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THE LONG TERM EFFECTIVENESS OF THREE TYPES OF STREAM IMPROVEMENT STRUCTURES INSTALLED IN MONTANA STREAMS

by

MARK EDMOND LERE

A thesis submitted in partial fulfillment
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of

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Approved:

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VITA

Mark Edmond Lere, son of Arthur (deceased) and Lorene Lere, was born in Bozeman, Montana, on June 29, 1954. He graduated from Bozeman Senior High School in June 1972. In September 1972 he entered Montana State University and received a Bachelor of Science degree in Fish and Wildlife Management in June 1976. He began graduate studies at Montana State University in September 1978.

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ABSTRACT

The long term effectiveness and durability of random boulders, rock jetties, and log step dams installed as improvement structures in three Montana streams were evaluated in 1979 and 1980. Random boulders and rock jetties placed in channelized sections of the St. Regis River appeared to have restored habitat for cutthroat trout (*Salmo clarki*) and brook trout (*Salvelinus fontinalis*) populations. Total numbers of trout were least in a partially altered control, greatest in a section mitigated with random boulders, and intermediate in a section mitigated with rock jetties. Total biomass of trout was similar in the control and jetty sections, but was greater in the boulder section. Total densities of trout in the control and jetty sections were less than estimates obtained 5 years previously. Sections with mitigative structures had greater pool frequencies than the control. Pool-riffle periodicity was significantly related to the total numbers of trout among sections ($P<0.01$). A majority of the boulders were functionally intact 8 years following installation. Twelve of 18 rock jetties were functionally intact 7 years following installation. Rock jetties placed in a channelized section of Little Prickley Pear Creek appeared to have restored habitat for a rainbow trout (*Salmo gairdneri*) population, but were ineffective in restoring habitat for a brown trout (*Salmo trutta*) population. The biomass of rainbow trout was similar in a control and a section mitigated with rock jetties, but was less in a channelized section that was unmitigated. Brown trout densities were greatest in the control and similar in the jetty and unmitigated sections. Brown trout densities and rainbow trout biomass in the control were less than estimates obtained 14 years previously. The jetty section had a pool frequency that was similar to that in the control. Pools were absent in the unmitigated section. Individual physical characteristics were not significantly related to the densities of trout among study sections ($P>0.10$). Fourteen of 16 rock jetties were functionally intact 16 years following installation. Log step dams placed in Sheep Creek were ineffective in enhancing habitat for a rainbow trout population. Densities of rainbow trout in a section containing step dams and a control were not different. Pool frequencies in the step dam section were greater than the control. Eight log step dams were functionally intact 19 years following installation.

INTRODUCTION

Randomly placed boulders, rock jetties, and log step dams are common types of stream improvement structures that have been utilized to restore or enhance trout habitat. These structures have been shown to produce changes in channel configuration that have enhanced trout populations in Montana streams (Swedberg 1964; Elser 1968; Schaplow 1976). However, these evaluations were made within 2 years following installation. This 2 year interval between installation and assessment is not adequate for evaluating the effectiveness of these structures to enhance trout populations (White 1975). Hunt (1976) found that the maximum response of a brook trout population did not occur until 5 years following habitat development of Lawrence Creek, Wisconsin. Furthermore, evaluations of these structures within 2 years of installation do not provide an assessment of their ability to remain intact and functional over a long term.

The present study was undertaken to evaluate randomly placed boulders, rock jetties, and log step dams that have been in Montana streams for at least 5 years. The objectives of this study were to evaluate: (1) the changes in physical habitat associated with these improvement structures; (2) the persistance and integrity of these structures; (3) the response of trout populations to the habitats created by these structures. Field studies were carried out from

July through September 1979 and July through October of 1980 on the St. Regis River, Little Prickley Pear Creek, and Sheep Creek.

DESCRIPTION OF STUDY AREAS

St. Regis River

The St. Regis River originates on the east slope of the Bitterroot Mountains in the northwest corner of Mineral County, Montana (Figure 1). It arises at an elevation of 1,707 meters (m) above mean sea level (msl) and flows southwesterly for approximately 60 kilometers (km) to its confluence with the Clark Fork River at an elevation of 805 m (msl). The mean gradient of the stream is about 1.5%. Mean, minimum, and maximum discharges measured near the town of St. Regis over a 17 year period ending in 1975 were 16.4, 1.16, and 273 m^3/second (sec), respectively (U. S. Geological Survey 1976).

The narrow valley of the St. Regis River has been used as a transportation route since the late 1800s. Much of the river has been channelized or encroached upon as a result of railroad and state highway construction. Additional alterations to the river have resulted from construction of Interstate Highway 90 which began in 1971. Rock step dams, random boulders, and rock jetties were installed in sections of the river above the town of Saltese in 1972 and 1973 to mitigate the destructive effects of the Interstate construction (Schaplow 1976).

Three study sections were established on the St. Regis River. They were located between the confluence of Dominion Creek and Saltese. Section 1 was located approximately 3.0 river km above Saltese at an elevation of about 1,078 m (msl). It began at a railroad trestle and

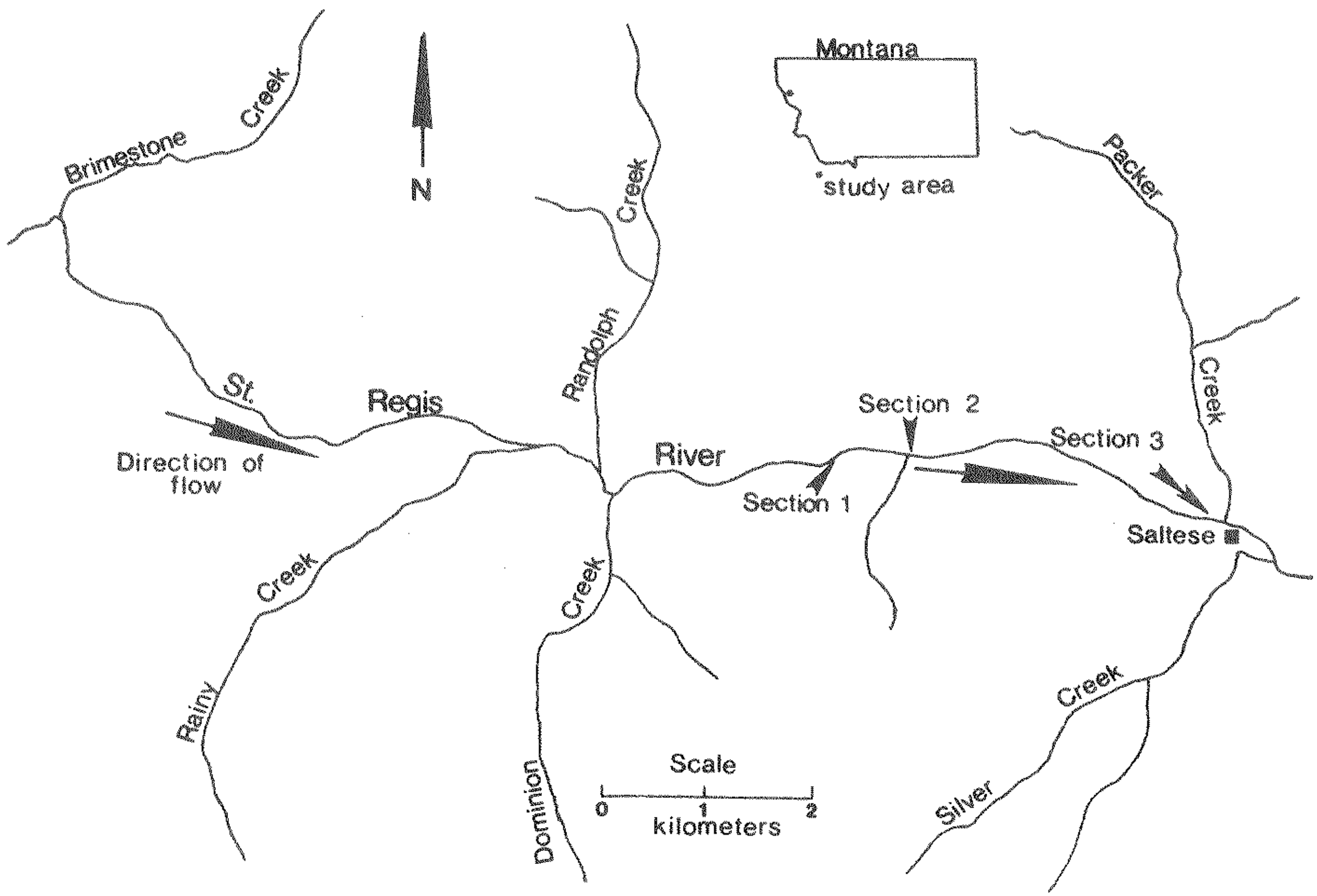

Figure 1. Map of the St. Regis River showing locations of study sections.

extended 510 m downstream. Construction of Interstate Highway 90 altered approximately 35% of this section (Schaplow 1976). Willow (*Salix* spp.) and red dogwood (*Cornus stolinifera*) dominated the riparian zone. This vegetation provided a moderate amount of cover overhanging the stream. This section served as a partially altered control.

Section 2 began about 2.5 river km above Saltese and extended 455 m downstream. The approximate elevation of the section was 1,057 m (msl). This section of stream was rechanneled and confined between Interstate Highway 90 and the roadbed of the railroad as a result of highway construction. Random boulders were installed as a mitigative device in 1972. The riparian zone was practically devoid of vegetation because of the placement of rock revetment at the time of construction. This section served as an altered stream reach mitigated with random boulders.

Section 3 began approximately 0.5 river km above Saltese at an elevation of 1,042 m (msl) and extended 387 m downstream. This section was situated in a relocated channel which was built to facilitate the construction of Interstate Highway 90. Nine pairs of offset rock jetties were installed at intervals of approximately 40 m within the section in 1973. Rock revetment was used to stabilize the stream channel which limited vegetation in the riparian zone to sparse patches of willow. This vegetation provided almost no cover overhanging the stream. This section served as an altered stream reach mitigated with rock jetties.

The three study sections established on the St. Regis River corresponded with sections studied by Schaplow (1976). The legal description of each study section is given in Appendix Table 1.

Water temperatures were measured in the first 2 weeks of September, 1980. Ranges for stations in Sections 1, 2, and 3 were 5.0-15.0, 5.0-16.0, and 8.0-15.0 Celsius (C), respectively. The mean diel difference between maximum and minimum temperatures for Sections 1, 2, and 3 were 8.8, 8.0, and 5.3 C, respectively.

Selected chemical and physical analyses of water made within the three study sections are presented in Table 1. Similar values of pH (7.0-7.3), hardness [20-34 milligrams/liter (mg/l)], alkalinity (21-35 mg/l), and conductivity [42-86 micromhos/centimeter (μmhos/cm)] have been reported for the St. Regis River near Saltese by Lund (1976).

Cutthroat trout (*Salmo clarki*) was the dominant game fish in the study area. Brook trout (*Salvelinus fontinalis*), mountain whitefish (*Prosopium williamsoni*), longnose dace (*Rhinichthys cataractae*), slimy sculpin (*Cottus cognatus*), and shorthead sculpin (*C. confusus*) were also present. No hatchery fish were stocked in the area during the study.

Table 1. Mean and range (in parentheses) of selected chemical and physical properties of water in study sections on the St. Regis River from September 2 through September 12, 1980.

Study Sections	pH	Total Hardness (as mg/l $CaCO_3$)	Total Alkalinity (as mg/l $CaCO_3$)	Conductivity (µmhos/cm at 25 C)
1	7.1 (7.0-7.2)	40 (40)	38.5 (35-40)	88.8 (85-90)
2	7.2 (7.1-7.3)	37.5 (35-40)	38.5 (35-40)	83.8 (80-85)
3	7.2 (7.0-7.3)	37.5 (35-40)	38.5 (35-40)	80 (80)

Little Prickley Pear Creek

Little Prickley Pear Creek is located in Lewis and Clark County in central Montana (Figure 2). It originates on the east slope of the Continental Divide and flows northeasterly for approximately 50 km to its confluence with the Missouri River. The elevation of the stream ranges from 1,475 m (msl) at the headwaters to 1,058 m (msl) at the mouth. The mean gradient of the stream is about 0.85%. Mean, minimum, and maximum discharges measured near the town of Wolf Creek over a 5 year period ending in 1967 were 3.65, 0.40, and 88.01 m^3/sec, respectively (U. S. Geological Survey 1968).

The lower 18 km of Little Prickley Pear Creek flows through Wolf Creek Canyon. This portion of the stream has been extensively altered for the construction of Interstate Highway 15. Eighty-eight rock jetties were installed at intervals of approximately 60 m in this reach

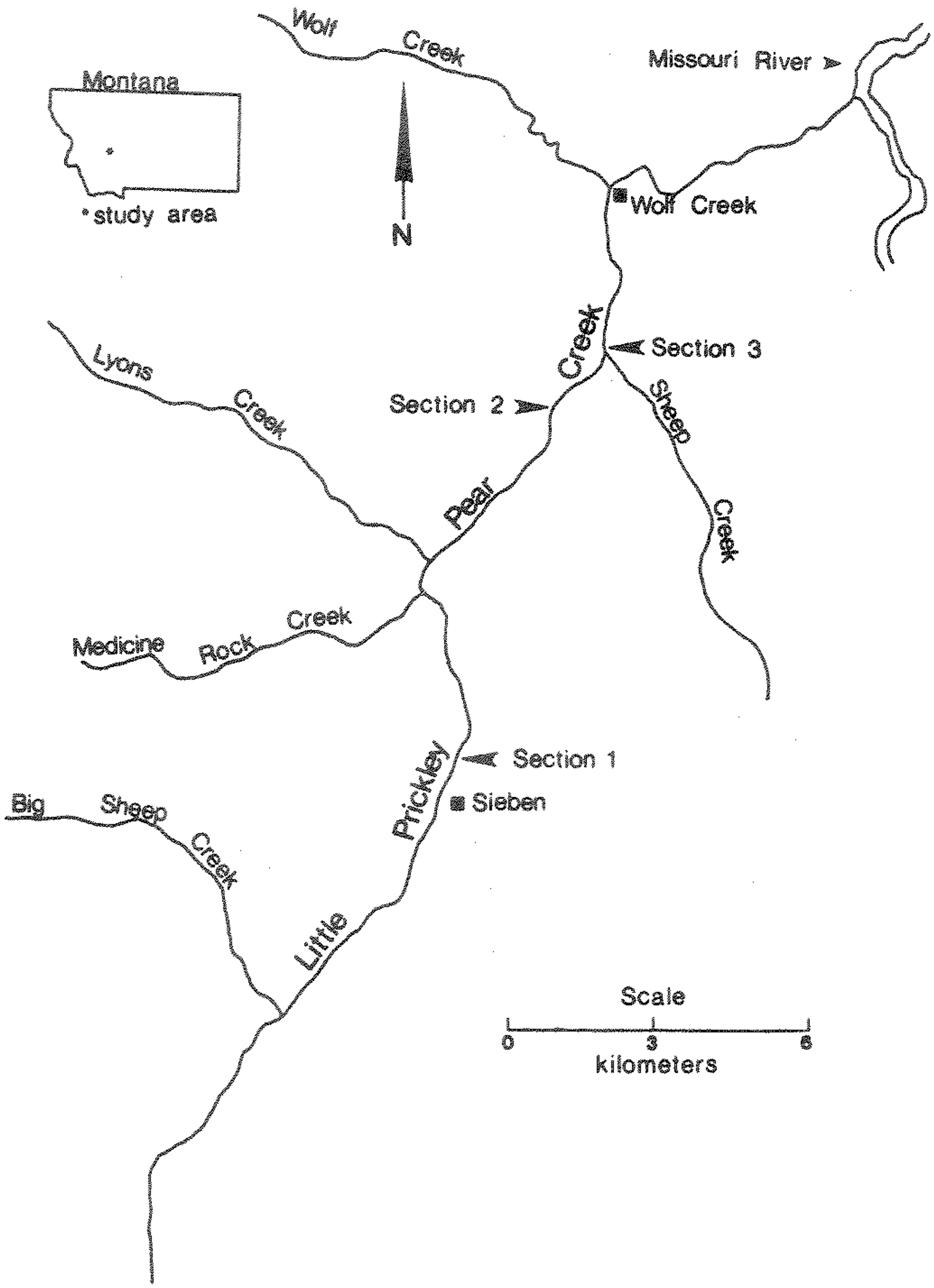

Figure 2. Map of Little Prickley Pear Creek showing locations of study sections.

of the stream during 1963 and 1964 to mitigate the harmful effects of the highway construction (Johnson 1967).

Three study sections were established on Little Prickley Pear Creek. Section 1 was located near the Sieben Interchange of Interstate Highway 15 just above the head of Wolf Creek Canyon. It began 150 m above a county bridge and extended 340 m downstream. The approximate elevation of the section was 1,176 m (msl). Approximately 90% of the section was in an unaltered condition. The remaining 10% was partially altered in 1962 by the construction of Interstate Highway 15. The mean discharge measured near Sieben over a 5 year period ending in 1967 was 1.96 m^3/sec (U. S. Geological Survey 1968). The riparian zone was dominated by willow and alder (*Alnus* spp.). This vegetation provided a substantial amount of cover overhanging the stream. Section 1 served as an unaltered control.

Section 2 was established in Wolf Creek Canyon. This section began about 4.3 river km below the confluence of Lyons Creek at an approximate elevation of 1,119 m (msl) and extended 468 m downstream. It was rechanneled and confined between Interstate Highway 15 and the roadbed of the railroad during the construction of the highway. Seven pairs of offset rock jetties spaced at intervals of approximately 60 m were located in this section. Willow, interspersed with cottonwood (*Populus* spp.), provided a sparse amount of cover overhanging the stream. This section served as an altered stream reach mitigated with rock jetties.

Section 3 was established in Wolf Creek Canyon near the confluence of Sheep Creek at an approximate elevation of 1,109 m (msl) and extended 238 m downstream. This section also was rechanneled and confined as a result of highway construction, however, rock jetties were not installed as mitigative structures. Willow and cottonwood dominated the riparian zone and provided a sparse amount of cover overhanging the stream. This section served as an altered stream reach without mitigative structures.

Sections 1 and 2 which were established in the present study on Little Prickley Pear Creek corresponded with sections studied by Elser (1968). The legal description of each study section is given in Appendix Table 1.

Water temperatures were measured for the month of September, 1980. Ranges for stations in Sections 1, 2, and 3 were 8.5-15.0, 7.0-16.0, and 8.5-17.0 C, respectively. The mean diel difference between maximum and minimum temperatures for Sections 1, 2, and 3 were 2.6, 3.3, and 3.0 C, respectively.

Selected chemical and physical analyses of water made within the three study sections are presented in Table 2. Slightly higher values of pH (8.0-8.7), hardness (215-235 mg/l), alkalinity (225-245 mg/l),

Table 2. Mean and range (in parentheses) of selected chemical and physical properties of water in study sections on Little Prickley Pear Creek from August 29 through October 6, 1980.

Study Sections	pH	Total Hardness (as mg/1 $CaCO_3$)	Total Alkalinity (as mg/1 $CaCO_3$)	Conductivity (μmhos/cm at 25 C)
1	8.0 (7.8-8.1)	204 (200-210)	208 (205-210)	396 (340-430)
2	8.4 (8.2-8.8)	191 (185-195)	194 (180-200)	372 (340-390)
3	8.5 (8.2-9.3)	194 (180-200)	191 (180-195)	378 (350-390)

and conductivity (410-445 μmhos/cm at 25 C) have been reported for Little Prickley Pear Creek near Section 1 by Elser (1968).

Rainbow trout (*Salmo gairdneri*) was the dominant game fish in the study area. Brown trout (*Salmo trutta*), brook trout, mountain whitefish, longnose sucker (*Catostomus catostomus*), white sucker (*C. commersoni*) and mottled sculpin (*Cottus bairdi*) were also present. No hatchery fish were stocked in the area during the study.

Sheep Creek

Sheep Creek is located in Meagher County in central Montana (Figure 3). The stream originates in the Little Belt Mountains near Kings Hill Pass and flows westerly for approximately 50 km to its confluence with the Smith River. The elevation of the stream ranges from 2,195 m (msl) at the headwaters to 1,335 m (msl) at the mouth. The

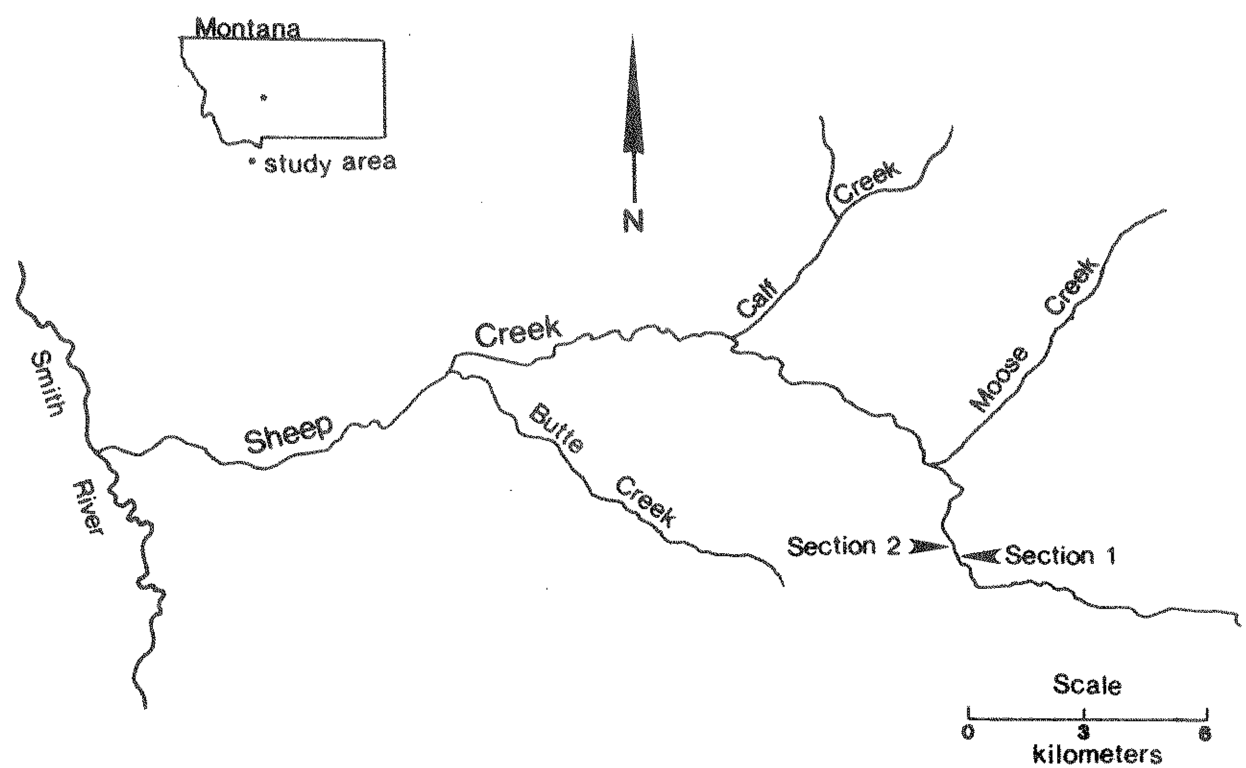

Figure 3. Map of Sheep Creek showing locations of study sections.

mean gradient of the stream is about 1.7%. Mean, minimum, and maximum discharges measured 11.3 km above the confluence of Moose Creek over a 31 year period ending in 1972 were 0.90, 0.10, and 13.02 m^3/sec, respectively (U. S. Geological Survey 1973).

Sheep Creek flows through a meadowed valley and is paralleled by U. S. Highway 89 for approximately 40% of its length. Log step dams were installed in a reach of the stream by the U. S. Forest Service in 1961 to improve trout habitat by producing scour holes and providing additional cover (Swedberg 1964).

Two study sections were established on Sheep Creek. Section 1 was located about 2.0 river km above the confluence of Moose Creek and extended 310 m downstream. The approximate elevation of the section was 1,707 m (msl). Eight log step dams spaced at intervals of 20-70 m were located in this section. Willow dominated the riparian zone and provided sparse amounts of cover overhanging the stream. This section served as a stream reach with improvement structures.

Section 2 began immediately below Section 1 and extended 300 m downstream. This section contained no stream improvement structures. Willow, interspersed with conifers, provided a moderate amount of cover overhanging the stream. Section 2 served as the control. The legal description of each study section is given in Appendix Table 1.

Water temperatures were measured from July 10 through July 22, 1980. Ranges for stations in Sections 1 and 2 were 8.0-17.0 and 9.0-

17.0 C, respectively. The mean diel difference between maximum and minimum temperatures for stations in Sections 1 and 2 were 5.7 and 5.0 C, respectively. Selected chemical and physical analyses of water made within the two study sections are presented in Table 3.

Table 3. Mean and range (in parentheses) of selected chemical and physical properties of water in study sections on Sheep Creek from July 16 through July 31, 1980.

Study Sections	pH	Total Hardness (as mg/l $CaCO_3$)	Total Alkalinity (as mg/l $CaCO_3$)	Conductivity (µmhos/cm at 25 C)
1	7.8 (7.5-7.9)	195 (185-197)	185 (180-190)	368 (360-375)
2	7.8 (7.5-8.0)	193 (190-195)	188 (185-190)	350 (350)

Rainbow trout was the dominant game fish in the study area. Brook trout, brown trout, cutthroat trout, mountain whitefish, longnose sucker, longnose dace, and mottled sculpin were also present. No hatchery fish were stocked in the area during the study.

METHODS

Physical Characteristics of Study Sections

Physical characteristics were measured in all study sections between July 17 and October 23, 1980. Transects were established perpendicular to the stream channel at intervals of 7.5, 7.5, and 10.0 m throughout the length of the study sections on the St. Regis River, Little Prickley Pear Creek, and Sheep Creek, respectively. Stream width was measured to the nearest 0.5 m from water edge to water edge of each transect. Water depth was measured to the nearest 1.0 cm at 0.5 m intervals along each transect. The deepest measurement along each transect was considered to be the thalweg of the cross section. The mean width, depth, and thalweg depth were computed for each study section.

Water velocities were measured with a model 622 Teledyne Gurley current meter at 0.6 of the depth below the water surface. Thalweg velocity was measured at each transect in study sections on the St. Regis River and Little Prickley Pear Creek. Water velocities were recorded at 0.5 m intervals along each transect in study sections on Sheep Creek. Mean thalweg velocity was computed for each section on the three study streams. In addition, mean water velocity was computed for each study section on Sheep Creek.

The total area of potential overhanging and instream cover was measured within 1.5 m on either side of every other transect on the

St. Regis River and on every transect on Little Prickley Pear Creek and Sheep Creek. Cover was classified as either brush, debris, undercuts, or rock shelves. Only features which were within the water or $\leq$ 1.0 m above the surface were considered cover. In addition, depth of water underneath these features had to be greater than 15 cm.

The sizes of bottom materials along the transects for each study section were classified visually using a modified Wentworth scale (Wentworth 1922) as bedrock (unbroken, solid rock), boulders (>26 cm in diameter), rubble (6.4-26 cm in diameter), gravel [2 millimeters (mm)-6.3 cm in diameter], or fines (<2 mm in diameter). The linear distance of each type of bottom material along a transect was estimated and expressed as a percentage of the total stream width.

Pool-riffle periodicity (average distance between the heads of successive riffles divided by the average stream width) and pool-riffle ratio (total length of pools divided by the total length of riffles) were determined for each study section from measurements along the thalweg. A pool was defined as a portion of the stream having reduced water velocities and a maximum depth greater than the average thalweg depth. Gradient (rise divided by run and expressed as a percentage) was measured with a transit and a stadia rod. Sinuosity was determined by dividing the thalweg length by the down valley distance. Discharge was determined in each study section using standard techniques of the

U. S. Geological Survey (Corbett et al. 1943). Section length was obtained by measuring down the center line of the stream.

Parameters of Fish Populations

Fish populations were sampled on the St. Regis River and Sheep Creek during August and early September, 1979 and on Little Prickley Pear Creek during July and August, 1980. The salmonid populations in each study section were censused by electrofishing. Captured fish were classified by species, measured to the nearest 1.0 mm (total length), and weighed to the nearest 5.0 grams (gm). Samples of scales were taken for analyses of age and growth. Salmonids were marked with a partial fin clip and released within the study section from which it was taken. Recapture runs were made at least 6 days after marking runs.

Population estimates of salmonids were made using Chapman's modification of Peterson's mark and recapture formula (Ricker 1975). A computer program developed by the Montana Fish, Wildlife, and Parks Department was used to calculate estimates of salmonid populations, condition factors for fish over 12.6 cm (total length), and corresponding 80% (P=0.20) confidence intervals. Estimates of numbers and biomass were made by length and age groups.

The regressions of total length with anterior scale radius were found to be linear (r=0.89 to 0.96), thus the direct proportionality formula as described by Tesch (1971) was used to back-calculate total lengths at previous ages. The predicted weights at age were computed using the relationships described by the formula (Ricker 1975):

$$\log W = \log a + b(\log L),$$

where W is weight (gm), L is the total length (mm), and a and b are constants.

Statistical Analyses

Statistical analyses were made according to the methods of Snedecor and Cochran (1980). Analyses were performed using programs described in MSUSTAT (Lund 1979) and SPSS (Nie et al. 1967).

RESULTS

St. Regis River

Physical Characteristics

The physical characteristics measured in the three study sections of the St. Regis River are presented in Table 4. Widths, depths, thalweg depths, and thalweg velocities were compared using analyses of variance and the studentized Newman-Kuels method ($P<0.05$). Means of the widths and depths were significantly different among all study sections. Widths were intermediate in Section 1 (partially altered control), least in Section 2 (mitigated with random boulders), and greatest in Section 3 (mitigated with rock jetties). Depths were intermediate in Section 1, greatest in Section 2, and least in Section 3. The mean thalweg depths in Sections 1 and 3 were not significantly different, but were significantly less than in Section 2. The channel of Section 2 had been relocated between Interstate Highway 90 and the bed of a railroad. The narrow widths and greater depths found in this section were associated with this channel confinement.

Mean thalweg velocities were not significantly different among all study sections. The narrow channel configuration and the relatively steep gradient of Section 2 should have resulted in greater water velocities, however, the random boulders installed in this section probably reduced these velocities by increasing the hydraulic roughness of the channel.

Table 4. Selected physical characteristics of the study sections in the St. Regis River measured during the summer of 1980 with comparable characteristics from Schaplow (1976). Standard deviations in parentheses.

Parameter	Section 1 (control)		Section 2 (random boulders)		Section 3 (jetties)	
	Present Study	Schaplow[a] (1976)	Present Study	Schaplow[a] (1976)	Present Study	Schaplow[a] (1976)
Mean width (m)	9.5 (2.2)	9.7	6.7 (1.3)	7.2	11.4 (3.1)	12.0
Mean depth (cm)	21.8 (15.4)	22.4 (6.1)	30.7 (19.1)	28.4 (8.3)	19.6 (11.7)	18.5 (5.4)
Mean thalweg depth (cm)	43.4 (16.8)	42.7 (6.8)	53.0 (14.1)	53.1 (5.3)	37.6 (10.8)	38.1 (4.7)
Mean thalweg velocity (m/sec)	0.56 (0.27)	0.52	0.53 (0.26)	0.69	0.52 (0.22)	0.61
Pool-riffle periodicity	10.6	8.6	6.3	5.5	6.6	3.3
Pool-riffle ratio	0.41		0.59		0.19	
Gradient (%)	1.00	1.06	1.57	1.48[b]	0.98	0.91[b]
Sinuosity	1.12	1.14	1.03	1.09	1.05	1.13
Discharge (m^3/sec)	0.73	0.48-0.91[c]	0.69	0.48-0.91[c]	0.65	0.48-0.91[c]
Area (hectares)	0.49	0.42	0.30	0.31	0.44	0.42
Section length (m)	510	428	455	432	387	353

[a]From measurements made in 1974 (Schaplow 1976)

[b]From measurements made in 1973 (Schaplow 1976)

[c]From measurements made in 1974 (Lund 1976)

Pool numbers as measured by pool-riffle periodicity were less in Section 1 than in Sections 2 and 3. In contrast, the pool-riffle ratio was intermediate in Section 1, greatest in Section 2, and least in Section 3. These differences indicated Section 1 contained fewer but larger pools than the two channelized sections.

Sections with mitigative structures appeared to have greater pool frequencies than the control section. However, the pool frequency found in the control may have been less than normal since it had been partially altered. In unaltered sections of the St. Regis River, pool-riffle periodicities ranged from 4.6 to 7.7 stream widths (Lund 1976). The mitigative structures installed in the channelized sections created pool frequencies that were comparable to frequencies found in these unaltered reaches.

The gradients of Sections 1 and 3 were similar and were approximately 37% less than that in Section 2. The sinuosity of Section 1 was approximately 8% greater than those of Sections 2 and 3. Discharges were similar among all study sections at the time measurements were made. The sample size (N) for each physical characteristic measured is presented in Appendix Table 2.

The profiles of the stream bed along the thalweg of the three study sections are shown in Figure 4. The thalweg appeared to undulate less in Section 1 than in Sections 2 and 3. In addition, deeper pools were formed in the thalwegs of Sections 1 and 2. Generally, the

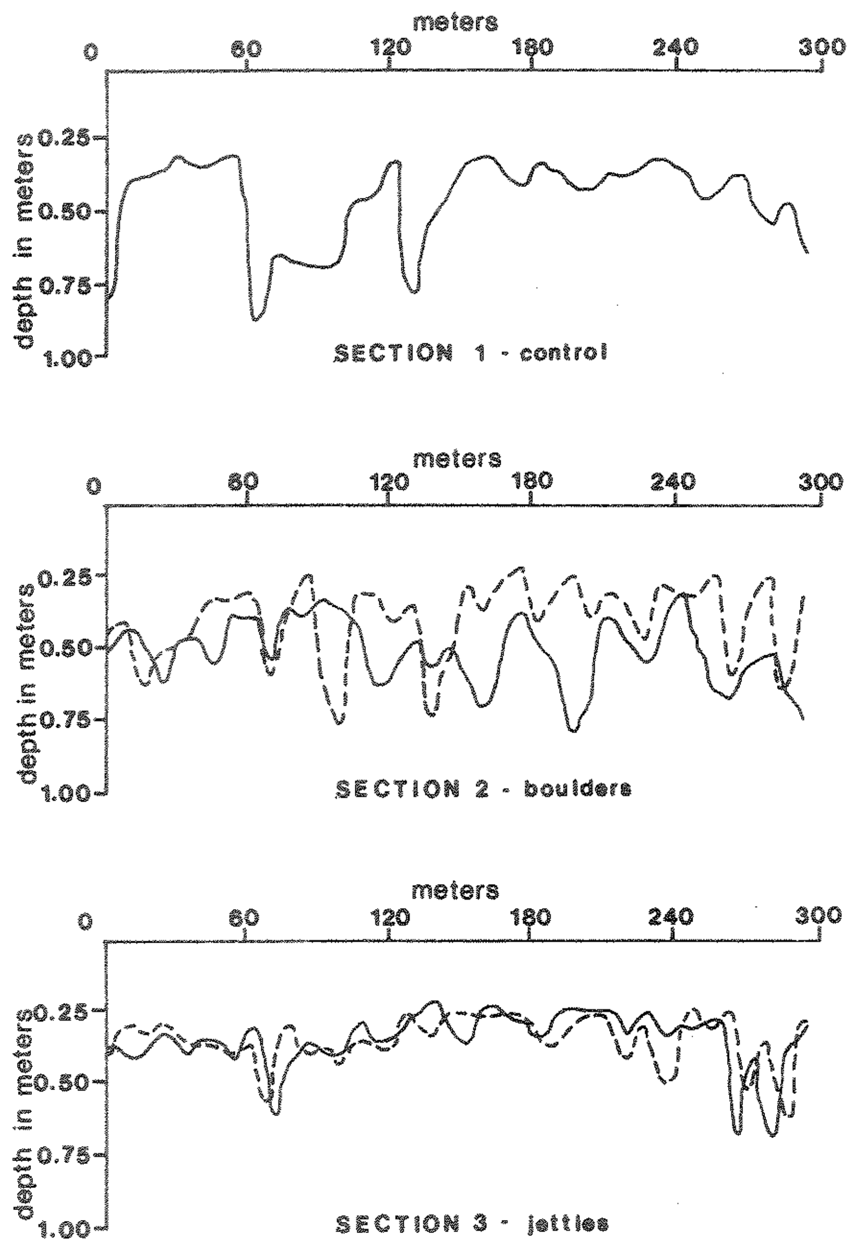

Figure 4. Profiles of the stream bed along the thalweg in the sections of the St. Regis River from the present study (solid line) with comparable measurements from Schaplow (1976) (dotted line).

undulations occurring in Sections 2 and 3 were associated with the mitigative structures that were installed.

The surface areas of potential overhanging and instream cover in the three study sections are presented in Table 5. Brush comprised approximately 90% of the total overhanging cover in Section 1, while rock shelves comprised 100% of the total overhanging cover in Sections 2 and 3. The lack of overhanging vegetation in Sections 2 and 3 was the result of the installation of rock revetment along the stream banks. Rock shelves provided a majority of the total instream cover in all study sections. The total amount of potential cover present was not significantly different among study sections (Analysis of variance; $P>0.05$).

The mean percentages of each class of bottom material measured in the three study sections are presented in Appendix Table 3. The mean percentages of boulders in Sections 1 and 3 were not different, but were less than in Section 2. Rock revetment and randomly placed boulders installed in Section 2 contributed to the greater percentages of boulders found in this section. Fine sediment was scarce in all study sections.

Changes in Physical Characteristics since 1974

The measured physical characteristics of the three sections in the present study were generally similar to those measured by Schaplow

Table 5. Area (m^2/300 m) of each cover classification from the study sections in the St. Regis River measured during the summer of 1980 with comparable measurements from Schaplow (1976).

Cover type	Section 1		Section 2		Section 3	
	Present study	Schaplow (1976)	Present study	Schaplow (1976)	Present study	Schaplow (1976)
Overhanging						
Brush[1]	60.6	79.0	0	0	0	0
(% of total overhanging cover)	(89.8)	(62.4)	(0)	(0)	(0)	(0)
Debris[2]	0.1	26.1	0	0	0	0
(% of total overhanging cover)	(0.1)	(20.6)	(0)	(0)	(0)	(0)
Undercuts[3]	0	21.6	0	0	0	0
(% of total overhanging cover)	(0)	(17.0)	(0)	(0)	(0)	(0)
Rock shelves[4]	6.8	0	35.5	47.0	37.2	23.9
(% of total overhanging cover)	(10.1)	(0)	(100)	(100)	(100)	(100)
Subtotal	67.5	126.7	35.5	47.0	37.2	23.9
Instream						
Debris[2]	4.7		0.2		2.4	
(% of total instream cover)	(46.1)		(1.0)		(32.4)	
Rock shelves[4]	5.5		19.5		5.0	
(% of total instream cover)	(53.9)		(99.0)		(67.6)	
Subtotal	10.2		19.7		7.4	
Total cover	77.7		55.2		44.6	

[1]Overhanging woody vegetation

[2]Snags, driftwood, and logs

[3]Undercut stream banks

[4]Shelves of rock within or overhanging the water

(1976) (Table 4). The mean depth and mean thalweg depth for each study section were not significantly different between the present and previous studies (t-tests; P>0.05). However, numbers of pools in all study sections had decreased since measurements were made in 1974. This decrease was probably a result of increased velocities and erosion associated with the channelizations.

The profiles of the thalweg in Sections 2 and 3 appeared similar between measurements obtained in the present study and those obtained in 1974 (Figure 4). Pools in Section 2 appeared out of phase between the two studies probably because measurements were taken at slightly different places on the stream.

Cover characteristics of the three study sections measured during the present study were generally similar to those measured by Schaplow (1976) except that the total overhanging cover in Section 1 was 88% greater in 1974 (Table 5). This loss of cover was probably caused by the sloughing of a large undercut since 1974. Vegetation on the stream banks in Sections 2 and 3 had not significantly increased in the 8 years following channelization of these sections.

Durability and Dimensions of Stream Improvement Structures

Randomly placed boulders appeared to be durable mitigative devices in the St. Regis River. A majority of the boulders placed in Section 2 during 1972 were functionally intact 8 years following installation. These boulders created a pool frequency that was comparable to frequencies found in unaltered sections. Boulders were grouped in clusters that created a series of cascades and "stair-step pools" throughout the length of the study section. Pools associated with the random boulders had an average maximum depth of 0.62 m (SD=0.14). The number of boulders in the channel had not significantly changed since installation, however, the positions of these boulders had apparently been altered to some extent.

Rock jetties appeared to be less durable as mitigative structures. Twelve of the 18 rock jetties placed in Section 3 during 1973 were functionally intact 7 years following installation. The nonfunctional remnants of 2 others were also present. Schaplow (1976) reported 5 of the jetties in the central portion of the section were destroyed and others were damaged as a result of an unusually severe flood during the spring of 1974. An installation interval of approximately two stream widths was probably not satisfactory in creating a stable pool-riffle periodicity. Although these structures had undergone some changes since 1973, the pool frequency in this section was similar to frequencies found in unaltered reaches.

The dimensions of the 12 functional jetties have remained essentially unchanged since 1974. Individual jetties, excluding those that were destroyed, were spaced at intervals averaging 1.6 stream widths (18.1 m, SD=3.9) on alternating banks of the stream. Each jetty contained 2 to 5 rocks (approximate mean of 4 rocks/jetty) that averaged 1.8 m^3/rock in volume. Functional jetties were oriented perpendicular to the stream and extended an average of 3.2 m (SD=1.1) into the channel. Pools were commonly associated with the downstream side of the functional jetties and averaged 0.48 m (SD=0.14) in maximum depth. The pool-riffle periodicity measured in this section was 50% less frequent than measurements obtained in the summer immediately following the severe flood. Damage to the structures apparently reduced their ability to scour pools.

Parameters of Trout Populations

The numbers and sizes of each species of trout captured in the study sections are presented in Appendix Table 4. Cutthroat trout was the dominant species in all study sections, comprising 87, 91, and 94% of the total trout numbers collected in Sections 1 (partially altered control), 2 (mitigated with random boulders), and 3 (mitigated with rock jetties), respectively.

Estimates of the numbers and biomass of I+ and older cutthroat trout, brook trout, and total trout in each study section are presented on an equivalent basis in Table 6. Estimates of the trout densities among study sections were compared using t-tests ($P<0.20$).

The total numbers of trout per hectare were significantly different among all study sections. Total trout numbers were least in

Table 6. Estimates of numbers (N), biomass, and age structures of trout in the study sections of the St. Regis River obtained during the summer of 1979. 80% confidence intervals in parentheses.

Section	Species	Age-group	Per Hectare N	Per Hectare Biomass (kg)
1 (control)	Cutthroat trout	I+	329	3.6
		II+	190	7.7
		III+ & older	39	5.0
		Total	558 (485-631)	16.3 (14.4-18.2)
	Brook trout	I+	27	0.4
		II+	41	2.6
		III+ & older	6	0.9
		Total	74 (60-88)	3.9 (3.0-4.8)
	Total trout	I+ & older	632 (558-706)	20.2 (18.1-22.3)
2 (random boulders)	Cutthroat trout	I+	827	7.6
		II+	420	18.9
		III+ & older	30	3.4
		Total	1277 (1144-1410)	29.9 (26.9-32.9)
	Brook trout	I+	40	1.2
		II+	67	6.8
		III+ & older	10	4.7
		Total	117 (94-140)	12.7 (9.7-15.7)
	Total trout	I+ & older	1394 (1259-1529)	42.6 (38.3-46.9)
3 (jetties)	Cutthroat trout	I+	648	6.4
		II+	195	9.7
		III+ & older	23	2.8
		Total	866 (752-980)	18.9 (16.8-21.0)
	Brook trout	I+	7	0.1
		II+	30	2.3
		III+ & older	7	3.0
		Total	44 (35-53)	5.4 (4.4-6.4)
	Total trout	I+ & older	910 (796-1024)	24.3 (22.0-26.6)

Section 1, greatest in Section 2, and intermediate in Section 3. The total biomass of trout per hectare in Sections 1 and 3 were not significantly different, but were significantly less than in Section 2.

Estimated numbers of cutthroat trout per hectare were significantly different among all study sections, being least in Section 1, greatest in Section 2, and intermediate in Section 3. Cutthroat trout in age-group I+ comprised a majority of the estimated numbers among age-groups in all study sections. The combined numbers of age I+ and II+ cutthroat trout were significantly less in Section 1 than in Sections 2 or 3. However, numbers of age III+ and older cutthroat trout in Section 1 were similar to those in Section 2 and significantly greater than those estimated in Section 3.

The estimated biomass of cutthroat trout per hectare in Sections 1 and 3 were not significantly different but were significantly less than in Section 2. Age II+ cutthroat trout comprised the greatest biomass among age-groups in all study sections. The combined biomass of age I+ and II+ cutthroat trout was significantly less in Section 1 than in Sections 2 or 3. In contrast, the biomass of age III+ and older cutthroat trout was significantly greater in Section 1 than in Sections 2 or 3.

Brook trout numbers per hectare were significantly different among all study sections. Estimated numbers were intermediate in Section 1, greatest in Section 2, and least in Section 3. Brook trout in age-group II+ comprised a majority of the estimated numbers among age-groups in all study sections. The combined numbers of age I+ and II+ brook trout were intermediate in Section 1, greatest in Section 2, and least in Section 3. Estimated numbers of age III+ and older brook trout were not significantly different among study sections.

The estimated biomass of brook trout per hectare was least in Section 1, greatest in Section 2, and intermediate in Section 3. Brook trout in age-groups II+ comprised the greatest biomass among age-groups in Sections 1 and 2. Age III+ and older brook trout comprised the majority of the biomass in Section 3. The combined biomass of age I+ and II+ brook trout in Sections 1 and 3 were not significantly different, but were significantly less than in Section 2. The estimated biomass of age III+ and older brook trout was significantly less in Section 1 than in Sections 2 or 3.

Regression equations used in the back-calculation of lengths and weights at age of cutthroat trout captured in the three study sections are presented in Appendix Table 5. The mean total length at time of capture and the back-calculated lengths and weights at age are given in Table 7. The mean back-calculated lengths and weights for each age among study sections were compared using analyses of variance and the studentized Newman-Kuels method ($P<0.05$).

The mean back-calculated length and weight at age I were significantly greater in Section 1 than in Sections 2 and 3. The

Table 7. Mean total length (TL) at time of capture and back-calculated mean total length and weight at age for cutthroat trout in the study sections of the St. Regis River during the summer of 1979. Standard deviations in parentheses.

Section	Age-group	N	Mean TL (mm) at capture	Calculated Length (mm) at Age I	II	III
1 (control)	I+	68	109	68		
	II+	63	163	69	128	
	III+	14	224	72	129	188
Mean back-calculated length (mm)				69(±14)	128(±23)	188(±30)
Mean increment of back-calculated length (mm)				69	59	60
Mean calculated weight (gm)				3.0(±2.4)	20.0(±12.9)	70.7(±42.5)
2 (random boulders)	I+	124	109	62		
	II+	69	173	67	126	
	III+	7	230	60	124	188
Mean back-calculated length (mm)				64(±11)	126(±22)	188(±25)
Mean increment of back-calculated length (mm)				64	62	62
Mean calculated weight (gm)				1.9(±1.3)	17.8(±11.2)	62.4(±31.3)
3 (jetties)	I+	116	109	64		
	II+	59	178	68	129	
	III+	7	219	73	119	183
Mean back-calculated length (mm)				65(±13)	128(±20)	183(±21)
Mean increment of back-calculated length (mm)				65	63	55
Mean calculated weight (gm)				2.5(±1.9)	16.5(±8.2)	45.4(±6.7)
Pooled total	I+	308	109	64		
	II+	191	171	68	127	
	III+	28	224	69	125	187
Mean back-calculated length (mm)				66(±13)	127(±22)	187(±26)
Mean increment of back-calculated length (mm)				66	61	60
Mean calculated weight (gm)				2.4(±2.1)	18.2(±10.1)	62.6(±33.2)

back-calculated lengths and weights at age II and III were similar among the study sections. Cutthroat trout in Section 1 appeared to grow more during their first year than in Sections 2 or 3, but cutthroat trout in Sections 2 and 3 reached similar lengths and weights to those in Section 1 in their second year.

Mean condition factors (K) were computed for cutthroat trout and brook trout greater than 12.7 cm in total length from the three study sections (Appendix Table 6). The mean condition factors for each species of trout did not vary significantly among study sections (t-tests, $P>0.05$).

Changes in Population Parameters since 1974

Estimated densities of total trout, cutthroat trout, and brook trout obtained from the three study sections during the present study and in 1974 by Schaplow (1976) are presented graphically in Figures 5-7, respectively. Comparisons between studies were made using t-tests ($P<0.20$). Total densities of trout in Sections 1 and 3 estimated during the present study were significantly less than those obtained in 1974. Cutthroat trout numbers in Section 1 and, numbers and biomass of cutthroat trout in Section 3, estimated during the present study were significantly less than the 1974 estimates. In addition, brook trout densities estimated in Section 3 during the present study were significantly less than the estimates obtained previously.

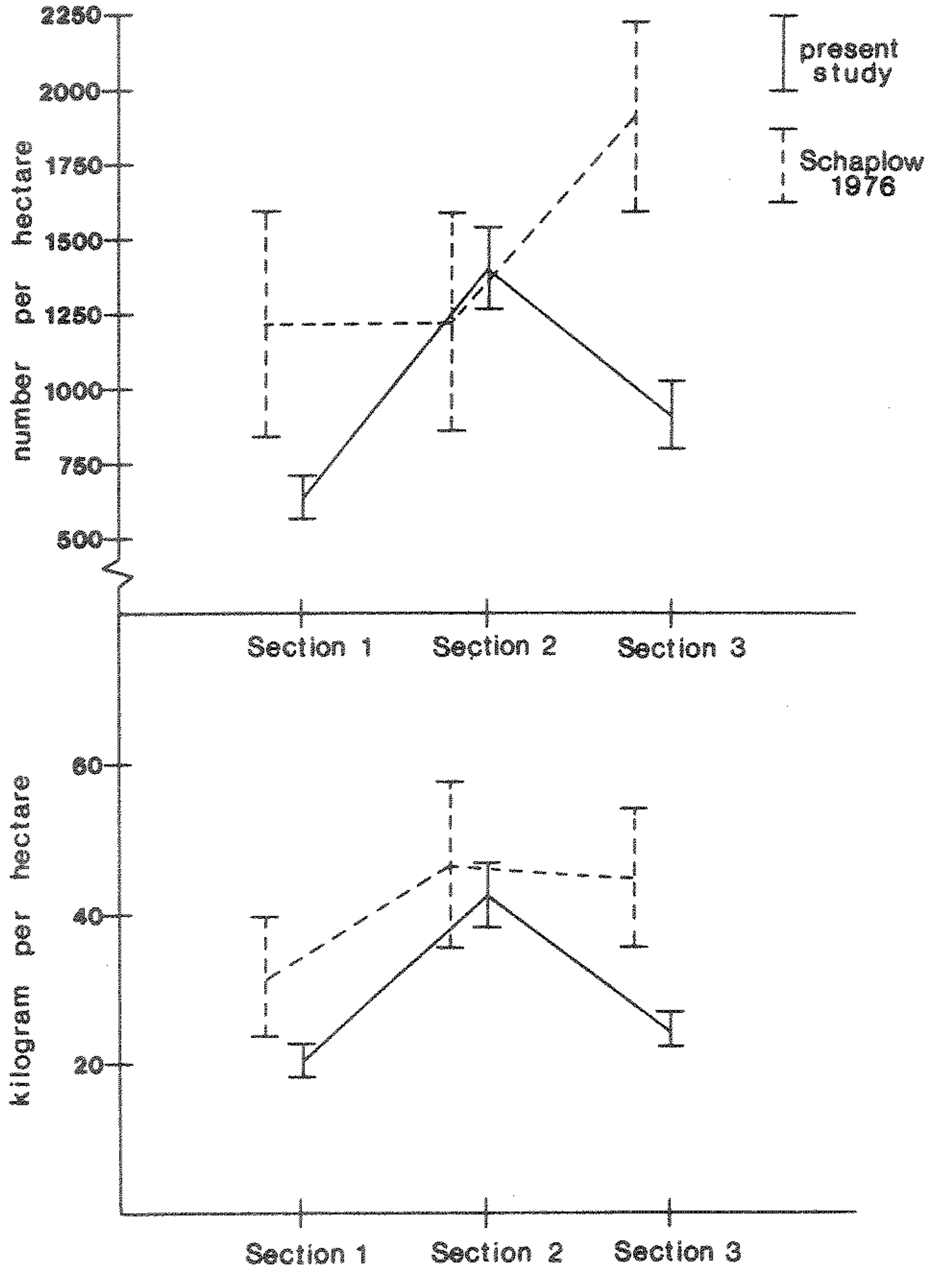

Figure 5. Estimates of total numbers and biomass of trout in the study sections of the St. Regis River with comparable estimates from Schaplow (1976). Bars represent 80% confidence intervals.

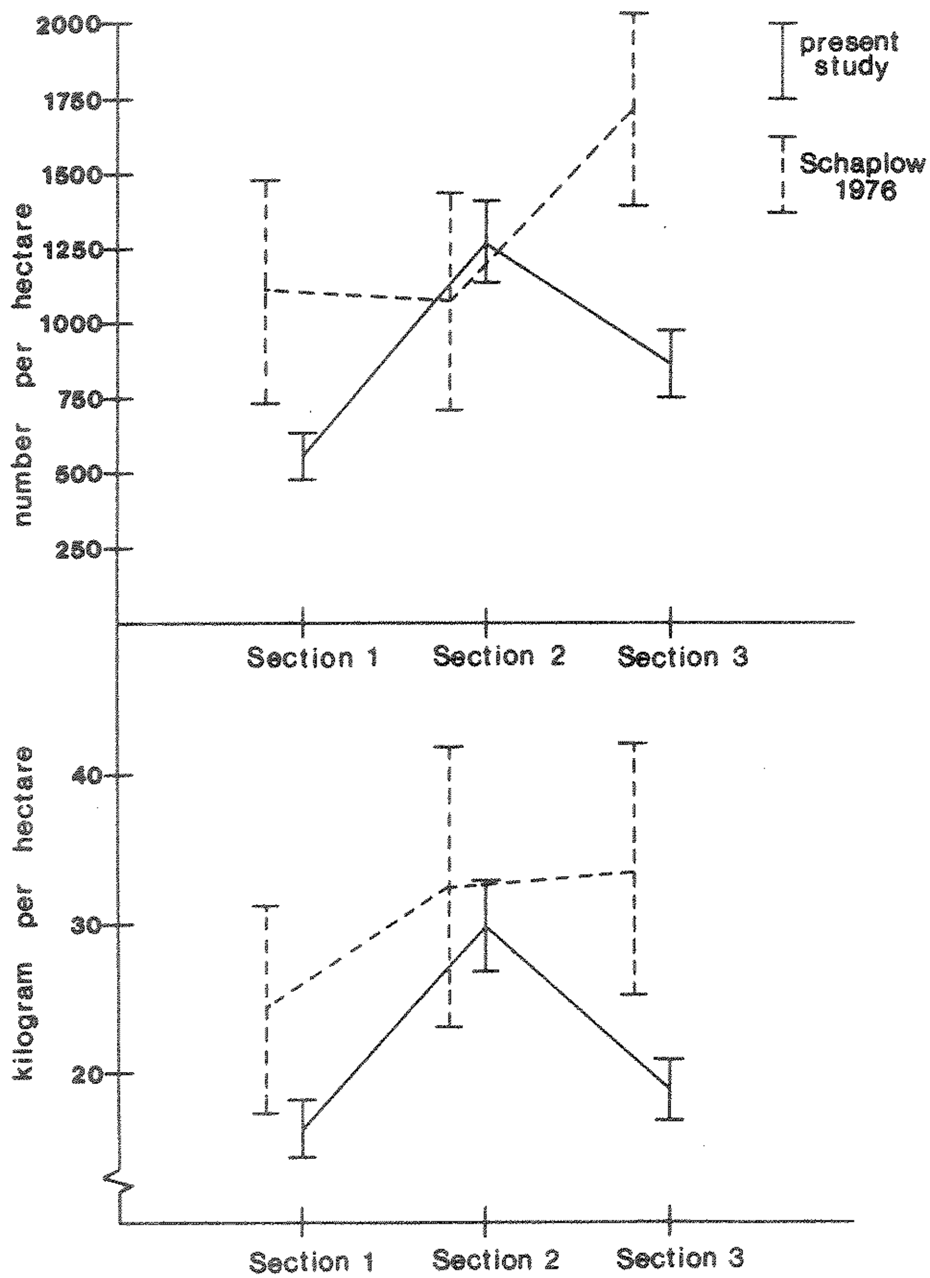

Figure 6. Estimates of numbers and biomass of cutthroat trout in the study sections of the St. Regis River with comparable estimates from Schaplow (1976). Bars represent 80% confidence intervals.

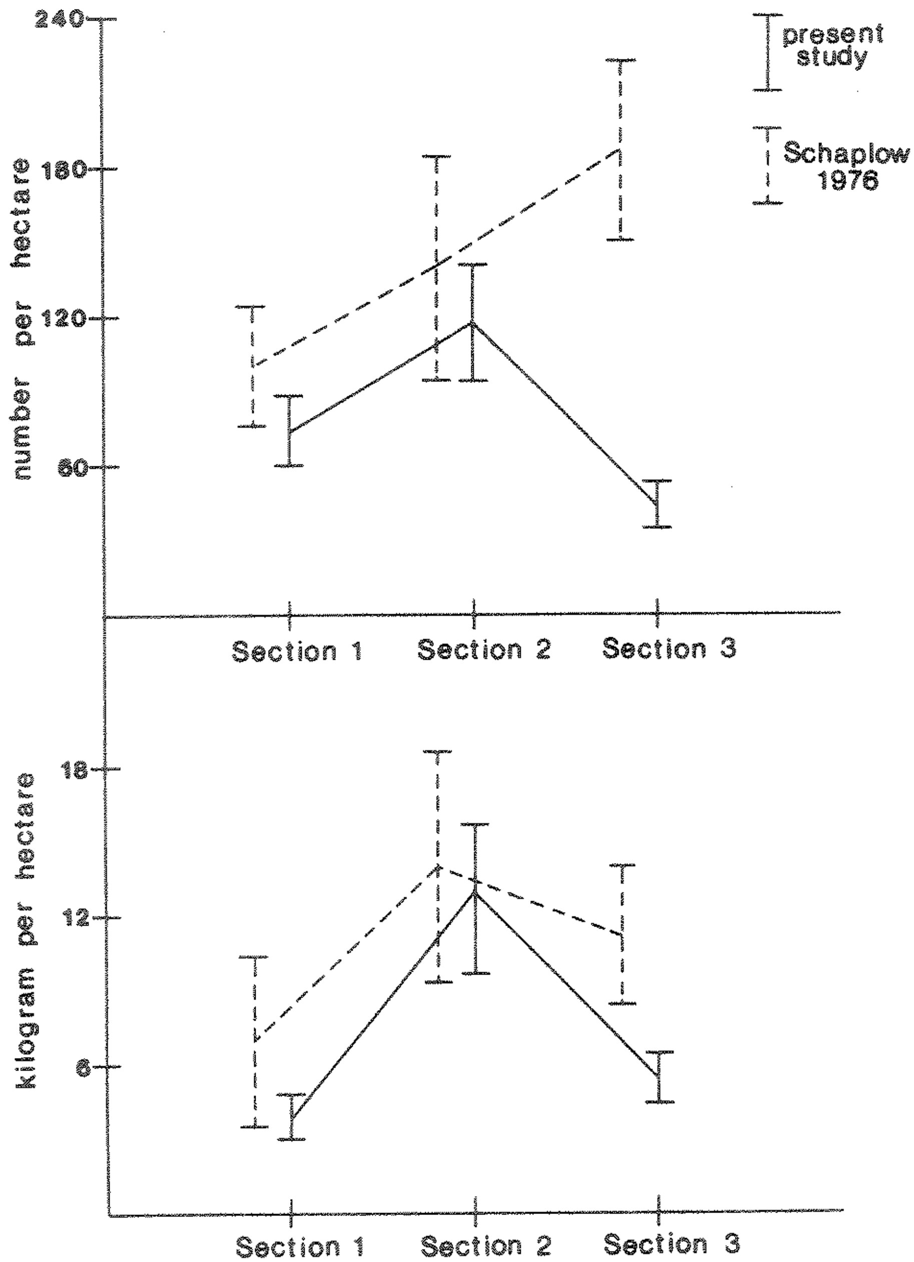

Figure 7. Estimates of numbers and biomass of brook trout in the study sections of the St. Regis River with comparable estimates from Schaplow (1976). Bars represent 80% confidence intervals.

The mean total length for each age at time of capture obtained in the present study was similar to those obtained in 1974. Although back-calculated lengths and weights of cutthroat trout were not computed by Schaplow (1976), there was no indication growth rates had changed significantly since Schaplow's study.

Condition factors for cutthroat trout and brook trout were not computed by Schaplow. As a result, comparisons between studies could not be made.

Relationships between Physical Charactistics and Trout Populations

Regression analysis was used to determine the amount of variation in the estimated numbers of trout among study sections that was attributable to individual physical characteristics measured in the St. Regis River. Point estimates of trout numbers obtained during the present study and in 1974 (Schaplow 1976) were used as cases of the dependent variable. Pool-riffle periodicity was the only physical characteristic that was significantly related to the total estimated numbers of cutthroat trout and brook trout among study sections ($P<0.10$). This feature was negatively related to numbers of trout and accounted for 77 and 61% of the variation in the total numbers of cutthroat trout and brook trout, respectively (Figure 8).

In general, estimated densities of trout in Section 3 (mitigated with rock jetties) were similar to those estimated in Section 1

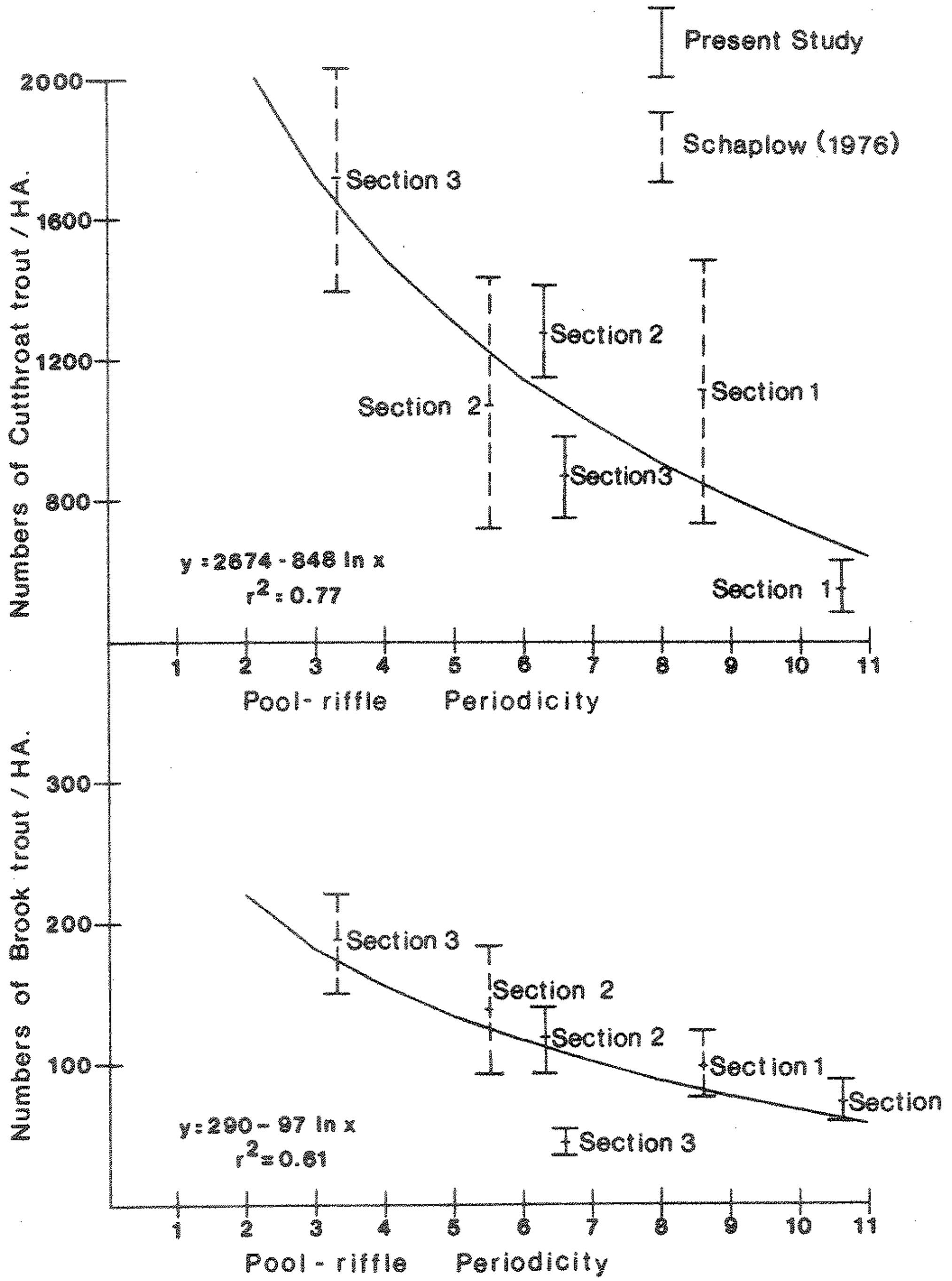

Figure 8. The curvilinear relationships of the total numbers of (A) cutthroat trout and (B) brook trout to pool-riffle periodicity. Bars represent 80% confidence intervals.

(partially altered control). Trout habitat available in this mitigated section appeared to be comparable to that in the control section. The greater estimated densities of both cutthroat trout and brook trout in Section 2 (mitigated with randomly placed boulders) indicated that this section provided the greatest amount of habitat for trout among all study sections. The randomly placed boulders and rock jetties appeared to be effective in restoring cutthroat trout and brook trout populations in the channelized sections of the St. Regis River.

Little Prickley Pear Creek

Physical Characteristics

The physical characteristics measured in the three study sections of Little Prickley Pear Creek are presented in Table 8. Widths, depths, thalweg depths, and thalweg velocities were compared using analyses of variance and the studentized Newman-Kuels method ($P<0.05$). Mean widths in Sections 1 (unaltered control) and 3 (without mitigation) were not significantly different, but were significantly less than that in Section 2 (mitigated with rock jetties). Mean depths and mean thalweg depths were not significantly different among study sections. The mean thalweg velocities in Sections 1 and 2 were not significantly different, but were significantly less than in Section 3.

Table 8. Selected physical characteristics of the study sections in Little Prickley Pear Creek measured during the summer of 1980 with comparable characteristics from Elser (1968). Standard deviations in parentheses.

Parameter	Section 1 (control)		Section 2 (jetties)		Section 3 (without mitigation)
	Present Study	Elser (1968)	Present Study	Elser (1968)	Present Study
Mean width (m)	9.9 (1.8)	7.6	12.2 (1.8)	13.4	10.3 (2.9)
Mean depth (cm)	31.3 (25.3)	30.5	32.4 (24.8)	33.5	29.9 (18.9)
Mean thalweg depth (cm)	56.5 (29.6)	54.9	55.7 (27.3)	61.0	54.6 (14.9)
Mean thalweg velocity (m/sec)	0.63 (0.29)		0.64 (0.27)		0.99 (0.34)
Pool-riffle periodicity	5.4	5.2	4.9	4.4	
Pool-riffle ratio	0.54		0.52		0
Gradient (%)	0.52	0.75	0.50	0.50	0.55
Sinuosity	1.07	1.18	1.03	1.12	1.02
Discharge (m^3/sec)	1.22	0.33[a]	1.34	1.00[a]	2.25
Area (hectares)	0.34	0.13	0.57	0.32	0.25
Section length (m)	340	213	468	366	238

[a]From U.S.G.S. (1967)

Pool-riffle periodicities and pool-riffle ratios were similar between Sections 1 and 2. Pools were absent in Section 3. The mitigative structures installed in Section 2 were effective in establishing a stable pool-riffle periodicity. Mitigative structures were not installed in Section 3 and, as a result, a normal pool-riffle periodicity was absent in this channelized section.

Gradients and sinuosities were similar among all study sections. Measured discharges were similar between Sections 1 and 2, but were almost twice as great in Section 3. Widths, depths, and thalweg velocities measured in Section 3 were consequently greater than those that would occur at more equitable flows. The sample size (N) for each physical characteristic measured is presented in Appendix Table 2.

The profiles of the stream bed along the thalweg of the three study sections are shown in Figure 9. The stream bed appeared to undulate more in Sections 1 and 2 than in Section 3. In addition, deep pools were formed in the thalwegs of Sections 1 and 2. The undulations occurring in Section 2 were associated with the mitigative structures that were installed.

The surface areas of potential overhanging and instream cover in the three study sections are presented in Table 9. Brush provided a majority of the total overhanging cover in all study sections. The amount of brush cover was significantly greater in Section 1 than in

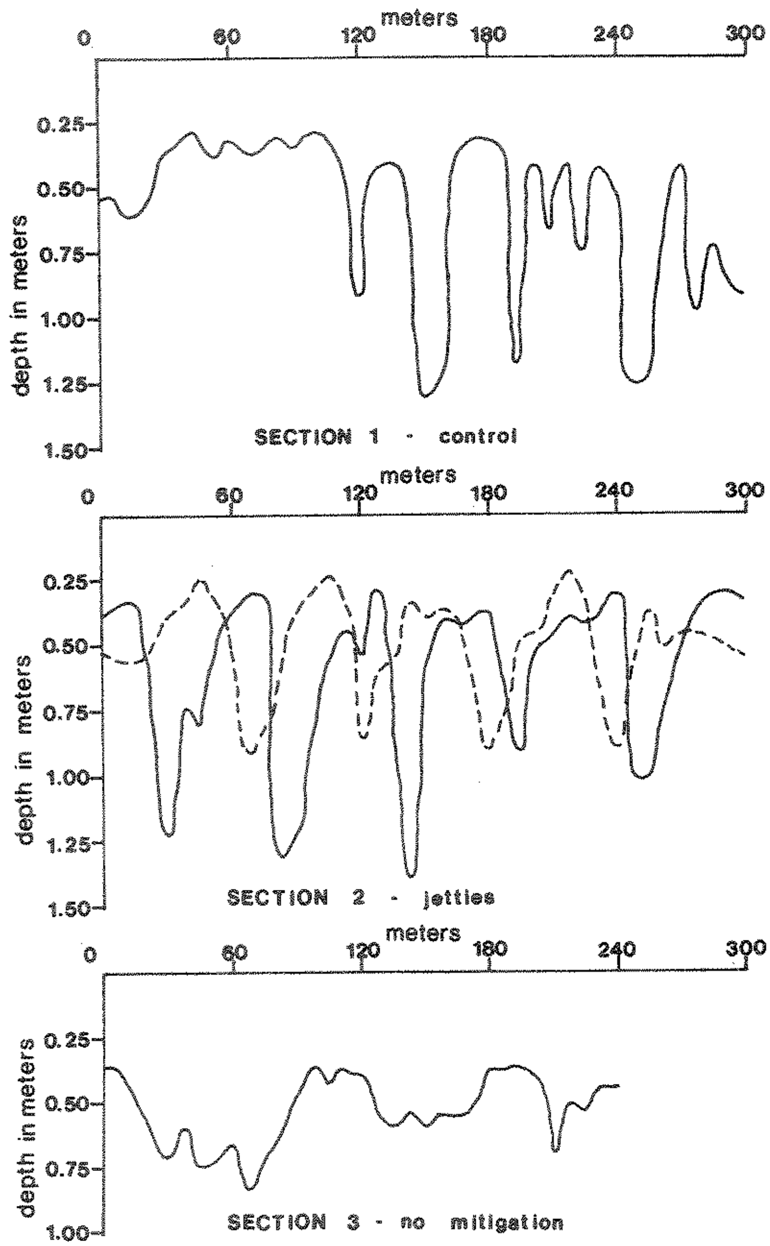

Figure 9. Profiles of the stream bed along the thalweg in the sections of Little Prickley Pear Creek from the present study (solid line) with comparable measurements from Elser (1968) (dotted line).

Table 9. Area (m^2/300 m) of each cover classification from the study sections in Little Prickley Pear Creek measured during the summer of 1980.

Cover Type	Section 1	Section 2	Section 3
Overhanging			
Brush[1]	339.3	14.5	13.6
(% of total overhanging cover)	(88.7)	(54.3)	(69.4)
Debris[2]	25.4	6.3	0
(% of total overhanging cover)	(6.6)	(23.6)	(0)
Undercuts[3]	0	0	2.8
(% of total overhanging cover)	(0)	(0)	(14.3)
Rock shelves[4]	17.7	5.9	3.2
(% of total overhanging cover)	(4.6)	(22.1)	(16.3)
Subtotal	382.4	26.7	19.6
Instream			
Debris[2]	1.2	2.0	0
(% of total instream cover)	(17.4)	(16.3)	(0)
Rock shelves[4]	5.7	10.3	3.4
(% of total instream cover)	(82.6)	(83.7)	(100)
Subtotal	6.9	12.3	3.4
Total cover	389.3	39.0	23.0

[1]Overhanging rooted woody vegetation

[2]Snags, driftwood, and logs

[3]Undercut stream banks

[4]Shelves of rock within or overhanging the water

Sections 2 and 3 (Analysis of variance; studentized Newman-Kuels method; $P<0.05$). The lack of overhanging vegetation in Sections 2 and 3 was the result of rock revetment installed along the stream banks. The frequency of occurrence of debris, undercuts, and rock shelves that provided overhanging cover along the shoreline were not significantly different among study sections (Chi-square analyses; $P>0.05$).

Rock shelves provided a majority of the total instream cover in all study sections. The frequency of occurrence of instream cover was not significantly different among study sections (Chi-square analyses; $P>0.05$).

The total amount of potential cover present was significantly greater in Section 1 than in Sections 2 or 3 (Analysis of variance; studentized Newman-Kuels method; $P<0.05$). The greater amount of potential cover in Section 1 was associated with the large quantity of brush overhanging the channel.

The mean percentage of each class of bottom material in the three study sections are presented in Appendix Table 3. The composite of boulders, rubble, gravel, and fines was not different among study sections. Generally, fine sediment was localized in the pools of the three sections.

Changes in Physical Characteristics since 1966

The physical characteristics of Sections 1 and 2 measured during the present study were generally similar to those measured by Elser (1968) (Table 8). Section 3 was not included in the research conducted by Elser. Although physical characteristics were similar between studies, discharges in Sections 1 and 2 were greater during 1980.

The profiles of the thalweg in Section 2 measured during the present study appeared similar to the one measured by Elser (1968) except pools were deeper in the present study (Figure 9). Pools in Section 2 appeared out of phase between the two studies probably because measurements were taken at slightly different places on the stream.

The amount of potential cover measured during the present study was not comparable to that measured by Elser (1968) because the methodologies utilized in the two studies were different. However, the relative difference in the amount of potential cover between Sections 1 and 2 obtained during the present study was similar to that of the previous study. Some vegetation had become established along the stream banks of Sections 2 and 3 in the 18 years following channelization, but the amount of overhanging cover in these sections had not significantly increased.

Durability and Dimensions of Stream Improvement Structures

The rock jetties installed in Section 2 of Little Prickley Pear Creek appeared to be durable mitigative structures. Fourteen of the 16 jetties placed in this study section during 1964 were functionally intact 16 years following installation. A nonfunctional remnant of one other jetty was also present. An installation interval of approximately 5 stream widths appeared to be satisfactory in creating a stable pool-riffle periodicity.

The existing jetties were located in pairs on opposite banks of the stream and were spaced at intervals averaging 4.5 stream widths (55.1 m, SD=6.0). Opposing jetties were offset by an average of 4.9 m (SD=2.9). Each jetty contained 3-16 rocks (approximate mean of 7 rocks/jetty) that averaged 0.7 m^3/rock in volume. Functional jetties were oriented at 30-90° angles from the downstream bank and extended an average of 4.5 m (SD=1.4) into the channel. The mean width of the jetties at the bank of the stream was 5.2 m (SD=0.8). The dimensions of the 14 functional jetties have undoubtedly changed in the 16 years following installation.

Pools in Section 2 were associated with the functional jetties and averaged 1.03 m (SD=0.26) in maximum depth. Twelve of the 14 jetties had been examined earlier by Elser (1968). He reported large pools were scoured immediately below the jetties 2 years following installation. Comparisons between the profiles of the thalweg obtained in the present and previous studies indicated deeper pools had been scoured in Section 2 since measurements were made in 1966 (Figure 9).

Parameters of Trout Populations

The numbers and sizes of each species of trout captured in the study sections are presented in Appendix Table 7. Rainbow trout was the dominant species in all study sections, comprising 57, 77, and 83% of the total trout numbers collected in Sections 1 (unaltered control), 2 (mitigated with rock jetties), and 3 (without mitigation), respectively.

Estimates of the numbers and biomass of I+ and older rainbow trout, brown trout, brook trout, and total trout in each study section are presented on an equivalent basis in Table 10. Estimates of the trout densities among study sections were compared using t-tests ($P<0.20$).

The total numbers of trout per hectare were not significantly different among all study sections. The estimated total biomass of trout per hectare was significantly different among study sections, being greatest in Section 1, intermediate in Section 2, and least in Section 3.

Estimated numbers of rainbow trout per hectare were not significantly different among study sections. Rainbow trout in age-group I+

Table 10. Estimates of numbers (N), biomass, and age structures of trout in the study sections of Little Prickley Pear Creek obtained during the summer of 1980. 80% confidence intervals in parentheses.

Section	Species	Age-group	Per Hectare N	Per Hectare Biomass (kg)
1 (control)	Rainbow trout	I+	512	18.8
		II+	144	17.4
		III+	47	11.4
		IV+ & older	9	3.9
		Total	712 (641-783)	51.5 (47.5-55.5)
	Brown trout	I+	171	8.5
		II+	74	12.8
		III+	76	23.7
		IV+ & older	24	13.7
		Total	345 (316-374)	58.7 (56.0-61.4)
	Brook trout	I+	65	4.6
		II+	59	8.5
		III+ & older	3	1.2
		Total	127 (103-151)	14.3 (11.6-17.0)
	Total trout	I+ & older	1184 (1102-1266)	124.5 (119.0-130.0)
2 (jetties)	Rainbow trout	I+	619	23.2
		II+	151	17.0
		III+	51	12.3
		IV+ & older	32	13.1
		Total	853 (525-1181)	65.6 (46.5-84.7)
	Brown trout	I+	40	2.8
		II+	12	2.0
		III+	37	14.8
		IV+ & older	12	8.5
		Total	101 (69-133)	28.1 (18.5-37.7)
	Total trout	I+ & older	954 (638-1270)	93.7 (72.3-115.1)
3 (unmitigated)	Rainbow trout	I+	640	19.4
		II+	148	9.2
		III+ & older	4	0.4
		Total	792 (568-1016)	29.0 (21.7-36.3)
	Brown trout	I+	40	1.5
		II+	4	0.5
		III+ & older	56	21.3
		Total	100 (64-136)	23.3 (14.2-32.4)
	Total trout	I+ & older	892 (665-1119)	52.3 (40.6-64.0)

comprised a majority of the estimated numbers among age-groups in all study sections. The combined numbers of age I+ and II+ rainbow trout were not significantly different among study sections. Estimated numbers of age III+ and older rainbow trout were significantly greater in Sections 1 and 2 than in Section 3.

The estimated biomass of rainbow trout per hectare in Sections 1 and 2 were not significantly different, but were significantly greater than in Section 3. Age I+ rainbow trout accounted for the greatest biomass among age-groups in all study sections. The combined biomass of age I+ and II+ rainbow trout in Section 1 was similar to estimates in Section 2 but significantly greater than those in Section 3. The biomass of age III+ and older rainbow trout was significantly different among all study sections, being intermediate in Section 1, greatest in Section 2, and least in Section 3.

Estimates of brown trout numbers per hectare were significantly greater in Section 1 than in Sections 2 or 3. Estimated numbers of brown trout in age-group I+ dominated the age structure in Section 1. Age III+ and older brown trout comprised a majority of the estimated numbers in Sections 2 and 3. Estimated numbers of age I+, II+, and III+ and older brown trout were each significantly greater in Section 1 than in Sections 2 or 3.

The estimated biomass of brown trout per hectare was significantly greater in Section 1 than in Sections 2 or 3. Age III+ and older brown trout comprised the greatest biomass among age-groups in all study sections. The combined biomass of age I+ and II+ brown trout was significantly different among all study sections, being greatest in Section 1, intermediate in Section 2, and least in Section 3. The biomass of age III+ and older brown trout was significantly greater in Section 1 than in Sections 2 or 3.

Brook trout were only captured in Section 1. The relationships in trout numbers between study sections did not change when densities of brook trout were excluded from analysis. However, the biomass of trout in Sections 1 and 2 became similar when densities of this species were excluded.

Regression equations used in the back-calculation of lengths and weights at age of rainbow trout and brown trout captured in the three study sections are presented in Appendix Tables 8 and 9, respectively. The mean total length at time of capture and the back-calculated lengths and weights at age of rainbow trout and brown trout are given in Tables 11 and 12, respectively. The mean back-calculated lengths and weights for each age among study sections were compared using analysis of variance and the studentized Newman-Kuels method ($P<0.05$).

In Sections 1 and 2, the mean back-calculated lengths and weights for age I and II rainbow trout were significantly greater than those in Section 3. The mean back-calculated lengths and weights of rainbow

Table 11. Mean total length (TL) at time of capture and back-calculated mean total length and weight at age for rainbow trout in the study sections of Little Prickley Pear Creek during the summer of 1980. Standard deviations in parentheses.

Section	Age-group	N	Mean TL (mm) at capture	Calculated Length (mm) at Age			
				I	II	III	IV
1	I+	102	157	76			
(control)	II+	46	229	84	174		
	III+	14	287	81	181	247	
	IV+	2	356	93	201	261	316
Mean back-calculated length (mm)				79(±15)	177(±28)	249(±30)	316(±9)
Mean increment of back-calculated length (mm)				79	98	72	67
Mean calculated weight (gm)				4.5(±3.0)	57.1(±28.3)	164.2(±56.0)	336.9(±31.3)
2	I+	81	152	89			
(jetties)	II+	34	218	95	170		
	III+	24	287	92	190	256	
	IV+	13	345	103	199	273	321
Mean back-calculated length (mm)				92(±15)	182(±31)	262(±25)	321(±23)
Mean increment of back-calculated length (mm)				92	90	80	59
Mean calculated weight (gm)				8.8(±5.6)	66.7(±33.5)	189.9(±53.9)	349.3(±75.5)
3	I+	83	142	81			
(unmitigated)	II+	23	175	82	144		
	III+	1	263	83	196	241	
	IV+	1	318	76	166	255	301
Mean back-calculated length (mm)				81(±16)	147(±39)	248(±10)	301
Mean increment of back-calculated length (mm)				81	66	101	53
Mean calculated weight (gm)				5.6(±3.5)	34.4(±25.9)	135.8(±15.8)	240.7
Pooled total	I+	266	151	82			
	II+	103	213	87	166		
	III+	39	286	88	187	252	
	IV+	16	345	100	197	271	320
Mean back-calculated length (mm)				84(±16)	174(±33)	258(±26)	320(±21)
Mean increment of back-calculated length (mm)				84	90	84	62
Mean calculated weight (gm)				6.3(±4.0)	57.8(±30.3)	183.8(±53.1)	341.0(±69.6)

Table 12. Mean total length (TL) at time of capture and back-calculated mean total length and weight at age for brown trout in the study sections of Little Prickley Pear Creek during the summer of 1980. Standard deviations in parentheses.

Section	Age-group	N	Mean TL (mm) at capture	Calculated Length (mm) at Age I	II	III	IV
1 (control)	I+	49	173	81			
	II+	24	257	88	194		
	III+	23	318	90	200	282	
	IV+	4	389	80	169	269	365
Mean back-calculated length (mm)				85(±16)	196(±33)	282(±36)	365(±55)
Mean increment of back-calculated length (mm)				85	111	86	83
Mean calculated weight (gm)				6.0(±3.8)	75.8(±35.0)	226.3(±87.0)	518.2(±263.0)
2 (jetties)	I+	16	180	89			
	II+	4	262	88	202		
	III+	16	340	93	210	302	
	IV+	5	411	85	208	307	383
Mean back-calculated length (mm)				90(±21)	208(±44)	303(±30)	383(±28)
Mean increment of back-calculated length (mm)				90	118	95	80
Mean calculated weight (gm)				6.2(±4.9)	94.5(±65.0)	289.0(±93.0)	612.6(±154.0)
3 (unmitigated)	I+	8	158	91			
	II+	2	211	65	132		
	III+	7	306	81	167	259	
	IV+	3	372	65	125	277	341
Mean back-calculated length (mm)				81(±19)	151(±36)	264(±32)	341(±8)
Mean increment of back-calculated length (mm)				81	70	113	77
Mean calculated weight (gm)				4.6(±3.4)	35.0(±29.7)	186.6(±75.7)	405.4(±30.0)
Pooled total	I+	73	173	84			
	II+	30	255	86	191		
	III+	46	324	90	198	285	
	IV+	12	394	78	174	287	367
Mean back-calculated length (mm)				86(±18)	192(±37)	285(±33)	367(±32)
Mean increment of back-calculated length (mm)				86	106	93	82
Mean calculated weight (gm)				5.9(±4.0)	75.5(±42.8)	242.2(±87.2)	529.3(±159.3)

trout at age III and IV were not significantly different among study sections. The mean back-calculated lengths and weights for age I and IV brown trout were not significantly different among study sections. However, in Sections 1 and 2, the mean back-calculated length and weight for age II brown trout were significantly greater than those in Section 3. In addition, the mean back-calculated length and weight of brown trout at age III in Section 2 were significantly greater than those in Section 3.

Mean condition factors (K) were computed for rainbow trout, brown trout, and brook trout greater than 12.7 cm in total length from the three study sections and are presented in Appendix Table 6. The mean condition factors of rainbow trout or brown trout did not vary significantly among study sections (t-tests; $P>0.05$).

Changes in Population Parameters since 1966

The estimated densities of total trout, rainbow trout, brown trout, and brook trout for Sections 1 and 2 during the present study and in 1966 by Elser (1968) are presented graphically in Figures 10-13, respectively. In Section 3, estimates of trout densities were unavailable during 1966. Comparisons between studies were made using t-tests ($P<0.20$).

Total numbers of trout in Section 1 estimated during the present study were significantly less than estimates obtained in 1966.

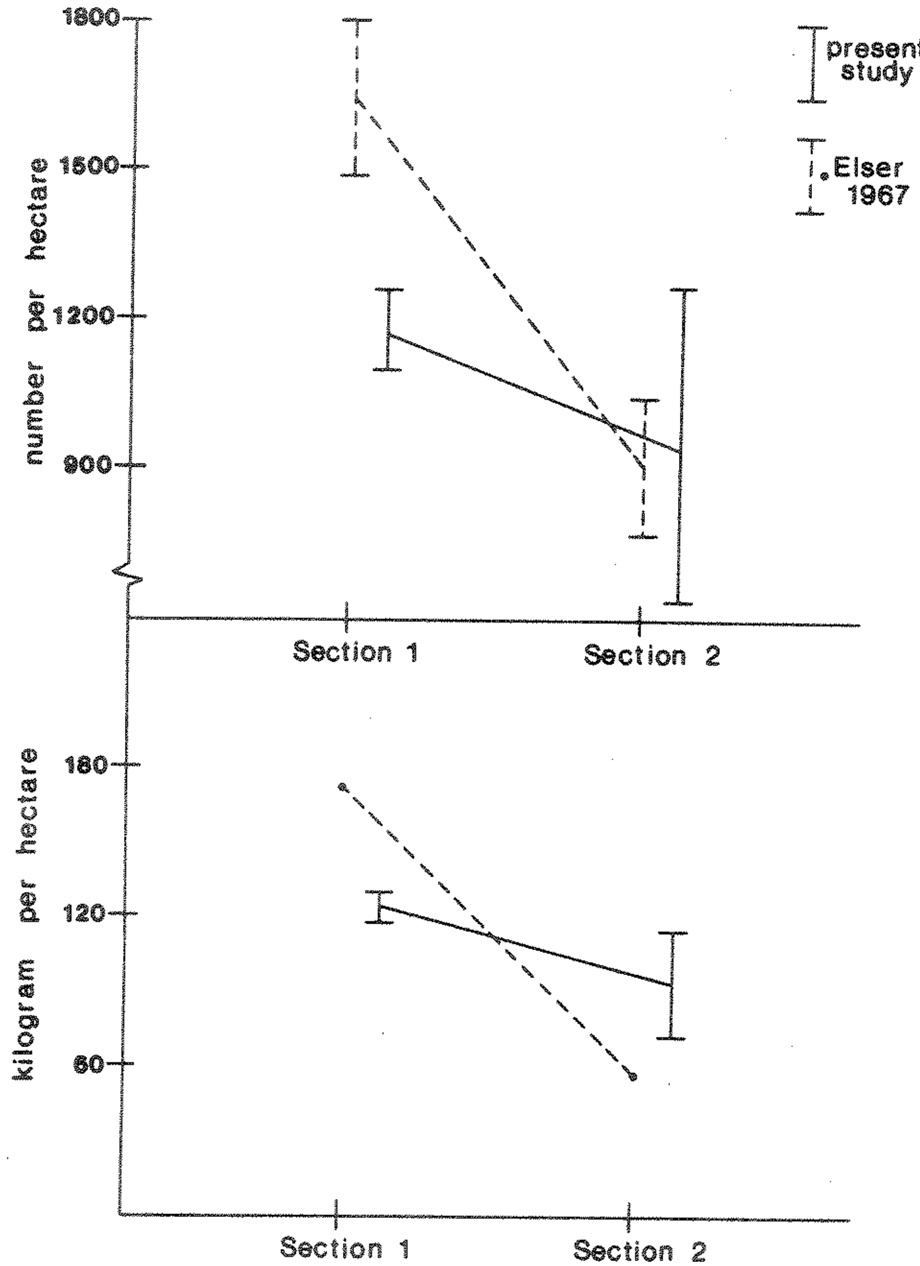

Figure 10. Estimates of total numbers and biomass of trout in the study sections of Little Prickley Pear Creek with comparable estimates from Elser (1968). Bars represent 80% confidence intervals.

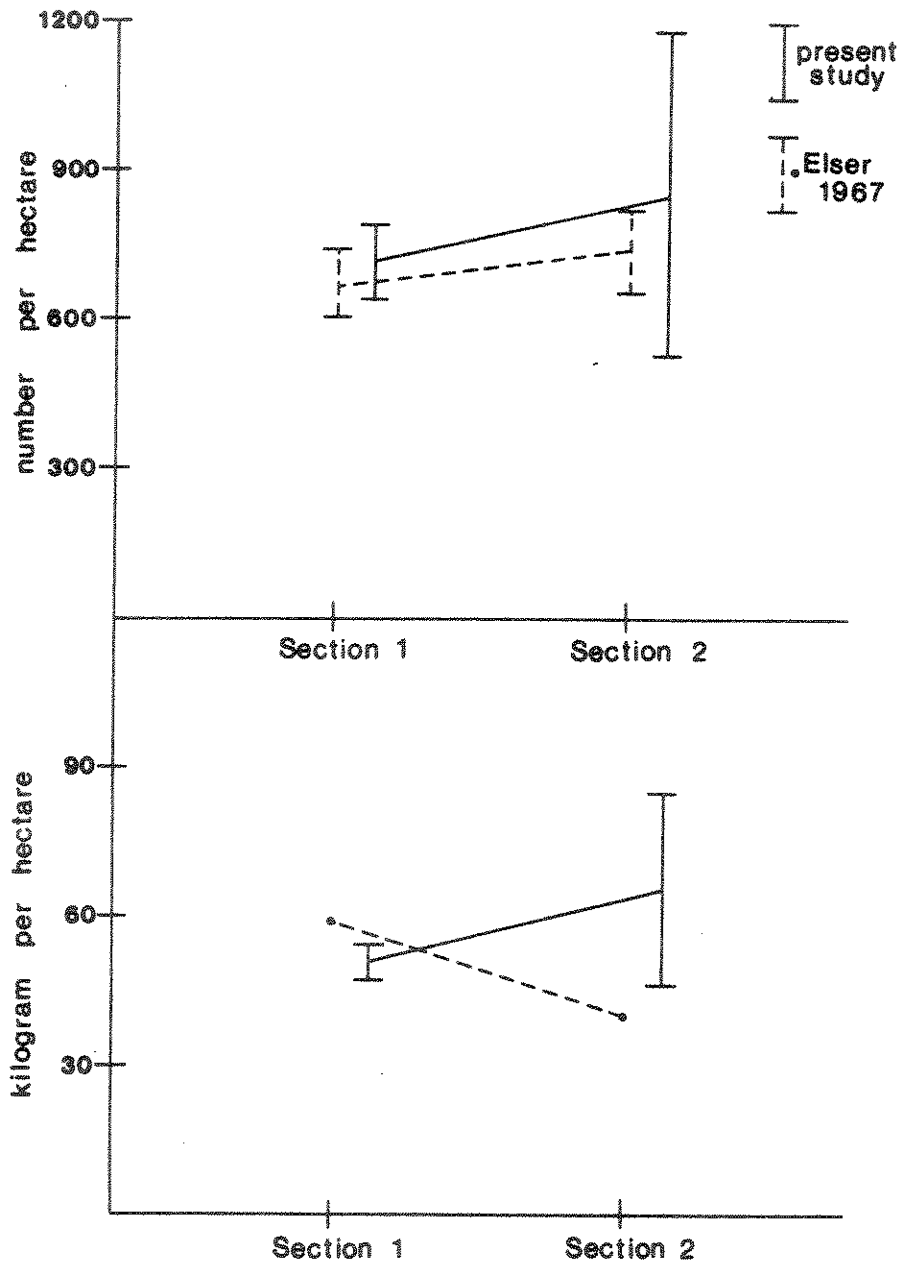

Figure 11. Estimates of numbers and biomass of rainbow trout in the study sections of Little Prickley Pear Creek with comparable estimates from Elser (1968). Bars represent 80% confidence intervals.

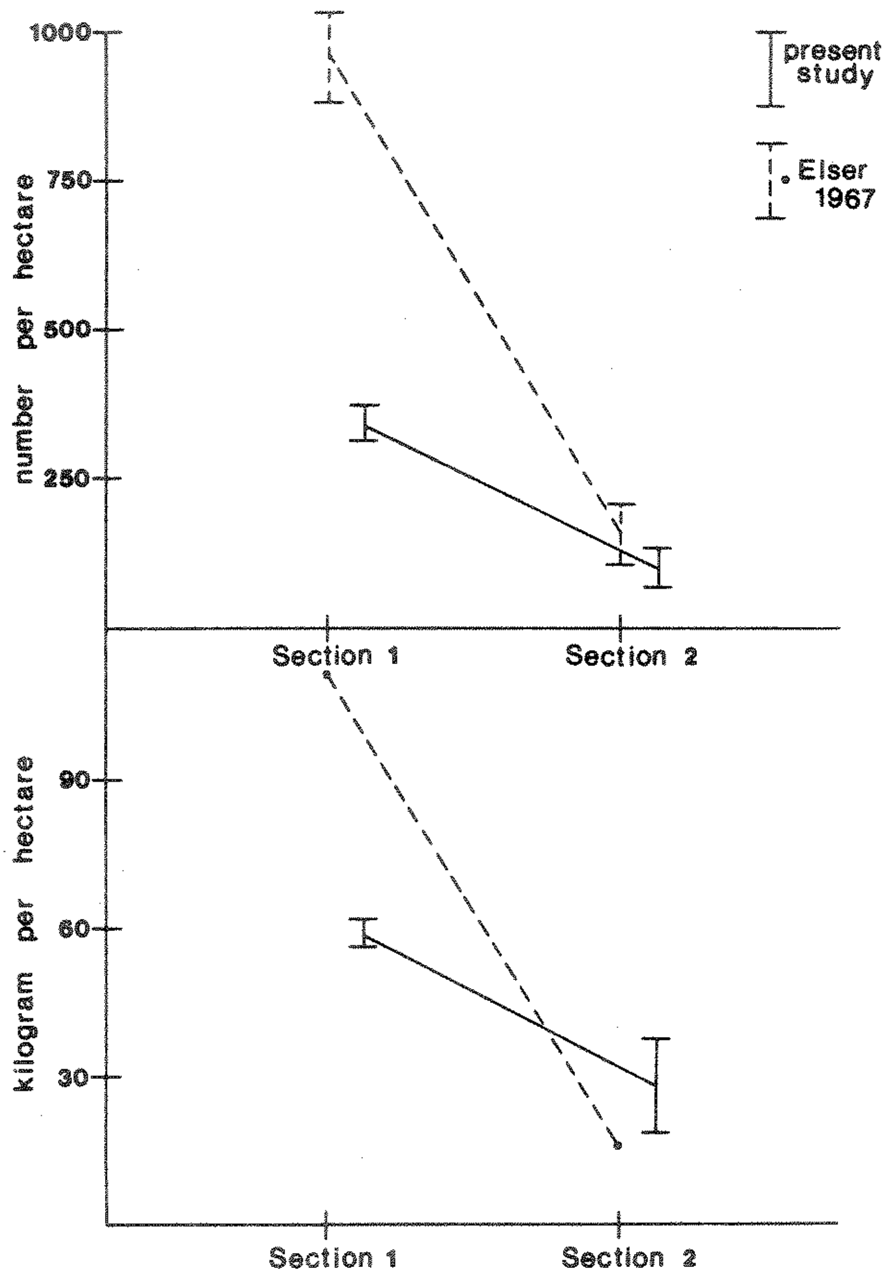

Figure 12. Estimates of numbers and biomass of brown trout in the study sections of Little Prickley Pear Creek with comparable estimates from Elser (1968). Bars represent 80% confidence intervals.

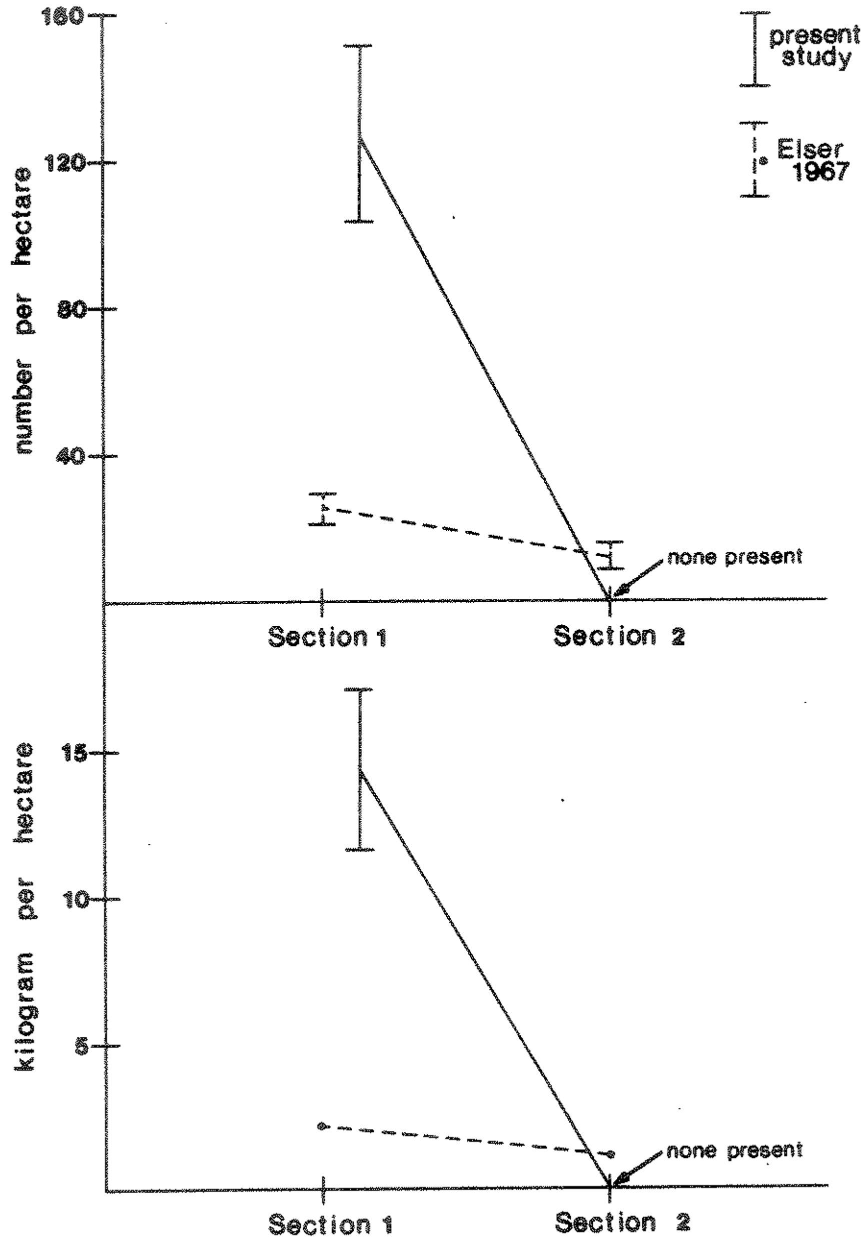

Figure 13. Estimates of numbers and biomass of brook trout in the study sections of Little Prickley Pear Creek with comparable estimates from Elser (1968). Bars represent 80% confidence intervals.

Rainbow trout numbers estimated in the two study sections during the present study were not significantly different than the 1966 estimates. Brown trout numbers in Section 1, and brook trout numbers in Section 2, estimated during the present study were significantly less than the previous estimates. In contrast, brook trout numbers estimated in Section 1 during the present study were significantly greater than the 1966 estimate.

The estimated biomass of total trout, rainbow trout, and brown trout obtained in Section 1 during the present study were less than estimates obtained in 1966. The biomass estimates of these trout groups obtained in Section 2 during the present study were greater than the 1966 estimates. In addition, the biomass of brook trout estimated in Section 1 during 1980 was greater than estimates made previously. Differences of biomass between studies could not be tested for significance because standard deviations were unavailable from Elser (1968).

The growth curves for rainbow trout and brown trout obtained during the present study and from Elser (1968) are presented graphically in Figure 14. The growth rates for both species appeared similar between studies. Condition factors for trout were not computed by Elser, therefore comparisons between studies could not be made.

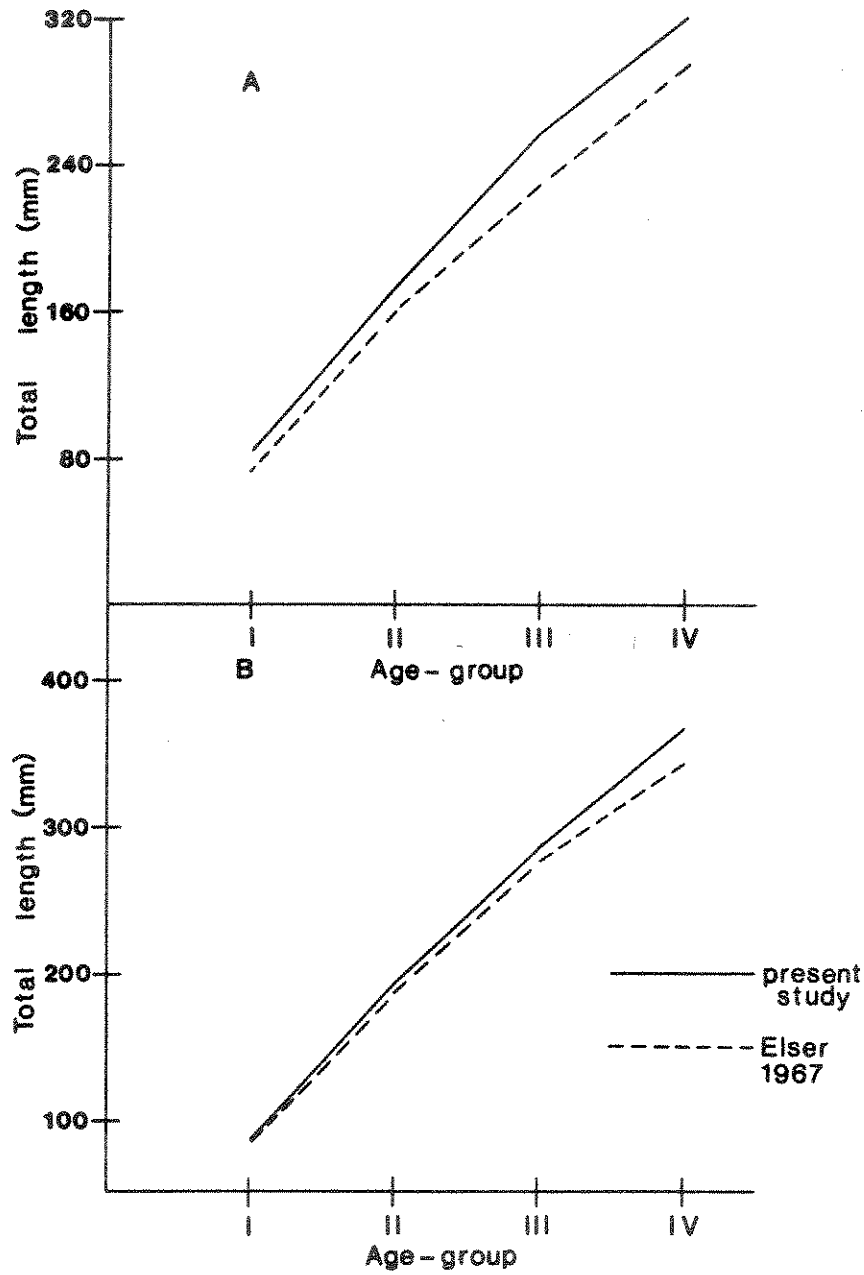

Figure 14. Growth curves of (A) rainbow trout and (B) brown trout in Little Prickley Pear Creek obtained during the present study with comparable curves from Elser (1968).

Relationships between Physical Characteristics and Trout Populations

Regression analysis was used to determine the amount of variation in the estimated numbers of trout among study sections that was attributable to individual physical characteristics measured in Little Prickley Pear Creek. Point estimates of trout numbers obtained during the present study and in 1966 (Elser 1968) were used as cases of the dependent variable. All cover measurements were not included in analyses because the methodologies utilized were not comparable between studies. In addition, thalweg velocities were excluded from regression analysis because measurements were not obtained in 1966.

None of the individual physical characteristics significantly related to the total estimated densities of rainbow trout or brown trout among study sections ($P>0.10$). The relatively large confidence intervals computed for rainbow trout estimates during the present study could have masked any meaningful correlations with physical characteristics that may have existed.

The greater estimated biomass of rainbow trout in Sections 1 (unaltered control) and 2 (mitigated with rock jetties) indicated that these sections had provided a greater amount of habitat for this species than Section 3 (without mitigation). Rainbow trout habitat available in Section 2 appeared to be comparable to that in Section 1. The jetties appeared to be effective in restoring the rainbow trout population in Section 2.

Densities of brown trout estimated in Section 1 were greater than those in Sections 2 or 3. These relationships indicated that the rock jetties installed in Section 2 had not created brown trout habitat that was comparable to Section 1. Densities of brown trout appeared to have been directly related to the total amount of overhanging cover that was present in each study section. This relationship was also found in 1966 by Elser (1968). In general, Section 1 (unaltered control) provided the greatest amount of habitat for trout among all study sections.

Sheep Creek

Physical Characteristics

The physical characteristics measured in the two study sections of Sheep Creek are presented in Table 13. Widths, depths, thalweg depths, thalweg velocities, and water velocities were compared using analyses of variance and the studentized Newman-Kuels method ($P<0.05$). The mean widths were not significantly different between Sections 1 (with step dams) and 2 (control). The mean depth and mean thalweg depth were significantly greater in Section 1 than in Section 2. Mean thalweg velocities were not significantly different between study sections. The mean water velocity was significantly less in Section 1 than in Section 2. The greater depths and lesser water velocities

Table 13. Selected physical characteristics of the study sections in Sheep Creek measured during the summer of 1980. Standard deviations in parentheses.

Parameter	Section 1 (step dams)	Section 2 (control)
Mean width (m)	9.3 (1.4)	9.2 (1.1)
Mean depth (cm)	32.7 (20.2)	24.5 (12.5)
Mean thalweg depth (cm)	53.8 (22.1)	43.4 (6.6)
Mean thalweg velocity (m/sec)	0.43 (0.24)	0.54 (0.26)
Mean water velocity (m/sec)	0.35 (0.21)	0.44 (0.25)
Pool-riffle periodicity	6.2	12.0
Pool-riffle ratio	1.34	0.15
Gradient (%)	0.95	1.10
Sinuosity	1.04	1.09
Discharge (m^3/sec)	0.94	0.94
Area (hectares)	0.29	0.28
Section length (m)	310	300

in Section 1 were associated with the numerous pools present in this section.

Numbers of pools as measured by pool-riffle periodicity were approximately twice as great in Section 1 than in Section 2. The pool-riffle ratio in Section 1 was 793% greater than that in Section 2. The greater numbers and lengths of pools in Section 1 were associated with the step dams installed in this section.

The gradient was approximately 14% less in Section 1 than in Section 2. Sinuosities were similar between both sections. Discharges in the two study sections were similar at the time measurements of physical characteristics were made. The sample size (N) for each physical characteristic measured is presented in Appendix Table 2.

The profiles of the stream bed along the thalweg of the two study sections are shown in Figure 15. The thalweg of the stream bed appeared to undulate with similar frequency in the two study sections. However, more numerous and deeper pools were formed in the thalweg of Section 1.

The surface areas of overhanging and instream cover in the two study sections are presented in Table 14. Brush provided over 90% of the total overhanging cover in both study sections. Although the total amount of overhanging cover in Section 1 was 63% greater than in Section 2, this difference was not significant (Analysis of variance; $P>0.05$).

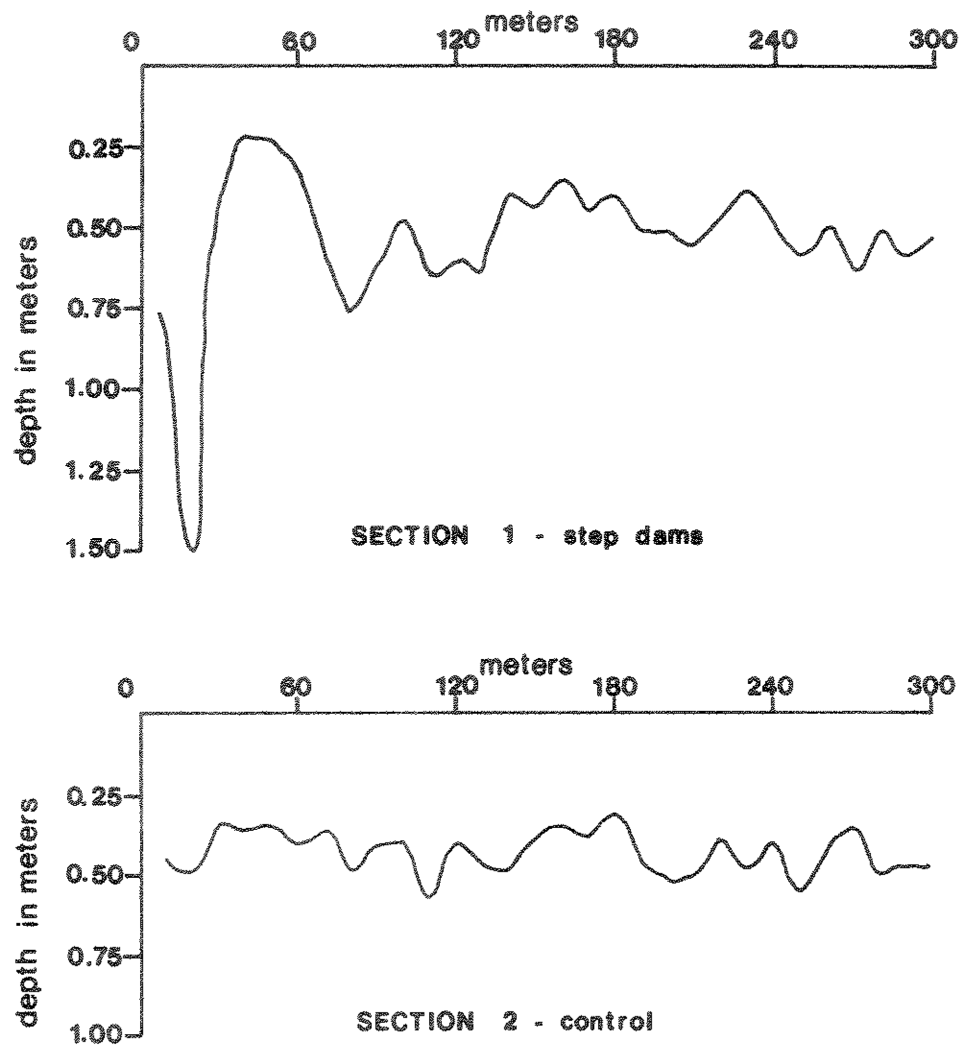

Figure 15. Profiles of the stream bed along the thalweg in the study sections of Sheep Creek.

Table 14. Area (m^2/300 m) of each cover classification from the study sections in Sheep Creek measured during the summer of 1980.

Cover Type	Section 1	Section 2
Overhanging		
Brush[1]	96.2	65.3
(% of total overhanging cover)	(90.6)	(100)
Debris[2]	3.6	0
(% of total overhanging cover)	(3.4)	(0)
Undercuts[3]	3.5	0
(% of total overhanging cover)	(3.3)	(0)
Rock shelves[4]	2.9	0
(% of total overhanging cover)	(2.7)	(0)
Subtotal	106.2	65.3
Instream		
Debris[2]	18.8	0
(% of total instream cover)	(77.7)	(0)
Rock shelves[4]	5.4	6.7
(% of total instream cover)	(22.3)	(100)
Subtotal	24.2	6.7
Total cover	130.4	72.0

[1]Overhanging rooted woody vegetation

[2]Snags, driftwood, and logs including those in step dams

[3]Undercut stream banks

[4]Shelves of rock within of overhanging the water

Debris provided over 75% of the instream cover in Section 1. Much of the potential instream cover in this section was comprised of the logs that were installed as improvement structures. Rock shelves provided 100% of the instream cover in Section 2. The total amount of instream cover was not significantly different between study sections (Analysis of variance; $P>0.05$).

Although the separate amounts of overhanging and instream cover were not significantly different between study sections, the total amount of potential cover was significantly greater in Section 1 than in Section 2 (Analysis of variance; $P<0.05$). This difference was mainly due to the greater amounts of brush and instream debris found in Section 1.

The mean percentages of each class of bottom material measured in the two study sections are presented in Appendix Table 3. The greater percentage of gravel and fines in Section 1 was probably correlated with the greater pool frequency measured in this section. Fine sediment was found to be localized in the pools impounded by the step dams.

Durability and Dimensions of Stream Improvement Structures

The log step dams installed in Section 1 appeared to be durable improvement structures. Eight of these structures placed in this section during 1961 were functionally intact 19 years following installation. These structures appeared to be effective in increasing pool-riffle periodicity. The pool frequency measured in Section 1 was almost 100% greater than that in Section 2. However, numerous small pools associated with individual boulders were present in the channel of Section 2. Because physical measurements were taken at 10 m intervals, many of these were missed and not classified as pools.

All of the step dams appeared to be in generally good condition. The dams consisted of two logs laid one on top of the other which formed a barrier with a height of approximately 0.30-0.60 m above the surface of the plunge pool created immediately downstream. The logs were installed diagonally to the main current across the full width of the stream and spaced at intervals averaging 4.5 stream widths (41.6 m, SD=21.2). The ends of the dams were embedded approximately 0.9-1.5 m into the banks of the stream. Pools impounded by the step dams averaged 0.58 m (SD=0.11) in maximum depth, while those formed by the scouring action of the water plunging over the dams averaged 0.69 m (SD=0.33) in maximum depth.

Parameters of Salmonid Populations

The numbers and sizes of each species of salmonid captured in the two study sections are presented in Appendix Table 10. Rainbow trout was the dominant species in both study sections, comprising 51 and 67%

of the total salmonid numbers collected in Sections 1 (with step dams) and 2 (control), respectively.

Estimates of the numbers and biomass of I+ and older rainbow trout and III+ and older mountain whitefish are presented on an equivalent basis in Table 15. Populations of brook trout and brown trout could not be estimated because the sample sizes for these species were inadequate. Estimates of salmonid densities among study sections were compared using t-tests ($P<0.20$).

The total numbers and total biomass of salmonids per hectare were significantly greater in Section 1 than in Section 2. Estimated numbers of rainbow trout per hectare were not significantly different between study sections. Numbers of age I+ rainbow trout were dominant among age-groups in Section 1. In contrast, numbers of age II+ rainbow trout dominated the age structure in Section 2. The combined numbers of age I+ and II+ rainbow trout were not significantly different between study sections. However, the numbers of age III+ and older rainbow trout were significantly less in Section 1 than in Section 2.

The estimated biomass of rainbow trout per hectare was not significantly different between study sections. The biomass of age III+ rainbow trout was dominant among age-groups in both study sections. The combined biomass of age I+ and II+ rainbow trout was significantly greater in Section 1 than in Section 2. However, the

Table 15. Estimates of numbers (N), biomass, and age structures of salmonids in the study sections of Sheep Creek obtained during the summer of 1979. 80% confidence intervals in parentheses.

Section	Species	Age-group	N	Biomass (kg)
1 (step dams)	Rainbow trout	I+	386	7.2
		II+	345	16.4
		III+	186	18.9
		IV & older	28	4.7
		Total	945 (848-1042)	47.2 (44.1-50.3)
	Mountain whitefish	III+	86	8.8
		IV+	403	62.4
		V+	272	53.0
		VI+	88	23.3
		VII & older	34	11.5
		Total	883 (790-976)	159.0 (140.2-177.8)
	Total salmonids		1828 (1694-1962)	206.2 (187.1-225.3)
2 (control)	Rainbow trout	I+	307	4.7
		II+	343	12.8
		III+	246	22.5
		IV+ & older	25	4.5
		Total	921 (811-1031)	44.5 (39.6-49.4)
	Mountain whitefish	III+	36	4.3
		IV+	239	38.0
		V+	196	38.6
		VI+	18	5.4
		VII+ & older	43	12.6
		Total	532 (400-664)	98.9 (77.8-120.0)
	Total salmonids		1453 (1281-1625)	143.4 (121.8-165.0)

biomass of age III+ and older rainbow trout was not significantly different between study sections.

The estimated numbers of mountain whitefish per hectare were significantly greater in Section 1 than in Section 2. Numbers of age IV+ mountain whitefish were dominant among age-groups in both study sections. Estimated numbers of age III+, IV+, V+, and VI+ mountain whitefish were each significantly greater in Section 1 than in Section 2. Numbers of age VII+ and older mountain whitefish were not significantly different between study sections.

The estimated biomass of mountain whitefish per hectare was significantly greater in Section 1 than in Section 2. The biomass of age IV+ mountain whitefish dominated the age structure in Section 1. The biomass of age V+ mountain whitefish was dominant among age-groups in Section 2. The estimated biomass of age III+, IV+, and VI+ mountain whitefish were each significantly greater in Section 1 than in Section 2. In contrast, the biomass of age V+ and VII+ and older mountain whitefish were not significantly different between study sections.

Regression equations used in the back-calculation of lengths and weights at age of rainbow trout captured in the two study sections are presented in Appendix Table 11. The mean total length at time of capture and the back-calculated lengths and weights at age of rainbow trout are given in Table 16. The mean back-calculated lengths and

Table 16. Mean total length (TL) at time of capture and back-calculated mean total length and weight at age for rainbow trout in the study sections of Sheep Creek during the summer of 1979. Standard deviations in parentheses.

Section	Age-group	N	Mean TL (mm) at capture	Calculated Length (mm) at Age I	II	III	IV
1	I+	64	130	74			
(step dams)	II+	62	170	83	137		
	III+	37	216	89	143	196	
	IV	7	257	84	159	185	242
Mean back-calculated length (mm)				81(±12)	141(±21)	187(±27)	242(±26)
Mean increment of back-calculated length (mm)				81	60	46	55
Mean calculated weight (gm)				4.8(±2.3)	26.2(±11.1)	64.0(±27.9)	135.1(±44.0)
2	I	33	125	72			
(control)	II+	45	157	81	126		
	III+	31	206	84	147	188	
	IV+	3	259	90	129	178	219
Mean back-calculated length (mm)				80(±6)	134(±20)	187(±26)	219(±43)
Mean increment of back-calculated length (mm)				80	54	53	32
Mean calculated weight (gm)				4.8(±2.0)	23.6(±10.6)	64.5(±28.5)	106.1(±64.1)
Pooled total	I+	97	128	74			
	II+	107	165	83	132		
	III+	68	211	87	145	186	
	IV+	10	258	86	150	191	235
Mean back-calculated length (mm)				81(±10)	138(±21)	187(±26)	235(±31)
Mean increment of back-calculated length (mm)				81	57	49	48
Mean calculated weight (gm)				4.8(±3.0)	25.1(±15.3)	64.2(±39.9)	127.2(±77.7)

weights of rainbow trout at age in each study section were compared using analyses of variance ($P<0.05$). The means for all ages of rainbow trout were not significantly different between study sections.

Mean condition factors (K) were computed for rainbow trout and mountain whitefish greater than 12.7 cm in total length from the two study sections (Appendix Table 6). The mean condition factors for each species did not vary significantly between study sections (t-tests; $P>0.05$).

Relationships between Physical Characteristics and Trout Populations

Densities of rainbow trout estimated in Section 1 (with step dams) were similar to those estimated in Section 2 (control). Densities of this species were apparently not correlated with the greater pool frequency found in Section 1. Consequently, the log step dams installed as improvement structures did not appear to enhance habitat for rainbow trout.

The greater densities of mountain whitefish in Section 1 indicated this step dam section provided a greater amount of habitat for this species than did Section 2. Apparently, mountain whitefish densities were correlated with the greater pool frequency formed by the step dams. However, mountain whitefish in the two study sections may have been migratory and not yearlong residents. The greater numbers of age IV+ mountain whitefish among age-groups captured in the study sections indicated that at least a portion of the population was migratory.

SUMMARY AND DISCUSSION

The preferred habitat for stream dwelling trout is primarily characterized by a combination of adequate cover and appropriate water velocities (Stalnaker and Arnette 1976). These factors provide shade, security from predators, and focal points (microhabitat) in water of lower velocities adjacent to higher velocities carrying principle lines of drift food (Chapman and Bjornn 1969). Trout compete for these preferred microhabitats to maximize efficiencies in feeding and, ultimately, improve their chances of survival (Kalleberg 1958; Chapman 1966). In stream improvement work for trout, the primary goal is to increase the availability of this suitable habitat and, as a result, increase population densities.

In general, instream structures for improvement and mitigation are installed to increase the quantity of pools (U. S. Forest Service 1969) thereby providing a greater number of slower water sites. The random boulders, rock jetties, and step dams installed in the three streams in this study were all effective in restoring or enhancing pool frequencies. However, these three types of structures were not equally effective in enhancing trout populations.

The random boulders were effective in restoring the stream bed configuration and trout populations in a relocated section of the St. Regis River. The steep and confined nature of this section prevented the use of jetties for mitigation. The boulders produced a pool frequency that was similar to that found in a section mitigated with jetties and greater than that which was measured in a partially altered control section.

Densities of cutthroat trout and brook trout estimated in this section were greater than in either the jetty or control sections. These mitigative devices appeared to provide considerable visual isolation for trout within and between the pools that were created. Kalleberg (1958) reported that increased visual isolation for juvenile salmon and brown trout acted as a mechanism for reducing territory size, thereby allowing for greater densities of these species. Greater visual isolation could, in part, explain the greater densities of trout found in the random boulder section.

Rock jetties were effective in restoring the stream bed configurations in channelized sections of the St. Regis River and Little Prickley Pear Creek. In the St. Regis River, rock jetties produced a pool frequency that was greater than that in the partially altered control and similar to the frequency formed in the boulder section. However, pools created by these structures were smaller and more shallow than those in either the control or boulder sections. The shallow depth of the pools in this section provided little security for trout. Shaplow (1976) reported a considerable amount of sediment was deposited in the jetty section. This coarse sediment appeared to still be present in 1980 and probably had partially filled these scour holes.

In addition, flood damage to the structures had reduced their ability to concentrate stream flow.

Rock jetties installed in the St. Regis River were not as effective in restoring cutthroat trout and brook trout populations as were the random boulders. Estimated densities of these species in the jetty section were generally similar to estimates obtained in the partially altered control but less than those obtained in the section with boulders.

In Little Prickley Pear Creek, the rock jetties produced a pool frequency that was comparable to an unaltered control section. Pools formed by these structures were similar in size and depth as those in the control. In the 16 years following channelization, pools had not naturally developed in the unmitigated section. Previous research has indicated old channelized stream beds lacking mitigative structures do not freely return to natural pool-riffle periodicities (Bayless and Smith 1964; Elser 1968; Lund 1976).

Pools formed by jetties appeared to enhance the rainbow trout population in Little Prickley Pear Creek. Estimated biomass of this species in the jetty section was similar to the control and greater than estimates obtained in the unmitigated section. In contrast, pools formed by these structures were ineffective in restoring the brown trout population. Densities of brown trout estimated in the jetty section were less than estimates in the control and similar to those obtained in the unmitigated section. Previous research has demonstrated that brown trout densities are highly correlated with overhanging cover (Lewis 1969; Enk 1977). The lack of overhanging cover in the jetty and unmitigated sections was probably limiting the population of this species. Future stream improvement work involving brown trout populations should attempt to provide overhanging cover along the shoreline.

The log step dams in Sheep Creek created a pool frequency that was greater than that in a control section. However, these structures were ineffective in enhancing the rainbow trout population. This finding contrasts with the apparent association between densities (biomass) of rainbow trout and pool frequency in Little Prickley Pear Creek. Many small pockets were interspersed throughout the control section and may have not been fully counted in measurements on Sheep Creek. These small pockets in this section may have provided rainbow trout security and resting areas that were comparable to the pools formed by the step dams.

The greater pool frequency created by the step dams did appear to be effective in enhancing the mountain whitefish population. Greater densities of this species were estimated in this section than in the control section. However, the mountain whitefish may not have been yearlong residents in the study sections. Stefanich (1951) found that mountain whitefish in Little Prickley Pear Creek tended to be migratory.

Differential fishing pressure and harvest may have altered the relationships of trout densities among sections of the three streams in this study. Lund (1976) found unaltered sections of the St. Regis River received greater fishing pressure than altered sections. There was no indication of differential harvest in the comparisons of growth rates of trout from sections within the streams.

The expense of installing instream structures for enhancement and mitigation make it imperative that placement will produce effective and long lasting results. The boulders installed in the St. Regis River were functionally stable 8 years following their installation. The stability of these boulders is primarily determined by their volume and the substrate type upon which they are placed. The U. S. Forest Service (1969) proposed that boulders should excede 0.6 m^3 in volume and should be placed upon substrate larger than gravel to prevent undermining and displacement into their own scour holes. A majority of the boulders installed in the St. Regis River appeared to exceed this minimum volume and were placed upon substrate composed of rubble and bedrock. Consequently, these boulders will probably exhibit long lasting stability and functionality as mitigative devices. Barton and Winger (1973) found this type of mitigation effectively created pools and aided in restoring trout populations in the Weber River and the U. S. Dept. of Transportation (1979) reported boulders may be the best mitigative treatment for relocated channels with steep gradients. Calhoun (1966) also reported large boulders might be beneficial in restoring channelizations. However, randomly placed boulders were ineffective in producing good trout habitat in Little Prickley Pear Creek because many became buried in the substrate (Johnson 1967).

In intermediate and lower gradient streams, jetties may be the best type of structure for stream improvement. The rock jetties in the St. Regis River were less durable than those installed in Little Prickley Pear Creek. The instability of these structures was probably associated with the placement interval between jetties. The structures in the St. Regis River and Little Prickley Pear Creek were installed at intervals of approximately 2 and 5 stream widths, respectively. Unaltered streams with varying sizes of coarse bed material generally have pool-riffle periodicities occurring at 5 to 7 stream widths (Leopold et al. 1964). An interval of 2 stream widths could have been a cause for the undermining and displacement incurred by the jetties in the St. Regis River. Additionally, jetties may be more permanent in streams having lesser high water flows.

The rock jetties and associated pool-riffle periodicities in the two streams have apparently reached an equillibrium with factors that determine channel configuration. As a result, the remaining structures will probably continue to be functional for some time. Barton and Winger (1973) have found this type of structure aided in restoring channelized sections of the Weber River over a 4-year period of study. Elser (1970) reported jetties restored pool-riffle periodicities in a channelized section of the East Gallatin River one year following installation. Jetties, if properly installed, are more durable and cause less disturbance to the stream bottom than step dams (U. S. Forest Service 1969).

The log step dams placed in Sheep Creek were functionally intact 16 years following installation. The stability of these structures is primarily determined by the way their ends are anchored into the stream banks and the substrate type upon which they are placed. Dams placed on unstable substrate tend to wash out from underneath the logs (U. S. Forest Service 1969). Elhers (1956) found the destruction of log step dams in a small stream in California was caused by inadequate anchoring. Only one dam in Sheep Creek was observed to be partially undermined. The rest of the structures were in generally good condition and will probably function beyond 20 years of age. Log step dams have been effective in enhancing pool frequencies in streams with widths ranging from 1 to 6 m, gradients ranging from 0.5 to 20%, and maximum discharges below 5.7 m^3/sec (Raleigh and Duff 1980). The U. S. Dept. of Transportation (1979) reported that step dams constructed of untreated logs could be expected to last about 20 years, depending on exposure to alternate wetting and drying.

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APPENDIX

Appendix Table 1. Location of study sections on the St. Regis River, Little Prickley Pear Creek, and Sheep Creek.

Stream	Study Section	Legal Description	Length (m)
St. Regis River	1	T.19N., R.31W., Section 14, NW¼	510
	2	T.19N., R.31W., Section 9, SE¼	455
	3	T.19N., R.31W., Section 9, SW¼	387
Little Prickley Pear Creek	1	T.13N., R.4W., Section 9, NW¼	340
	2	T.14N., R.4W., Section 15, SE¼	468
	3	T.14N., R.4W., Section 11, SW¼	238
Sheep Creek	1	T.12N., R.6E., Section 24, SE¼	310
	2	T.12N., R.6E., Section 24, NE¼	300

Appendix Table 2. Sample size (N) of the physical characteristics measured from the St. Regis River, Little Prickley Pear Creek, and Sheep Creek obtained during the summer of 1980.

Stream	Parameter	Section 1	Section 2	Section 3
St. Regis River	Width	68	58	51
	Depth	1351	755	1135
	Thalweg depth	68	58	51
	Thalweg velocity	68	58	51
	Pool-riffle periodicity	5	11	5
	Number of transects	68	58	51
Little Prickley Pear Creek	Width	46	61	22
	Depth	881	1452	455
	Thalweg depth	46	61	22
	Thalweg velocity	46	61	22
	Pool-riffle periodicty	6	7	0
	Number of transects	46	61	22
Sheep Creek	Width	30	30	
	Depth	548	504	
	Thalweg depth	30	30	
	Thalweg velocity	30	30	
	Water velocity	505	474	
	Pool-riffle periodicity	5	2	
	Number of transects	30	30	

Appendix Table 3. The average percentages of each class of bottom material of the study sections in the St. Regis River, Little Prickley Pear Creek, and Sheep Creek measured during the summer of 1980. Standard deviations in parentheses.

Bottom Type	Section 1	Section 2	Section 3
	St. Regis River		
Bedrock	3.56 (17.39)	0 (0)	0 (0)
Boulders (over 26.0 cm)	39.42 (20.44)	56.90 (20.37)	33.80 (14.53)
Rubble (6.4-26.0 cm)	50.59 (19.38)	32.93 (16.56)	52.80 (10.90)
Gravel (2.0 mm-6.3 cm)	6.18 (11.94)	8.45 (8.87)	12.40 (11.00)
Fines (under 2.0 mm)	0.29 (1.71)	1.72 (3.35)	1.00 (2.04)
	Little Prickley Pear Creek		
Bedrock	0.22 (1.04)	0 (0)	0 (0)
Boulders (over 26.0 cm)	1.09 (3.00)	5.00 (10.09)	5.45 (12.14)
Rubble (6.4-26.0 cm)	54.57 (20.05)	50.50 (16.63)	58.18 (13.93)
Gravel (2.0 mm-6.3 cm)	29.13 (11.35)	31.17 (10.23)	30.91 (13.93)
Fines (under 2.0 mm)	15.00 (23.35)	13.33 (20.44)	5.45 (12.93)
	Sheep Creek		
Bedrock	1.67 (9.13)	1.67 (6.34)	
Boulders	38.25 (20.55)	58.67 (20.82)	
Rubble	32.71 (22.04)	31.92 (18.89)	

Appendix Table 3. (Continued)

Bottom Type	Section 1	Section 2	Section 3
	Sheep Creek (continued)		
Gravel (2.0 mm-6.3 cm)	21.62 (18.79)	7.33 (10.44)	
Fines (under 2.0 mm)	5.75 (11.95)	0.42 (2.28)	

Appendix Table 4. Catch statistics for trout collected in the study sections of the St. Regis River during the summer of 1979.

Section	Species	Size Group (mm)	Number Marked	Number Captured	Number Recaptured
1 (control)	Cutthroat trout	76-112	56	50	18
		114-163	42	33	15
		165-213	34	27	18
		216-328	12	9	7
		Total	144	119	58
	Brook trout	89-188	16	12	7
		190-290	9	6	6
		Total	25	18	13
2 (boulders)	Cutthroat trout	76-112	79	67	27
		114-137	37	46	22
		139-201	69	54	33
		203-277	15	15	10
		Total	200	182	92
	Brook trout	114-391	23	17	11
		Total	23	17	11
3 (jetties)	Cutthroat trout	64-112	88	95	28
		114-137	30	35	14
		139-188	41	43	24
		190-379	15	14	7
		Total	174	187	73
	Brook trout	102-175	5	6	4
		178-340	10	5	4
		Total	15	11	8

Appendix Table 5. Total length-total scale radius and total length-weight regression equations used to back-calculate length and weight at age of cutthroat trout in the study sections of the St. Regis River during the summer of 1979.

Section	Regression Equation	N	Correlation Coefficient r
	Total length-total scale radius regressions		
1 (control)	L = 4.593 Sc + 12.848	162	0.897
2 (random boulders)	L = 4.312 Sc + 21.764	209	0.891
3 (jetties)	L = 4.174 Sc + 22.474	220	0.903
Pooled total	L = 4.350 Sc + 19.446	591	0.898
	Total length-weight regressions		
1 (control)	log W = -5.338 + 3.125 log L	162	0.985
2 (random boulders)	log W = =5.683 + 3.278 log L	209	0.982
3 (jetties)	log W = -4.957 + 2.917 log L	220	0.962
Pooled total	log W = -5.333 + 3.109 log L	591	0.974

where:

L = total length (mm)
Sc = total anterior scale radius (mm) x 66
W = weight (gm)

Appendix Table 6. Mean condition factors (K) for salmonids greater than 12.7 cm in total length from the study sections of the St. Regis River, 1979; Little Prickley Pear Creek, 1980: and Sheep Creek, 1979. Standard deviations in parentheses.

Section	Date	Species	Number	K
		St. Regis River		
1	8/8 & 8/14/79	Cutthroat trout	117	0.897 (0.133)
		Brook trout	30	0.957 (0.198)
2	8/9 & 8/15/79	Cutthroat trout	171	0.806 (0.157)
		Brook trout	29	1.042 (0.154)
3	8/8 & 8/9/79	Cutthroat trout	133	0.776 (0.225)
		Brook trout	18	0.923 (0.204)
		Little Prickley Pear Creek		
1	8/15 & 8/22/80	Rainbow trout	196	0.945 (0.168)
		Brown trout	105	0.976 (0.083)
		Brook trout	37	1.033 (0.094)
2	8/4 & 8/11/80	Rainbow trout	138	0.995 (0.204)
		Brown trout	38	1.003 (0.101)
3	8/4 & 8/11/80	Rainbow trout	97	1.009 (0.197)
		Brown trout	18	0.983 (0.122)

Appendix Table 6. (continued)

Section	Date	Species	Number	K
		Sheep Creek		
1	8/28 & 9/4/79	Rainbow trout	213	0.930 (0.184)
		Mountain whitefish	199	0.902 (0.087)
2	8/28 & 9/4/79	Rainbow trout	189	0.934 (0.174)
		Mountain whitefish	88	0.966 (0.077)

Appendix Table 7. Catch statistics for trout collected in the study sections of Little Prickley Pear Creek during the summer of 1980.

Section	Species	Size Group (mm)	Number		
			Marked	Captured	Recaptured
1 (control)	Rainbow trout	114-163	58	42	21
		165-201	38	42	25
		203-264	42	35	37
		267-366	14	11	9
		Total	152	130	92
	Brown trout	140-213	38	32	21
		216-277	16	14	11
		279-315	14	16	12
		318-505	19	13	13
		Total	87	75	57
	Brook trout	127-226	18	13	9
		229-315	10	11	6
		Total	28	24	15
2 (jetty)	Rainbow trout	114-251	41	71	6
		254-391	20	18	6
		Total	61	89	12
	Brown trout	127-315	11	14	4
		318-455	7	14	4
		Total	18	28	8

Appendix Table 7. (continued)

Section	Species	Size Group (mm)	Number		
			Marked	Captured	Recaptured
3 (unmitigated)	Rainbow trout	102-163	33	46	9
		165-264	15	19	7
		Total	48	65	16
	Brown trout	140-429	12	11	5
		Total	12	11	5

Appendix Table 8. Total length-total scale radius and total length-weight regression equations used to back-calculate length and weight at age of rainbow trout in the study sections of Little Prickley Pear Creek during the summer of 1980.

Section	Regression Equation	N	Correlation Coefficient r
	Total length-total scale radius regressions		
1 (control)	L = 3.310 Sc + 13.857	179	0.932
2 (jetties)	L = 2.822 Sc + 38.880	160	0.943
3 (unmitigated)	L = 3.039 Sc + 24.694	113	0.930
Pooled total	L = 3.006 Sc + 28.091	452	0.940
	Total length-weight regressions		
1 (control)	log W = -4.955 + 2.960 log L	179	0.987
2 (jetties)	log W = -5.048 + 3.025 log L	160	0.984
3 (unmitigated)	log W = -5.455 + 3.194 log L	113	0.975
Pooled total	log W = -5.123 + 3.045 log L	452	0.983

where

L = total length (mm)
Sc = total anterior scale radius (mm) x 66
W = weight (gm)

Appendix Table 9. Total length-total scale radius and total length-weight regression equations used to back-calculate length and weight at age of rainbow trout in the study sections of Little Prickley Pear Creek during the summer of 1980.

Section	Regression Equation	N	Correlation Coefficient r
	Total length-total scale radius regressions		
1 (control)	L = 3.304 Sc - 0.950	113	0.960
2 (jetties)	L = 3.102 Sc + 16.510	46	0.957
3 (unmitigated)	L = 3.240 Sc + 6.517	22	0.953
Pooled total	L = 3.232 Sc + 4.931	181	0.959
	Total length-weight regressions		
1 (control)	log W = -5.241 + 3.096 log L	113	0.993
2 (jetties)	log W = -5.709 + 3.286 log L	46	0.990
3 (unmitigated)	log W = -5.550 + 3.221 log L	22	0.997
Pooled total	log W = -5.406 + 3.164 log L	181	0.992

where:

L = total length (mm)
Sc = total anterior scale radius (mm) x 66
W = weight (gm)

Appendix Table 10. Catch statistics for salmonids collected in the study sections of Sheep Creek during the summer of 1979.

Section	Species	Size Group (mm)	Number: Marked	Number: Captured	Number: Recaptured
1 (step dams)	Rainbow trout	89-150	68	56	27
		152-201	55	38	25
		203-239	25	26	17
		241-302	11	14	11
		Total	159	134	80
	Brook trout	75-282	12	10	1
	Brown trout	320	1	0	0
	Mountain whitefish	178-226	18	8	5
		229-251	37	29	15
		254-302	70	69	34
		305-353	15	13	6
		Total	140	119	60
2 (control)	Rainbow trout	102-150	58	58	24
		152-201	40	45	22
		203-239	14	15	8
		241-366	12	10	9
		Total	124	128	63
	Brook trout	81-265	13	6	2
	Mountain whitefish	203-277	40	20	7
		279-366	30	17	12
		Total	70	37	19

Appendix Table 11. Total length-total scale radius and total length-weight regression equations used to back-calculate length and weight at age of rainbow trout in the study sections of Sheep Creek during the summer of 1979.

Section	Regression Equation	N	Correlation Coefficient r
	Total length-total scale radius regressions		
1 (step dam)	$L = 2.790\ Sc + 37.035$	198	0.883
2 (control)	$L = 2.786\ Sc + 35.067$	132	0.916
Pooled total	$L = 2.795\ Sc + 35.930$	330	0.909
	Total length-weight regressions		
1 (step dam)	$\log W = -5.312 + 3.123 \log L$	198	0.977
2 (control)	$\log W = -5.152 + 3.053 \log L$	132	0.975
Pooled total	$\log W = -5.229 + 3.087 \log L$	330	0.976

where:

L = total length (mm)
Sc = total anterior scale radius (mm) x 66
W = weight (gm)