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Brook Trout Enhancement Through Rainbow Trout Removal by Electroshocking in the Great Smoky Mountains National Park

Jeanne Dyanne Riley
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Jeanne Dyanne Riley entitled "Brook Trout Enhancement Through Rainbow Trout Removal by Electroshocking in the Great Smoky Mountains National Park." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Wildlife and Fisheries Science.

Richard J. Strange, Major Professor

We have read this thesis and recommend its acceptance:

Donald C. Samson, J. Larry Wilson

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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BROOK TROUT ENHANCEMENT THROUGH RAINBOW TROUT REMOVAL BY ELECTROSHOCKING IN THE GREAT SMOKY MOUNTAINS NATIONAL PARK

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Jeanne Dyanne Riley

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ABSTRACT

Brook trout (Salvelinus fontinalis) populations have declined in the Great Smoky Mountains National Park since the early 1900's. The continuing range loss of the Parks' only native trout species has been attributed mainly to the introduced rainbow trout (Salmo gairdneri). Past studies have indicated that removal of introduced trout by electroshocking results in the enhancement of brook trout populations.

Twelve study streams in the Park were grouped as control and treatment streams. Removal efforts of one, two, and three passes consecutively were conducted on treatment streams to determine the effort needed to control rainbow trout populations. Rainbow trout were removed from these streams and released below a downstream barrier.

One year after renovation efforts, the streams were again surveyed. Results of these surveys indicated that the decline of rainbow trout populations was no greater in three-removal streams than the decline in one-removal streams. Rainbow trout populations decreased in one of the two-removal streams, but increased in the other two-removal streams. This increase was attributed to the lower capture rate in these wider-than-average treatment streams. Brook trout populations increased in the one-removal and two-removal streams, but decreased in the three-removal streams. The two-removal and three-removal efforts required a 60% increase in time over the one-removal effort. The large time increase and the population results in the two-removal and three-

removal streams do not warrant use of more than a one-removal effort for restoration.

Restoration with one-removal efforts on a regular basis should continue in these streams and other Park streams for the recovery of the brook trout.

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CHAPTER I

INTRODUCTION

The brook trout (*Salvelinus fontinalis*) is the only native trout species of the Great Smoky Mountains National Park (GRSM). The population in the GRSM, hereafter referred to as the Park, is near the southern extreme of its range (MacCrimmon and Campbell 1969). The range of the brook trout originally extended from the Arctic Circle into eastern Canada, southward from the New England states through Pennsylvania, and southward along the crest of the Appalachian Mountains to northeastern Georgia. Manitoba southward through the Great Lakes states was the most western range (MacCrimmon and Campbell 1969). Introductions of brook trout have extended its range into Western Canada and the United States.

In the Park, the brook trout population has declined, losing 70% of its former range since the early 1900's (Kelly et al. 1980). Once occurring in nearly every stream above the elevation of 600 meters (2000 feet), the brook trout now is confined to headwater streams above 900 meters (3000 feet) as a reproducing population (King 1937, 1939, 1942; Lennon 1960, 1967). This trend is not unique to the Park. There has been a steady decline of brook trout in the southeastern states over the past 50 years (Seehorn 1978). Several factors contributed to the decline of brook trout in the Park. These included extensive logging, heavy fishing pressure, and the introduction of rainbow trout (*Salmo gairdneri*) in the early 1900's (Holloway 1945; Kelly et al. 1980).

Since rainbow trout introduction, there has been a steady decline in brook trout range (Moore et al. 1981).

The rainbow trout are native to the United States west coast, inland to the Rockies. This original range extended from Southwestern Alaska into Mexico (Behnke 1979). Perhaps the most widely introduced fish species, the rainbow trout now ranges from the Arctic Circle to 55 degrees south latitude (MacCrimmon 1971).

Brook trout appear to be sensitive to rainbow trout introduction and are usually displaced by them (Raleigh 1982). This displacement is believed to be influenced by competition between the species. Studies by Helfrich et al. (1982) indicate that brook trout can compete with rainbow trout of equal size. However, Whitworth (1980) found that rainbow trout initially outgrow brook trout and thereafter maintain their size advantage in southern Appalachian streams.

The brook trout found in the small, cold streams of the Park are short-lived and small in size (Robinette 1978). They appear to be opportunistic sight feeders, utilizing both bottom-dwelling and drifting aquatic macroinvertebrates and terrestrial insects (Raleigh 1982). Male brook trout usually mature sexually before females (Mullen 1958). In Park streams, spawning occurs in the early winter months.

Rainbow trout in the Park have comparatively the same life span and size range as the brook trout. Rainbow trout are also opportunistic feeders, but their diet consists mainly of aquatic insects (Raleigh et al. 1984). Sexual maturity usually occurs during the third year for females and the second or third year for the males (Lagler 1956).

Spawning occurs in the late winter in the Park streams.

In the 1970's, several studies were initiated to develop management plans to reverse the brook trout range loss. Electroshocking was implemented from 1976 to 1978 to remove rainbow trout from streams containing the two species. The investigations indicated that brook trout populations showed increases in biomass as the exotic species were removed (Moore 1979). This finding suggested that rainbow trout have a negative effect on brook trout. Removal of rainbow trout was apparently a major factor leading to substantial increases in brook trout standing crops in sympatric populations (Moore et al. 1981). A second removal program in 1978 by the U.S. Fish and Wildlife Service gave the same results (Tim Broadbent, pers. commun.)

In areas outside the Park, electroshocking is used in conjunction with man-made barriers to restore brook trout populations. Several streams have been renovated in the Cherokee National Forest using this method (Elsen 1985). Gordon Sloane (pers. commun.) with the U.S. Forest Service indicated that restoration through brook trout relocation from other area streams is a valuable method for reestablishing populations. The brook trout are relocated into streams after rainbow trout removal.

In these studies, the rainbow trout were not completely removed from any stream by electroshocking. Electroshocking is a useful technique for population control, but it does not completely eradicate rainbow trout. However, electroshocking falls within the guidelines of National Park Service management policies. Electroshocking also has the advantages of being fast, efficient, and repeatable (Van Deventer and Platts 1983).

The objective of this study was to enhance brook trout populations through the relocation of rainbow trout. Also, the study was designed to determine sampling effort required for restoration to control a rainbow trout population through electroshocking. The results can be used to implement a plan for brook trout restoration in the GRSM.

CHAPTER II

METHODS

Twelve streams were selected and grouped as treatment and control streams. One group consisted of control streams to be used for population comparisons with the treatment streams. The three remaining groups were treatment streams where rainbow trout were to be removed.

These streams were chosen by two criteria. First, the streams must be located in different watersheds throughout the Park. The study areas represented most Park subdistricts and provided a variety of physical characteristics. The second criterion was that the streams contain populations of both brook and rainbow trout. This was determined by trout population distribution maps displayed in Resource Management at Park Headquarters in Gatlinburg, Tennessee (Kelly et al. 1980). The streams were randomly selected after they met these criteria.

Each of the treatment streams was electroshocked upstream from a chosen barrier to the brook trout allopatric zone. Removal efforts of one, two, and three passes consecutively with a 700 V AC backpack electroshocker were conducted to determine the effort needed to control the rainbow trout populations in these streams. The electroshocker was designed as described by Seehorn (1970). Numbered metal tags mark the renovated areas and population estimate sections of each stream. These locations are given in Appendix A. An additional 300 meters (984.3 feet) in the allopatric zone were surveyed to insure the absence of rainbow trout. Before rainbow trout were removed, two population estimates were conducted on each control and treatment stream. Two 100 meter (328.1 feet) sections in each stream were chosen, one at the lower (Section I) and one at the upper (Section II) part of the stream. A three run depletion method (Van Deventer and Platts 1983) was used where all fish were kept in holding nets until the last pass was completed. Natural barriers deterred the movement of fish from the sections during the depletion shocking. A Basic computer program from Platts et al. (1983) was used to calculate population estimates. Significant differences between the population estimates of each year were found (0.05 probability level). The population estimate sections represent the stream population results. These estimates provided population comparisons before and after renovation within the streams.

Man-hours were recorded to determine the time involved in each removal effort. The actual shocking time was derived from individual removal efforts based on a stream that was shocked three times.

The most favorable structure on the downstream section of each stream for inhibiting the movement of trout was chosen as the downstream barrier, where rainbow trout removal began. The downstream barriers varied with each stream and were classified into three categories : passable-barrier, semi-barrier, and barrier. A passable-barrier classification represented structures that trout could pass with little difficulty. A semi-barrier represented those that could be passed with difficulty. A barrier, in this study, is a structure that trout can pass only with great difficulty.

During 1984 (the first year), the right pectoral fin was clipped as a means of marking the rainbow trout that were removed from the treatment area and released below the barrier. The left pectoral fin was clipped during 1985 (the second year). This method was used to determine possible reinvasion of these fish. Barrier Characteristics and movement of fish were recorded to provide information on the effectiveness of these barriers. The width and height of the barrier and the pool depth below the barrier were recorded in meters (m). The percent gradient of the barrier was measured with a clinometer. A description of barrier structures and composition was also recorded.

The upstream boundaries of the treatment streams were often barriers to trout movement as well. Boundary characteristics were measured on the upstream barriers that separated sympatric zones from the allopatric brook trout zone to determine why rainbow trout did not occur above them. A barrier to rainbow trout is defined as a 2.4 m (8.0 ft) vertical falls (Kelly et al. 1980). This type of upstream barrier was not present in all treatment streams at the allopatric brook trout zones.

Weights in grams (gm) and total length in millimeters (mm) were recorded from individual trout. The young-of-year (YOY) trout in the Park were designated as less than or equal to 90 mm in length as established in a previous study by Steve Moore (pers. commun.). All other fish were measured in total weight and a length range of smallest to largest fish. The data provided a basis for comparisons of average length and condition factor of fish before and after renovation. A Database II program (Herndon and Riley 1986) which incorporated the

the Student's t-test was used to indicate significant differences ($p = 0.05$) between these factors. After measurements were recorded, brook trout were released throughout the shocked area, and rainbow trout were put in holding nets. Each day, the holding nets were collected and the rainbow trout were placed in buckets and moved to below the downstream barrier. During the second year, population estimates were repeated in the same stream sections. Each of the treatment streams was then electroshocked once, and rainbow trout were removed.

Brown trout (Salmo trutta) were removed from lower Collins Creek (17 captured) and lower Sahlee Creek (1 captured). Blacknose dace (Rhinichthys atratulus) was captured in the lower sections of Collins Creek and Cosby Creek and in one control stream, Chasteen Creek. Sculpin (Cottus spp.) were found in the lower sections of Collins Creek and Chasteen Creek.

Brook trout were randomly selected for relocation to above the downstream barriers, into areas where rainbow trout were removed. The numbers of brook trout relocated depended on the population of the stream. According to Whitworth (1979), the transport to renovated areas gives the brook trout population a head start on establishment and reduces the expansion of remaining rainbow through competition. Population elevations were noted using U.S. Geological Survey topographical maps (1:24,000 scale). Collins Creek was the only stream which did not contain brook trout all the way to the downstream barrier. During the second year, population changes were recorded. In McGinty Creek, the waters above the treatment area did not contain an allopatric brook trout population. Historically, brook trout were present in these waters. Brook trout were relocated to above the treatment area during the second year.

Fifteen trout of each species were taken from the sympatric zone and fifteen brook trout from the allopatric zone to examine food habits. These specimens were preserved in 10% formalin and later transferred to 70% alcohol (Fink et al. 1979). Macroinvertebrates were collected from each zone in pool, riffle, and mixed areas in a random manner with a kick seine. This was to determine if direct competition exists between the two species because there is a lower diversity in food organisms in the high elevation study streams (Lennon 1967; Harshbarger 1978). This analysis has not been completed.

Certain parameters were measured for comparisons among watersheds, among streams, and among population estimate sections within a stream. Water quality, compared among watersheds, was recorded at the mid-point of the trout population in each stream. A Hach kit (Model AL-36B) was used to measure pH, dissolved oxygen, and alkalinity (Boyd 1980). Conductivity was measured with a YSI-Model 33 conductivity meter. Water temperature (degrees C) was averaged from daily recordings.

Stream characteristics such as average width (m) and average depth (m) were taken from population estimate sections. Velocity in meters/second (m/s) was measured by timing a submerged object as it traveled downstream 7.6 m (25 ft), to obtain crude velocity estimates (Buchanan and Somers 1969). The pool-riffle ratio was determined by dividing the lengths (m) of riffles into the lengths (m) of pools in each population estimate section (Platts et al. 1983). A clinometer was used to determine the percent gradient at 30.5 m (100 ft). The degree of siltation (light, moderate, heavy) was noted visually. The percent stream shading was noted by observing canopy density over the stream. These parameters were compared among streams and among population estimate sections within streams.

Watershed descriptions included vegetation composition (bank, understory, canopy) and disturbance history (logged or virgin timber). The disturbance history was recorded from maps in the Park archives (Pyle 1985).

Daily weather and stream flow conditions were noted. All water samples and fish sampling were taken with low to normal water levels. There was no high water sampling.

CHAPTER III

RESULTS

Population Estimates

Population estimates from both sections of each stream were compared between study years (Figures 1 and 2). The total numbers of rainbow trout removed and the length of each renovated stream are given in Appendix B.

Control Streams

Chasteen Creek

There was a significant increase in rainbow and brook trout populations without removal efforts. Brook trout were not present in Section I.

Pretty Hollow Creek

The only significant change in this stream was an increase in the brook trout population of Section I. The rainbow trout populations decreased slightly.

Figure 1. Population estimate comparisons between study years in each stream section. (A) represents rainbow trout population estimates and (B) represents brook trout populations. Each bar in the graph is labeled with the initial letters of the stream name that it represents.

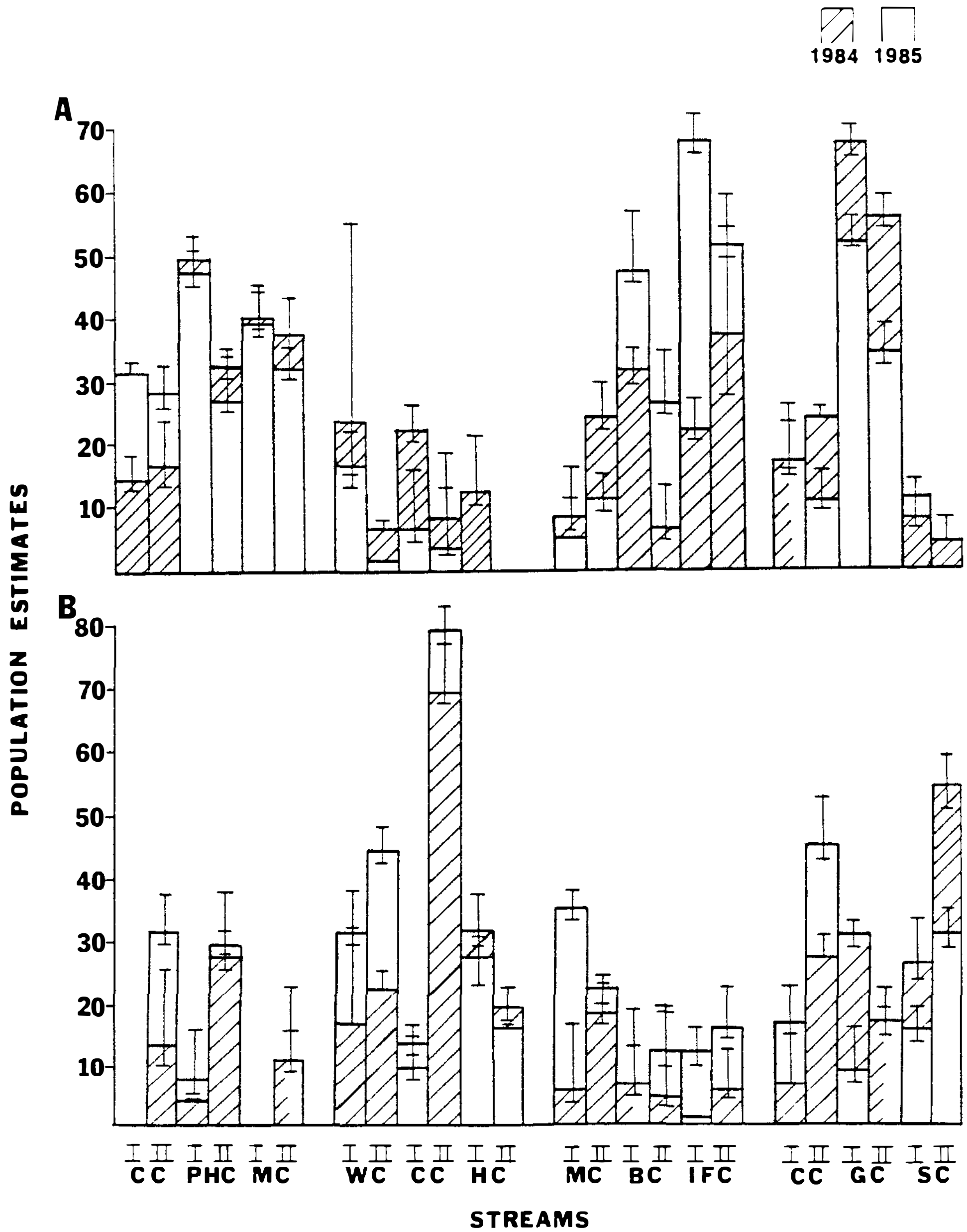
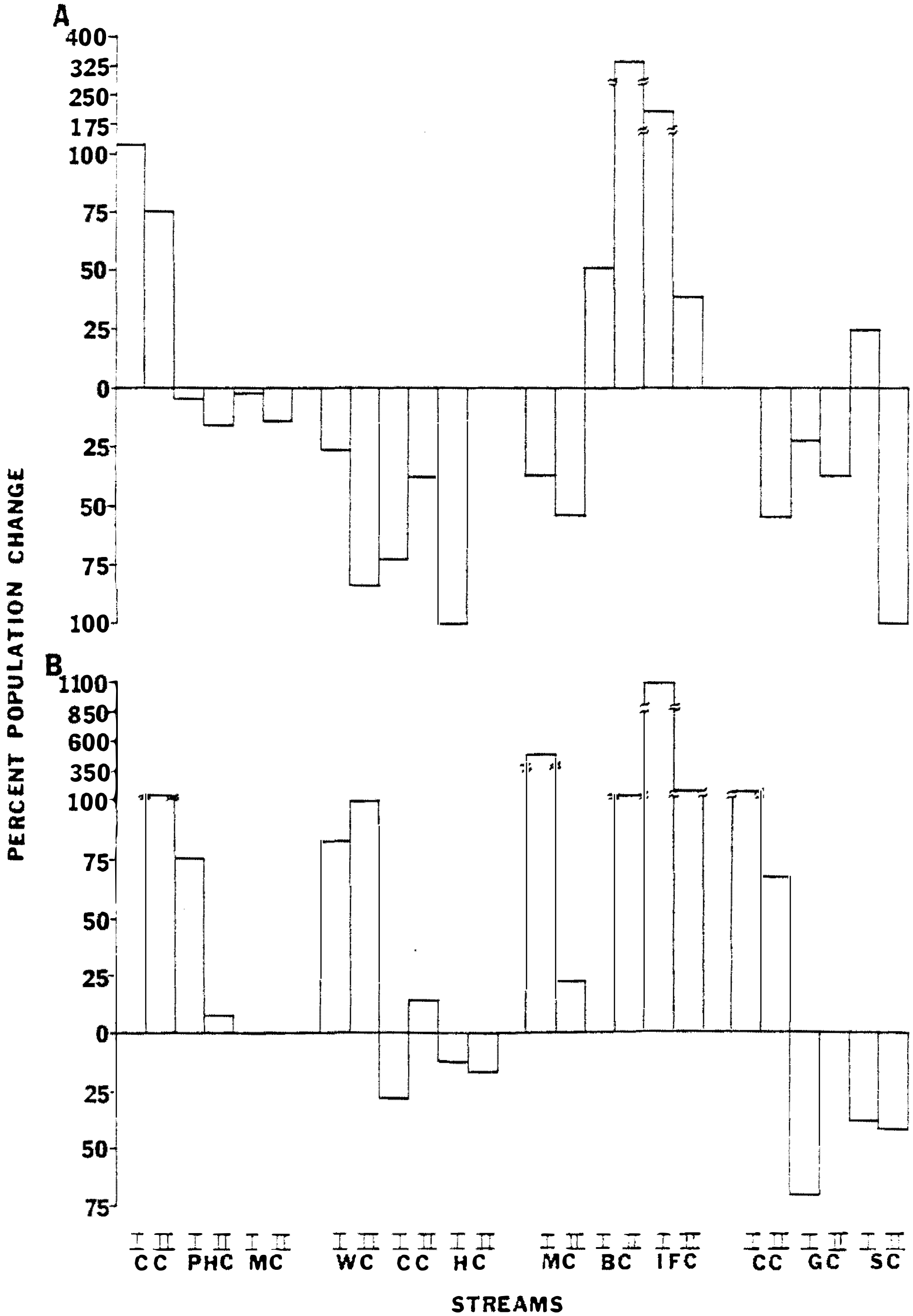

1984 1985
A
70
60
50
40
30
20
10
B
80
70
60
50
40
30
20
10
POPULATION ESTIMATES
I II I II I II
CC PHC MC
I II I II I II
WC CC HC
I II I II I II
MC BC IFC
I II I II I II
CC GC SC
STREAMS

Figure 2. Percent change from year one to year two in rainbow and brook trout populations. (A) represents rainbow trout population changes and (B) represents brook trout population changes. Each bar in the graph is labeled with the initial letters of the stream name that it represents.


A
400
325
250
175
100
75
50
25
0
25
50
75
100
B
1100
850
600
350
100
75
50
25
0
25
50
75
PERCENT POPULATION CHANGE
I II I II I II I II I II I II I II I II I II I II I II I II
CC PHC MC WC CC HC MC BC IFC CC GC SC
STREAMS

Marks Creek

There were no significant differences in either species' populations. The rainbow trout decreased in number, and the brook trout numbers remained the same. Section I did not contain a brook trout population.

The YOY in the control streams increased in all sections where the species were found, except in Section II of Marks Creek (Figure 3). In this section, there was a decline of YOY brook trout to 0%.

One-Removal Streams

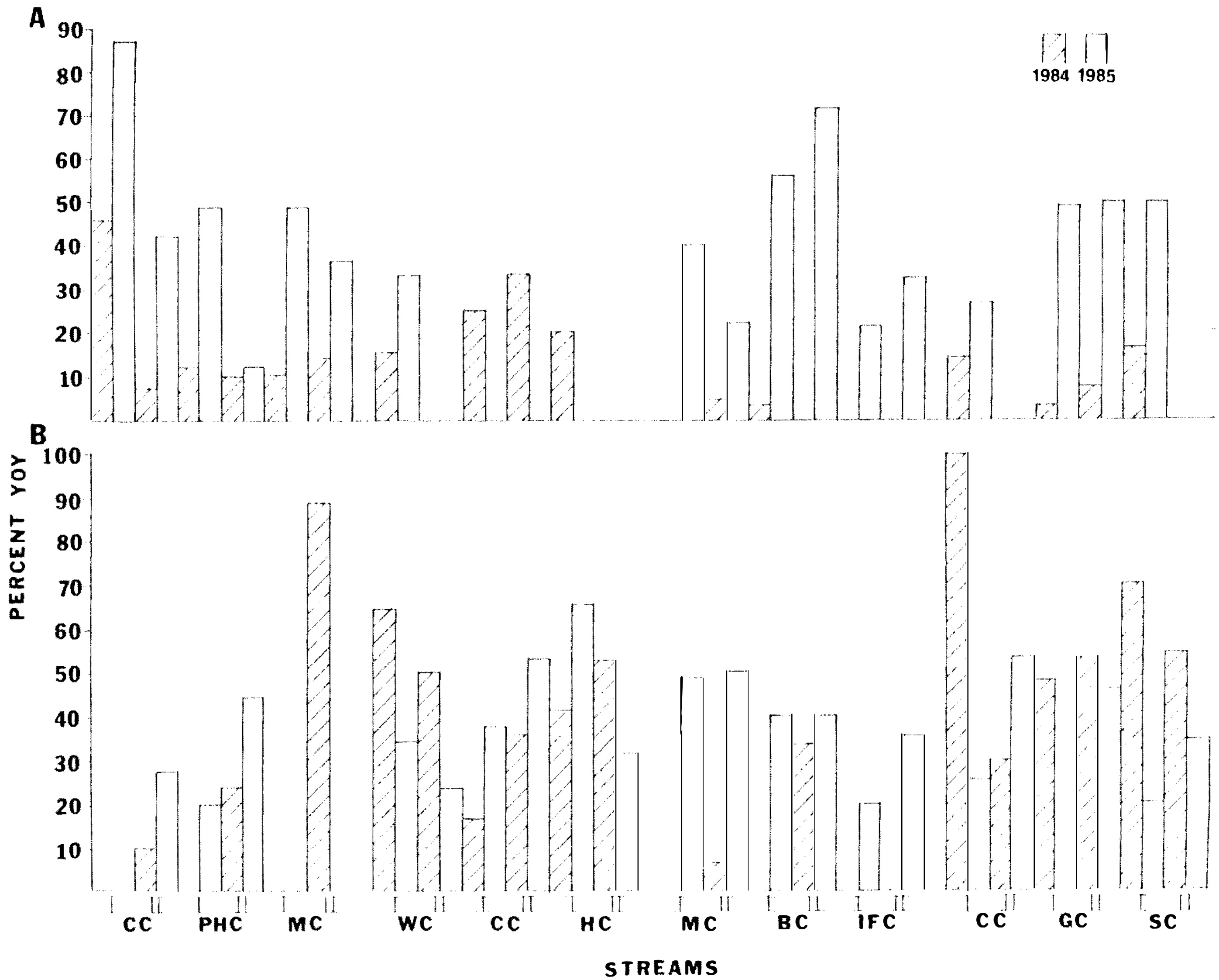
Woody Branch

The rainbow trout population decreased significantly in Section II, where only one fish was captured in the second year. The brook trout population increased significantly in Section II. However, there was an increase in YOY rainbow trout and a decrease in YOY brook trout in this upper section.

Cosby Creek

The rainbow trout population decreased in both sections of Cosby Creek. This decrease was significant in Section I. The brook trout population decreased in Section I but increased in Section II. No YOY rainbow trout were captured in the second year, but there was an increase of YOY brook trout.

Figure 3. Comparison between study years of percent young of year. (A) represents young of year rainbow trout and (B) represents young of year brook trout. Each bar graph is labeled with the initial letters of the stream name that it represents.


A
B
1984
1985
PERCENT YOY
CC
PHC
MC
WC
CC
HC
MC
BC
IFC
CC
GC
SC
STREAMS

Hyatt Creek

No rainbow trout were captured in the second year in the entire stream. The brook trout population decreased significantly in Section II (allopatric zone) where renovation efforts were not applied.

In general, the rainbow trout populations were reduced significantly in three stream sections (Figure 2). Where brook trout populations decreased with renovation efforts, the decreases were not statistically significant.

Two-Removal Streams

McGinty Creek

Rainbow trout populations decreased significantly in Section II. There was a significant increase in the brook trout populations in Section I and an increase in Section II. The YOY of both species increased in both sections.

Buck Fork

There were significant increases in rainbow trout populations in both sections. The brook trout remained the same in Section I and increased in Section II. The YOY of both species increased from the first year to the second year.

Indian Flats Creek

The populations increased in both sections. The rainbow trout population increased significantly in Section I and the brook trout populations increased significantly in both sections. The YOY of both species exhibited the same increases.

Of the two removal streams, only McGinty Creek showed a significant decrease in rainbow trout populations (Figure 1). The Buck Fork and Indian Flats Creek rainbow trout populations responded with large increases. The YOY of both species increased in all these streams (Figure 3).

Three-Removal Streams

Collins Creek

The number of rainbow trout in Section I remained the same, but decreased significantly in Section II. The brook trout population increased significantly in Section II. YOY rainbow trout were absent in Section II during both years. The reestablishment of adult brook trout in Section I was indicated by the decrease in YOY brook trout as percent of the total brook trout population.

Grouse Creek

Significant decreases in rainbow trout populations occurred in both sections. There was a significant decrease of the brook trout population in Section I, while the population remained the same in Section II. YOY rainbow trout increased in both sections. No YOY brook trout were captured in Section I of the second year, and there was a decrease in Section II.

Sahlee Creek

The rainbow trout population increased in Section I, but there was a significant decrease to zero in Section II. The brook trout population decreased significantly in both sections. The YOY of both species showed comparable decreases.

Three-removal streams exhibited similar significant results to one-removal streams in rainbow trout populations (Figure 1). But in three-removal streams, the brook trout populations decreased (Figure 2).

Removal Efforts Time

Based on a three-removal stream of 4,588.5 m (49,372.3 ft), the actual electroshocking time was 33.5 hours. The first removal took 21 man-hours. The percent increase in time with the two-removal effort was 33%, or 7 hours. The third removal effort took 26% more time, or 5.5 hours. The two-removal and three-removal efforts combined had an increase in time of 60% over the one-removal effort.

This was actual shocking time in the stream. This did not include lost time (equipment failure, high water problems, adverse weather conditions), measuring stream parameters, driving and hiking to and from the stream, and other logistics. All of the streams except Collins Creek were renovated within four to five days total time.

Average Length and Condition Factor

From the first year to the second, average length and condition factor differed significantly in three stream sections (Figures 4, 5, and 6). In Section I of Buck Fork (a two-removal stream), YOY rainbow trout decreased in average length. As discussed earlier, this population increased in numbers of fish in the second year. This increase also occurred in Section II, but there were no YOY captured in the first year for average length comparisons.

A second significant difference occurred with YOY brook trout in Section II of Hyatt Creek (a one-removal stream). Average length decreased with the decrease in YOY numbers. This section was in the allopatric brook trout zone and therefore did not pertain to renovation efforts. In Section II of Chasteen Creek (a control stream), the average condition factor decreased significantly for adult brook trout. This accompanied an increase in the second year population estimate.

Figure 4. Comparison between study years of average length of young of year. (A) represents young of year rainbow trout and (B) represents young of year brook trout. Each bar is labeled with the initial letters of the stream name that it represents.

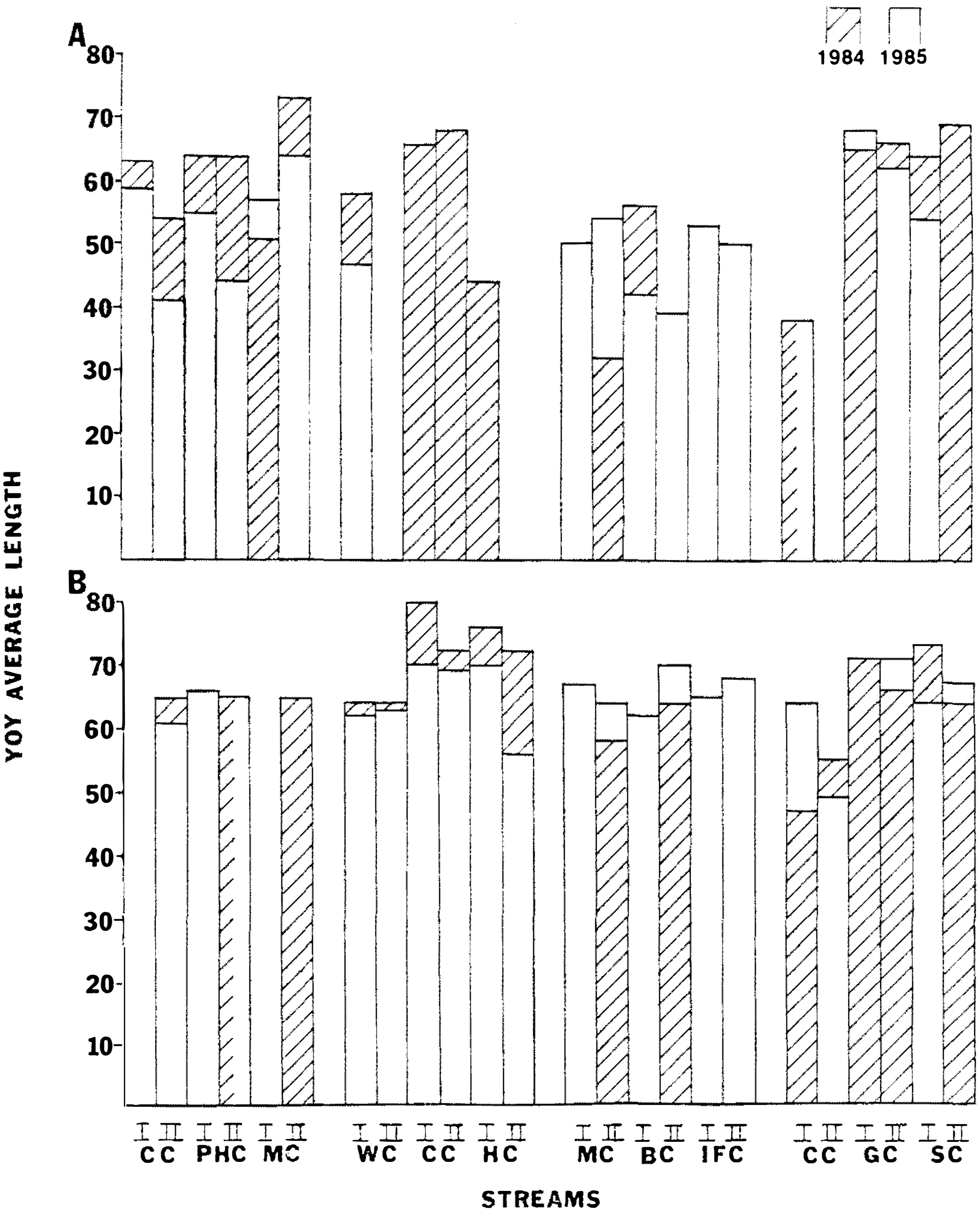

A
B
1984
1985
80
70
60
50
40
30
20
10
YOY AVERAGE LENGTH
I II I II I II I II I II I II I II I II I II I II I II I II
CC PHC MC WC CC HC MC BC IFC CC GC SC
STREAMS

Figure 5. Comparison between study years of average length of adults. (A) represents adult rainbow trout and (B) represents adult brook trout. Each bar is labeled with the initial letters of the stream name that it represents.

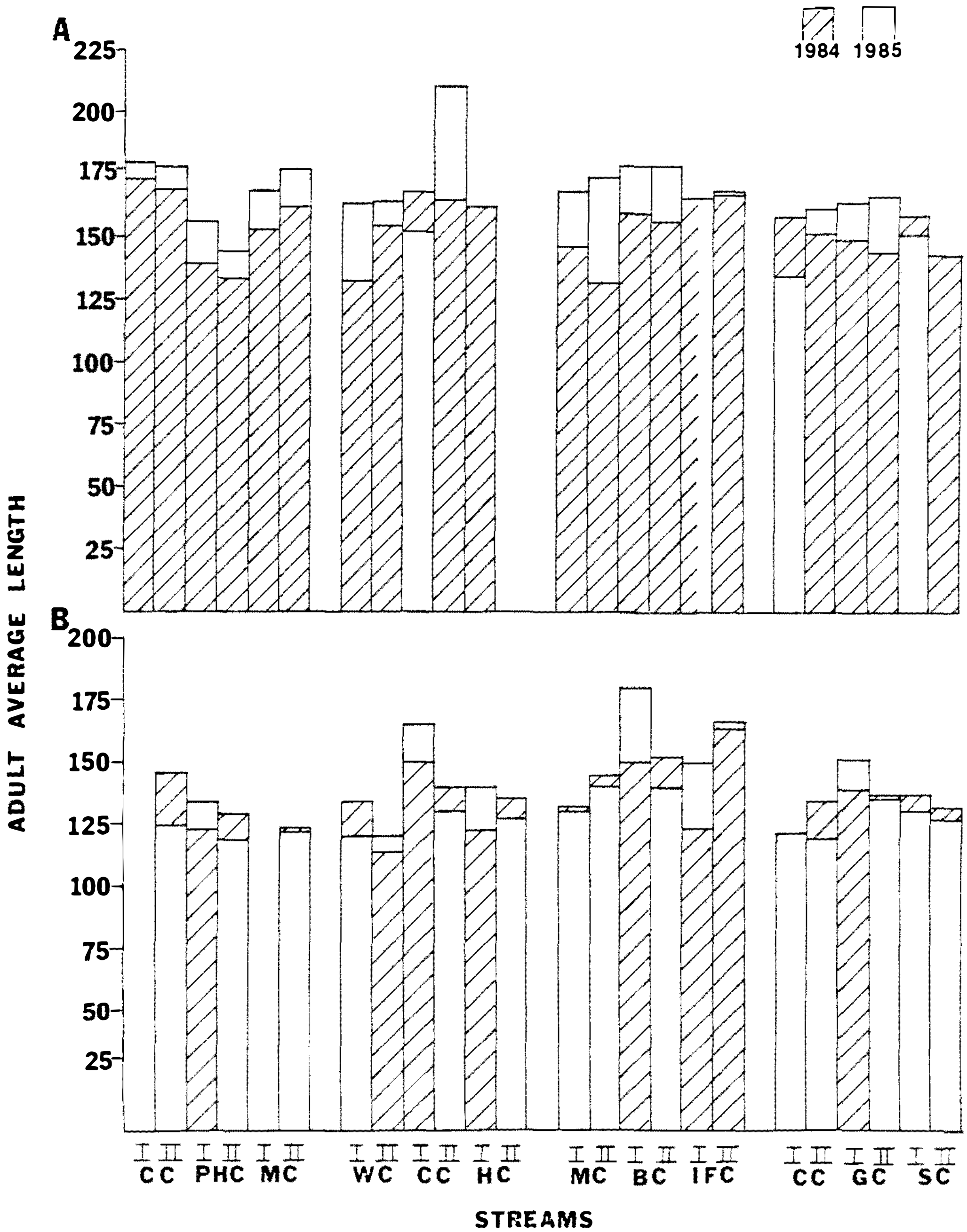
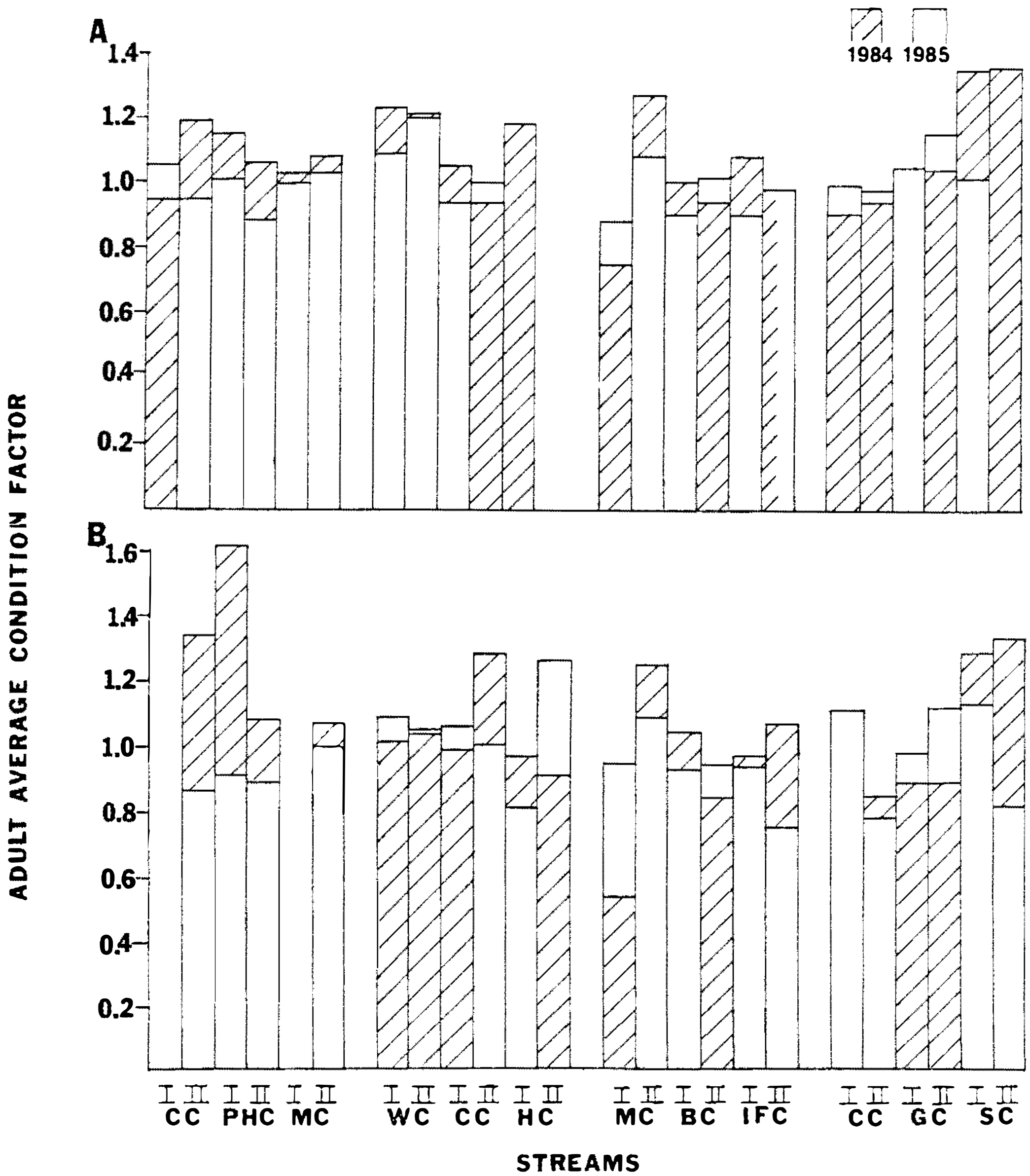

1984
1985
A
225
200
175
150
125
100
75
50
25
B
200
175
150
125
100
75
50
25
ADULT AVERAGE LENGTH
I II I II I II I II I II I II I II I II I II I II I II I II
CC PHC MC WC CC HC MC BC IFC CC GC SC
STREAMS

Figure 6. Comparison between study years of average condition factor of adults. (A) represents adult rainbow trout and (B) represents adult brook trout. Each bar is labeled with the initial letters of the stream name that it represents.


A
B
1984
1985
ADULT AVERAGE CONDITION FACTOR
1.4
1.2
1.0
0.8
0.6
0.4
0.2
1.6
I II I II I II I II I II I II I II I II I II I II I II I II
CC PHC MC WC CC HC MC BC IFC CC GC SC
STREAMS

Other Species

The brown trout captured in Collins Creek and Sahlee Creek did not constitute a large portion of the introduced trout population. Therefore, they are not included in the study results. The presence of dace and sculpin does not have a negative effect on brook trout, according to Gray and Pardue (1978). They found that adult and juvenile brook trout successfully feed and defend their territories against these species. However, Harned (1976) found brook trout populations to be lower when dace were present. He suggested that interspecific competition for food might be involved. Because these species constituted less than 5% of the total fish collected, they are not considered as a threat to the brook trout populations.

Relocation Efforts

Brook trout were reestablished in lower Collins Creek (a three-removal stream) where rainbow trout were removed. Only YOY brook trout were found in Section I of the second year. Adults and YOY were captured in the second year. The YOY constituted 100% of the brook trout population in the first year. In the second year, 26% of the total population was adult brook trout. Adults were found 201.1 m (659.8 ft) downstream from the year before to an elevation of 795.9 m (2410 ft). There is the possibility of the reestablishment of a brook trout allopatric zone in McGinty Creek. Because relocation of fish did not occur until the second year, results cannot be reported at this time.

Stream Characteristics

Among watersheds and among streams, no great difference in water quality existed (Appendix C). Average width and depth were greater in Buck Fork and Indian Flats Creek. Other streams varied slightly in water quality among stream sections. Mean water column velocity differed among streams and among stream sections. These differences did not seem to affect the capture of fish. This was illustrated in the two-removal streams, where the capture rate was lower but velocities were moderate compared to other treatment streams. Results from pool-riffle ratios indicated differences among streams. However, no among stream population differences were attributed to this factor. Silt load and gradient varied among streams and among stream sections. The percent stream shading was similar among stream sections and varied slightly among streams.

Canopy composition was similar in all watersheds. The exception was the absence of tulip poplar in the unlogged watersheds. Birch, beech, maple, hemlock, and buckeye were the predominant species in the canopy. The understory consisted of rhododendron and hemlock. Bank vegetation included moss, forbes, doghobble, and nettle. A disturbance history table is provided in Appendix D.

There were no obvious correlations among stream characteristics and trout populations. However, the average width of streams had a direct effect on the sampling effort using one shocker. Buck Fork and

Indian Flats Creek were wider-than-average treatment streams in this study. They had average widths of 8.7 m (28.5 ft) and 7.3 m (23.9 ft), respectively. These widths and a large average depth hampered the capture of fish with one shocker. These two-removal streams had overall large increases in the second year populations.

Barrier Characteristics

The barrier characteristics of treatment streams are listed in Appendix E. During the second year, marked rainbow trout were captured above the downstream barrier in only one stream, Grouse Creek. This stream had a passable-barrier classification. Although marked fish were not found in other streams, there may have been movement of unmarked rainbows from below the downstream barrier into the renovated waters.

In three of the treatment streams, allopatric brook trout zones were not separated from sympatric trout zones by an upstream barrier as described by Kelly et al. (1980). In Woody Branch, there was no evident upstream barrier at the allopatric brook trout zone. A phasing out of rainbow trout occurred up to that point in the stream, where there was a series of small boulder cascades. The population zone change took place at 1109.5 m (3640 ft) in elevation.

The upstream barriers in two other streams were impassable to rainbows. The Collins Creek barrier consisted of logs across the stream at a height of 1.4 m (4.7 ft). A slab rock in the 0.31 m (1.0 ft) deep pool below the logs inhibited the use of a jump pool by fish. In Sahlee Creek, the upstream barrier consisted of a large boulder 1.8 m (5.8 ft) in height that angled sharply into the water above a set of cascades. The depth of the pool below the boulder was 0.18 m (0.59 ft).

CHAPTER IV

DISCUSSION

According to the results, one-removal and three-removal streams responded to treatment with significant decreases of rainbow trout populations in six out of 12 stream sections. Where brook trout populations decreased with renovation efforts in one-removal streams, the decreases were not significant. Significant decreases did occur in brook trout populations in three sections of the three-removal streams. These decreases were not seen in the control streams. However, the control stream population estimate sections were located in different watersheds and at lower elevations than the Sahlee Creek treatment area. Perhaps natural components (stream or weather conditions) affected the brook trout populations in Sahlee Creek. Lennon (1967) found that extreme water temperatures and anchor ice during the winter months in the Park have a detrimental effect on brook trout redds. The Grouse Creek rainbow trout population was at least twice as large as the brook trout population. It is possible that when rainbow trout outnumber brook trout, the brook trout do not respond to removal in the same manner as when the populations are equal or the brook trout populations are greater than the rainbow trout populations. This was suggested by Alston (1984) when he found that reclamation effectiveness depended largely on the size of rainbow trout populations.

In the two-removal streams, a rainbow trout population decrease and a brook trout population increase occurred in McGinty Creek. Buck

Fork and Indian Flats Creek showed a significant increase in rainbow trout numbers. Moore et al. (1983) found that standing crops and numbers of fish were reduced when a substantial portion of the trout biomass was captured by electroshocking. This finding was the result of renovation with three electroshocker passes for four consecutive years. This was four times the removal effort used in this study. The population increases in Buck Fork and Indian Flats Creek indicated a lower capture rate with one shocker in these wider-than-average study streams. Populations subject to number decreases, in this case removal of rainbow, respond with an increase in biomass (Everhart and Youngs 1981). This was evident in these two streams, which exhibited large increases of YOY in the second year. The rainbow trout population was reduced enough that the response was an increase in standing crop through reproduction (Figure 3). With a greater capture rate, we can assume that the two-removal streams would give similar results to the one-removal and three-removal streams. This assumption is based on the McGinty Creek populations.

The three-removal effort required a 60% increase in time over the one-removal effort. In those streams, brook trout populations decreased significantly. Thus this method is not warranted over the one-removal effort. The decrease in rainbow trout numbers in McGinty Creek was not any greater than the one-removal stream decreases. Therefore, the two-removal effort with a 33% increase in time was no more effective than the one-removal efforts.

The average length and condition factor of populations was not greatly altered by one year of renovation efforts. A significant decrease in average length occurred in YOY rainbow trout in one of the treatment streams, Buck Fork. However, differences in these populations may not be evident after one year of renovation.

The greater average width of Buck Fork and Indian Flats Creek reduced the capture rate of fish with one shocker. A maximum average width of 6.1 m (20 ft) should be an additional criterion for streams chosen to be renovated with one shocker. This would require observation of the stream prior to selection. The Park trout population distribution map that was used to choose study streams needs to be updated. Discrepancies in distribution were found during this study One stream, Dudley Creek, was originally designated as part of this study. Survey results showed that not only were brook trout absent, but also rainbow trout. In one and a half miles of stream, only one rainbow trout was captured. This can be attributed to habitat degradation. Dudley Creek waters were discolored by soil erosion from adjacent horse trails. This problem was also encountered in lower Chasteen Creek, where the stream bed was filling in with eroded trail soil.

The downstream barriers with passable-barrier and semi-barrier classifications obviously will not restrict rainbow trout upstream movement into renovated waters. The streams in these categories may have experienced invasion of unmarked rainbows, because marked rainbow were found above the Grouse Creek passable-barrier. These barriers can be restrictive under certain circumstances, such as low water flows. This is especially true when the barriers consist of structures that hamper movement, as in the allopatric upstream barrier examples where jump pools were absent. The elimination of jump pools below the barriers is an important factor inhibiting upstream movement (Stuart 1964; Seehorn 1985).

CHAPTER V

MANAGEMENT RECOMMENDATIONS

One-removal efforts are recommended to control the rainbow trout populations, resulting in the restoration of brook trout populations in the Park. This treatment requires less time than two-removal and three-removal efforts and provides comparatively good results. Renovation efforts on these streams should continue to keep the rainbow trout populations from regaining dominance in the treatment streams where reductions occurred. Reproducing adult rainbow trout should be removed until no YOY are present (Whitworth 1979). Elsen (1985) found that repeated electroshocking efforts from 1980 to 1985 in the Cherokee National Forest removed enough rainbow trout that spawning was halted. The chance of brook trout recovery will be decreased if reproducing rainbow trout remain in the streams. Populations of streams in this study should be monitored to keep the rainbow trout at low numbers for the reestablishment of brook trout.

The reestablishment of an adult brook trout population in the lower renovated area of Collins Creek should also be monitored. The relocation of adults may be an important factor in the downstream movement of brook trout populations (Whitworth 1979).

It is also recommended that man-made barriers of rock and fallen trees be constructed for renovated streams. This can be accomplished in a low impact manner by using native materials found around the streams. The restricted upstream movement of rainbow trout is an important factor in reestablishing brook trout populations (Whitworth 1979). Reinvasion of marked rainbow trout occurred in Grouse Creek, and it is possible that unmarked rainbow trout invaded other treatment streams.

Restoration efforts should continue in these streams and other Park streams in order to restore brook trout populations. No restoration effort at all would be detrimental to the brook trout populations, resulting in the possible loss of the only native trout species of the Great Smoky Mountains National Park.

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APPENDIXES

APPENDIX A

LOCATIONS OF STREAMS AND POPULATION ESTIMATE SECTIONS

Control Stream	Chasteen Creek
Watershed	Oconoluftee River
County	Swain
State	NC
Quadrangle	Smokemont

Section I

Downstream Tag #	318D
Upstream Tag #	319U
Elevation	731.5 m (2400 ft)
Landmarks	Tag # 318D is located on the right upstream side on a hemlock, 100 m (328.1 ft) upstream from the first bridge crossing on Chasteen Creek Trail.

Section II

Downstream Tag #	2D
Upstream Tag #	1U
Elevation	914.4 m (3000 ft)
Landmarks	Tag # 1U is located on the right upstream side below a steep embankment dropping off the jeep trail. A tag (#147U) on the right side of the trail on a poplar marks the point directly above the upstream tag.

Control Stream	Pretty Hollow Creek
Watershed	Cataloochee Creek
County	Haywood
State	NC
Quadrangle	Luftee Knob

Section I

Downstream Tag #	110D
Upstream Tag #	109U
Elevation	950.9 m (3120 ft)
Landmarks	This section is located upstream from the topo map campsite where the trail leaves the creek. Tag # 110D is on a maple on the left upstream side and tag # 109U is on the right upstream side.

Section II

Downstream Tag #	122D
Upstream Tag #	121U
Elevation	1121.7 m (3680 ft)
Landmarks	This section is located 12.2 m (40 ft) above the first bridge trail crossing. Tag # 121U is on a birch on the left upstream side and tag # 122D is on a birch on the right upstream side.

<u>Control Stream</u>	<u>Marks Creek</u>
Watershed	Middle Prong Little River
County	Sevier
State	TN
Quadrangle	Thunderhead

Section I

Downstream Tag #	120D
Upstream Tag #	119U
Elevation	688.9 m (2260 ft)
Landmarks	This section is located 200 m (656.2 ft) upstream from the confluence with Lynn Camp Prong. Tag # 120D is on a birch on the right upstream side and tag # 119U is on a birch on the left upstream side.

Section II

Downstream Tag #	114D
Upstream Tag #	113U
Elevation	780.3 m (2560 ft)
Landmarks	This section is located just above the first tributary coming in from the left. Tag # 114D is on a birch on the left upstream side.

<u>One-Removal Stream</u>	<u>Woody Branch</u>
Watershed	Little Cataloochee Creek
County	Haywood
State	NC
Quadrangle	Cove Creek Gap

Section I

Downstream Tag #	182D
Upstream Tag #	183U
Elevation	938.8 m (3080 ft)
Landmarks	This section is located 50 m (164 ft) above the confluence with Andy Branch. Tag # 183U is on a rhododendron on the right upstream side and tag # 182D is on a beech on the right upstream side.

Section II

Downstream Tag #	186D
Upstream Tag #	185U
Elevation	987.6 m (3240 ft)
Landmarks	This section begins at a large island. Tag # 186D is on a beech on the right upstream side and tag # 185U is on a beech on the left upstream side.

Woody Branch (Continued)

Renovated Area

Downstream Tag #	180D
Elevation	926.6 m (3040 ft)
Upstream Tag #	181U
Elevation	1121.7 m (3680 ft)
Landmarks	Tag # 180D is on a birch on the right upstream side at the confluence with Andy Branch. Tag # 181U is on a birch on the right upstream side where an old field closes off on the left upstream side of the stream.

<u>One-Removal Stream</u>	<u>Cosby Creek</u>
Watershed	Pigeon River
County	Cocke
State	TN
Quadrangle	Hartford

Section I

Downstream Tag #	112D
Upstream Tag #	105U
Elevation	707.1 m (2320 ft)
Landmarks	This section begins above the road crossing to Bryants Horse Barns at Cosby Campground. Tag # 105U is on a buckeye and tag # 112D is on a poplar 100 m (328.1 ft) upstream from the road crossing.

Section II

Downstream Tag #	124D
Upstream Tag #	123U
Elevation	780.3 m (2560 ft)
Landmarks	This section begins 75 m (246.1 ft) above the first foot bridge. Tag # 124D is on a hemlock on the right upstream side and tag # 123U is on a hemlock on the right upstream side.

Renovated Area

Downstream Tag #	106
Elevation	780.3 m (2560 ft)
Upstream Tag #	123U
Elevation	792.5 m (2600 ft)
Landmarks	Tag # 106 is on a poplar at the dam at the road crossing on the right upstream side and tag # 123U is as described in Section II.

<u>One-Removal Stream</u>	<u>Hyatt Creek</u>
Watershed	Straight Fork
County	Swain
State	NC
Quadrangle	Bunches Bald

Section I

Downstream Tag #	134D
Upstream Tag #	139U
Elevation	914.4 m (3000 ft)
Landmarks	This section is located 100 m (328.1 ft) above the Big Cove Road bridge. Tag # 139U is on a poplar on the right upstream side and tag # 134D is on a maple on the left upstream side.

Section II

Downstream Tag #	108D
Upstream Tag #	111U
Elevation	1109.5 m (3640 ft)
Landmarks	This section begins above the first trail crossing. Both tags are on maples on the left upstream side.

Renovated Area

Downstream Tag #	140D
Elevation	914.4 m (3000 ft)
Upstream Tag #	159U
Elevation	975.4 m (3200 ft)
Landmarks	Tag # 140D is on a maple on the right upstream side 3.1 m (10 ft) above Big Cove Road. Tag # 159U is above a boulder dam on a poplar on the right upstream side.

<u>Two-Removal Streams</u>	<u>McGinty Creek</u>
Watershed	Big Creek
County	Haywood
State	NC
Quadrangle	Luftee Knob

Section I

Downstream Tag #	4D
Upstream Tag #	3U
Elevation	1036.3 m (3400 ft)
Landmarks	This section is located just above the Swallow Fork Trail crossing. Tag # 4D is on a birch on the right upstream side and tag # 3U is on a birch on the right upstream side.

McGinty Creek (Continued)

Section II

Downstream Tag #	8D
Upstream Tag #	7U
Elevation	1097.3 m (3600 ft)
Landmarks	This section is located 300-400 m (984.3-1312.4 ft) above the end of Section I. Tag # 8D is on a beech on the left upstream side and tag # 7U is on a beech on the right upstream side.

Renovated Area

Downstream Tag #	6D
Elevation	1036.3 m (3400 ft)
Upstream Tag #	5U
Elevation	1133.9 m (3720 ft)
Landmarks	The area begins at the dam at the Swallow Fork Trail crossing. Tag # 6D is on the right upstream side and tag # 5U is at the bottom of the large falls on a beech on the right upstream side.

<u>Two-Removal Stream</u>	<u>Buck Fork</u>
Watershed	Middle Prong Little Pigeon River
County	Sevier
State	TN
Quadrangle	Mt. Guyot

Section I

Downstream Tag #	12D
Upstream Tag #	17U
Elevation	883.9 m (2920 ft)
Landmarks	This section is located 100 m (328.1 ft) above the confluence with Chapman Prong.

Section II

Downstream Tag #	14D
Upstream Tag #	13U
Elevation	1036.3 m (3400 ft)
Landmarks	This section is located at the mid-point of the sympatric zone.

Renovated Area

Downstream Tag #	12D
Elevation	883.9 m (2920 ft)
Upstream Tag #	19U
Elevation	1167.4 m (3830 ft)
Landmarks	The downstream boundary begins at Section I and tag # 19U is on a beech 150 m (492.2 ft) above the falls marked with a "Stream Closed To Fishing" sign.

<u>Two-Removal Stream</u>	<u>Indian Flats Creek</u>
Watershed	Middle Prong Little River
County	Sevier
State	TN
Quadrangle	Thunderhead

Section I	
Downstream Tag #	102D
Upstream Tag #	117U
Elevation	865.6 m (2840 ft)
Landmarks	This section is located at the confluence with Lynn Camp Prong. Tag # 102D is on a birch on the right upstream side and tag # 117U is on a birch on the left upstream side.
Section II	
Downstream Tag #	104D
Upstream Tag #	15U
Elevation	877.8 m (2880 ft)
Landmarks	This section is located 60.9 m (200 ft) below Double Trestle Branch. Tag # 104D is on a birch on the right upstream side and tag # 15U is on a birch on the right upstream side. This section ends 100 m (328.1 ft) below the first bridge crossing on the stream.
Renovated Area	
Downstream Tag #	102D
Elevation	865.6 m (2840 ft)
Upstream Tag #	103U
Elevation	963.2 m (3160 ft)
Landmarks	The renovated area begins at Section I. Tag # 103U is located above the series of falls.

<u>Three-Removal Stream</u>	<u>Collins Creek</u>
Watershed	Oconoluftee River
County	Swain
State	NC
Quadrangle	Smokemont

Section I	
Downstream Tag #	316D
Upstream Tag #	317U
Elevation	743.7 m (2440 ft)
Landmarks	This section begins 100 m (328.1 ft) above the pump station where a small stream comes in on the right upstream side. Tag # 316D is on a poplar on the right upstream side and tag # 317U is on a hemlock on the right upstream side.

Collins Creek (Continued)

Section II

Downstream Tag #	311
Upstream Tag #	143U
Elevation	816.9 m (2680 ft)
Landmarks	This section is located 300 m (984.3 ft) upstream from the trail crossing. Tag # 311 is 15 m (50 ft) downstream from the renovated tributary that comes in from the right upstream side. Tag # 143U is on a poplar on the right upstream side.

Renovated Area

Downstream Tag #	399
Elevation	731.5 m (2400 ft)
Upstream Tag #	102
Elevation	853.4 m (2800 ft)
Landmarks	The renovated area begins at the concrete slab under the Collins Creek bridge on Hwy. 441. Tag # 399 is on the left upstream side. The area ends 155.5 m (510 ft) above the confluence with the renovated tributary. Tag # 102 is on a buckeye on the left upstream side.

Renovated Tributary

Upstream Tag #	286
Elevation	963.2 m (3160 ft)
Landmarks	The area ends at a fallen log that forms a barrier on the tributary at the confluence of two creeks.

<u>Three-Removal Stream</u>	<u>Grouse Creek</u>
Watershed	Little River
County	Sevier
State	TN
Quadrangle	Silers Bald

Section I

Downstream Tag #	136D
Upstream Tag #	135U
Elevation	1048.5 m (3440 ft)
Landmarks	This section is located above the confluence with Spud Town Branch. Tag # 135U is on a hemlock on the left upstream side and tag # 136D is on a birch on right upstream side.

Grouse Creek (Continued)

Section II

Downstream Tag #	154D
Upstream Tag #	323U
Elevation	1097.3 m (3600 ft)
Landmarks	This section is located 100 m (328.1 ft) above a dry tributary coming in on the right upstream side. Tag # 154D is on a birch 6 m (20 ft) off the creek on the left upstream side. Tag # 323U is on a birch on the right upstream side.

Renovated Area

Downstream Tag #	136
Elevation	1048.5 m (3440 ft)
Upstream Tag #	313U
Elevation	1133.9 m (3720 ft)
Landmarks	The renovated area begins at the confluence of Spud Town Branch. The area ends at the barrier falls. Tag # 313U is on a birch on the right upstream side above the third set of falls.

<u>Three-Removal Stream</u>	<u>Sahlee Creek</u>
Watershed	Deep Creek
County	Swain
State	NC
Quadrangle	Clingmans Dome

Section I

Downstream Tag #	128D
Upstream Tag #	127U
Elevation	1109.5 m (3640 ft)
Landmarks	This section begins 5 m (16.4 ft) above the confluence with Deep Creek. Tag # 128D is on a hemlock on the right upstream side and tag # 127U is on a birch on the left upstream side.

Section II

Downstream Tag #	132D
Upstream Tag #	131U
Elevation	1280.2 m (4200 ft)
Landmarks	This section is located where two ridges slope down to the creek after the clearings disappear on the left upstream side. Tag # 131U is on a birch on the left upstream side and tag # 132D is on the left upstream side.

Sahlee Creek (Continued)
Renovated Area

Downstream Tag #	130D
Elevation	1109.5 m (3640 ft)
Upstream Tag #	118
Elevation	1402.1 m (4600 ft)
Landmarks	The renovated area begins at the confluence with Deep Creek. Tag # 118 is on a buckeye on the left upstream side.

APPENDIX B

RENOVATED STREAMS

Table 1. Length of renovated waters and number of rainbow trout removed in each treatment stream.

Stream	Length (m)	(mi)	Number Removed 1984	1985	Renovation Date 1984	1985
One-Removal Streams						
Woody Branch	1609	1.00	104	98	8/8-8/10	7/1-7/4
Cosby Creek	805	0.50	86	18	8/21-8/22	7/16
Hyatt Branch	805	0.50	14	0	10/9-10/10	7/17
Two-Removal Streams						
McGinty Creek	805	0.50	78	62	7/24-7/27	8/5-8/7
Buck Fork	2011	1.25	107	146	8/7-8/9	7/8-7/10
Indian Flats Creek	1006	0.63	176	267	8/15-8/16	7/22-7/25
Three-Removal Streams						
Collins Creek	2615	1.63	483	171	6/13-7/13	6/5-6/25
Grouse Creek	805	0.50	446	150	9/10-9/14	8/12-8/15
Sahlee Creek	2414	1.50	129	18	8/27-8/31	7/29-8/1
Totals	12875	8.01	1623	930		

APPENDIX C

STREAM CHARACTERISTICS

Table 2. Water quality taken at the mid-point of trout populations in each study stream.

Stream	pH	Conductivity (u mhos/cm)	DO (mg/l)	Alkalinity (mg/l CaCO3)	Temperature C	F
Control Streams						
Chasteen Creek	6.5	16.0	10.0	17.1	14.6	58.3
Pretty Hollow Creek	6.5	17.0	9.0	17.1	15.2	59.4
Marks Creek	6.5	19.9	9.0	17.1	16.9	62.4
One-Removal Streams						
Woody Branch	6.5	18.0	9.0	17.1	14.3	57.7
Cosby Creek	6.5	19.9	9.0	17.1	16.0	60.8
Hyatt Creek	6.5	15.0	9.0	17.1	10.4	50.7
Two-Removal Streams						
McGinty Creek	6.5	19.0	9.0	17.1	13.6	56.4
Buck Fork	6.5	19.0	9.0	17.1	15.4	59.7
Indian Flats Creek	6.5	19.0	9.0	17.1	15.6	60.1
Three-Removal Streams						
Collins Creek	6.5	12.0	7.0	17.1	14.1	57.4
Grouse Creek	6.5	21.0	9.0	17.1	14.2	57.6
Sahlee Creek	6.5	19.9	9.0	17.1	13.8	56.8

Table 3. Physical characteristics of all study streams.

Stream	Section	Mean Width (m)	Mean Depth (m)	Mean Water Column Velocity (m/s)	Pool-Riffle Ratio	Silt Load	Gradient (%)	Stream Shading (%)
Control Streams								
Chasteen Creek	I	5.2	5.6	8.3	1: 0.33	Heavy	5	95
	II	5.6	26.5	9.8	1: 0.35	Moderate	9	85
Pretty Hollow Creek	I	5.5	23.3	17.8	1: 0.87	Moderate	6	60
	II	3.9	23.6	13.1	1: 0.95	Light	11	70
Marks Creek	I	5.1	36.2	7.6	1: 0.74	Heavy	12	90
	II	5.1	23.0	8.2	1: 0.55	Heavy	12	90
One-Removal Streams								
Woody Branch	I	5.0	25.4	15.9	1: 0.24	Heavy	9	75
	II	4.4	14.4	12.9	1: 0.32	Heavy	13	70
Cosby Creek	I	6.7	20.0	10.7	1: 0.88	Heavy	16	80
	II	5.0	29.1	10.9	1: 0.70	Heavy	16	75
Hyatt Creek	I	4.8	13.6	10.9	1: 0.21	Light	19	70
	II	1.9	9.8	3.7	1: 0.34	Light	16	75
Two-Removal Streams								
McGinty Creek	I	5.5	25.4	5.9	1: 0.35	Moderate	14	80
	II	5.4	29.3	6.7	1: 0.44	Moderate	15	85
Buck Fork	I	9.3	37.6	8.6	1: 0.50	Heavy	14	60
	II	8.1	33.4	11.2	1: 0.63	Heavy	11	60
Indian Flats Creek	I	7.4	33.6	7.2	1: 0.51	Heavy	5	65
	II	7.2	26.4	7.3	1: 0.49	Heavy	9	65
Three-Removal Streams								
Collins Creek	I	5.5	30.7	6.8	1: 0.51	Light	6	95
	II	5.4	28.6	13.2	1: 0.33	Light	11	95
Grouse Creek	I	6.5	19.7	3.2	1: 0.64	Light	13	90
	II	4.8	29.3	5.1	1: 0.37	Light	8	65
Sahlee Creek	I	4.6	19.3	12.6	1: 0.79	Light	12	70
	II	4.4	15.4	13.1	1: 0.88	Light	9	65

APPENDIX D

DISTURBANCE HISTORY

Table 4. Disturbance history prior to 1930 of all study streams.

Stream	Description
Control Streams	
Chasteen Creek	Heavily logged
Pretty Hollow Creek	Virgin hardwoods
Marks Creek	Heavily logged
One-Removal Streams	
Woody Branch	Virgin hardwoods
Cosby Creek	Heavily logged
Hyatt Creek	Heavily logged
Two-Removal Streams	
McGinty Creek	Lightly logged
Buck Fork	Virgin hardwoods
Indian Flats Creek	Heavily logged
Three-Removal Streams	
Collins Creek	Heavily logged
Grouse Creek	Heavily logged
Sahlee Creek	Virgin hardwoods/spruce

APPENDIX E

BARRIER CHARACTERISTICS

Table 5. Downstream barrier characteristics of treatment streams.

Stream	Barrier Classification	Elevation (m)	Width (m)	Height (m)	Pool Depth Below Barrier (m)	Gradient (%)	Composition
One-Removal Streams							
Woody Branch	passable-barrier	929.6	3.0	0.5	0.65	12	Large boulders
Cosby Creek	barrier	707.1	13.4	1.3	0.24	12	Log dam above boulders
Hyatt Creek	semi-barrier	896.1	0.3	0.8	0.31	19	Cascades
Two-Removal Streams							
McGinty Creek	barrier	1036.3	9.1	2.7	0.76	14	Boulders, logs
Buck Fork	semi-barrier	890.0	5.2	0.9	0.51	14	Boulders
Indian Flats Creek	passable-barrier	865.5	8.1	0.3	0.56	5	Small boulders
Three-Removal Streams							
Collins Creek	passable-barrier	731.5	5.8	0.2	0.20	2	Concrete slab under bridge
Grouse Creek	passable-barrier	1048.5	2.9	0.3	0.27	15	Boulders
Sahlee Creek	semi-barrier	1097.5	2.9	1.2	0.30	12	Boulders

Table 6. Allopatric upstream barrier characteristics of treatment streams.

Streams	Elevation (m)	Width (m)	Height (m)	Pool Depth Below Barrier (m)	Gradient (%)	Composition
One-Removal Streams						
Woody Branch	1109.5	no evident barrier observed			15	Series of small boulder cascades
Cosby Creek	804.7	11.6	1.5	0.41	12	Large boulders with log across creek
Hyatt Creek	975.4	3.4	1.9	2.60	21	Large boulders mixed with logs
Two-Removal Streams						
McGinty Creek	1133.9	9.3	9.2	0.52	23	Solid rock face
Buck Creek	1167.4	3.7	2.6	0.78	18	Boulders with log jam resting on top
Indian Flats Creek	932.7	10.4	3.3	>1.85	20	Rock falls
Three-Removal Streams						
Collins Creek	838.2	7.5	1.4	0.31	17	Logs with slab rock in pool below
Grouse Creek	1133.9	16.0	4.7	1.50	26	One large boulder
Sahlee Creek	1402.1	2.8	1.8	0.18	15	One large boulder angled sharply into cascades

VITA

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