequently, the offspring of the spawners that returned to the Toutle are subject to a high mortality rate. If enough recruits are not produced to replace the parent population, the population will decline. Straying in the second generation spawners would compound the declining trend causing the population to reach a level where it may never recover. Thus more spawners are needed to counteract the low reproductive efficiency of the Toutle River.

Concentrations of sediment are expected to remain high in the Toutle River for 35 years as a result of erosion from the avalanche deposit in the upper North Fork Toutle River (Mr. Robert Willis, U.S. Army Corps of Engineers, personal communication). Therefore, salmon will continue to stray to other streams, especially later returning stocks (i.e., October or later) that migrate during the autumn rainy period when river turbidity is high. Fish that return during the late summer low-flow period (i.e., spring chinook and early coho) will be more successful in reaching the spawning habitat in the Toutle River and will probably become the first stocks to recover after the eruption. River dredging and sediment control measures that cause elevated suspended sediment levels should be curtailed during periods of naturally low turbidities that would coincide with peak salmon migration periods.

Natural Production and Embryonic Survival

Natural reproduction of salmonids was unexpectedly high despite high concentrations of intragravel sediment caused by mudflows in the Toutle River. Embryonic survival to the emergence phase is known to be inversely associated with the amount of intragravel sediment present (Koski 1966; Hall and Lantz 1969; and Phillips 1970). High concentrations of fines (sizes $\leq$ 0.850 mm) in the gravel reduce intragravel permeability causing a reduction in oxygen supply (McNeil and Ahnell 1964) that subsequently may result in embryo mortality. Mean concentrations of sediment in spawning gravels of Studebaker

Creek, lower Wyant Creek, and Cline Creek ranged from 18.3 percent to 33.5 percent (Table 7) during 1982. The predicted survival to emergence for coho eggs buried in gravel with 18 percent and 33 percent fines is less than 30 percent and less than 15 percent, respectively (Tagart 1976). However, large numbers of fry were observed in these streams. Similarily, high survival of eggs to hatching was measured in the egg plant experiment.

Factors that may account for the observed high egg survival are high intragravel permeability and a sufficient dissolved oxygen supply. Unfortunately, neither parameter was measured during the study. But, field observations of substrate characteristics provide evidence that indicates a high intragravel permeability was present in the mudflow streams. All of the mudflow streams located in the North Fork Toutle, lower South Fork Toutle, and lower Mainstem Toutle valleys contained large areas of quicksand in the stream bed and banks. The quicksand areas were very soft and would not support the weight of a person walking across a stream during 1980. Following winter (1980-81), the size of most quicksand areas were reduced and an armor layer formed across the surface of the streambed making it possible for a person to walk across a stream. The substrate below the cement-like armor layer was very soft and had a high water content that was under pressure. When steel posts driven into the stream bed of lower Wyant Creek were removed during July 1982, water fountains were observed at each post hole. Numerous steelhead and coho redds were observed during the previous spring and autumn in the vicinity of the upwelling areas. Adult spawners must have detected the upwelling areas over the quicksand and were induced to construct redds despite the high sediment levels in the gravel. The high artesian like flow of water must have provided a high dissolved oxygen supply and subsequently maintained a high egg survival. Quicksand was present below the armor layer at all study sites used for the egg plant experiment except Herrington Creek. Perhaps the lower egg survival measured at Herrington Creek (Table 9) was due to a low intragravel permeability.

Observations of natural production and results of egg plant experiments indicate that survival during incubation was not impacted in all areas where mudflows smothered the stream bed. The high water content of mudflow deposits has temporarly created strong upwelling conditions within the stream bed that counteracts the negative effects of sediment on embryo survival. The magnitude and duration of upwelling in mudflow streams is decreasing as mudflow deposits drain and harden. During summer 1982, smaller areas of quicksand were present than were observed in 1981. Therefore, the trend in survival to emergence should decline in response to the high concentration of sediment present, followed by a slow recovery as sediments are scoured out of the impacted streams.

Juvenile Rearing

Effects of Water Temperature

Extremely high water temperature is the single most important factor limiting juvenile coho production during the summer months in the Toutle River drainage. Water temperature in four of the impacted streams equaled or exceeded 25°C (considered the upper incipient lethal level for coho, from Brett 1952) for short periods of time during summer 1981 and 1982. Significant correlation between juvenile mortality and the maximum diel temperature fluctuation suggests temperature is the causal factor. But, in streams receiving lethal temperatures many fish survived through the summer, despite predictions from Brett (1952). Factors that could account for survival are: fish have a greater resistance when acclimated to a fluctuating temperature regime, fish may be moving to a temperature refuge, or both. Examination of fluctuating temperature regimes by Golden (1978) showed that cutthroat trout can withstand exposures to large diel cycles up to 13-27°C daily variation with 10% or less mortality over a one week period. A similar study on coho found the total amount of time above the incipient lethal level is the determinant for thermal resistance in a fluctuating environment, and effects may be accumulated over a period of days (DeHart 1975). As long as temperature did not exceed 28°C, mortality was not a result of the temperature reached, but rather as a result of the amount of time spent above 25°C. The temperature recorders used in this study were not accurate enough to measure the amount of time temperatures were above 25°C. However, the magnitude of the maximum diel fluctuation is indicative of the amount of time water temperature exceeded the lethal level.

Streams with the greatest diel fluctuation suffered the greatest loss of fish despite the magnitude of other environmental perturbations. Therefore, we assume fish mortality occurred as a result of high temperature and complete population mortality may have been prevented by the temperature acclimation mechanism described.

Fish movement cannot account for fish survival as movement would probably result in fish losses in the present study. Streams with the highest summer temperatures (i.e., Bear Creek and Herrington Creek) had blockages within several hundred meters of the study reach that would have prevented juvenile fish from moving upstream or returning from downstream. Movement of juveniles into the main river were probably unsuccessful, as river temperatures were often equal to or greater than most tributary streams. Shade from riparian vegetation is the primary factor controlling water temperature and subsequently the survival of juvenile salmonids during summer.

Effects of Cover and Channel Morphology

During the summer, the overriding effects of temperature and the probable difference in predation among study streams, act to mask any habitat relationships with coho populations. But, during winter the presence of instream cover structures and channel morphology were found to have a significant effect on population abundance and overwinter mortality. The high correlations between area of wood related cover and spring population abundance (R^2 = .62) or overwinter mortality (R^2 = .57) suggest that recovery of salmonid populations in the Toutle drainage may be limited by the recovery of woody debris inputs. Residual deposits of woody debris observed in impacted streams after the eruption (e.g., Lower Wyant, Deer and Elk Creeks) were uncovered by channel degradation and were readily utilized by rearing juvenile salmonids.

Residual woody debris influenced the routing of water through the mudflow impacted channels resulting in greater diversity in channel morphology. Woody debris provided a resistant structure to erosion and caused the formation of lateral scour pools (e.g., Herrington Creek) and plunge pools (e.g., lower Deer and lower Wyant Creeks) that provided habitat for juvenile coho. The functional importance of woody debris in shaping channel morphology may be as important to rearing salmonids as the refuge provided by debris structures. Therefore dead wood debris present after the eruption of Mount St. Helens will play a vital role in habitat recovery and survival of salmon populations in the Toutle River drainage.

Effects of Sediment During Smolt Outmigration

Results from the fyke net data indicate encouraging expectations of downstream survival of coho smolts in the Toutle River system. Wetherall (1971) estimated survival rates for migrating chinook smolts to be 37-99% over a distance of 21 km. He reports that higher survival was associated with high streams flows. The minimum estimate of 42% for migrating coho smolts in the Toutle River would fall into this range. In contrast to Wetherall's findings, it is most likely that survival would decrease as stream flows increase in the Toutle system. Suspended sediment concentrations have reached 300,000 mg/l in the North Fork Toutle River following storms subsequent to the eruption. Noggle (1978) reports that for wild coho, 96 hour LC50's are 1200 mg/l in the summer, and 30,000 mg/l in the winter. Stober et al. (1981) calculated 96 hour LC50 values of 509 mg/l for coho smolts in live-box bioassays in the Toutle and Cowlitz Rivers. Whereas, laboratory static bioassays with volcanic ash produced an average 96 hour LC50 of 28,184 mg/l. The sediment concentrations facing coho smolts in this study was approximately 5000 mg/l, which is in the middle of the lethal range found by Stober et al. The short exposure time (9 hrs) of the smolts in this study is the most likely factor accounting for the relatively high survival. If smolt migration does not coincide with a spring storm event, relatively high survival during outmigration can be expected.

Habitat Recovery

Sediment and Channel Morphology

Fish habitat recovery to pre-eruption conditions is dependent upon the reduction in sediment load, establishment of riparian vegetation, and development of fish cover structures (e.g., boulders, logs, debris jams, overhanging vegetation, and undercut banks). In the tributary habitat studied the rate of channel development and stability were directly related to the depth of channel inundated by the mudflow or debris avalanche. Old channels buried by mudflows backing up the stream (e.g., lower Wyant Creek) had scoured down to pre-eruption levels by summer 1982, and will be the first channels to recover from volcanic impacts. The increase in pool frequency and increased pool depth had an associated increase in area of water with low velocity, and an increase in area of larger substrate. This increased diversity in habitat parameters, especially pool development, will increase the probability of survival for juvenile coho salmon.

New channels developing on mudflow or avalanche debris materials are recovering at a slower rate than the old channels discussed. The depth of mudflow and avalanche deposits is too great in many cases for the channel to scour down to pre-eruption base level. Instead the channels are developing a new base level in equilibrium with the new levels of the north and south forks of the Toutle River. Channel stability is developing as smaller substrate particles (sand & silt) are removed and gravel-cobble size material form a new stream bed. By summer 1982, the increased area of cobble and rock substrate in Herrington Creek suggests that the rate of channel degradation will decrease and the channel will begin to stabilize at a new base level. A similar process is occurring in Bear Creek on the avalanche deposit, however the rate of recovery is much slower than Herrington Creek because of the smaller size composition of the volcanic deposits. Since stable pools were beginning to form in Herrington Creek by summer 1982 a diverse channel morphology (alternating pool and riffle topography) could be expected within several more years. On the other hand, the lack of channel heterogenity and low stability observed in Bear Creek prevents an estimate of time for habitat recovery. The U.S. Army Corps of Engineers estimates that channel scour by the North Fork Toutle River will stabilize in 30 to 35 years. Therefore, we could assume that Bear Creek and similar tributaries on the avalanche deposits would form stable channels in a similar time frame.

Riparian Vegetation, Shade, and Cover

The recovery of riparian vegetation will be critical for the recovery of fish habitat in tributaries of the Toutle River. As shown, the vegetative canopy provides shade for temperature control which is vital for juvenile coho survival during summer. Also, the roots and stems of riparian vegetation resist channel widening and promote the development of undercut bank habitat. Wind throw of trees and bank undercutting of trees supply large organic debris to streams providing cover structures that are necessary for overwintering juvenile salmonids.

Because stream water temperature is primarily a function of shade from riparian vegetation, in the absence of ground water seepage (i.e., springs) (Brown and Krygier 1970), the rate of tree regeneration will determine the rate of recovery to a pre-eruption temperature regime. The height of riparian trees required to shade small third to fourth order tributaries in the Toutle drainage can be computed from a prediction equation developed by Brown (1971). Using the temperature records from Bear Creek (N.F. Toutle) and Devils Creek (Table 10) as representative of impacted and unimpacted temperature regimes, respectively: a tree height of 4.2 m would be required to provide temperature control. The time require for tree regeneration to reach 4.2 m would depend upon the rate of seed recolonization, species composition, and quality of soil (Virginia Dale, unpublished data). Given that riparian vegetation is beginning to recolonize mudflow areas; tree growth rate data for mudflow soils projects that Alders will require six years and Douglas fir 20 years to reach sufficient height to provide temperature control (Figure 32, from Virginia Dale, unpublished data). The temperature of the larger mainstem rivers in the Toutle drainage is controlled by the temperature of incoming water. Therefore, riparian regeneration along tributary streams is the key to reducing water temperature for the entire Toutle drainage.

The distribution and survival of juvenile coho in the newly disturbed environments were found to be closely associated with the presence of riparian vegetation and instream concentrations of large organic debris (LOD). The recruitment of LOD and re-establishment of streambank integrity is vital to the recovery of stream habitat. Therefore the time required for habitat recovery will depend upon the regeneration rate of riparian trees. In third and fourth order streams thickets of brushy type vegetation that hung low (<1 m) over the water surface provided fish cover and reduced streambank erosion. The majority of instream woody debris was composed of either a large rootwad or tree stems ranging 25 cm to 35 cm in diameter. The re-establishment of bushy type vegetation is part of the initial phase in forest recovery, and would probably colonize riparian areas in less than 10 years, depending upon distance to seed source. On the other hand, recruitment of LOD in stream areas where residual debris is not available will take a longer time. Based on tree growth data developed by Virginia Dale (unpublished data), 50-75 years are required for Alder grown on mudflow substrate to become large enough to

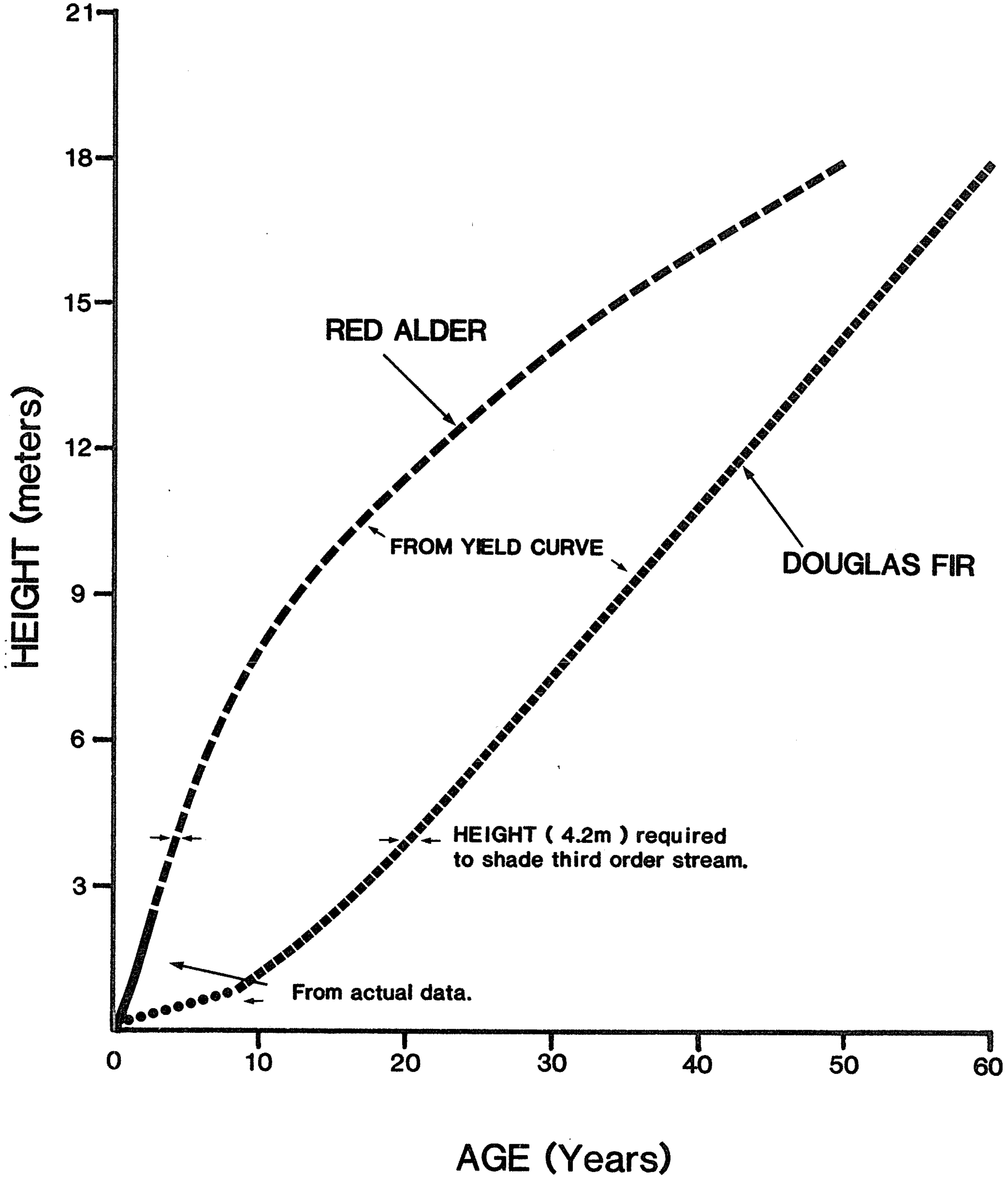

Figure 32. Projected tree height versus age relation for red alder and Douglas fir grown on mudflow substrate for 32 months (Virgina Dale, Oak Ridge National Laboratory, unpublished data). Relationship after 32 months is from yield tables: for red alder the relationship is from Worthington, et al. (1960) using site index 60, and for Douglas fir the relationship is from McArdle et al. (1949) using a site index of 80.

provide refuge cover (Figure 33). Larger mainstem rivers will require larger trees that will not be available for an estimated 75-100 years. Therefore the lack of instream cover provided by LOD will be a limiting factor for refuge habitat recovery in the Toutle watershed.

Effects of Human Intervention

Habitat recovery in the Toutle drainage is a function of both natural forces and human intervention. Therefore, the recovery of fish habitat will be closely associated with watershed management activities. The Toutle watershed is intensively managed for timber production and a large-scale flood prevention project is being conducted in the North Fork Toutle River.

Sediment production from the tributary streams and hillside erosion of blast deposits is being slowed by timber salvage operations and tree-planting programs. The harvesting of blown-down timber has proved to be an effective erosion prevention measure, because soil disturbance during yarding mixes blast deposits into the mineral soil resulting in greater water infiltration rates and less erosion (Collins, et al., 1982; Fiksdal 1981). Tree planting along the North Toutle River began in 1981 and was continued for most of the impacted tributaries (outside of the National Volcano Monument) during 1982 (John Keatley, Weyerhaeuser Co., and Tom Robinson, Wash. Dept. Nat. Res., pers. commun.). Revegetation of the riparian zone will reduce bank erosion, stabilize stream banks, and eventually provide stream temperature control from shading.

Salvage of blown-down timber from stream channels has both positive and negative effects on habitat recovery. Removing the large woody debris opens the channel for fish passage and accelerates the flushing of blast deposits leading to recovery of pool and riffle habitat. On the other hand, removal of all large woody debris can destablize the stream channel that results in a

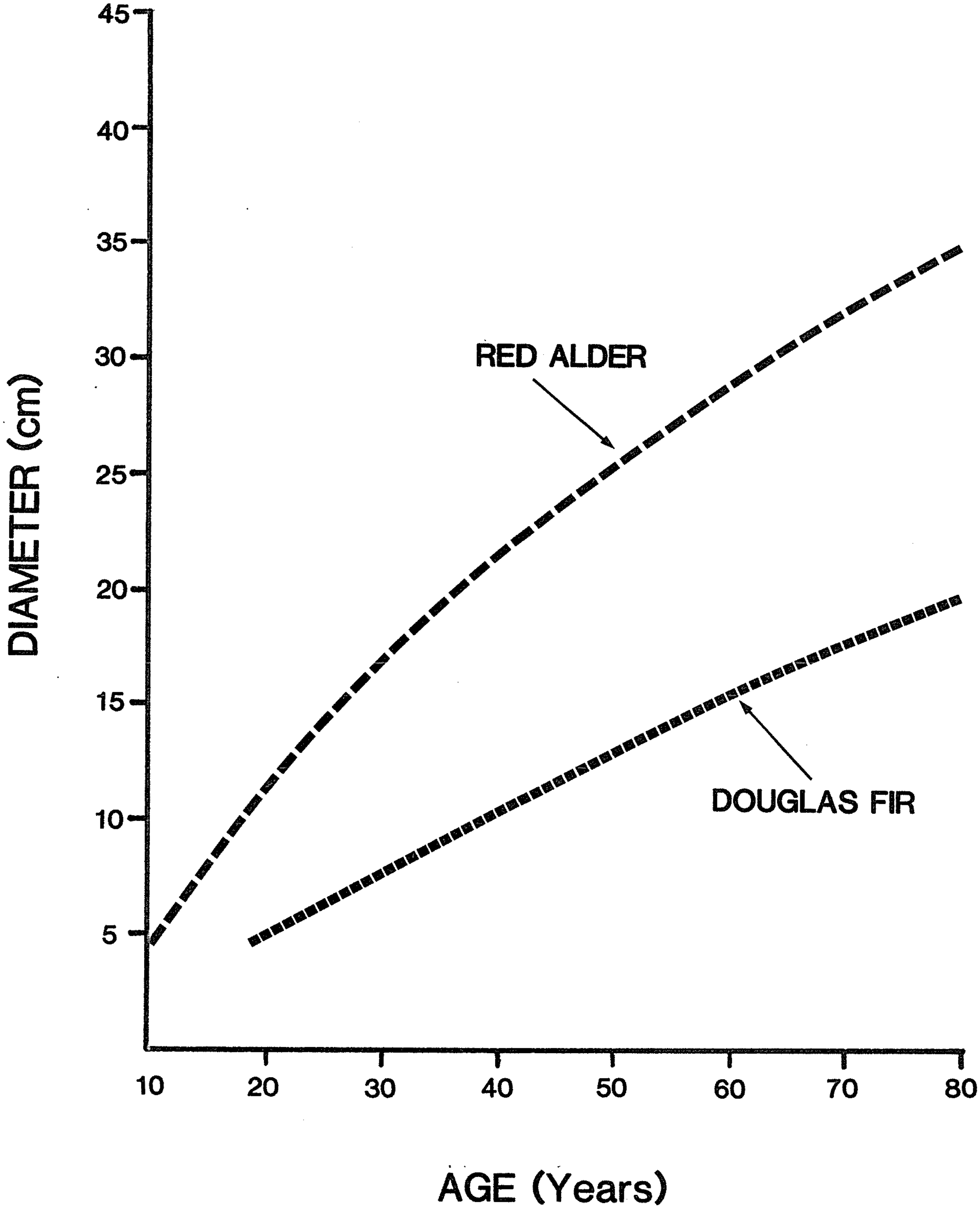

Figure 33. Project tree diameter versus age for red alder and Douglas fir from yield tables: for red alder the relationship is from Worthington et al. (1960) using site index 60, and for Douglas fir the relationship is from McArdle et al. (1949) using a site index of 80.

complete loss of pools and riffles. The logs and debris jams function as energy dissipators, causing the formation of riffles and pools, and providing stream bed stability. Consideration for the effects of timber salvage operations on habitat recovery are now being addressed by the State Departments of Fisheries and Game (Steve Keller and Bob Lucas, pers. commun.). However, more than 50% of the downed timber was already salvaged before this problem was recognized. New sources of LOD will not be available until riparian vegetation has recovered. Intensive timber harvesting with a 50-75 year rotation cycle will preclude future inputs of large old-growth timber unless provisions for debris management are scheduled into future harvest plans.

Following the eruption of Mount St. Helens the U.S. Army Corps of Engineers initiated a massive effort to reduce the potential for flooding in the Cowlitz Valley by trapping and removing large volumes of sediment from the Toutle River. Debris retention structures and sediment stabilization basins proved effective in reducing sediment output from the Toutle River (U.S. Army Corps of Engineers 1981). However the large debris retention structure on the North Fork Toutle River blocked fish passage, until it was breeched in march 1982, and poses an obstacle to channel meandering and natural channel development. During winter 1982-83, the dam deflected high streamflows into the lower Deer Creek valley resulting in severe scour and destruction of anadromous salmonid habitat in Deer Creek. The continuous operation of sediment stabilization basins in the lower river will prevent habitat recovery in these reaches and increase suspended sediment loads than could inhibit adult migrations or affect outmigrating smolts. Habitat recovery following completion of sediment control projects will be slow, unless measures are taken to restore a natural channel configuration.

The proposal to construct a large retention dam in the North Fork Toutle River above the confluence with the Green River would interrupt upstream fish migration and eliminate a significant amount of salmon habitat. Although habitat in the Toutle River downstream from the dam would recover more quickly than without the dam, the habitat upstream would be permanently lost. the reservoir would likely inundate all anadromous habitat in Alder, Dear, Hoffstadt and Bear Creeks. If upstream fish passage were not provided all habitat above the dam would not be available to salmon. The new tributary streams developing on the avalanche deposit have low gradients and would provide suitable salmon habitat within 30 to 35 years. Historically, the tributaries above the Green River plus those adjacent to Spirit Lake provided the best salmon habitat in the Toutle drainage. Past eruptions of Mount St. Helens and the eruption of 1980 created a broad floodplain in the region above the Green River. Steep tributaries draining the valley walls of the Toutle watershed intersect the flat valley floor and develop low gradient meandering channels suitable for spawning and rearing of salmon.

Recovery of Salmon Stocks[a]

The recovery of salmon stocks in the Toutle River will depend upon: 1) the species specific habitat requirements, 2) the condition or population size of surviving stocks, and 3) future management considerations. Habitat recovery will occur first in tributary streams and last in the silt laden North Fork and mainstem Toutle River. Therefore, coho which use the tributaries for spawning and rearing will have an earlier opportunity to recover than fall chinook which concentrate this spawning and rearing in the mainstem rivers. Spring chinook and steelhead utilize tributaries and rivers for habitat and are considered intermediate to coho and fall chinook in time

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[a] The term stock is used loosely and is synonymous with race or run.

frame for potential recovery.

Salmon and trout returning to the Toutle River after the eruption would provide the natural recruitment for re-establishment of wild stock populations. At the time of the eruption adult salmonids maturing in the ocean included two brood years of coho and spring chinook (1977, 1978), and three brood years of fall chinook and steelhead (1976, 1977, 1978); estimates based on predominant age of returning adults for Toutle. Therefore, stocks produced in the Toutle River before the eruption would return to their natal stream from 1980 through 1982. As discussed earlier many adults avoided the Toutle River due to high suspended sediment levels and the spawner populations that were observed were relatively small (see Table 4 and Shuck and Kurose 1982). A commercial net fishery operated at the mouth of the Cowlitz River during autumn 1980 and 1981 undoubtly had a significant impact on coho and fall chinook returning to the Toutle River. Based on the poor conditions of fish habitat in the Toutle drainage and our observations on the small size of returning fish stocks we believe the wild stocks of fall chinook are probably destroyed and wild stocks of coho and steelhead are on the verge of being destroyed. Spring chinook are derived from the Cowlitz hatchery stock and could be replaced when suitable habitat is available.

Fisheries Management

The recovery of salmon and steelhead in the Toutle River will require a complex fisheries management plan that considers timberland management, flood protection programs, and exploitation by the commercial fishery. Management constraints imposed by the various resource user groups limits the probability of maintaining wild populations of salmon in the Toutle River. On the one hand, the Toutle River is tributary to the Cowlitz River which is managed for hatchery production of salmon and steelhead. Thus, any management strategy used in the Toutle River must be compatible to Cowlitz and lower Columbia River management programs (i.e., mixed stock fishery with a high catch to escapement ratio) which require production from hatcheries. On the other hand, resource management agencies and Cowlitz County have developed management plans to protect and restore salmonid habitat. Implicit in this goal is the assumption that: fish managers are planning to make full utilization of natural habitat in the Toutle drainage. Based on this premise, watershed managers are weighing the value of fish habitat, hence, wild fish production, against the flood protection benefits of constructing a large debris retention dam near the Green River. Therefore, a fish management plan that explicitly incorporates habitat utilization is the only way to insure against further habitat destruction.

Alternative Management Strategies

Given the management constraints described, what alternative fish management strategies are available and what is the likelihood for success? We attempt to answer this question by discussing the benefits and limitations of four alternative management strategies.

I. Rebuild Toutle Fish Hatchery.

  A. Benefits

    1. High productivity (i.e., high yield to commercial fishery per spawner) and a program compatible with the present Cowlitz-Columbia River management.

    2. Excess fry from the hatchery could be planted in accessible streams; making use of some stream habitat.

  B. Limitations

    1. Requires continued fry planting to utilize habitat because of the low escapement of hatchery fish.

2. Is labor intensive and could never utilize all available habitat.
3. Conflicts with wild stocks by reducing productivity through: intraspecific competition of juveniles in freshwater, dilution of biological integrity, and increased harvest rate in a mixed stock (hatchery - wild) fishery.
4. High cost of hatchery construction and operation which are vulnerable to funding cuts, and high risk of loss if destroyed by another eruption.
5. Spawning and rearing Habitat is not needed, thus, hatchery program weakens need for habitat protection.

II. Fry Planting with Fry from other Hatcheries.

A. Benefits

1. Fry plants make use of some natural habitat.
2. If repeated annually, fry plants would maintain production yet enable a high catch to escapement ratio.

B. Limitations

1. Production would be lower than a hatchery program because of habitat limitations.
2. Requires continued outplanting because low escapements would not be sufficient to maintain stock.
3. Would not use all habitat because of limited access.
4. Population production would be vulnerable to shifts in availability of fry.
5. Creates conflicts with wild stocks as described in I.

III. Wild Stock Enhancement with Streamside Incubation or Hatchery Assist.

A. Benefits

1. Provides potential for full utilization of natural habitat.
2. Could eventually become selfsustaining.
3. Overall would have a low cost and low economic risk.
4. Provides biological diversity inherent to wild stocks.

B. Limitations

1. Requires fishery management of lower Columbia River that would ensure adequate escapement of Toutle stock, thus, result in underutilization of other stocks.
2. Would have a low productivity compared to hatchery stocks.

IV. No Fish Enhancement

A. Benefits

1. None

B. Limitations

1. Underutilization of habitat.
2. Probable loss of remanent wild stocks.
3. Low productivity.

Of the four alternative management strategies number III could be successful for steelhead because sport harvest occurs in the terminal area and catch can be controlled by regulations. In terms of coho and chinook slamon, none of the management strategies could provide the high productivity of a hatchery stock and full habitat utilization with a wild stock. The solution requires a hatchery operation and fishery that compliments wild stock management, rather than conflicts with wild stock production. We propose that an early returning coho stock and spring chinook stock be developed for wild stock management in the Toutle drainage. The Toutle has an early returning coho run that enters the river during September (Figure 34). The Toutle stock has been propagated in hatcheries for the past 30 years but the run timing has

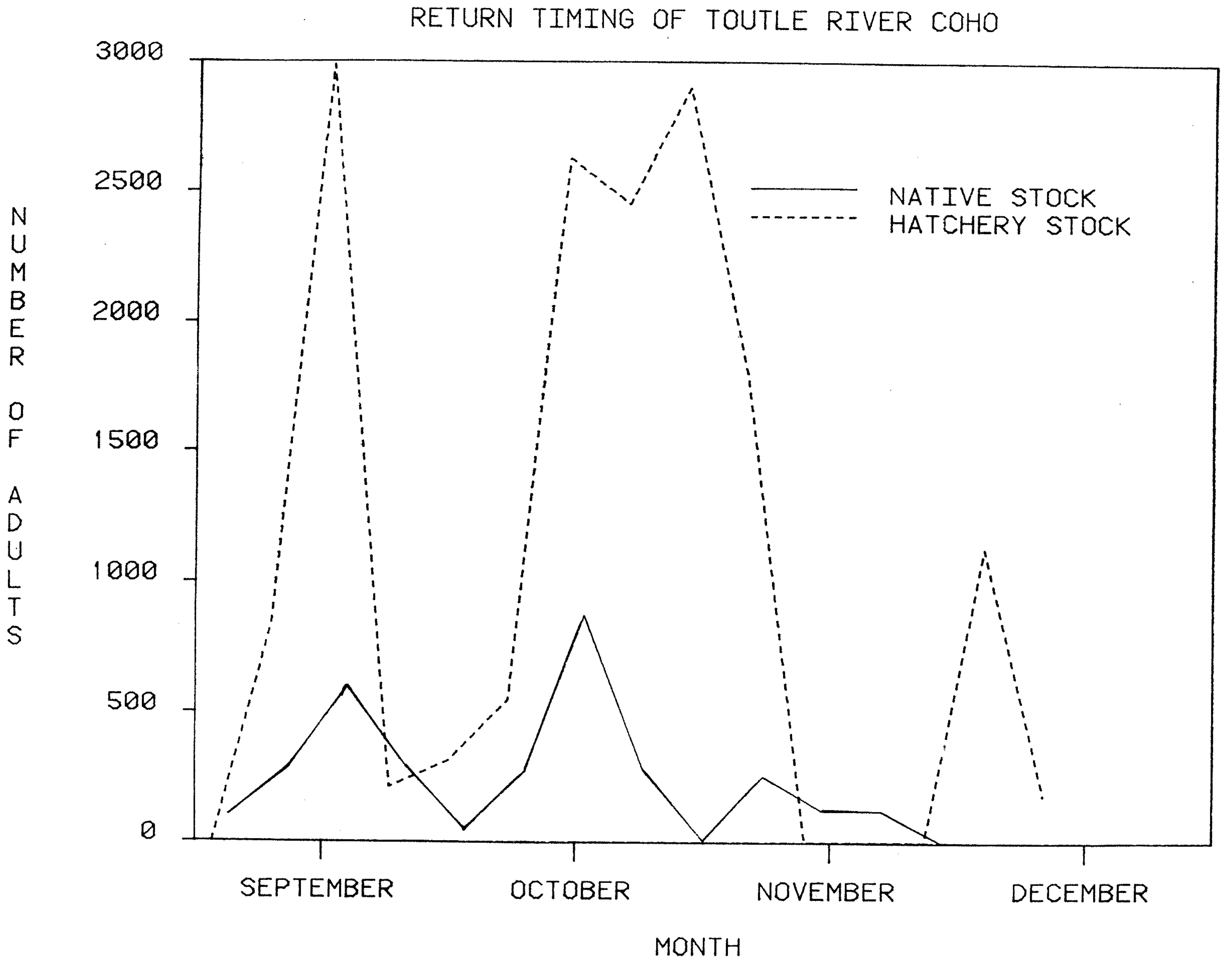

Figure 34. Return timing of adult Toutle River coho for wild stock (1954) and hatchery stock (1978) at the Toutle River Hatchery.

not changed despite eight generations of culture (Figure 34). The early coho could be protected from overharvest in the Columbia River because the run timing coincides with fishery closures for conservation of upper Columbia River chinook stocks. Management of the early stock for wild production would utilize the natural productivity capacity of the Toutle drainage yet provide harvest for a terminal sport and commercial fishery. The late returning coho could be propagated in the Cowlitz Hatchery or new Toutle Hatchery; thus provide the high productivity necessary to sustain the commercial net fishery. Enhancement of spring chinook as a wild stock would more likely succeed than fall chinook because they tend to spawn in tributaries which will be recovering sooner than mainstem habitat. The Toutle fall chinook stock is probably destroyed and would not be available for enhancement. Whereas the transplantation of Cowlitz spring chinook into the Toutle River prior to the eruption was successful.

Recovery of the fishery in the Toutle drainage is dependent upon the recovery of habitat and fish stocks. This study demonstrates that: salmonids can survive in the Toutle system, that natural habitat recovery is occurring, and that steps can be taken to accelerate recovery. A given amount of physical recovery will take place regardless of man's activities. But, the burden of making full utilization of this resource is dependent upon future management decisions. Managers have the opportunity to begin anew and develop a management plan that balances hatchery and wild production to provide a diverse yet strong fishery resource.

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Appendix Table A. Length (km) of rivers and tributary streams accessible to anadromous salmonids before the eruption of Mount St. Helens and, length of streams with associated impact caused by the eruption.[5]

	STREAM LENGTH		
Stream/Location	Accessible Before Eruption, km	Impacted By Eruption, km	Type of Impact
Mainstem Toutle R.	24.9	24.9	Mudflow
Cline Cr.	0.4	0.4	Mudflow
Rock Cr.	1.2	1.2	Mudflow
Outlet Cr.	4.4	0.6	Mudflow
Sucker Cr. (Silver L)	4.3	0	No Impact
South Fork Toutle R.	45.1	45.1	Mudflow
Studebaker Cr.	7.1	0.3	Mudflow
Johnson Cr.	3.6	0.9	Mudflow
Brownell Cr.	0.9	0.1	Mudflow
Thirteen Cr.	1.3	0.1	Mudflow
Eighteen Cr.	0.4	0.1	Mudflow
Big Wolfe Cr.	0.5	0.1	Mudflow
Whitten Cr.	0.7	0.1	Mudflow
Bear Cr.	2.3	0.6	Mudflow
Herrington	0.3	1.5[1]	Mudflow
Un-named Tributary Cr.	0.1	1.5[1]	Mudflow
Trouble Cr.	1.1	0.8	Mudflow
Flye Cr.	0.4	0.1	Mudflow
Clancy Cr.	1.1	0.1	Mudflow
Dollar Cr.	2.3	2.1	Mudflow
Disappointment Cr.	1.0	0.3	Mudflow
Goat Cr.	2.0	2.4	Mudflow
North Fork Toutle R.	55.3		
Below Corp Dam		31.3	Mudflow
Corp Dam to Coldwater Cr.		15.5	Landslide Debris
Coldwater Cr. to Spirit L.		8.5[2]	Landslide Debris
Wyant Cr.	9.8	0.9	Mudflow
Pullen Cr.	2.4	0.7	Mudflow
Alder Cr.	7.5	0.2	Mudflow
Hoffstadt Cr.	9.5	7.2	Mudflow
Deer Cr.	2.3	2.6	Mudflow
Bear Cr.	10.5	6.1	Landslide Debris
Un-named Tributary	0.1	1.1[1]	Landslide Debris
Jackson Cr.	4.0	1.2	Landslide Debris
Elk Cr.	0.7	3.0	Landslide Debris
Marratta Cr.	2.0	1.6	Landslide Debris
Castle Cr.	4.8	3.6[3]	Landslide Debris
North & South Coldwater Cr.	4.4	1.4[4]	Landslide Debris

Appendix Table A. (continued)

Stream/Location	STREAM LENGTH Accessible Before Eruption, km	 Impacted By Eruption, km	Type of Impact
Spirit Lake Tributaries			
Bear Cr.	0.6	0.6	Landslide debris
Donneybrook Cr.	0.8	0.8	Ash, Tephra & Woody Debris
Margaret Cr.	0.5	0.1	Ash, Tephra & Woody Debris
Coe Cr.	0.5	0.1	Ash, Tephra & Woody Debris
Harmony Cr.	0.1	0.1	Ash, Tephra & Woody Debris
Green R.	38.0		
Inside Blast Zone		18.0	Ash, Tephra & Woody Debris
Outside Blast Zone		20.0	Ash & Tephra
Beaver Cr.	0.3	0	No Impact
Devils Cr.	5.2	0	No Impact
Cascade Cr.	1.2	1.2	Ash & Tephra
Elk Cr.	11.1	4.8	Ash & Tephra
Shultz Cr.	2.3	2.3	Ash, Tephra & Woody Debris
Tradedollar Cr.	0.2	0.2	Ash, Tephra & Woody Debris
Miners Cr.	1.2	1.2	Ash, Tephra & Woody Debris
All Rivers Combined	163.3	163.3	
All Tributaries Combined	117.4	54.3	
Total Rivers & Tributaries	280.7	217.6	

[1] New valley bottom tributary formed by junction of valley wall tributaries.

[2] Length uncertain because only a portion of the stream has developed and is flowing, as of summer 1982.

[3] Does not include east tributary that enters below Castle Lake outlet.

[4] Does not include north and south forks that now enter Coldwater Lake

Appendix Table A. (continued).

[5] Information compiled from:

- Stream inventory analysis, Cowlitz/Toutle River Watershed Management Plan Task Force, Sarah Deatherage, personal communication;
- Bryant, F. G. 1951. A survey of the Columbia River and its tributaries with special reference to the management of its fishery resources. Washington streams from the mouth of the Columbia River to and including the Klickitat River (Area I). U. S. Fish and Wildlife Service Sci. Report No. 62;
- Allen, G. H., J. S. Chambers, and R. T. Pressey. 1982. Pre-eruption characteristics of coho salmon (*Oncorhynchus kisutch*) spawning grounds adjacent to Spirit Lake, Mount St. Helens, Washington. Unpublished M.S.;
- Mount St. Helens and vicinity, 1981. 1:100,000 scale map, produced cooperatively by: U.S. Geological Survey, USDA Forest Service, and Washington State Department of Natural Resources;
- USGS, 1:24,000 scale topographic maps dated 1980;
- Stream surveys by Fisheries Research Institute

Appendix Table B. Length (mm) and weight (g) statistics for coho salmon in affected (*) and unaffected tributaries of the Toutle River during 1981 and 1982. All values are population means.

Stream	May 1981		July 1981		September 1981		March 1982		September 1982	
	Length (SD)	Weight (SD)	Length (SD)	Weight (SD)	Length (DS)	Weight (SD)	Length (SD)	Weight (SD)	Length (SD)	Weight (SD)
Alder	41.0	.93	62	3.19	76	6.12	90	9.1		
	(2.9)	(1.16)	(8.7)	(2.1)	(7.4)	(1.8)	(7.9)	(2.0)		
Upper Wyant	41.5	.94	52	1.54	59	3.19	91	9.9	64	3.8
	(6.6)	(0.24)	(7.2)	(0.8)	(6.3)	(1.1)	(12.4)	(3.7)	(10.3)	(1.9)
Devils	41.5	.94	64	3.67	76	6.50	92	9.6		
	(6.6)	(0.24)	(6.2)	(1.0)	(6.7)	(1.6)	(6.6)	(1.9)		
Elk*	41.5	.94	62	3.39	74	5.30	84	7.8		
	(6.6)	(0.24)	(5.9)	(1.1)	(6.7)	(1.5)	(8.6)	(2.0)		
Upper Deer*	41.0	.93	57	2.25	81	7.36			87	9.4
	(2.9)	(1.16)	(6.5)	(0.8)	(8.2)	(2.0)			(10.5)	(11.8)
Lower Wyant*	41.5	.94	60	3.47	76	5.76	84	7.6	62	3.1
	(6.6)	(0.24)	(6.9)	(0.9)	(6.5)	(1.5)	(4.9)	(1.1)	(7.4)	(1.3)
Lower Deer*	41.0	.93	56	2.51	92	10.80	95	7.6	79	6.8
	(2.9)	(1.16)	(5.4)	(0.7)	(10.8)	(3.3)	(4.1)	(1.0)	(8.1)	(2.2)
Herrington*	41.0	.93	54	2.38	86	7.66			71	4.2
	(2.9)	(1.16)	(5.2)	(0.6)	(8.6)	(2.8)			(5.5)	(2.0)
Bear*	42.8	.96	51	1.52	66	4.20	74	4.8	65	3.0
	(4.1)	(0.38)	(6.1)	(0.6)	(5.7)	(1.2)	(8.5)	(1.9)	(4.7)	(1.0)