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Evaluation of Electrofishing as a Management Technique for Restoring Brook Trout in Great Smoky Mountains National Park

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EVALUATION OF ELECTROFISHING AS A MANAGEMENT TECHNIQUE FOR RESTORING BROOK TROUT IN GREAT SMOKY MOUNTAINS NATIONAL PARK

by Jerry L. West
Department of Biology
Western Carolina University
Cullowhee, North Carolina 28723

Stephen E. Moore
Natural Resources Division
Great Smoky Mountains National Park
Gatlinburg, Tennessee 37738

and

M. Randall Turner
Department of Biology
Western Carolina University
Cullowhee, North Carolina 28723

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ABSTRACT

To evaluate the success of rainbow trout removal by electrofishing in Taywa, Silers, Sams, Beetree and Starkey Creeks in Great Smoky Mountains National Park (GRSM), trout standing crop biomass in each stream in 1986 and 1987 was compared to what it was before and during the removal period (1976-1981). All streams had not been electrofished for at least five years since the removal period. In addition, the number of trout collected in 1987 in Road Prong and Desolation Creeks was compared to that collected by the U.S. Fish and Wildlife Service 8 and 9 years earlier. Measurements (taken in 1987) of some physical features of the streams were used in an attempt to show how they correlated with rainbow trout removal success.

Our findings indicate that rainbow trout can be removed from small GRSM streams by electrofishing if downstream barriers to rainbow trout recolonization exist, and if repeated and long-term removal can be accomplished. The technique is not as reliable on larger, more complex streams, but still has potential if the above conditions are met. No removal effort on a large stream has been intense and long enough to adequately determine its feasibility, however.

The relationships between the physical features of streams measured in 1987 and the trout standing crop biomass difference (1987 biomass minus the beginning biomass) were not strong. Depth and percent boulders were positively correlated to the biomass difference for rainbow trout, but the other correlations were not significant. Thus, rainbow trout biomass in deeper streams and in streams that had a higher percentage of boulders was greater in 1987 than when removal began. It is also interesting that the brook trout tended to show negative correlations.

INTRODUCTION

The range of the native brook trout (Salvelinus fontinalis) has decreased greatly in the southern Appalachian region since the turn of the century (King 1937, Lennon 1967, Seehorn 1978). Initial reductions were attributed to logging and exploitative fishing practices. Encroachment of nonnative rainbow trout (Oncorhynchus mykiss) and brown trout (Salmo trutta) into upstream areas may be a major cause for the continued decline (Kelly et al. 1980).

This decline in the native brook trout range is well documented in Great Smoky Mountains National Park (GRSM). Distribution studies by Powers (1929) and King (1937) documented the range of native brook trout prior to and just after the establishment of the park in 1934. These authors stated that brook trout were usually found in watersheds where logging had not occurred. Rainbow trout were stocked in streams devoid of brook trout starting about 1910. The majority of these were stocked at the lower elevations, but some were also stocked at mid- to high elevations (Larson and Moore 1985). Park offficals during these early years did not consider this stocking a natural resource management problem, and believed the brook trout would reclaim stream mileage previously lost as the forests regenerated (King, personal communication). Trout distribution studies in the 1950s (Lennon 1967) and the 1970s (Kelly et al. 1980), however, clearly demonstrated that brook trout had lost considerable range while the rainbow trout expanded into areas previously occupied only by brook trout. The severity of the problem (Jones 1975) concerned park officials, as National Park Service policies and mandates state that native fauna and flora are to be protected and managed according to natural ecosystem processes (National Park Service 1988). If nonnative species are shown to threaten native species, control measures, including eradication, can be attempted. Based on these policies, the use of chemical toxins and/or electrofishing were considered for the removal of rainbow trout. Park officials decided to use electrofishing because of its lower ecological impacts.

In 1976, GRSM conducted a study to determine the possibility of using electrofishing to eradicate rainbow trout from mixed populations upstream of natural obstructions to fish movement and to monitor the response of the brook trout (Moore et al. 1981, 1983). From 1976 to 1979, rainbow trout were removed from several park streams and brook trout standing crops subsequently increased. Although electrofishing did not completely eradicate rainbow trout, the reductions in their numbers and standing crops implied that it had potential as a population control measure. Once the rainbow trout populations were reduced, additional electrofishing was needed to keep them under control (Moore et al. 1986).

Using the experience of Moore et al. (1981, 1983), the U.S. Fish and Wildlife Service's (USFWS) fisheries assistance program in GRSM attempted to use electrofishing to reduce the numbers of nonnative trout in several large park streams. Young Adult Conservation Corps (YACC) crews were used to electrofish Road Prong Creek in 1978, Sams Creek in 1978 and 1979, and Desolation Creek in 1979.

Whitworth (1979) evaluated the success of the USFWS renovation effort in Sams Creek downstream of the area studied by Moore et al. (1981, 1983). In one lower section that contained large boulders and deep pools from 0.3 to 1.2 m (1-4 feet) deep, the number of rainbow trout were reduced by 78.7%. The reduction in this section would have been 89.8% if only adult fish were included in the estimate. In the two other sections, where intermediate-sized boulders and medium pools of about 0.6 m deep were encountered, the reduction was 92.7% and 98.2%, respectively. No young-of-the-year rainbow trout were found in these two sections. Whitworth (1979) stated that the variation in reduction success was due to differences in habitat type. He postulated that the number of large boulders and deep pools affected the reduction success by providing more areas in which trout could escape. He questioned the practicality of using electrofishing for renovating brook trout in the park because it is labor-intensive and usually not completely effective. In addition, Whitworth speculated that the reduction of rainbow trout would allow faster growth and reproduction of those fish that escape and thus reduce the chance of brook trout recovery.

Moore et al. (1985) observed that 83.3% of marked brook trout were found in either the same 300-m section or one section upstream or downstream of where they had been captured the previous year. They also observed that a few brook trout did make more extensive movements, with some fish being recaptured over 2 km downstream from the allopatric population. Whitworth and Strange (1983) also found limited movement of stream salmonids in the southern Appalachians. Because of this limited movement and possible stimulation of the rainbow trout that escape, Whitworth (1979) recommended that brook trout be stocked into the stream after the removal of rainbow to facilitate recruitment within the renovated area. He also indicated that several years of monitoring streams from which rainbow trout were removed were needed before the technique could be used in a widespread renovation of brook trout streams in the park.

Habera (1987) found that moderate electrofishing effort (1-3 passes) resulted in significant reductions in mean rainbow trout density and biomass relative to control populations in 7 of 9 streams in GRSM, with subsequent brook trout increases in both mean density and biomass. In two streams (Buck Fork and Indian Flats Prong), however, the rainbow trout populations increased after removal. These streams are characterized by larger, more complex channels, a mean stream width of over 6 m, pools over 1 m in depth, a large initial rainbow trout population, and the absence of barriers to upstream fish migration. In addition, the release of large numbers of rainbow trout into dense downstream populations may have contributed to the increase. Habera et al. (1989, in review) concluded that with the wide channels (mean=7.4 m) and many pools deeper than 1 m (mean=6.3/1000 m), rainbow trout densities and biomass increased despite two consecutive years of removal. They believed a significant portion of the rainbow trout population was uncatchable due to these physical features. The removal of rainbow trout on these larger streams thus had a stimulatory effect and were not the result of increased catchability. In streams that were narrower and with fewer deep pools, the densities and standing crops of rainbow trout decreased. They concluded that when attempting to control salmonids by electrofishing, stream morphology, the presence of barriers to fish movement, and the numbers of rainbow trout in the population prior to removal should be carefully considered. This work tended to substantiate the conclusions of Moore et al. (1981, 1983): the removal of rainbow trout by electrofishing might be used as a management technique to control nonnative trout species, especially if the initial reduction is followed by further effort to control the population. However, it probably cannot be used to eliminate them from larger park streams.

OBJECTIVES

The goal of this study was to evaluate the effect of rainbow trout removal on GRSM brook trout populations and eventually develop a brook trout restoration plan. The effectiveness of electrofishing as a field management technique is essential for such a plan. Moore et al. (1981, 1983, 1986) provided at least 5 years in which rainbow trout were removed, and a minimum of 5 years had elapsed since the end of the removal efforts. This enabled us to compare the long-term population changes in these streams. The objectives of this study were to:

1. Evaluate the effectiveness of the past efforts by Moore et al. (1981, 1983, 1986) to remove rainbow trout from Silers, Sams, Taywa, and Beetree Creeks by comparing the initial biomass to that found in 1987. Standing crop, the total population present at a given time, may be expressed as either density (#/100 m^2) or biomass (kg/h). Biomass was compared in this study since it is a more accurate measure of the total standing crop and is not influenced by fish size. Moore and Larson (1989) analyzed the densities.

2. Evaluate the effectiveness of the past removal efforts of the USFWS on Road Prong and Desolation Creeks by comparing the total numbers of fish captured during the removal to the total captured in 1987. Standing crop comparisons were not possible on these streams because the USFWS did not use a population estimation procedure.

3. Determine if the physical characteristics of streams can be used to predict the success of rainbow trout removal by electrofishing.

4. Evaluate the change in the distribution of brook trout since the 1970s in five GRSM streams.

METHODS

Removal Efforts

The removal efforts varied between streams. Rainbow trout were removed by electrofishing from Taywa, Silers, Sams, and Beetree Creeks from 1976 through 1979 (Moore et al. 1981, 1983). In 1980 and 1981, rainbow trout continued to be removed from Taywa and Silers Creeks; however, removal operations in Sams and Beetree Creeks were terminated and the responses of the trout populations to no more removal were monitored (Moore et al. 1986). In 1978 and 1979, the USFWS attempted to restore brook trout in Sams Creek by using electrofishing to remove rainbow trout from 3500 m of the stream. This removal began downstream from the 1976-1979 sections of Moore et al. (1981, 1983) and continued upstream through their sections. The USFWS also attempted to remove rainbow trout in Road Prong Creek in 1978 and in Desolation Creek in 1979. These streams had not been sampled previously by Moore et al. (1981). Table 1 shows the years in which the streams were sampled, the section lengths, the number of sections sampled, and the number of allopatric rainbow, sympatric rainbow/brook, and allopatric brook trout sections sampled.

Table 1. Years sampled, section length (m), and number of allopatric rainbow (A), sympatric rainbow/brook (B), and allopatric brook trout (C) sections sampled.

Stream	Years Sampled	Section Length (m)	Number of Sections	A	B	C
Beetree	1976-79	300	3	1[a]	2[b]	0
	1980	100	4	0	4	0
	1987	100	4	0	4	0
Sams	1976-79	300	5	0	5[c]	0
	1978-79	100-160	35	21	14	0
	1980	100-160	9	3	5	1
	1981	100-160	5	3	1	1
	1986-87	100-160	6	3	2	1
Starkey	1976-79	300	2	0	0	2
	1980-81	100	2	0	0	2
	1986-87	100	1	0	0	1
Silers [d]	1976-79	300	4	0	3	1
	1980-81	100	12	0	9	3
	1986-87	100	4	0	0	4

Table 1. Continued

Stream	Years Sampled	Section Length (m)	Number of Sections	A	B	C
Taywa [e]	1976-79	300	4	0	3	1
	1980-81	100	12	0	9	3
	1986-87	100	4	0	0	4
Road Prong	1978	100	14	5	9	0
	1987	100	4	0	4	0
Desolation	1979	100	25	0	24	1
	1987	100	3	0	3	0

[a] Allopatric rainbow in the last 90 m of Section 2 and first 113 m of Section 3. No fish collected in the last 187 m of Section 3.

[b] Sympatric in Section 1 and the first 210 m of Section 2.

[c] Section 4 was only 60 m in length.

[d] Equipment failures in 1976 resulted in only 1/2 of the study area being sampled.

[e] Equipment failures in 1977 resulted in only 1/2 of the study area being sampled.

Station Locations

Five streams were selected for restoration by Moore et al. (1981). Four of these (Beetree, upper Sams, Silers, Taywa) were selected for resampling in 1986 and 1987. Three larger streams (lower Sams, Road Prong, Desolation) were selected by the USFWS for restoration in 1978 and 1979. All streams were located in steep forested terrain and were typical second- and third-order montane streams. Detailed descriptions of all sections sampled in 1986-87, including the identifying tag numbers, are given in Appendix A. The sections sampled by the USFWS are given in Appendix B. Each area selected for renovation began upstream of natural barriers (e.g., waterfalls or cascades) and ended at either an allopatric brook trout population or an upstream waterfall or cascade.

Beetree, Sams, Starkey and Silers Creeks were electrofished in 1976 but were not divided into sections. In 1977, each of these streams was subdivided into 300-m sections, which were used until 1979 (Table 1). Moore et al. (1981) provide a detailed description of the streams and sections, including allopatric brook trout sections in Silers, Taywa, and Starkey Creeks.

In 1978, the USFWS selected Road Prong, Sams, and Desolation Creeks for restoration efforts. They numbered their sections beginning with the most upstream section, whereas Moore et al. (1981) and the 1980-1987 sampling numbered them from the most downstream section. Road Prong was divided by the USFWS into 14 contiguous sections approximately 100 m in length, and removal began at the confluence with the West Prong of the Little Pigeon River and ended at the third stream crossing. In 1987, five of these sections (2, 6, 9, 10 and 13) were sampled. USFWS efforts on Sams Creek began at a small cascade approximately 20 m upstream of its confluence with Thunderhead Prong (elev. 639 m) and ended about 400 m upstream of the confluence with Starkey Creek (elev. 1018 m). The stream was subdivided into 35 sections, with section lengths varying from about 85 to 150 m. Natural breaks, such as a small cascade or waterfall, were used to delimit sections. On Desolation Creek, the USFWS divided the stream into 25 contiguous sections of approximately 100 m, beginning at the confluence with Bone Valley Creek. In 1987, three of these sections (2, 8, and 14) were sampled.

In 1980, the sampling design of Moore et al. (1981, 1983) was modified in an attempt to assess the effects of continued removal or no additional removal. The Silers and Taywa Creek study areas were selected for continued rainbow trout removal; the original 300-m sections were divided into 100-m sections, all of which were sampled in 1980 and 1981. Sections that had the highest densities of rainbow trout in 1981 were selected in 1986 and 1987. A section was located in each of the original 300-m sections of 1977-1979, as well as a representative allopatric brook trout section. Rainbow trout were returned to Beetree and Sams Creeks. In 1980 and 1987, sampling in Beetree Creek was reduced to one representative section in Sections 1 and 3 of 1977-1979 and two sections in Section 2 of 1977-1979. This stream was not sampled in 1981 or 1986. On Sams Creek in 1980, representative USFWS sections along the length of the restored area were selected; two of which were in the area sampled by Moore et al. (1981). An upstream allopatric brook trout section was also added. Time constraints forced reductions in the number of sections sampled in 1981, including the inadvertant omission of one of the sections sampled by Moore et al. (1981). These areas, including the omitted section, were sampled in 1986 and 1987.

Fish Collection

Fish were collected with backpack electrofishing units that generate alternating current. The units used during 1976-1979 are described in Moore et al. (1981). In 1980, a new generator and motor (Tas Model QEG 300) were used and the electrodes were improved. In 1986, this unit was further modified by adding a variable-control voltage transformer so voltages could be adjusted to differing electrofishing conditions. The units were mounted on insulated plastic backpack frames for better safety. There did not appear to be any differences in the efficiency of the various units as indicated by capture probabilities. From 1976 to 1979, the capture probabilities varied from .5357 to .7449, and from 1980 to 1987 they varied from .5401 to .8333.

Three electrofishing passes were made through each section. All sections were blocked by nets or natural barriers. Fish were held in nets and returned to the stream following data collection. Each fish was anesthesized in MS 222, measured to the nearest mm, and weighed with a hand-held Ohaus spring scale. Population estimates, capture probabilities, mean condition factor, mean length and mean weight, together with their 95% confidence intervals, were calculated using the Microfish computer program (Van Deventer and Platts 1986). Standard deviations were also computed for length and weight.

The larger streams sampled by the USFWS required the use of more than one backpack electrofishing unit. YACC crews made as many electrofishing passes as necessary in each section until no rainbow trout were collected. The total number of trout collected in each section was recorded by species, but data on length, weight, and stream widths were not obtained. Therefore, population and biomass estimates could not be calculated, and only comparisons of the total number of fish collected were possible.

Stream Characteristics

In an attempt to determine the effects of the physical features of streams on rainbow trout removal success, several characteristics were measured during the 1987 sample using the techniques of Platts et al. (1983). At each 10-m transect, the following measurements were taken: width, depth at 1/4, 1/2, and 3/4 the width, substrate composition at the points where depth was measured, whether the transect crossed a pool or riffle, and the width of the stream relative to its mean width. Gradient was measured with a clinometer by sighting upstream to the next transect.

From these measurements, mean width, depth, gradient, and percent pools were obtained. The substrate type (bedrock, boulder, cobble, gravel, sand, silt) was recorded by placing an A, B, or C on the data sheet for a particular substrate if it was dominant at the 1/4 (A), 1/2 (B), or 3/4 (C) points across the transect at which the depth measurements were taken. If more than one substrate type was abundant, this was also noted.

The total number of substrate observations were summed for all transects at the station and the percentage of each substrate type was determined. Since it appeared that the proportion of boulders would be one of the indicators of rainbow trout removal success, this was the substrate class analyzed. The width of the transect with respect to mean stream width was quantified by recording a negative sign if the transect was narrower than the mean stream width, a positive if it was wider, and a zero if it was the same. These values were summed for all transects for a given station. Thus, a rating of +10 indicated that the width at each transect of a 100-m section was wider than the mean width, and a rating of -10 indicated that it was narrower.

To determine if there were any relationships between the physical measurements made in 1987 with the success of the rainbow trout removal, the change in biomass at each station was determined by subtracting the biomass in the first year of the removal from that of 1987. In our analysis, we assumed that the best measure of the effects of the removal was to compare the biomass at the time the removal began with that found in 1987. The biomass when the removal began is the best measure of the population composition prior to removal, and the 1987 biomass gives the greatest time span since the removal ceased, which for some streams was 1978 or 1979 (Sams, Beetree, Road Prong, Desolation) or 1981 (Taywa and Silers). If electrofishing is to be an effective technique for restoring brook trout in GRSM streams, it must have long-term effects on the rainbow trout populations. Thus, the 1987 sample is appropriate for showing the long-term trends. In addition, the 1987 sample is the only one that included all the streams from which rainbow trout were removed by both Moore et al. (1981, 1983, 1986) and the USFWS. If the biomass difference between the year when the removal began and 1987 is positive, it indicates that there was a greater biomass in 1987 than when the removal began, and if it is negative, a smaller biomass. If the removal was successful, the rainbow trout should have been eliminated with a large negative biomass difference, and the brook trout biomass should have increased with a large positive biomass difference.

The biomass difference was compared to the mean width, depth, percentage of the transects that crossed a pool, width rating, percentage of boulders, and the mean gradient. A scatter plot of these data points was made and a simple linear regression curve was fitted to the points to obtain the equation of the line. Analyses of variance of the resulting regression equations were performed and the correlation coefficients and coefficents of determination (r^2) obtained.

RESULTS

Taywa Creek

Rainbow trout were removed from Taywa Creek for 6 consecutive years beginning in 1976 (Table 1). Rainbow trout biomass decreased from 26 kg/h in 1976 to zero at all stations by 1986 (Figure 1). Rainbow trout appeared to have been almost eliminated from stations 3 and 4 by 1979; only 4 fish have been taken from station 3 since 1978 and only 3 from station 4. In 1980, the beginning of station 4 was set immediately above a cascade that was 30-40 m above the beginning of the section in 1977-1979. Brook trout biomass increased from 2.3 kg/h in 1976 to 20.3 kg/h in 1987 in station 1, 31.9 kg/h in station 2, 17.0 kg/h in station 3, and 7.6 kg/h in station 4. Brook trout biomass ranged from 3.3 to 13.7 times greater in 1987 than it was in 1976.

In stations 1, 2, and 3, the brook trout biomass since the end of rainbow trout removal (1981) was considerably higher than in 1976 or during the removal years. This conclusion is partly confounded by the fact that in 1976 the stream was not divided into sections and the biomass figure for this year is a composite for the entire 900-m stream reach. However, lower brook trout biomass in subsequent years and the dramatic increases since 1980 lead us to conclude that stations 1, 2, and 3 had considerably more brook trout in 1987 than in 1976 when sampling began. Even though many factors may have affected this, it appears that rainbow trout removal by electrofishing on this stream has resulted in an increase in brook trout populations. At station 4, the increase in brook trout was not as dramatic as in the other stations, but historically this station has had the highest brook trout biomass, so few rainbow trout were removed.

Silers Creek

At Silers Creek rainbow trout removal began in 1976 and continued for 5 consecutive years. Equipment failure in 1976 prevented complete sampling. Rainbow trout biomass decreased from 10.6 kg/h in station 1, 19.6 kg/h in station 2, 25.6 kg/h in station 3 and 1.4 kg/h in station 4 in 1977 to zero or near zero by 1980 (Figure 2). Brook trout biomass increased from 15.1 kg/h in 1977 to 21.5 kg/h in 1987 in station 1, 9.6 kg/h to 39.1 kg/h in station 2, and 5.9 kg/h to 20.1 kg/h in station 3. These differences represent a 1.4 to 4.1-fold increase. Brook trout biomass was about the same in station 4, being 26.2 kg/h in 1977 and 25.9 in 1987; however, this was an allopatric brook trout control station.

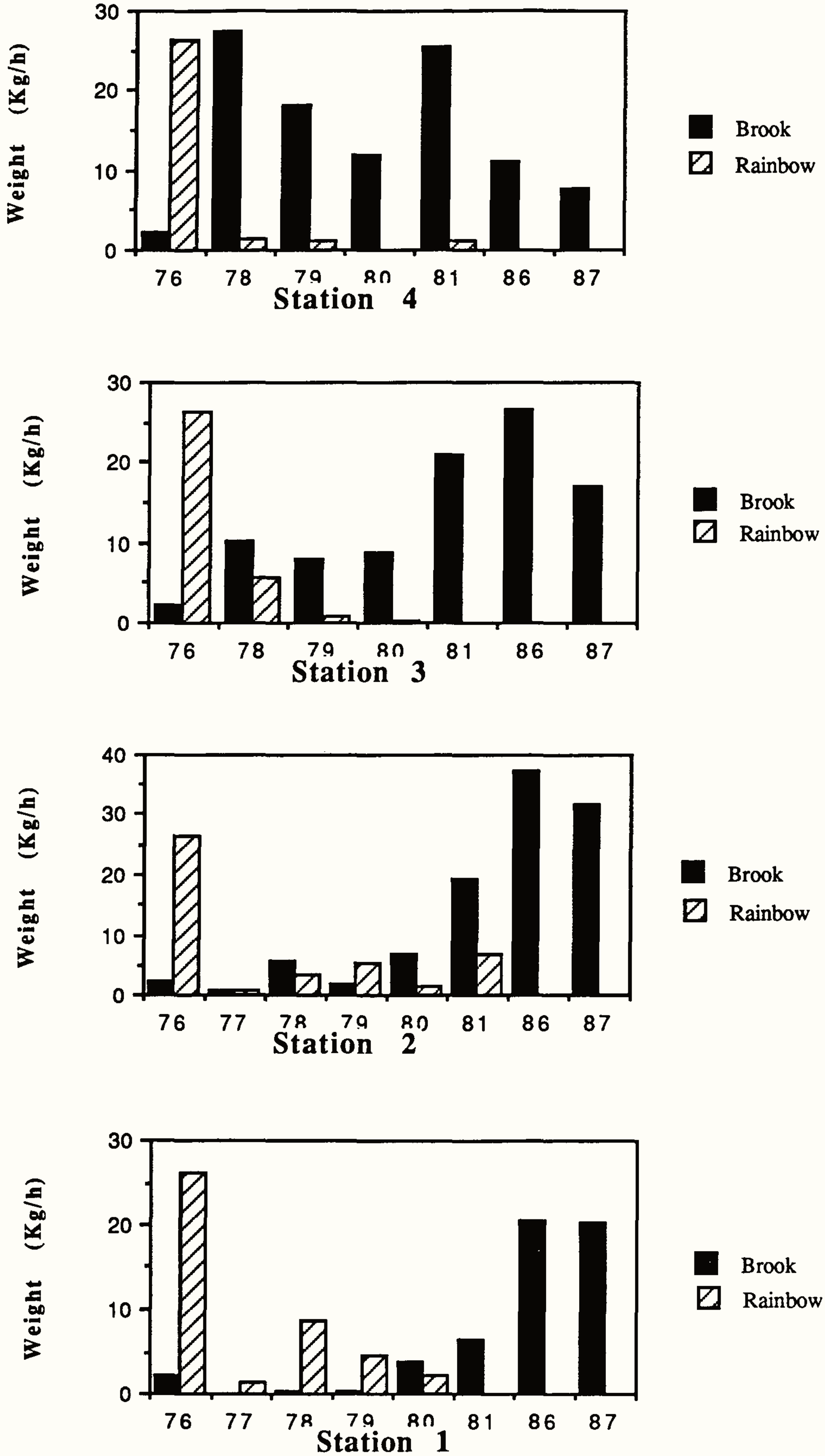

Figure 1. Standing crops of trout in Taywa Creek.

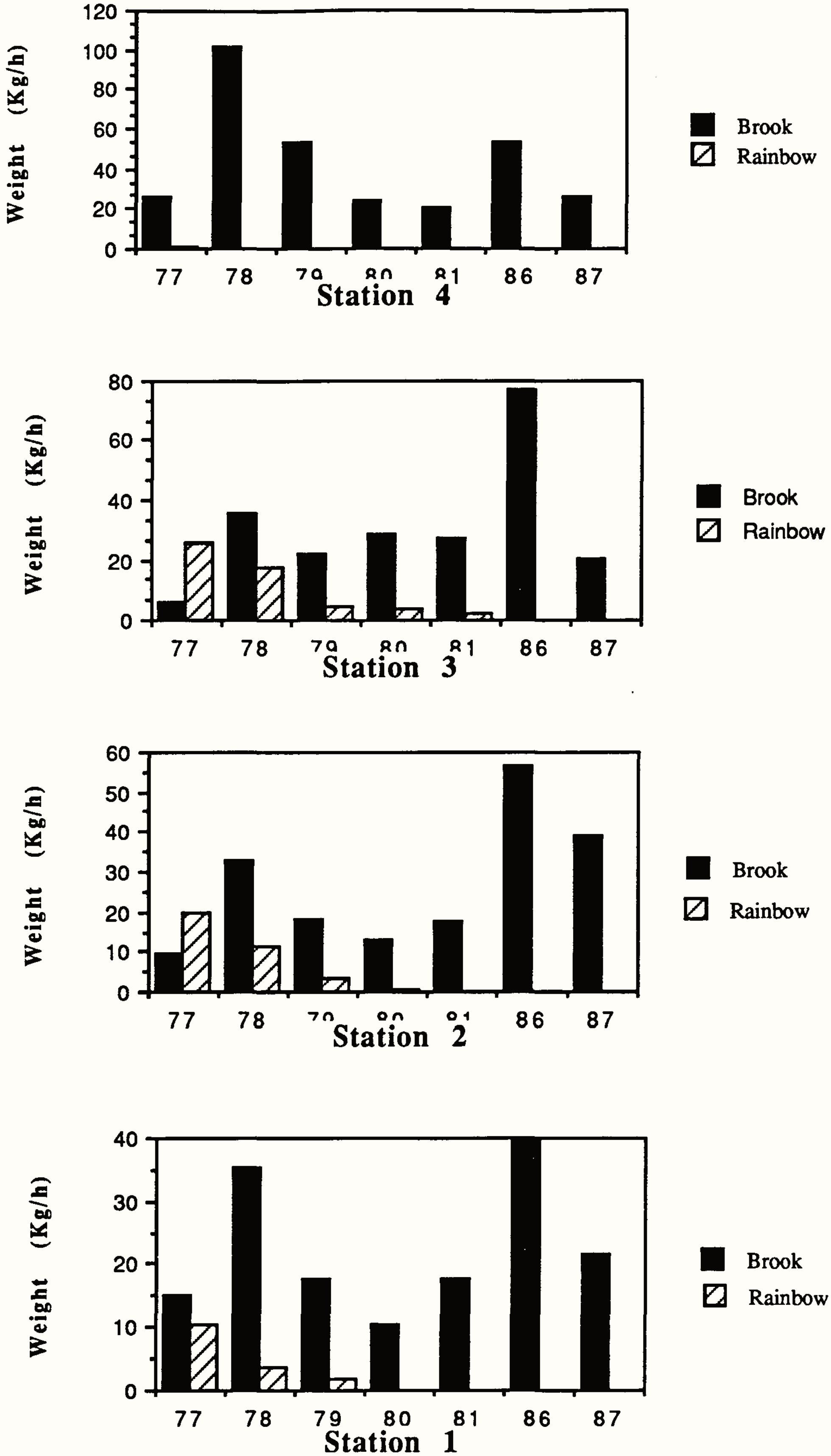

Figure 2. Standing crops on trout in Silers Creek.

In 1978, a sharp increase in brook trout biomass occurred at all stations, followed by a decrease in 1980 and 1981. Another sharp increase occurred in 1986 with extremely high biomasses recorded; 39.5 kg/h in station 1, 56.8 kg/h in station 2, 76.8 kg/h in station 3 and 53.0 kg/h in station 4. In 1987 there were rather drastic decreases. Despite these fluctuations, however, it is clear that the removal of rainbow trout resulted in an overall greater biomass of brook trout in Silers Creek.

Beetree Creek

Rainbow trout were removed from Beetree Creek for 4 consecutive years from 1976-1979 (Table 1). They have not been removed since. The stream was not sampled in 1981. Rainbow trout biomass was reduced from 22.2 kg/h in 1976 to zero in 1987 in stations 1, 2, and 4 and to 3.9 kg/h in station 3 (Figure 3). This indicates that electrofishing greatly reduced the rainbow trout populations. As was true of Taywa Creek, the 1976 biomass is a composite of the entire 900 m sampled.

Brown trout were taken from station 1 in 1977, 1978, 1979, and 1987 with the biomass varying from 3.3 kg/h to 6.3 kg/h. They had not been taken from any other station until 1987, when one fish (1.3 kg/h) was taken in station 4. This is an interesting development because this station is located about 600 m from its confluence with Deep Creek, a stream with one of the best brown trout populations in GRSM. This fish had to have passed five natural obstructions to get to this section.

After rainbow trout removal began in 1976, the biomass of brook trout increased in 1977, but decreased from 1978 to 1979 in stations 1, 2 and 3. A further decrease occurred in station 1 in 1980, but increases occurred in stations 2 and 3. No brook trout were collected in station 4 in 1980. In 1987, brook trout biomass increased in stations 1 and 4 and decreased in stations 2 and 3. During the 11-year period, the brook trout biomass varied from 1.2 to 12.8 kg/h in station 1, 6.1 to 26.2 in station 2, 6.1 to 28.3 in station 3, and 0 to 6.1 in station 4. These wide fluctuations led us to conclude that there has been no significant increase in brook trout in Beetree Creek as a result of the rainbow trout removal, and the changes in the brook trout populations do not appear to be related to the removal.

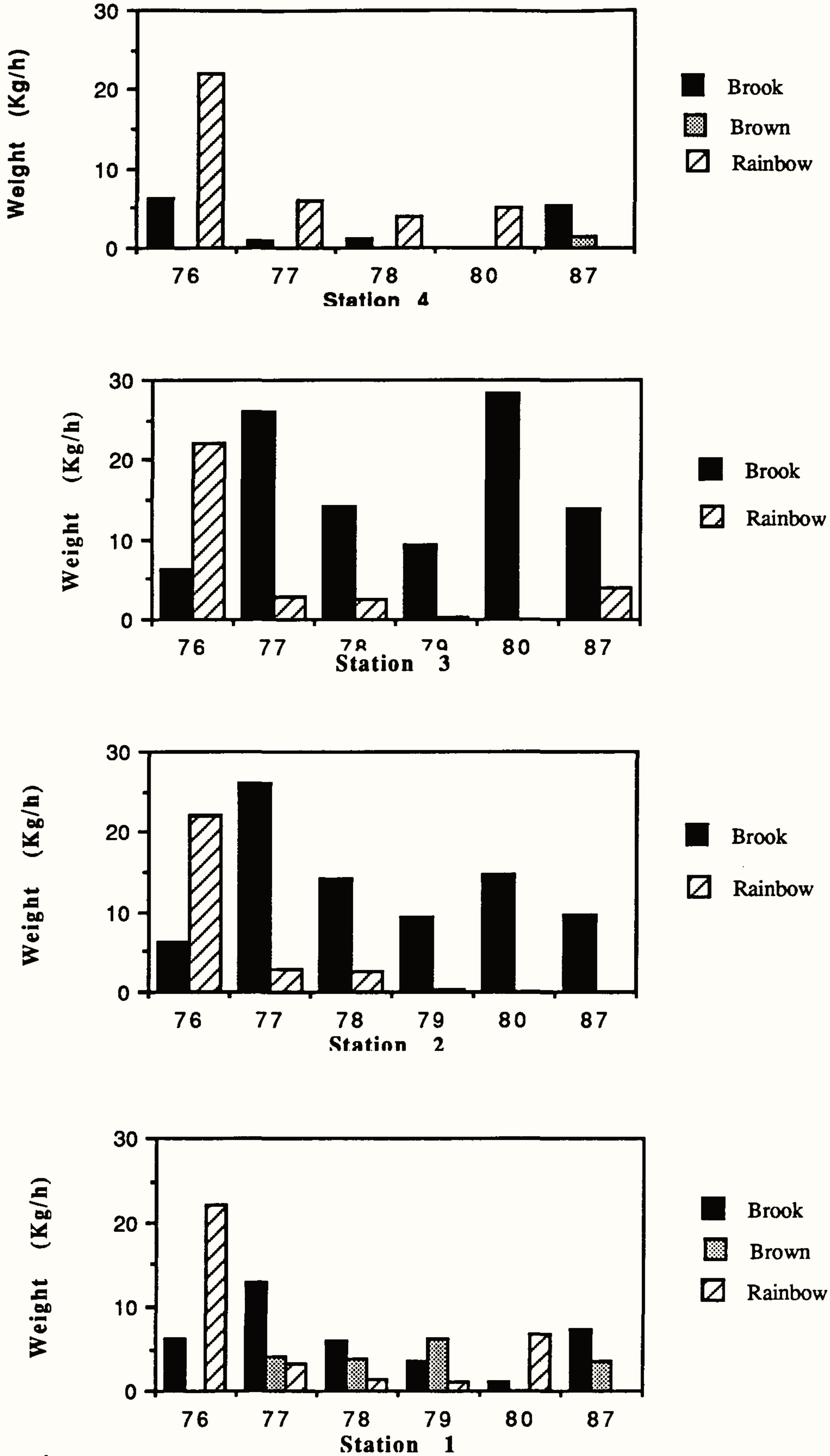

Figure 3. Standing crops of trout in Beetree Creek.

Sams Creek

Rainbow trout were removed from the lower 2500 m of Sams Creek by the USFWS in the fall of 1978 and in March of 1979, downstream of the removal sections sampled by Moore et al. (1981, 1983). In the present study, stations 1, 2, and 3 were within this stream reach. The USFWS removals are the only attempts to reduce the rainbow trout populations. Whitworth (1979) also sampled this area in 1979, but no rainbow trout were removed. In all three stations, we found a steady increase in rainbow trout biomass from 1980 to 1987 (Figure 4). In 1987 the rainbow trout biomass was 81.8 kg/h in station 1, 49.3 in station 2, and 17.1 in station 3. Very few brook trout have been taken from stations 1 and 2 during the evaluation period. In station 3, the brook trout biomass of 16.4 kg/h in 1981 dropped to zero in 1987. These data lead us to conclude that the two USFWS rainbow trout removals in the lower sections of Sams Creek did not enhance the brook trout and may have had a stimulatory effect on the rainbow trout that remained.

Rainbow trout were removed from the upper sections of Sams Creek by Moore et al. (1981, 1983) from 1976-79, and the USFWS in 1978 and 1979. The biomass of rainbow trout in stations 4 and 5 was greater in both 1986 and 1987 than during the removal in 1976. The biomass of brook trout does not appear to have increased. It was 10.1 kg/h in station 4 in 1977 and 10.3 in 1987, and in station 5 it was 13.4 in 1977 and 20.0 in 1987. Station 6 had only brook trout at a rather high biomass (41.7-63.4 kg/h) and was an allopatric control station. The four years of removal by Moore et al. (1981, 1983) and the two years of removal by the USFWS apparently did not enhance the brook trout in the upper sections of Sams Creek, nor did it reduce the rainbow trout.

Starkey Creek

Only brook trout inhabited Starkey Creek. Consequently, the populations were monitored mainly to determine the extent of invasion by rainbow trout from Sams Creek, and to serve as an allopatric brook trout control stream for comparisons with removal effects. No barrier is present to prevent rainbow trout from moving into this stream from the sympatric rainbow/brook trout population in Sams Creek. Except for one rainbow trout taken in 1977 and another in 1981, the population has remained allopatric for brook trout (Figure 5). It appears that factors other than the presence of a barrier have prevented rainbow trout from invading this stream. Brook trout biomass has fluctuated from 12.5 kg/h to 44.7 kg/h in station 1 and 12.0 kg/h to 22.6 kg/h in station 2.

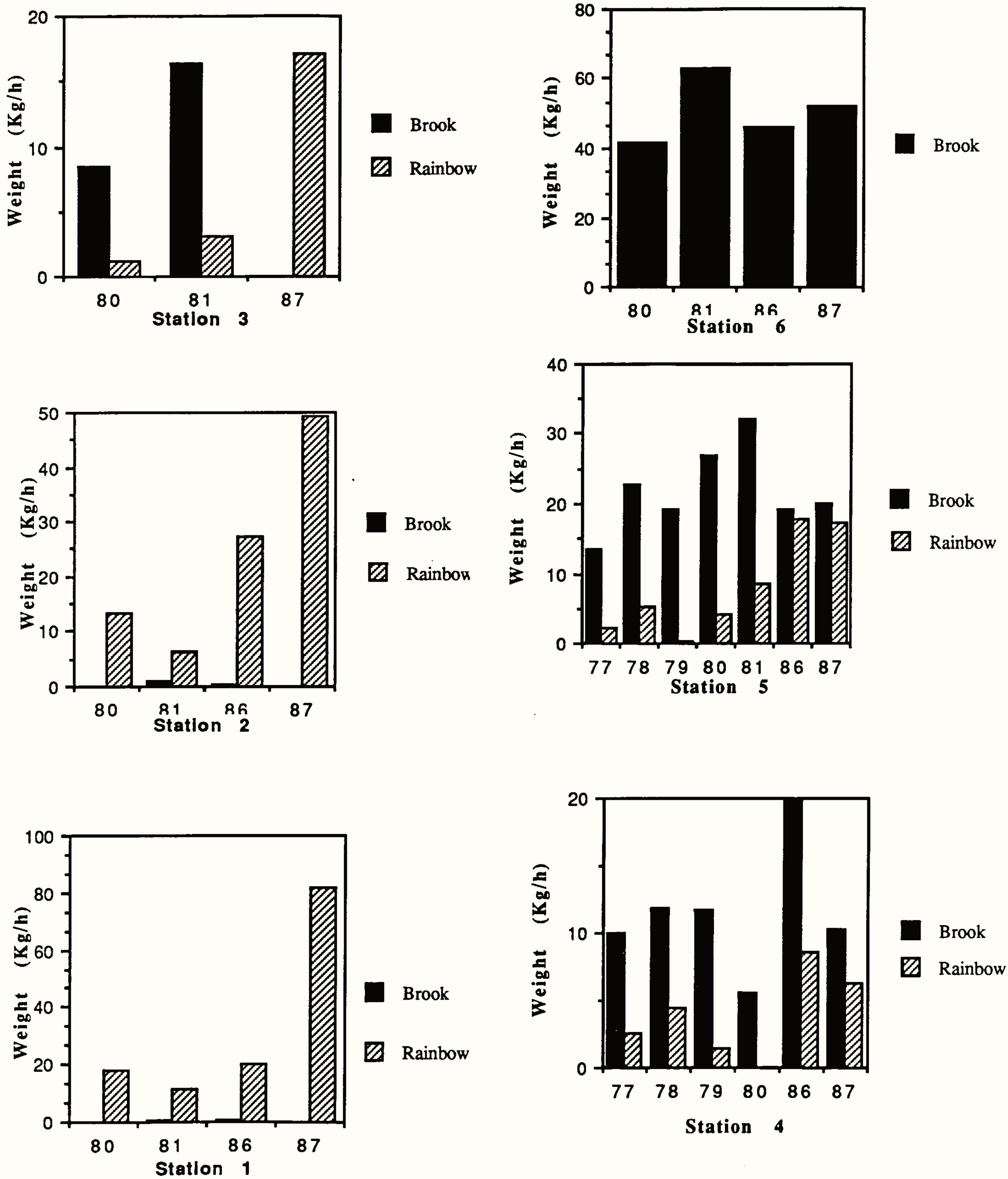

Figure 4. Standing crops of trout in Sams Creek.

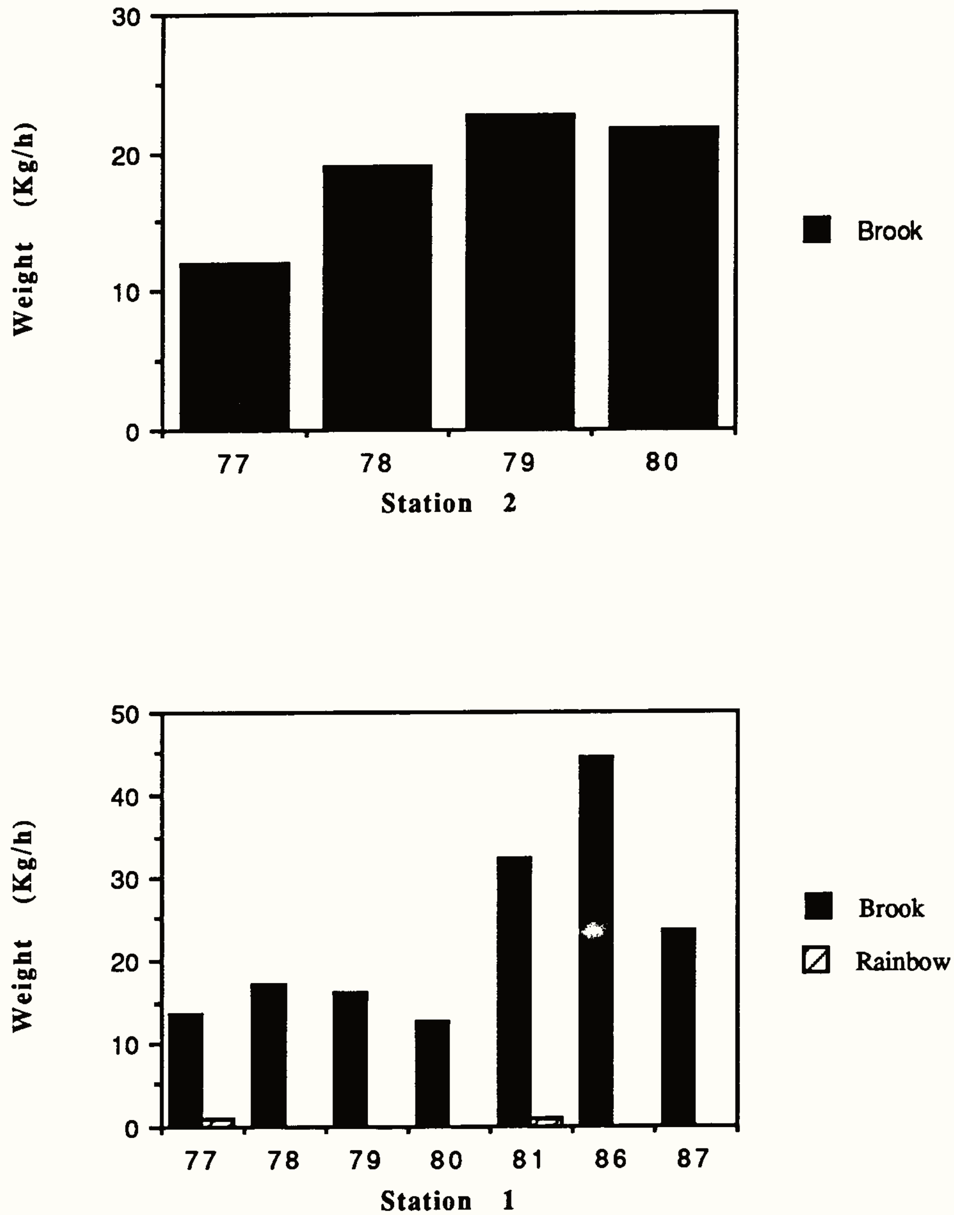

Figure 5. Standing crops of trout in Starkey Creek.

Road Prong Creek

At Road Prong Creek, rainbow trout were removed from 14 contiguous sections approximately 100 m in length by the USFWS in 1978. No additional removals have occurred since that time. The only data available from the 1978 removal are the total number of trout captured. We sampled 5 of the 14 sections in 1987. The total numbers of trout captured in 1978 were compared to the total collected in 1987 (Figure 6). However, this comparison may not be accurate because the sampling efforts during the two years were different. The effort was greater in 1978 because the purpose was to remove as many rainbow trout as possible, while in 1987 three electrofishing passes constituted the entire effort. With the exception of station 6, in 1978, the number of brook trout captured increased from the downstream station (station 13) to the upstream station (station 2), and the number of rainbow trout decreased (Figure 6). The same trend seemed to prevail in 1987. The proportions of brook trout to rainbow trout remained relatively constant from 1978 to 1987 (Table 2).

Table 2. Total number captured and percentages of total catch consisting of rainbow trout in Road Prong Creek in 1978 and 1987.

Station	1978		1987	
	Total	% Rainbow	Total	% Rainbow
Station 13	93	100	72	93
Station 10	81	90	72	88
Station 9	142	78	68	83
Station 6	31	54	44	50
Station 2	55	10	78	.02

This constancy indicates that, with the possible exception of station 2, the proportion of rainbow trout was similar in 1987 and 1978. An initial reduction in the number of rainbow trout occurred after the removal in 1978, but the effect was short-lived due to incomplete removal and movement back into the area from downstream. It appears that the numbers and proportions of trout in 1987 were similar to what they were in 1978; the single removal had little effect on either the rainbow or brook trout populations during 8 years thereafter. Differences between years are probably due to natural year-to-year fluctuations in the populations, a condition that was also observed in other streams that were sampled more

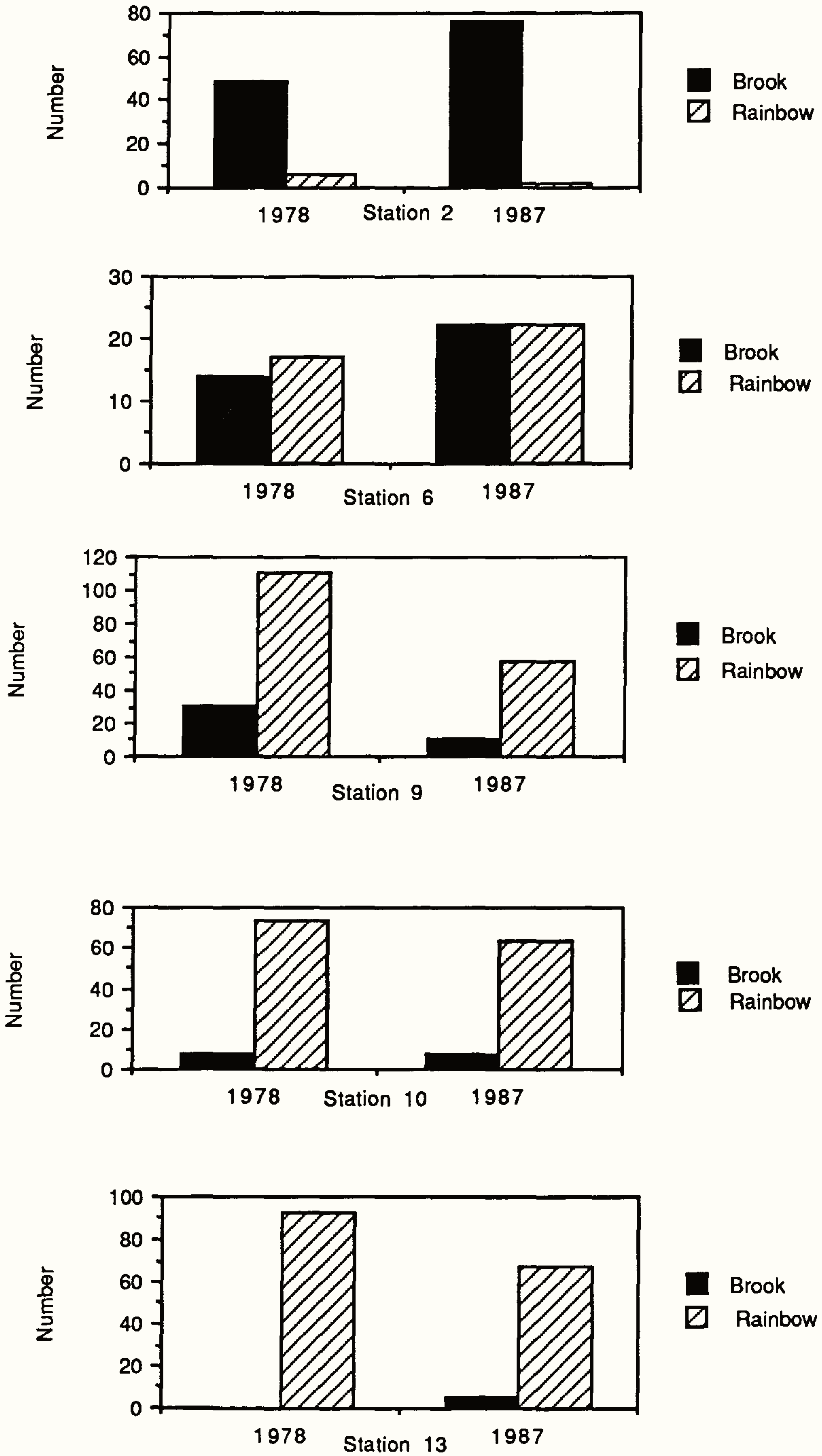

Figure 6. Numbers of trout collected in Road Prong Creek.

frequently (Figures 1, 2, 3, 4, 5). Despite the rather imprecise level of this analysis, it appears the attempt to restore brook trout in Road Prong Creek using a single removal was not successful.

Desolation Creek

At Desolation Creek, rainbow trout were removed by the USFWS in 1979 from 25 100-m contiguous sections. Three of these were sampled in 1987 (Table 1). As in Road Prong Creek, the only data collected in 1979 were the total number of fish captured. The number of rainbow trout collected was greater in 1987 in stations 2 and 12, and slightly less in station 8 (Figure 7). Despite an initial decrease in the number of rainbow trout, there appears to be no long-term effect. No stimulatory effect on the rainbow trout seems to have occurred. In all three stations, the number of brook trout captured increased dramatically from 1979 to 1987. This result is probably not due to differences in the two sampling efforts since the 1987 effort was not as great as in 1979. It may merely reflect natural annual fluctuations in the trout populations (see also Figures 1, 2, 3, 4, 5). On the other hand, it may indicate a real increase in brook trout in this stream. We doubt the rainbow trout removal had any long-term effect on the brook trout population in Desolation Creek, as it apparently contains a healthy brook trout population.

Brook Trout Distribution

In 1986 and 1987, we surveyed five streams (Bunches, Hazel, Proctor, and Walker's Creeks and Defeat Branch) using permanent 100-m sampling sections. The resulting brook trout distributions of these streams were compared to those reported in the 1970s by Kelly et al. (1980) in an attempt to determine if changes had occurred since they were last sampled. Table 3 shows the population estimates and their 95% confidence intervals, the standing crop biomass, and the section elevations. The range of allopatric brook trout populations had not changed in Defeat Branch, Walkers Creek, and Bunches Creek. Each of these streams has a natural barrier to upstream fish movement. Since 1976, however, the rainbow trout have advanced upstream to the base of the cascades in upper Hazel Creek (section 2), resulting in the loss of approximately 0.5 km of previously allopatric brook trout stream. Based on the size and configuration of the Hazel Creek cascades, it is highly unlikely that any additional upstream migration of rainbow trout will occur.

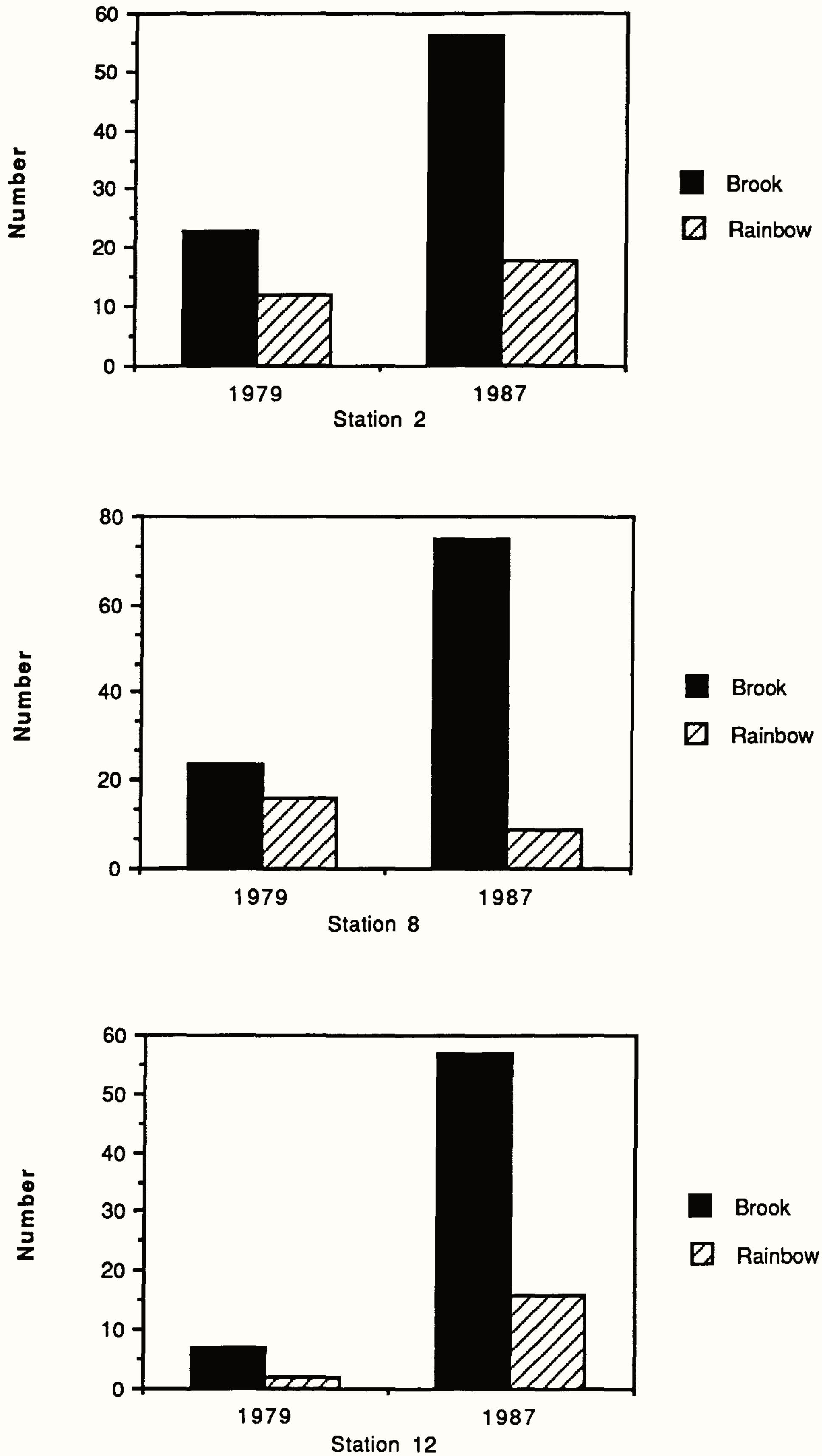

Figure 7. Numbers of trout collected in Desolation Creek.

Table 3. Population estimates and standing crops of trout during 1987 in Bunches, Hazel, Proctor, and Walker's Creeks and in Defeat Branch.

Stream	Section	Elevation (m)	Pop. Estimate (95 % C.I.) rainbow	Pop. Estimate (95 % C.I.) brook	Standing Crop (Kg/h) rainbow	Standing Crop (Kg/h) brook	Barrier
Bunches	1	1372	-	192 (179-205)	-	44.67	yes
	2	1433	-	202 (195-210)	-	49.23	yes
	3	1457	-	144 (135-154)	-	53.93	yes
	4	1463	-	72	-	66.58	yes
Defeat	1	853	-	6 (16-18)	-	8.53	yes
Hazel	1	1189	34 (34-35)	67 (67-69)	19.45	16.04	no
	2	1210	-	88 (78-101)	-	15.07	yes
Proctor	1	1006	42 (42-44)	42 (42-44)	11.64	26.02	unknown
Walkers	1	1036	-	28 (28-29)	-	10.51	yes

In 1976, brook trout in Walkers Creek comprised 78% of the total number of trout collected upstream of a cascade at 975 m. Samples taken in this area in 1987 showed that the trout population is now 65% rainbow and only 35% brook. In 1976 in Defeat Branch, rainbow trout dominated the population downstream of the barrier at 853 m. This was similar to what was found in 1987. In Proctor Creek in 1976, rainbow trout were also dominant, but the fish collected in 1987 were equally divided between rainbow trout and brook trout.

Population estimates and standing crop biomass cannot be obtained from the 1976 data and comparisons with the 1987 data were not possible. However, when we compared the limited length and weight data collected from the 1970s surveys, it appeared the population size class structure for each species was similar to that of 1987.

Relationships Between Removal Success and Stream Physical Characteristics

For all physical measurements, except mean gradient, there appeared to be positive relationships between the difference in biomass in 1987 and when the removal began for rainbow trout and negative relationships for brook trout (Figures 8 and 9). The tendency for positive relationships for rainbow trout was due to positive biomass differences in Sams Creek (station 1-64.0 kg/h, station 2-36.2, station 3-16.0, station 4-3.8, station 5-15.1). The rainbow trout biomass was zero or negative for all stations on other streams. The tendency for negative relationships for brook trout was due to large positive biomass differences at stations with smaller physical features, and few negative biomass differences. With the exception of stations 1,2, and 3 on Sams Creek and the upper station on Silers and Beetree Creeks, all brook trout biomass differences were positive.

The only significant relationships were depth and percent of boulders for rainbow trout (Table 4). This indicates that as the depth and percent of boulders increased, the difference in rainbow trout biomass increased. Thus rainbow trout biomass was greater in 1987 than when the removal began in deeper stations and in stations that had a higher percentage of boulders.

The biomass difference between 1987 and the time when the removal began compares the physical characteristics at one time period (1987) to the total change in biomass over the 11-year study period. There were probably also changes in the physical features during this time period which affected the biomass. To determine if the relationships were stronger for a single time period, a regression analysis and an analysis of variance were carried out for the biomass and the physical measurements for 1987. The only significant relationship was depth for rainbow trout. Even for the same time period, the relationships between trout biomass and the physical characteristics were not strong. Many factors, both physical and biological, affect trout biomass. A more detailed analysis of the physical features of the streams will be necessary before predictions can be made about the relationships between the physical characteristics and removal success. The means of the stream measurements taken in 1987 are listed in Appendix C.

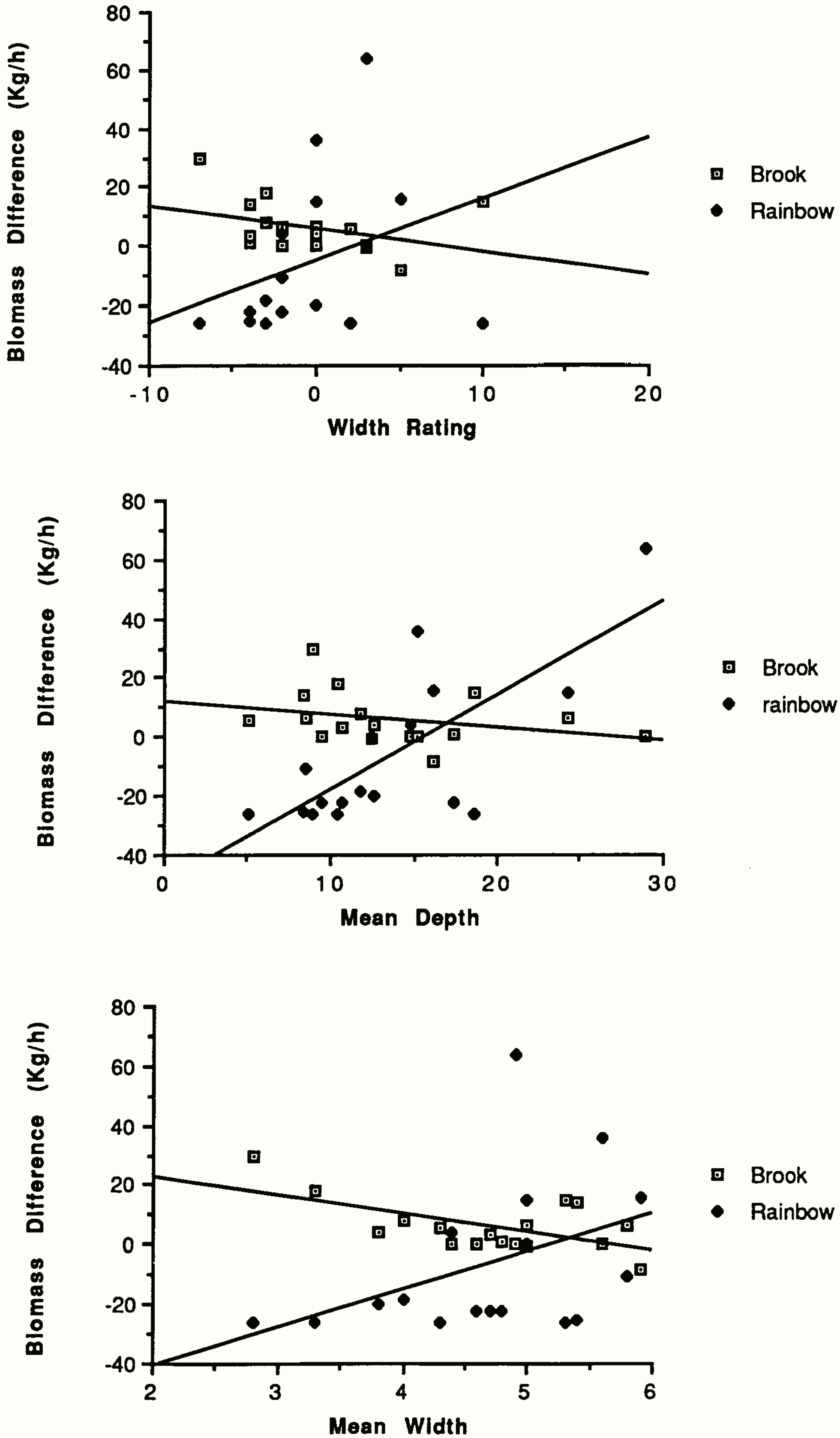

Figure 8. Scatter plots of difference in biomass and width rating, mean depth (cm), and mean width (m).

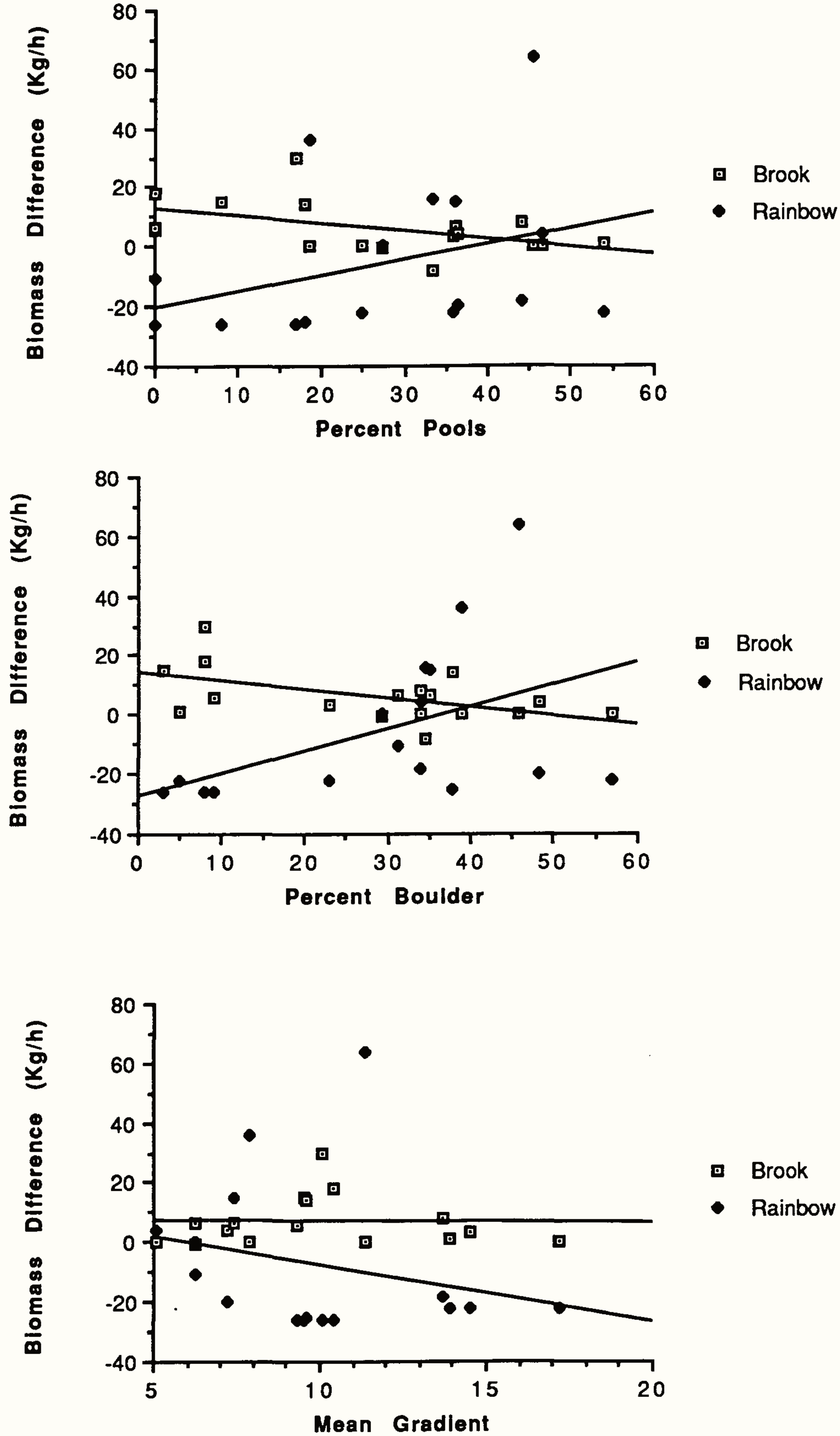

Figure 9. Scatter plots of biomass difference and percent pools, percent boulder, and mean gradient (percent).

Table 4. F-ratios (F) and probabilities (p) from the analysis of variance of the regression of difference in biomass on stream characteristics.

	Width		Depth		% Pools	
	F	p	F	p	F	p
Rainbow	3.09	.099	12.90	.003*	1.81	.20
Brook	4.19	.059	.154	.701	1.50	.24
	Width Rating		**Gradient**		**% Boulder**	
	F	p	F	p	F	p
Rainbow	2.49	.136	.82	.381	4.88	.04*
Brook	.007	.934	.003	.954	2.68	.12

DISCUSSION

Elimination of Rainbow Trout

Moore et al. (1981, 1983, 1986) evaluated the effectiveness of one backpack electrofishing unit for removing nonnative trout species from small montane streams. Although the density of rainbow trout in sympatric areas was reduced to less than 1 fish per 100 m^2, they were not eradicated. Initial rainbow trout densities, incomplete samplings due to equipment failure, and stream channel complexity influenced the efficiency of rainbow trout removal.

Our 1987 study shows that 5 years after the removals ceased, rainbow trout were no longer present in Silers and Taywa Creeks (Figures 1 and 2). During the last year of removal (1981) on both streams, the few rainbow trout remaining were found in small isolated areas separated by 200-400 m of stream (Moore, unpublished data). If the last removal did not eradicate the rainbow trout, it seems likely that natural mortality, widely-spaced populations, and competition from brook trout may have caused the disappearance of those remaining. These results indicate that rainbow trout can be eradicated from small streams with a single backpack electrofishing unit. To accomplish this success, however, it was important for the channels to be relatively simple with few deep pools and a downstream barrier to prevent future reinvasion by rainbow trout.

The effectiveness of electrofishing to remove rainbow trout in larger, more complex stream systems is not as clear because of the lack of long-term efforts similar to those in Silers and Taywa Creeks. Kelly (personal communication) speculated that if the first removal can reduce the population size by 90%, then backpack electrofishing techniques could be used to eradicate nonnative trout. Whitworth's (1979) evaluation of the Sams Creek removal project demonstrated that the reduction in rainbow trout population size averaged 89.9%, lending support to Kelly's hypothesis.

Information from Moore et al. (1983) reveals the labor-intensive nature of using backpack electrofishing techniques. These authors show that one man-day was required for a two-person crew to electrofish a 100-m section. Moore (unpublished data) found that approximately one man-day per 100-m section was still required when the crew size was increased to four. Information on which to base man-day estimates per section for USFWS crews are not available; however, the labor-intensive nature of the work is evident by the size of the crew (10) and the length of time required to remove the rainbow trout from each stream. For example, approximately 40 crew-days at 8 hours per day were required for the first effort in Sams Creek. The Desolation Creek effort required approximately 17 crew-days. These estimates do not include travel time to and from work sites nor preparation time. Obviously, the larger GRSM streams require substantially more effort and larger crews than the smaller streams. Moore et al. (1986) found that the use of multiple electrofishing units may increase capture efficiency, but do not eliminate the variations in removal efficiency between streams.

Habera et al. (1989) listed some factors that could influence removal success, including electrofishing effort, reinvasion of rainbow trout from downstream, large pre-removal rainbow populations, and streams with mean widths exceeding 6 m with more than 4 partially unfishable pools/1000 m. One or more of these factors may have contributed to the elimination of rainbow trout in Taywa and Silers Creeks, as well as the failure to eliminate them on Sams, Road Prong, and Desolation Creeks. It appears that any initial removal must be continued for several years in succession to eliminate rainbow trout, or at least keep their numbers at sufficiently low levels (Moore et al. 1983). Failure to continue removal may allow rainbow trout populations to reestablish themselves at levels higher than before (Figure 4).

Both Taywa and Silers Creeks have barriers downstream of the removal area, but there is no barrier separating stations 4 and 5 from the downstream rainbow trout populations on Sams Creek. Downstream barriers on Taywa and Silers Creeks prevented recolonization by rainbow trout and contributed to the successful removals. The lack of a barrier on Beetree Creek may have allowed recolonization by rainbow and brown trout. In addition, no barriers to fish movement were present in the area renovated on Road Prong Creek.

Pre-removal rainbow trout biomass in stations 4 and 5 of Sams Creek (Figure 4) was considerably less than in either Taywa Creek (Figure 1) or Siler's Creek (Figure 2). These results suggest that the presence of a large pre-removal rainbow trout biomass was not the factor that led to success or failure. Because it was not possible to obtain biomass estimates for the 1978-1979 removals on Road Prong and Desolation Creeks, it is difficult to determine if there were large pre-removal rainbow trout populations. However, if large rainbow trout populations were present, it is not believed to have been a factor in the failure to remove them on these streams.

Riley (1986), Habera (1987) and Habera et al. (1989) attributed success of rainbow trout removal to stream width. Habera et al. (1989) concluded that the channel width (mean: 7.4 m) of several GRSM streams influenced the efficiency of rainbow trout removal, and Riley (1986) indicated that an average width of 6.1 m should be the maximum for attempts to eliminate rainbow trout with one electrofishing unit. There did not appear to be any differences in mean channel width between Sams Creek stations 4 and 5 (4.7 m) and Silers Creek (5.0 m) or Taywa Creek (3.9 m), and all are less than the mean widths reported by Habera et al. (1989) and Riley (1986). The mean widths of Road Prong Creek (6.1 m), Desolation Creek (4.8 m), and the lower three stations on Sams Creek (5.5 m) also did not appear to be excessive.

Electrofishing efficiency is probably influenced by the entire stream morphology rather than just stream width. In 1987, stations 4 and 5 of Sam's Creek had a mean depth of 19.5 cm, and 41.5% of its transects crossed pools. In comparison, Silers and Taywa Creeks had mean depths of only 10.4 cm and 10.7 cm respectively and 20.5% and 6.2% of their transects crossed pools. It is possible that the success in eliminating rainbow trout in Silers and Taywa Creeks may have been due to increased electrofishing efficiency because of shallow water and the lack of deep pools. Failure to eliminate them in stations 4 and 5 in Sam's Creek may have been due to decreased electrofishing efficiency resulting from deeper water and more pools.

Increase in Rainbow Trout Biomass

In Sams Creek, biomass comparisons are not possible in those sections sampled by the USFWS since they did not measure lengths and weights. Density estimates (#/100 m^2) in 1987, however, were higher than obtained in 1978. These differences appear to be the result of natural year-to-year variations. Rainbow trout biomass in the sections sampled by Moore (unpublished data) in 1980 and 1981 were considerably lower than in 1987. It is possible that this increase began with limited rainbow trout reproduction in downstream reaches, as indicated by Whitworth (1979). Moore (unpublished data) in 1980 found adults large enough to spawn in all sections and limited reproduction in downstream areas. In 1981, the number of adults decreased downstream, but increased upstream. Young-of-the-year rainbow trout were collected in all but the most upstream sections in 1981. In 1986, when the next sample was taken, population densities, biomass, and age structure were similar to those taken at the time of removal, suggesting that the populations had returned to pre-removal conditions. No data were obtained to document the changes during the intervening years. Population changes on Road Prong and Desolation Creeks also were not obtained, but it is possible that either the process was similar to that described above for Sams Creek, or that rainbow trout from downstream areas reoccupied the stream.

Change in Brook Trout Biomass

Moore et al. (1981, 1983, 1986) demonstrated that removal of rainbow led to an increase in standing crop biomass of brook trout. In Taywa Creek in 1987 brook trout biomass was 3.3 to 13.7 times greater than when the removal began in 1976 (Figure 1). A similar pattern was seen in Silers Creek where the brook trout standing crop biomass was 1.4 to 4.1 times greater in 1987 than it was in 1976 (Figure 2). These data suggest that the removal of rainbow trout resulted in increases in brook trout biomass and density. The variability in biomass estimates reflects the natural spatial and temporal variations that occurred during the 11-year period (Figures 1 and 2). Larson and Moore (1985) found that as rainbow trout densities decreased, brook trout population characteristics became more like those of allopatric populations. The population changes in Taywa and Silers Creeks during the removal process also reflect those observed by Larson and Moore (1985).

Brook trout biomass and density changes in the other streams are more difficult to assess due to incomplete removal and, in some cases, lack of sufficient data, especially in Road Prong and Desolation Creeks. In Sams Creek, however, rainbow trout populations were drastically reduced by the efforts of Moore et al. (1983) and the USFWS (Whitworth 1979). Brook trout responded to the removal through increased numbers and biomass and the immigration of young-of-the-year brook trout into downstream areas (Moore unpublished). In 1986 and 1987, however, brook trout were not collected in the downstream areas of Sams Creek where they were collected in 1980 and 1981 (Figure 4). The most probable reason for this loss is the increase in rainbow trout density. It is evident that the restoration effort did have short-term positive effects on brook trout populations in Sams Creek. Based on this information and the data from Moore et al. (1981, 1983, 1986), it seems probable that other streams followed this same recovery pattern for rainbow trout.

Year-to-year and between-stream variations in biomass may mask the effect of rainbow trout removal. One approach to test this hypothesis would be to compare the annual variations in the allopatric brook trout stream segments with segments from which rainbow trout were removed. It is assumed that the annual variation in the allopatric segments reflects the natural variation of southern Appalachian brook trout populations. The difference between the highest and lowest biomass for the 11 years of the study for the allopatric and sympatric stream segments was compared with an unpaired, two-tailed t-test. The mean difference for the allopatric segments (33.8 kg/h) was not significantly different from the sympatric segments (26.7 kg/h, t=0.64, p=.53). Other authors have shown that the biomass of brook trout varies annually (Moore et al. 1981, 1983; Harshbarger 1978). Harshbarger (1978) reports data from 20 brook trout streams in GRSM, in which the biomass varied from 5.6 to 25.4 kg/h, had a mean of 19.3, and a standard deviation of 17.9. He quotes North Carolina Wildlife Resources Commission fishery biologists Ratledge and Louder, who indicated that the usual carrying capacity for trout in western North Carolina streams ranged from 4.5 to 25.8 kg/h. Habera et al. (1989) also found considerable variation in rainbow trout biomass during 3 years of sampling. The long-term data of the year-to-year variation in biomass reported in the present study is the most comprehensive database available for the southern Appalachians and emphasizes the importance of continued long-term monitoring of trout populations in the GRSM.

Relationships Between Removal Success and Stream Physical Characteristics

The relationships between the physical characteristics of the streams and the difference between rainbow and brook trout biomass before and after removal were not strong (Table 4). Several factors could have affected these relationships, including the annual variation in biomass, the subjectivity of measuring some of the physical features (including the pool width ratings and the substrate determinations), and the variations that occurred in the physical characteristics of the streams during the 11-year period. Data on the physical features of the streams were taken only during 1987, yet the difference in biomass between rainbow and brook trout reflects the changes from the time when the removal began to 1987. This biomass difference was probably influenced by the physical conditions of the streams during the entire 11-year period, not just 1987. For example, an increase or decrease in depth and water velocity would probably have affected the biomass for the period of time in which the changes occurred and thus would be reflected in the biomass difference. The physical measurements taken in 1987, however, may not have reflected that change in depth and water velocity.

Even though we found no strong overall relationships between the biomass difference and the physical characteristics of the streams, some interesting trends were observed. Stream depth was found to have a significant influence on biomass difference for rainbow trout (Table 4). There was also a significant relationship for only the 1987 biomass. This indicates that as depth increased, the biomass difference increased. The deeper the stream, the less effective the removal, and the greater the rainbow trout biomass subsequent to the removal. This positive relationship supports the hypothesis of Habera et al. (1989): that the number of pools greater than 1 m in depth affects the removal success. Therefore it appears that the best streams for removing rainbow trout in GRSM using electrofishing are those shallow enough to ensure efficient removal.

The probability of a significant relationship between the difference in brook trout biomass and width (.059, Table 4) was only slightly greater than the $p < .05$ level of significance. A similar probability level (.052) was obtained for the 1987 biomass. Even though these probabilities are not significant, they are so close that a tendency for a greater brook trout biomass in 1987 than at the beginning of the removal is indicated, and this difference decreases with width. Riley (1986), Habera (1987), and Habera et al. (1989) believed the success of removal is related to stream width. The tendency of a negative relationship indicates that as stream width increases, the enhancement of the brook trout populations via rainbow trout removal decreases.

With the exception of gradient, there was a tendency for a negative relationship between the biomass difference and the physical characteristics of the streams for brook trout and a positive one for rainbow trout. Even though the relationships are not strong, this tendency is interesting and may indicate that as stream width, depth, percent pools, percent boulders, and pool width ratings increase, rainbow trout removal is less successful and their post-removal populations are greater than before the removal; whereas these same characteristics result in decreased post-removal populations of brook trout.

CONCLUSIONS

The data collected from this study show that the use of electrofishing to restore brook trout in GRSM is possible in small streams with downstream barriers that prevent rainbow trout recolonization. The data on Sams Creek also indicate that the technique has potential in larger, more complex streams. It is obvious, however, that one or two removal efforts will not eliminate nonnative trout from any stream. The results clearly show the need for long-term commitment and funding for this type of project.

Prior to attempting any restoration project, several factors should be considered. First, the historical presence of the native species in the stream should be documented. Second, the presence of a downstream barrier or a modifiable natural obstruction is essential to prevent nonnative trout reoccupation from downstream (non-electrofished) areas. Third, the complexity of the stream channels must be evaluated. Finally, a brook trout restoration plan with specific short- and long-term goals should be developed in accordance with the policies and objectives of the agency.

Most of the relationships between the physical characteristics of streams measured in 1987 and the difference in trout biomass from the beginning of the removal until 1987 were not significant, but some interesting trends were seen. The tendency for positive relationships for rainbow trout and negative ones for brook trout indicate that physical features of the streams may play a role in determining removal success. Further studies using more precise and repeated measurements of the physical features are needed to help clarify these relationships.

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APPENDIX A

Description of study sites in 1986 and 1987. Tag locations are described looking upstream.

Bunches Creek

Watershed: Oconaluftee River
County: Swain
State: N.C.
Quadrangle: Bunches Bald

Station 1
Downstream Tag#: 128D
Upstream Tag#: 128U
Elevation: 1372m (4500ft)
Landmarks: This section begins at the top of a large cascade (not to be confused with cascades in this section). Tag 128D is in the rock overhang on the right side. Tag 128U is on a gray beech on the left side. This section is 100m in length.

Station 2
Downstream Tag#: 129D
Upstream Tag#: 129U
Elevation: 1433m (4700ft)
Landmarks: The section is located approximately 400m downstream of the Flat Creek Trail crossing. Both tags are located on gray beech trees on the left side of the stream. This section is 95.3m in length.

Station 3
Downstream Tag#: Bun 3D
Upstream Tag#: Bun 3U
Elevation: 1463m (4800ft)
Landmarks: This section begins about 200m upstream of the Flat Creek Trail crossing. Tag Bun 3D is on a red spruce and Bun 3U is on a yellow birch. Both tags are on the left side of the stream. This section is 100m long.

Station 4

Downstream Tag#: Bun 4D and 71 BTR

Upstream Tag#: Bun 4U

Elevation: 1463m (4800ft)

Landmarks: This section begins approximately 300-400m upstream of section 3. A very large gray beech is across the stream approximately 20m downstream of the lower end of the section. Tags Bun 4D and 71 BTR are on a red spruce on the right upstream side. Tag Bun 4U is on a red maple on the right upstrem side. This section is 105.3m in length.

Road Prong Creek

Watershed: West Prong of the Little Pigeon River

County: Sevier

State: TN.

Quadrangle: Mt. Lecont

Station 1 (USFWS Section 13)

Downstream Tag#: 119

Upstream Tag#: 118

Elevation: 3400ft

Landmarks: This section begins approximately 50m upstream of the confluence of Road Prong and West Prong Little Pigeon River. Sampling began at the top of a 1.22m cascade about 75m upstream of the first bridge. Tag 119 is on a hemlock and 118 is on a birch tree, both tags are on the right side of the stream. This section is 114m long.

Station 2 (USFWS Section 10)

Downstream Tag#: 117

Upstream Tag#: 116

Elevation: 3450ft

Landmarks: The sample area begins about 100m downstream of the second bridge and ends at the bridge. The section was 90m long. Tag 117 is on a birch tree on the left side, Tag 116 was under the bridge but could not be found.

Station 3 (USFWS Section 9)
Downstream Tag#: 116
Upstream Tag#: 115
Elevation: 3480ft
Landmarks: The sample area began at the second bridge crossing and was 100m in length. Tag 116 was under the bridge (not found) and Tag 115 is on a birch on the left side of the stream at the top of a cascade.

Station 4 (USFWS Section 6)
Downstream Tag#: 112
Upstream Tag#: 111
Elevation: 3530ft
Landmarks: The section was 100m in length.

Station 5 (USFWS Section 2)
Tag#: 108
Upstream Tag#: 107
Elevation: 3770ft
Landmarks: The section begins approximately 160m downstream of the third bridge crossing, and ends about 50m downstream of this crossing. Tag 109 is on a spruce tree on the left side of the stream. And Tag 108 was not found. The section ends at the upstream end of a large pool, 109.5m upstream of Tag 109. This was the only logical place for the sampling to end.

Sam's Creek

Watershed: Middle Prong Little River
County: Blount
State: TN.
Quadrangle: Thunderhead Mtn.

Station 1
Downstream Tag#: 152
Upstream Tag#: 151
Elevation: 710m (2330ft)
Landmarks: This section begins about 100m upstream of where the old railroad grade leaves the switchback on Thunderhead Prong. The downstream end of the section is straight out from a "Stream Closed to Fishing" sign. Tag 152 is on a maple on the right side of the stream and Tag 151 is on a poplar on the left side at the top of a cascade. The section is 104.4m in length.

Station 2

Downstream Tag#: 148
Upstream Tag#: 147
Elevation: 765m (2510ft)

Landmarks: The sample area begins about 110m downstream of the second stream crossing and ends 30-40m upstream of this crossing. Tags 148 and 147 are on poplar trees on the right side of the stream. This section is 149.3m long.

Station 3

Downstream Tag#: 141
Upstream Tag#: 140
Elevation: 838m (2750ft)

Landmarks: Section ends at the downstream edge of the third stream crossing and begins 148.5m downstream from this point. Tags 140 and 141 are located on poplar trees on the right side of the stream.

Station 4

Downstream Tag#: 133
Upstream Tag#: 132
Elevation: 914m (300ft)

Landmarks: This section begins at the top of a small cascade, and a small stream crosses the trail from the left. Tag 133 is on a buckeye at the top of the cascade and Tag 132 is on a yellow birch. Both are on the left side of the stream. This section is 150m long.

Station 5

Downstream Tag#: 127
Upstream Tag#: 126
Elevation: 954m (3130ft)

Landmarks: Section begins approximately 50m downstream of the campsite at 954m. Tag 127 is on a poplar on the right side of the stream. Tag 126 was not found. The section length is 116.5m.

Station 6

Downstream Tag#: 75 BTR
Upstream Tag#: None
Elevation: 3420ft

Landmarks: This section begins approximately 600m upstream of the confluence of Sams and Starkey Creek. Tag 75 BTR is on a yellow birch on the left side of the stream. This section is 100m long.

Starkey Creek

Watershed: Middle Prong Little River
County: Blount
State: TN.
Quadrangle: Thunderhead Mnt.

Station 1
Downstream Tag#: 77 BTR
Upstream Tag#: None
Elevation: 3050 ft.
Landmarks: The sample area begins about 100m upstream of the confluence of Sams and Starkey Creek. Tag 77 BTR is located on a basswood tree on the left side of the stream.

Beetree Creek

Watershed: Deep Creek
County: Swain
State: N.C.
Quadrangle: Clingman's Dome

Station 1
Downstream Tag#: BT 1U
Upstream Tag#: BT 1D
Elevation: 866m (2840ft)
Landmarks: This section begins about 50m upstream from the confluence with Deep Creek. Tag locations were not recorded on field data sheets. The section length is 110.5m.

Station 2
Downstream Tag#: BT 2D
Upstream Tag#: BT 2U
Elevation: 884m (2900ft)
Landmarks: This section begins about 300m upstream of the confluence with Deep Creek. Tag BT 2D is on a yellow birch on the right side of the stream. The location of BT 2U was not recorded. The section is 87.2m long.

Station 3

Downstream Tag#: BT 3D

Upstream Tag#: BT 3U

Elevation: 914m (3000ft)

Landmarks: This station begins about 30m upstream of the end of Section 2, at the top of a cascade and ends at the base of another cascade. Tag BT 3D is on a basswood about 5m upstream of the downstream end of the section.

Station 4

Downstream Tag#: BTR 82 and BT 4

Upstream Tag#: None

Elevation: 957m (3140ft)

Landmarks: The section begins about 600m upstream from the confluence with Deep Creek. Tags BTR 82 and BT 4 are at the downstream end of the section on a yellow birch on the left side. The section ends at the base of a large cascade at 975m. This section is 97.8m long.

Taywa Creek

Watershed: Bradley Fork

County: Swain

State: N.C.

Quadrangle: Smokemont

Station 1

Downstream Tag#: TAY 1D and 89BTR

Upstream Tag#: TAY 1U

Elevation: 1012m (3320ft)

Landmarks: Section begins at the top of a cascade when the road comes back to the stream. Tag TAY 1D is on a yellow birch on the left side and tag TAY 1U is on a buckeye on the right side. This section is 111.5m long.

Station 2

Downstream Tag#: TAY 4D and 94 BTR

Upstream Tag#: TAY 4U

Elevation: 1030m (3380ft)

Landmarks: This section starts about 15m upstream of the second bridge. The downstream tag is on a yellow birch on the left side and the upstream tags are on a northern red oak on the left side. This section is 122.6m long.

Station 3

Downstream Tag#: 96 BTR
Upstream Tag#: None
Elevation: 1100m (3610ft)

Landmarks: This station begins about 140m downstream of a small cascade at 1109m. The location of tag 96 BTR was not recorded. The section length is 100m.

Station 4

Downstream Tag#: None
Upstream Tag#: 99 BTR
Elevation: 1113m (3650ft)

Landmarks: This section starts at the top of the small cascade at 96 BTR. The location of tag 99 BTR was not recorded. The section length is about 100m.

Siler's Creek

Watershed: Little River
County: Sevier
State: TN.
Quadrangle: Silers Bald

Station 1

Downstream Tag#: SIL 1D
Upstream Tag#: SIL 1U and 48 BTR
Elevation: 1036m (3400ft)

Landmarks: Sampling began at the top of a large cascade at 1036m and ends at a small island approximately 100m upstream. Tags SIL 1U and 48 BTR are on a sweet birch on the left side of the stream at the downstream tip of the island.

Station 2

Downstream Tag#: SIL 5D
Upstream Tag#: SIL 5U and 168 BTR
Elevation: 1082m (3550ft)

Landmarks: The section begins 500m upstream of the cascade at 1036m and is about 100m in length. Tag 5D is on a yellow birch on the left side of the stream. The location of the upstream tags was not recorded.

Station 3

Downstream Tag#: SIL 9D

Upstream Tag#: SIL 9U

Elevation: 1123m (3685ft)

Landmarks: The section begins about 800m upstream of the cascade at 1036m and ends at the base of a cascade at 1128m. Tag SIL 9D is on a buckeye on the left side and SIL 9U is on a yellow birch on the right side of the stream. The section is approximately 104m in length.

Station 4

Downstream Tag#: SIL 10D

Upstream Tag#: SIL 10U

Elevation: 1141m (3745ft)

Landmarks: The section begins at the top of the cascade at 1128m and is 103.5m long. Tag SIL 10D is on a sweet birch on the left side and SIL 10U is about 4m off the stream on the left side of the stream.

Desolation Branch

Watershed: Hazel Creek

County: Swain

State: N.C.

Quadrangle: Thunderhead Mtn.

Station 1 (USFWS Section 2)

Downstream Tag#: DES 1U

Upstream Tag#: DES 2U

Elevation: 2940 ft.

Landmarks: The section began approximately 100m above the 8 ft. falls which was the beginning of the USFWS sampling. DES 1U is on a birch on the left side of the stream, and DES 2U is on the left side of the stream on a birch. The section was 106.3m in length.

Station 2 (USFWS Section 8)

Downstream Tag#: DES 3U

Upstream Tag#: DES 4U

Elevation: 3000 ft.

Landmarks: The section began approximately 500m upstream of the end of Station 1 (tag # DES 2U) or 700m above the 8 ft. falls at the beginning of the USFWS sampling. It was in Section 8 of the USFWS. DES 3U is on the right side of the stream in a popular and DES 4U on the left side in a birch.

Station 3 (USFWS Section 12)
Downstream Tag#: none
Upstream Tag#: DES 1D
Elevation: 3200 ft.

Landmarks: The section began approximately1200m upstream of the 8 ft cascade or 500m upstream of Station 2. DES 1D is on the right side of the stream on a yellow birch.

Defeat Branch

Watershed: Hazel Creek
County: Swain
State: N.C.
Quadrangle: Thunderhead Mtn.

Station 1
Downstream Tag#: DEF 1D
Upstream Tag#: DEF 1U
Elevation: 853m (2800ft)

Landmarks: The section begins about 400m upstream of the confluence of Defeat Branch with Bone Valley Creek at the top of a waterfall. Tag DEF 1D is on a basswood on the left side of the stream at the top of the falls, and DEF 1U is on a basswood approximately 102m upstream.

Walker Branch

Watershed: Hazel Creek
County: Swain
State: N.C.
Quadrangle: Thunderhead Mtn.

Station 1
Downstream Tag#: WLK 1D
Upstream Tag#: WLK 1U
Elevation: 1036m (3400ft)

Landmarks: The section begins about 2.6km upstream from the confluence with Hazel Creek at the top of a waterfall. Tag WLK 1D is on a poplar about 8m upstream of the barrier on the right side and Tag WLK 1U is on a yellow birch on the left side. The section is 100m long.

Proctor Creek

Watershed: Hazel Creek
County: Swain
State: N.C.
Quadrangle: Silers Bald

Station 1
Downstream Tag#: PROC 1D
Upstream Tag#: PROC 1U
Elevation: 1006m (3300ft)

Landmarks: This section is approximately 1 mile upstream of the end of the road and above the confluence of Long Cove Branch. Tag PROC 1D is on the left side of the stream immediately above the barrier on a yellow birch. PROC 1U is on a yellow birch on the right side of the stream approximately 100m upstream of the barrier and near the tail of a pool. A side branch of the stream runs parallel to the stream about 5m above the barrier.

Hazel Creek

Watershed: Hazel Creek
County: Swain
State: N.C.
Quadrangle: Thunderhead Mtn.

Station 1
Downstream Tag# HAZ 1D
Upstream Tag#: HAZ 1U
Elevation: 1198m (3930ft)

Landmarks: This section begins about 115m downstream of the base of the Hazel Creek Cascades. Tag HAZ 1D is on a birch on the left, and HAZ 1U is on a birch on the right side of the stream. The latter tag is about 5m downstream of where the section ends. This section is 102m long.

Station 2
Downstream Tag#: HAZ 2D
Upstream Tag#: HAZ 2U
Elevation: 1210m (3970ft)

Landmarks: The sample area starts at the footbridge, which is just upstream of the Hazel Creek Cascades. Tag HAZ 2D is on a birch on the right approximately 5m upstream of the start, and HAZ 2U is on a birch on the left side of the stream. The section is 100m in length.

APPENDIX B

Sections of Road Prong sampled by the USFWS in 1978

Section	Tag No.	Elevation (ft.)
1	107	3770
2	108	3675
3	109	3640
4	110	3560
5	111	3530
6	112	
7	113	
8	114	
9	115	
10	116	3480
11	117	3450
12	118	3430
13	119	3420
14	120	3400

Sections of Sams Creek sampled by USFWS in 1978

-1	121	3350
-2	122	3300
-3	123	3240
1	124	3180
2	125	3140
3	126	3130
4	127	3120
5	128	3090
6	129	3060
7	130	3050
8	131	3020
9	132	3000
10	133	2970
11	134	2920
12	135	2890
13	136	2880
14	137	2860
15	138	2830
16	139	2780
17	140	2750

Section	Tag No.	Elevation (ft.)
18	141	2720
19	142	2690
20	143	2670
21	144	2625
22	145	2590
23	146	2540
24	147	2510
25	148	2460
26	149	2420
27	150	2380
28	151	2330
29	152	2290
30	153	2240
31	154	2160
32	155	2120

APPENDIX C

Mean Physical Characteristics Measured in 1987

Creek	Station	mean width (m)	mean depth (cm)	% pools	width rating	cover(%) good	fair	poor
Silers	1	5.76	8.48	0	-2	10	60	30
	2	3.79	12.63	36.36	0	9.09	27.27	63.64
	3	5.43	8.32	18.18	-4	0	27.27	72.73
	4	4.96	12.54	27.27	3	0	45.45	54.55
Sams	1	4.91	28.88	45.45	3			
	2	5.65	15.52	18.75		31.25	43.75	25
	3	5.88	16.24	33.33	5	56.67	0	13.33
	4	4.43	14.78	46.67	-2	40	20	40
	5	5.05	24.24	36.36	0			
	6	2.91	11.93	50	-7			
Starkey	1	2.86	9.53	70	-3			
Desolation	2	5.35	16.03	45.45	-1	27.27	18.18	54.55
	8	4.5	18.98	27.27	2	0	36.36	63.64
	12	4.65	9.43	27.27	5	10	30	60
Road Prong	2	6.43	21.17	83.33	0	16.67	50	16.67
Road Prong	13	7.81	39.94	44.44	-4			
	6	5.96	24.66	40	-1			
	9	5.88	27.48	50	-3			
	2	6.99	18.63	40		20	10	
	10	6.39	22.78		-1	33.33	8.33	
Beetree	1	4.82	17.4	54	-4			
	2	4.72	10.7	36	-4			
	3	3.97	11.8	44	-3			

Creek	Station	mean width (m)	mean depth (cm)	% pools	width rating	cover(%) good	fair	poor	
Beetree	4	4.62	9.4	25	-2				
Taywa	1	3.29	10.4	0	-3	0	0	100	
	2	2.88	8.9	17	-7	0	16.7	83.3	
	3	5.31	7.8	18.6	8	10	0	50	50
	4	4.29	5.1	0	2	9.1	36.36	54.55	2.94

Substrate Characteristics Measured in 1987

Percentages

Creek/Station	bedrock	boulder	cobble	gravel	sand	silt	gradient
Silers 1	0	31.34	19.40	29.85	14.93	4.48	6.2
Silers 2	0	48.21	14.29	21.43	6.07	0	7.18
Silers 3	0	37.71	27.87	16.39	9.84	8.19	9.6
Silers 4	17.65	29.41	11.76	25	16.18	0	6.18
Sams 1	0	45.71	22.86	20	11.43	0	11.45
Sams 2	1.49	38.81	22.39	19.4	4.93	0	7.88
Sams 3	0	34.55	25.45	21.82	12.73	0	
Sams 4	5.36	33.93	25	25	10.71	0	5.07
Sams 5	0	35.14	32.43	29.73	5.41	0	7.4
Sams 6	2.78	27.78	25	25	16.67	0	10
Starkey 1	0	28.95	28.95	15.79	26.32	0	9
Desolation 2	7.14	21.43	33.3	11.9	23.81	2.38	7.7
Desolation 8	0	21.57	17.65	35.29	25.49	0	8.09
Desolation 12	0	7.41	37.04	22.22	31.48	1.85	5.8
Road Prong 6							6.3
Road Prong 9							12.2
Road Prong 10							5.75

Percentages

Creek/Station	bedrock	boulder	cobble	gravel	sand	silt	gradient
Beetree 2		23	19	34.88	23.26	0	14.5
Beetree 3		34.21	21.05	21.05	23.68	0	13.7
Beetree 4		57.14	38.1	4.76	0	0	17.2
Taywa 1	10.14	8.7	30.43	23.19	27.54	0	10.4
Taywa 2	6.02	9.64	26.51	27.72	30.12	0	10.1
Taywa 3	10.99	3.3	28.57	28.57	28.57	0	9.5
Taywa 4	2.9	8.82	29.41	29.41	29.41	0	9.3

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U.S. DEPARTMENT OF THE INTERIOR

NATIONAL PARK SERVICE
SOUTHEAST REGIONAL OFFICE
75 SPRING ST., S.W.
ATLANTA, GEORGIA 30303