# Removal of Woody Streambank Vegetation to Improve Trout Habitat

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# ABSTRACT


Woody vegetation, primarily speckled alder *(Alnus rugosa)*, was removed at ground level from 30-ft strips paralleling both banks of three small trout streams to improve trout habitat, trout populations and fishing.

Channel morphometry of the Treatment Zone on Spring Creek improved as trout habitat after reduction of shade canopy. In the adjacent brushy Reference Zone, trout habitat deteriorated during the study. Mean width of this Treatment Zone increased unexpectedly by 40%, mean depth increased by 74% and water volume increased by 34%. Concurrently, in the Reference Zone mean width increased by 17%, but mean depth and water volume decreased. Aquatic macrophytes increased greatly in the Treatment Zone after brushing but the magnitude of increase was not precisely measured.

Prior to brushing, the Treatment Zone held 18% fewer wild brook trout *(Salvelinus fontinalis)*/mile in the Octobers of 1971 through 1973 than did the adjacent Reference Zone. After brush removal, the Treatment Zone held 106% more brook trout/mile in the Octobers of 1974 through 1977 than the unbrushed Reference Zone. For the same time periods, trout biomass/mile changed from 3% less to 96% more in the Treatment Zone than in the Reference Zone. Number and biomass of brook trout in the Treatment Zone in April also increased after streambank brushing, in comparison both to pretreatment values and to concomitant changes in number and biomass of trout in the Reference Zone.

In the Little Plover River and Lunch Creek, most of the posttreatment changes in channel dimensions of Treatment Zones were not beneficial to trout. Steadily declining base flow during the last four years of study probably interfered with anticipated improvements in channel shape.

In the Little Plover River, abundance and biomass of wild brook trout increased in the Treatment Zone more than in the brushy Reference Zone the first year (1973) after brushing the Treatment Zone only, but during the remaining four posttreatment years trout stocks declined dramatically in both zones, in the Treatment Zone more than in the Reference Zone. In Lunch Creek, wild brown trout *(Salmo trutta)* stocks in the Treatment and Reference Zones also declined during the posttreatment phase (1974-77) compared to the pretreatment phase (1971-73); and for most stock parameters, declines were greater in the Treatment Zone than in the natural meadow Reference Zone. Stock declines probably reflected the limiting influence of declining stream discharge.

In all three streams, despite variations in discharge and trout abundance, posttreatment growth rates of most age groups of trout were slightly better in Treatment Zones than in Reference Zones. Prior to brushing, Treatment Zone growth rates were usually less than in Reference Zones.

Aquatic macrophytes increased in the Treatment Zone of the Little Plover River from virtually zero prior to brushing to coverage of 10% of the stream bottom in September 1977, four years after reduction of shade canopy. Net radiation increased 287% (from 15 to 58 g cal/$cm^2$/min). In the unbrushed Reference Zone aquatic vegetation increased from coverage of 2% of the stream bottom in the fall of 1972 to 6% in 1977, and average net radiation decreased from 14 to 11 g cal/$cm^2$/min from August 1972 to August 1976. Quantitative measures of aquatic plants and net radiation were not made in study zones of Lunch Creek and Spring Creek. In subjective terms, response of aquatic vegetation in the Lunch Creek Treatment Zone was negligible, but in the Spring Creek Treatment Zone aquatic plants flourished after brushing.

Maximum summer water temperature increased 5°F through the 800-yd Treatment Zone the first summer after brushing along the Little Plover River. In successive summers the maximum daily temperature gain due to brushing declined and was only 1.5°F the fifth summer. However, because of steadily declining stream flow, the maximum temperature of water entering the Treatment Zone in-

creased each summer from 1974 to 1977 such that a maximum of 85°F was recorded at its upstream boundary in July 1977. However, no temperature-induced mortality of brook trout was observed. Zones contained substantial numbers of trout three months later when the fall electrofishing inventory was conducted.

Reduction of shade canopy probably had less impact on water temperature in Treatment Zones on Lunch Creek and Spring Creek than on the Little Plover River, but temperature data supporting that conclusion were much less complete than the Little Plover data.

Angling use and exploitation rates increased in all study zones on the Little Plover River during the posttreatment phase of creel census (1976 only) compared to the two seasons of pretreatment creel census (1970 and 1972). Increased harvest of a previously lightly exploited stock was the only benefit for the sport fishery of removing woody streambank vegetation. No census was conducted on the other two study streams.

Unanticipated extremes in streamflow variation confounded planned evaluations of changes in trout stocks, trout habitat and the sport fishery in response to removal of woody streambank vegetation. But in retrospect these conditions provided bonus insights that increased the previous limited knowledge of the impact that abnormally low stream flows have on trout stream ecosystems in Wisconsin. In all study zones of the Little Plover River, fall biomass of brook trout and mean summer flow (June through August) were significantly correlated; so too were maximum summer temperature and mean summer discharge.

As an overview assessment of this pioneering experiment to improve trout habitat and sport fishing on small, heavily shaded trout streams in Wisconsin, I conclude that the technique has enough practical management application to merit additional testing of the kind used in my study (preferably during periods of more stable stream discharge) and experimentation with less severe modifications of shade canopy.

# REMOVAL OF WOODY STREAMBANK VEGETATION TO IMPROVE TROUT HABITAT

By

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# INTRODUCTION

Despite the fact that most famous trout streams in the world are meadow streams, as opposed to streams flowing through dense canopied forests, scientific and nontechnical literature concerning management of trout stream ecosystems is weighted toward promoting streamside growth of trees and shrubs to increase shading of stream channels. Characteristic of this bias are recommendations for springtime plantings of willow or alder shoots in publications prepared by natural resource agencies for dissemination to volunteer organizations of conservationists or individual anglers. Two quotations from such publications are illustrative: (1) "Without a doubt, Stream Side Planting is one of the most important phases of Stream Improvement, if not the most important . . . . They definitely improve the condition of the stream so that it can support a greater population of trout." (Bersing and Phillips 1936); (2) "Of all the conservation projects that you could take part in this time of year, few if any are more rewarding, less expensive, more practical, less trouble than willow planting" (James 1949).

Loss of bank vegetation is also of contemporary and growing concern for managers of trout and salmon streams likely to be influenced by commercial harvest of timber. Consequences to stream ecosystems of such harvest and removal can be devastating, as numerous studies have shown (Brown and Krygier 1970; Brown 1970; Burns 1972; Ringler and Hall 1975; Ritchie 1972; Sheridan and McNeil 1968; Swift and Messer 1971; U.S. Forest Service). Water temperatures unfavorable to salmonids, massive intrusions of silt and debris into streams and outright blockage of fish movement during spawning runs are three of the commonest disruptions. More judicious location of construction roads plus retention of buffer strips of undisturbed forest along the banks of streams are two preventive measures generally agreed on as being most helpful in preserving streams in a condition suitable for salmonids while still allowing commercial timber harvest.

The possibility that more careful removal of commercial timber from buffer zones along streams could actually be beneficial to salmonid production was advocated by Chapman (1962) in his review paper dealing with effects of logging on fishery resources. He reasoned that removal of streamside vegetation could result in greater algal production under the stimulation of increased sunlight, which in turn could supply a better food base to support more aquatic invertebrates and ultimately more fish.

Theoretical support for the concept of deliberately increasing solar energy input to trout stream ecosystems by reducing streambank shade was also voiced more recently by Sharpe (1975) in regard to timber harvest in hardwood forests of the eastern United States. "There is potential for increasing the productivity of headwater streams and improving existing fisheries by manipulating vegetation" so that more sunlight reaches stream channels. He particularly had in mind improving living conditions for populations of wild brook trout *(Salvelinus fontinalis)*.

Published empirical evidence to support such conjectures by Chapman and Sharpe is still rare, but one such sample is that of Mills (1969), who determined the standing stocks of brown trout *(Salmo trutta)* in several reaches of a small stream in England. He emphasized not the potential value of increased solar energy input with decreased shading, but the better physical quality of stream banks and more stable stream bottom in reaches where forest canopy was sparse. Biomass of brown trout in these study zones was 3 times greater (80 vs 27 lb/acre) than in study zones flowing through a mature conifer forest where an absence of understory streamside vegetation "had led to considerable erosion of the banks and consequently less cover (for trout) and the loss of an important food supply" for trout. The loss of food supply in this instance was attributed to greater scouring of the stream bottom in the forested reaches during floods than had occurred in the meadow/early forest stage reaches of the same stream.

During the 1955-65 decade, field sampling to determine standing stocks of trout in Wisconsin streams was accelerated, in part because of greater use of increasingly effective electrofishing gear by DNR fish managers, and in part because of more sampling effort by biologists engaged in trout research studies. One finding that emerged from this surge of quantitative sampling was that the best stocks of trout (in abundance and growth rate) tend to be found in meadow-type reaches. On the basis of this finding, White and Brynildson (1967) devoted a substantial portion of their recommendations for managing Wisconsin trout streams to the subject of protecting and managing streambank vegetation. They advocated establishment and maintenance of a "sturdy turf" of grasses, broad-leafed annuals and low shrubs through use of such techniques as controlled burning, periodic mechanical brush cutting, application of selective herbicides, seeding and fencing to exclude livestock. They advocated the radical concept that planting trees beside trout streams should be actively discouraged in Wisconsin — "except where there is reasonable evidence" that summer temperatures for trout would be improved by doing so.

If increased solar heat does not produce deleteriously high water temperatures, reduction of woody shade canopy could have several beneficial consequences for trout and the sport fishery they sustain:

1. Creation of more desirable habitat for trout as a result of greater growth of aquatic macrophytes which both provide shelter for trout directly and constrict flow to increase scouring, deepening of pools and undercutting of banks.

2. Firmer stream banks consisting of grassy turf less susceptible to erosion; a gradual narrowing of the stream

*Overarching speckled alder like this is common to several hundred miles of small trout streams in Wisconsin. Such streambank vegetation tends to weaken the banks, particularly as branches are tipped into the stream by accumulations of ice and snow, and fail to straighten up again the following growing season. Gradually the stream channel becomes wider, shallower and straighter. Maximum water depth tends to move toward midchannel where associated hiding-resting cover for trout is sparse.*

channel and accentuation of channel sinuousity rather than the widening and straightening process associated with tree-lined reaches, particularly reaches dominated by speckled alder *(Alnus rugosa)*.

3. Increased production of aquatic invertebrates used as food by trout due to increased abundance of aquatic plants that provide aquatic invertebrates with both substrate and their source of food, either directly or indirectly.

4. An increase in terrestrial invertebrates accidentally entering the stream and available as food for trout, particularly during the summer months when physiological conditions are good for trout growth but abundance of aquatic invertebrates is often declining (Hunt 1975).

5. Improved growth of trout as a result of increased availability of food and an improved temperature regime for growth. Within their genetic constraints on converting food to body tissue, two of the most important factors limiting growth of trout are the amount of food consumed and the water temperature regime. Growth is generally considered to be best in the 55-65°F range. Yet even in a good trout stream such as Lawrence Creek, located in central Wisconsin, water temperature may reach the 55°F threshold on fewer than 50% of the days of the year (Lovshin 1966). Therefore, it seems logical that warming up temperature regimes of some Wisconsin trout streams could be a way of improving physiological processing of food consumed by trout so that more food energy is converted to body growth.

6. Easier season-long fishing conditions, more hours of angling recreation and greater harvest of presently underutilized trout stocks in small streams. Of the nearly 9,000 miles of trout streams in Wisconsin, several hundred miles consist of small streams (average width 15 ft or less) that are heavily shaded during leaf-out periods by overarching canopies of woody vegetation, particularly speckled alder. These streams tend to provide sport fishing for only a month or two in the spring and early summer, prior to maximum leaf-out of streambank vegetation. Thereafter, foot travel along these streams and presentation of fishing baits to the trout tends to be discouragingly difficult. Although too few creel census assessments have been made of such sport fisheries to draw a firm conclusion, it is probable that the wild stocks of trout in these small streams are generally being lightly exploited. Consequently, even if streambank brushing were to have no positive impact on trout habitat, the practice could be a useful management tool by providing fishing conditions that would stimulate anglers to use such managed streams more often throughout a fishing season.

These six theoretically beneficial consequences of reducing woody shade canopy along streams where there is no apparent danger of increasing water temperatures to deleterious levels for trout provided the rationale for a research study initiated in 1970 with two specific objectives:

1. To test the hypothesis that trout abundance, trout growth rates, angler use and angler harvest can be substantially increased by removing dense growths of woody vegetation from the banks of small trout streams.

2. To provide fishery managers with better information for deciding whether such manipulation of streambank vegetation should be done, and, if so, what magnitude of trout population responses and improvements in the sport fishery are likely to be realized.

During the progress of this pioneering study, it became increasingly apparent that assessing changes in the trout stocks and habitat quality were more complex than had been expected during the planning process for the study, largely because of the uncontrollable natural variable of stream discharge. For example, stream flow of the Little Plover River increased dramatically during the middle years of the study, then declined sharply during the latter years. Trout stocks in all study zones followed a similar pattern, seemingly independent of brushing treatment or no brushing treatment. Discharge regimes of Lunch Creek and Spring Creek were much less well documented, but the sparse data that were collected suggested similar patterns of stream flow during 1970-76 and changes in trout stocks and stream channel morphometry that were not hypothesized. Consequently, the objectives of this report (not the study objectives) were enlarged to incorporate much greater emphasis on assessing the importance of stream flow in the ecology of trout streams, highlighting specific samples of the limiting role that discharge played when an experimental management treatment was made to beneficially modify three trout stream ecosystems.

# DESCRIPTION OF STUDY STREAMS

Portions of three small Class I* trout streams were selected to evaluate the impact of streamside brush removal on trout habitat, trout populations and the sport fishery (Fig. 1). The Little Plover River and Spring Creek are brook trout streams. The portion of Lunch Creek chosen for study contains primarily brown trout plus a few brook trout.

**Little Plover River.** This 4.1-mile-long stream is located in central Portage Co. (Plover Twp.). All phases of this study except the creel census were confined to the 1.7-mile reach between Eisenhower Avenue and Kennedy Avenue (R8E T23N Sec. 13). Three study zones were established (Fig. 1). They are referred to in this report as the Reference Zone, Treatment Zone and Meadow Zone. The Reference Zone consisted of two stretches, the first a 0.23-mile stretch immediately upstream from the 0.45-mile-long Treatment Zone, and the other, of the same length, immediately downstream. Field data for these two reference stretches were combined and considered as representing one Reference Zone of the same approximate length as the Treatment Zone which was to be cleared of woody streambank vegetation. Prior to removal, streambank vegetation was similar in the Treatment Zone and both stretches of the Reference Zone. Speckled alder was predominant, plus an overstory of more scattered elms *(Ulmus americana)*, ash *(Fraxinus* spp.), birch *(Betula papyrifera)*, maple *(Acer rubrum)* and occasional clumps of dogwood shrubs *(Cornus alternifolia* and *C. racemosa)*.

Dominating the stream edges in the 0.75-mile Meadow Zone were reed canary grass *(Phalaris arundinacea)* and scattered clumps of speckled alder and dogwood. American elm provided some channel shading but most of these were dead or dying or became so during the study due to infestation by Dutch elm disease.

Most of the natural reproduction of brook trout in the Little Plover River occurs in the upper half of the Meadow Zone, where numerous lateral feeder springs and upwelling groundwater enter the channel. Exposed gravel constituted a measured maximum of 15% of the stream bottom in the Meadow Zone. About 5% of the streambed in the Reference Zone and 2% in the Treatment Zone consisted of gravel substrate, but no spawning was ever observed in these zones during the study. Additional data on surface area, mean depth, pH, alkalinity and conductivity are summarized in Table 1 for each study zone. Aquatic macrophytes were virtually absent in the Treatment Zone prior to alteration of the zone's streambank vegetation and only sparsely present in the upper portion of the Reference Zone, but an important feature of the habitat in the Meadow Zone.

**Lunch Creek.** This 15.6-mile-long stream is located in south central Waushara Co. (Dakota Twp.). A 1.3-mile section in the upper third of the stream was chosen for study and divided into two study zones, a 0.54-mile Treatment Zone, and downstream from it a 0.78-mile Reference Zone. Most of the channel shading in the Treatment Zone was provided by tamarack *(Larix laricina)* and a scattering of shrub clumps of speckled alder, dogwood, ninebark *(Physocarpus opulifolius)*, poison sumac *(Rhus vernix)* and elderberry *(Sambucus pubens)*.

The Reference Zone constituted a natural sedge meadow dominated by several species of sedges *(Carex* spp.), grasses, perennial lowland flowers and weeds. Woody vegetation, consisting primarily of widely scattered clumps of speckled alder and northern willow *(Epilobium glandulosum)* provided some taller canopy shade over the stream channel.

Exposed gravel made up less than 1% of the channel substrate in both study zones. No natural reproduction of brown trout occurred in either zone.

*Streams that support trout populations by natural reproduction only.

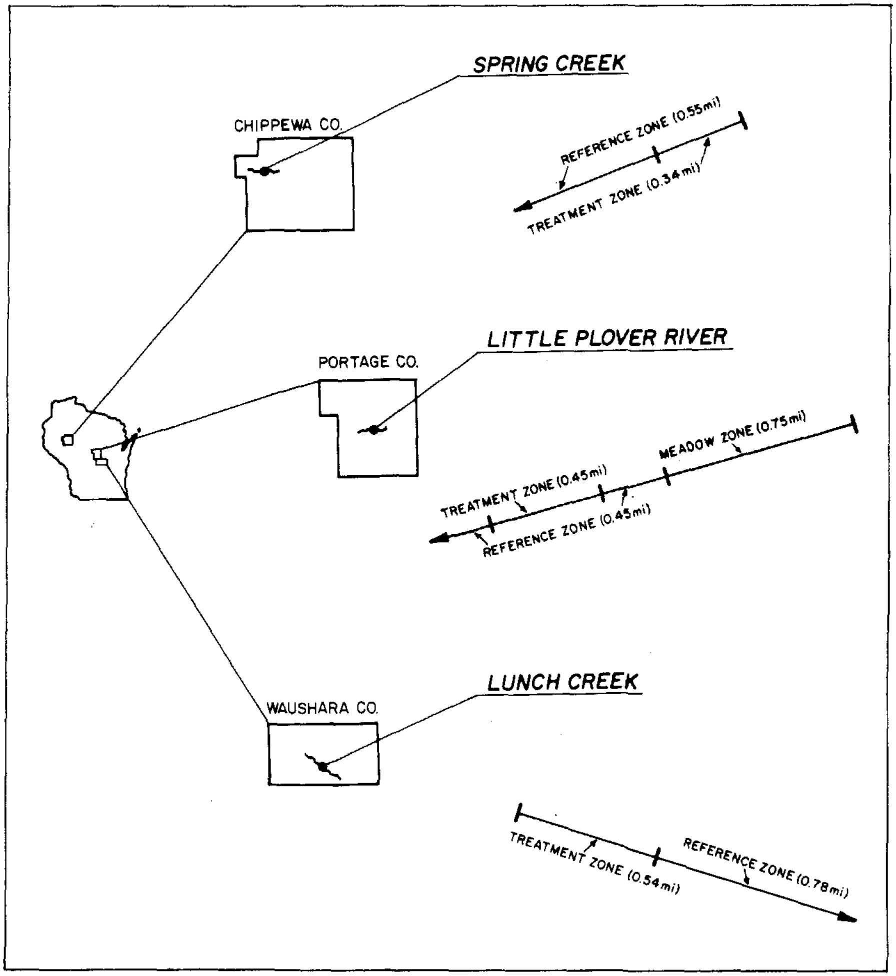



**FIGURE 1.** *Locations of study streams, linear dimensions of study zones and direction of flow of study streams.*

Most of the stream bottom was sand with organic silt and detritus along the calm water borders. Aquatic macrophytes were virtually absent in the Reference Zone and also in the Treatment Zone prior to removal of woody streamside vegetation. Lunch Creek was less fertile than the Little Plover River, but pH was about the same (Table 1).

**Spring Creek.** This small brook trout stream is a 2.3-mile-long tributary of Sand Creek and is located in west central Chippewa Co. (Auburn Twp.). A 0.55-mile Reference Zone was established, extending upstream from the junction with Sand Creek. The Treatment Zone extended from the upstream boundary of the Reference Zone another 0.34 mile to the County Trunk M bridge. Prior to cutting in the Treatment Zone, both study zones were heavily shaded during leaf-out periods by an overarching growth of speckled alder. Stinging nettle *(Urtica dioica)*, elderberry, reed canary and clumps of ninebark also shaded reaches of both study zones where alder was less dense.

Spring Creek is the least fertile of the three study streams and the most acidic (Table 1). Its study zones were also shallower and narrower than those on the other two streams during the pretreatment phase.

Exposed gravel comprised less than 1% of the stream substrate in both study zones. No spawning by brook trout occurred in the Reference Zone. A few redds were concentrated at two or three gravel bottom sites in the upper Treatment Zone, but most recruitment came from spawning upstream from the Treatment Zone. Sand and silt substrates dominated both zones. Despite the unstable character of such substrates, some aquatic macrophytes were present in both zones prior to brush removal, principally speedwell *(Veronica connata)* and water buttercup *(Ranunculus longirostris)*. However, maximum annual abundance probably did not exceed 5% of the bottom area in either zone prior to brush removal.

In all three streams, the only common fish species other than trout was the mottled sculpin *(Cottus bairdi)*. Other species collected in all three streams were white sucker *(Catostomus commersoni)*, central mudminnow *(Umbra limi)*, brook stickleback *(Culaea inconstans)*, pearl dace *(Semotilus margarita)*, blacknose dace *(Rhinichthys atratulus)*, and, in Lunch Creek only, a few northern pike *(Esox lucius)*, which were always removed when captured.

Surface runoff and precipitation directly into the stream channels of all three streams normally contributed little to their annual discharge. Groundwater discharge was the predominant year-round source and was calculated to constitute 82-91% of the annual discharge during three years of record for the Little Plover River (Weeks et al. 1965). Similar percentages probably apply to Lunch Creek and Spring Creek, since both have aquifers similar to that of the Little Plover River (Threinen and Poff 1963).

**TABLE 1.** *Physical and chemical characteristics of study zones on the Little Plover River, Lunch Creek and Spring Creek before and after removal of woody vegetation in Treatment Zones.*

| Study Phase | Study Stream | Study Zone | Midchannel Length (mile) | Surface Area (acres) | Mean Depth (in.) | Mean Width (ft) | Channel Volume ($ft^3$) | pH | Total Alkalinity (ppm $CaCO_3$) | Conductivity ($\mu$mhos/cm) |
|---|---|---|---|---|---|---|---|---|---|---|
| Pretreatment | Little Plover | | | | | | | | | |
| | | Meadow | 0.75 | 1.36 | 6.3 | 15.0 | 31,303 | 8.2 | 226 | 360 |
| | | Treatment | 0.45 | 0.77 | 6.8 | 14.2 | 18,983 | 8.3 | 232 | 360 |
| | | Reference | 0.46 | 0.77 | 6.6 | 13.7 | 18,446 | 8.4 | 232 | 360 |
| | Lunch Creek | | | | | | | | | |
| | | Treatment | 0.54 | 0.88 | 11.8 | 13.5 | 37,560 | 8.2 | 167 | 309 |
| | | Reference | 0.78 | 1.02 | 14.8 | 10.7 | 54,644 | 8.2 | 167 | 309 |
| | Spring Creek | | | | | | | | | |
| | | Treatment | 0.34 | 0.40 | 5.8 | 9.5 | 8,267 | 7.1 | 22 | 81 |
| | | Reference | 0.55 | 0.64 | 7.1 | 9.7 | 16,482 | 7.0 | 20 | 76 |
| Posttreatment | Little Plover | | | | | | | | | |
| | | Meadow | n.c.** | 1.42 | 5.4 | 15.6 | 27,904 | * | * | * |
| | | Treatment | n.c. | 0.56 | 6.3 | 10.3 | 12,805 | * | * | * |
| | | Reference | n.c. | 0.69 | 6.0 | 12.4 | 15,029 | * | * | * |
| | Lunch Creek | | | | | | | | | |
| | | Treatment | n.c. | 0.86 | 11.8 | 13.2 | 36,712 | * | * | * |
| | | Reference | n.c. | 1.14 | 13.3 | 12.1 | 55,121 | * | * | * |
| | Spring Creek | | | | | | | | | |
| | | Treatment | n.c. | 0.42 | 10.1 | 9.9 | 15,368 | * | * | * |
| | | Reference | n.c. | 0.73 | 6.0 | 11.0 | 15,895 | * | * | * |

* No posttreatment measure.

** n.c. = no change.

# METHODS

Midchannel length, average depth, average width and surface area dimensions of study zones were determined from field measurements. Widths were recorded at 50-ft intervals along a midchannel course. Water depth was determined at 1-ft intervals across the channel at each width transect. Channel dimensions were measured during pretreatment and posttreatment phases. No predetermined effort was made to duplicate the precise locations of pretreatment and posttreatment transects.

Quantitative estimates of rooted aquatic macrophytes in the Reference and Treatment Zones of the Little Plover River were made once during the pretreatment phase and four times during the posttreatment phase to assess the impact of removing streambank vegetation on abundance of aquatic plants. Surveys were made in September when seasonal growth was believed to be near its annual maximum. Field sketches were made of each bed of aquatic plants and species were noted. Sketches were later drawn to smaller scale on graph paper and planimetered to determine areas. No quantitative assessments were made of aquatic plants in study zones of Lunch Creek and Spring Creek. A species list of most of the terrestrial plants that were present in the Treatment and Reference Zones of the Little Plover River and Lunch Creek in September 1976 is on file at the Cold Water Group station. The list is based on a field survey by William Tans, DNR botanist.

Discharge characteristics for the Little Plover River were obtained from annual published reports (Water Resource Data for Wisconsin) prepared by the U.S. Geological Survey (USGS). Stevens Type F water level recorders were maintained by the USGS at sites of Parshall flumes installed at the upper boundary of the Meadow Zone (1970-75) and 2.4 miles below the lower boundary of the Reference Zone (1970-77). A few measurements of "instantaneous discharge" were also made with a Gurley meter at the upper boundary of the Treatment Zone to calculate a relationship of flow at that point to the continuous discharge record at the USGS site. The few estimates of stream flow at boundaries of study zones on Lunch Creek and Spring Creek were also "instantaneous" based on Gurley meter cross-channel measurements at 1-ft intervals.

Stream temperatures (°F) were recorded continuously (except for periods of instrument malfunction) at two sites on the Little Plover River during the pretreatment phase (upper boundary of Treatment Zone and lower boundary of Reference Zone) and at three sites during the posttreatment phase (lower boundary of Treatment Zone added). Taylor Model 76J thermometers were used and record charts were usually changed weekly. Taylor maximum-minimum thermometers (No. 5458) were used to obtain water temperature data year-round at the boundaries of the Treatment Zone on Lunch Creek during 1972-77 and during June-September periods of 1972-73 and 1976-77 at the boundaries of the Spring Creek Treatment Zone. Recording periods were weekly or biweekly for Lunch Creek and Spring Creek.

Net radiation, the difference between incoming and reflected sunlight, was measured in the Treatment and Reference Zones of the Little Plover River in August 1972, before removal of shade canopy, and again in both zones in August of 1974 and 1976. Measurements were made at random locations with a Sanberer-Dirmhirn radiation balance probe, Model 29AM100. The probe was held about 1 ft above the water surface. Output readings of net radiation were recorded in g cal/$cm^2$/min. All readings were made on cloud-free days between 10 a.m. and 2 p.m. CDT.

Water samples were collected from all study zones for chemical analysis — from the Little Plover zones in June 1973, and from Lunch Creek and Spring Creek zones in April 1974. No effort was made to assess the impact of shade canopy reduction on water chemistry. Analyses were aimed at simply characterizing the study streams on sample dates in terms of pH, total alkalinity, and conductivity. Samples were analyzed at the DNR laboratory in Delafield.

Trout populations in study zones were sampled with dc electrofishing gear to obtain data needed for calculating Petersen mark and recapture estimates of abundance, biomass, age structure and growth. Recapture data were obtained 2-3 days after the marking period. Age structures were primarily determined from length frequency distributions of known-age individuals within inch-groups. Known-age stocks were established by permanently marking each year class with distinctive fin clips when individuals of a year class were collected as age 0 in September or October.

To enhance the potential of the brook trout stock in the Treatment Zone of the Little Plover River to respond to improved environmental conditions, if such improvement occurred as a result of brush removal, a fish refuge was established in the Treatment Zone during 1973-75. This action was taken because the stream is located only a few miles southeast of a major urban area. If a substantial increase in angling effort occurred in the Treatment Zone soon after brush removal because fishing was easier, increased exploitation would probably result, too. Such an increase could negate potential positive responses in abundance and biomass of the trout stock. The zone was therefore given fish refuge status for three years. Refuge status was also applied during 1973-75 to the Reference and Meadow Zones, where parallel comparative studies were in progress.

Statistical tests were applied to comparisons of six types of pretreatment vs posttreatment data for trout stocks in study zones: number/mile in spring and fall; biomass of trout/mile in spring and fall; and number of legal-sized (6 in. or longer) trout/mile in spring and fall for Spring Creek and Little Plover River. For Lunch Creek, number of brown trout over 10 in./mile was used rather than number of legal-sized trout. The 10-in. rather than 6-in. length was selected as the criterion for brown trout because this species tends to live longer and grow larger than brook trout. For any given index the Reference Zone values were subtracted from appropriate Treatment Zone values. These "remainders" were then averaged for the pretreatment and posttreatment periods. The two averages thus derived were then tested (*t* test for independent means) to see if the magnitude of difference was greater than would be expected by chance (Tables 11-13, Append.). Relationships of fall biomass of brook trout to average June-August discharge in study zones of the Little Plover River and the relationship of discharge to maximum water temperature in the Treatment Zone of the Little Plover River were tested with simple least squares linear correlations.

Creel census data were collected in study zones of the Little Plover River only in 1970, 1972 and 1976. Data for the 1970 and 1972 trout fishing seasons were averaged to provide a "pretreatment picture" of the sport fishery. Census was conducted on a random basis 5 days/wk and 8 hr/day throughout the fishing season. Workdays normally started at 6 a.m. or 1 p.m. Fishing effort (hours and trips) was estimated from "instantaneous" counts of angler vehicles (including bicycles) in the study area every 2.5 hr during an 8-hr shift (Lambou 1961). Between counts, personal contacts were made with anglers to obtain other angling information and examine any trout kept. Emphasis was placed on interviews with anglers who had finished fishing. Trout harvest was estimated monthly from the product of average number of trout caught/hour/zone (based on interview information), and estimated total number of angling hours/month/zone. Hours of fishing were derived from data on average number of anglers/vehicle, average number of vehicles/hour (based on instantaneous counts), number of hours of fishing represented by each interval between counts and number of days/month. A 15-hr "fishing day" was assumed (6 a.m.-10 p.m.) except for opening weekend, when 16-hr fishing days were assumed. At least one census shift was conducted each weekend and four shifts were usually conducted on weekdays.

Woody vegetation was cut at ground level and removed from strips approximately 30 ft wide parallel to both streambanks through the Treatment Zones. Trees and shrubs near the stream edge were carefully felled away from the stream to avoid disturbing the channel. Cut material was piled along the edge of the cleared zone distal from the stream. Most cutting was done with chain saws, and hand labor was employed during removal.

Cutting and clearing was done in April and early May 1973 in the Treatment Zone of the Little Plover River and during November-December 1973 in the Treatment Zones of Lunch Creek and Spring Creek. Much of this effort on the latter two streams was accomplished by volunteer cooperation (members of Trout Unlimited chapters, U.S. Naval Reserve personnel, high school students and Boy Scouts). All cutting and clearing along the Little Plover River was done by DNR personnel; consequently that was the only site where a realistic economic assessment could be made.

Cut stumps of trees and shrubs were sprayed with herbicides. Kuron, a Dow Chemical Company product (active ingredient is 2,4,5-TP), was used for the initial spraying at an application rate of 10.4 lb of chemical applied/acre. Spraying was done in June 1973 along the Little Plover River and in May-June 1974 at Lunch Creek and Spring Creek. In July 1974 use of this herbicide was banned on DNR properties. Consequently, follow-up spraying of regrowth in all three Treatment Zones was done with the herbicide Ammate X-NI, a DuPont product containing 95% ammonium sulfamate as the active ingredient. Concentration of the application was 24 lb/acre.

A few days after spraying, the Treatment Zone of the Little Plover River was seeded with a commercial mixture of three grasses: Kentucky bluegrass *(Poa pratensis)*, creeping red fescue *(Festuca rubra)* and birdsfoot trefoil *(Lotus corniculatus)* at a mixture of 1:2:2.5. Application concentration was approximately 10 lb/acre. The other two Treatment Zones were not seeded.

# RESULTS

## STREAM CHANNEL MORPHOMETRY

**Little Plover River.** Mean width of the Treatment Zone decreased after treatment as hypothesized, by 28% as compared to only a 9% decrease in the Reference Zone, but mean depth of the Treatment Zone did not increase as expected (Table 1). Posttreatment mean depth was actually 7% less in the Treatment Zone and 9% less in the Reference Zone. Channel volumes (cubic feet of water) at the time of posttreatment measurement (38 months after brush removal) had also decreased, by 33% in the Treatment Zone and 19% in the Reference Zone.

During the posttreatment phase (1973-77), stream discharge followed a pattern of exceptionally high flow during most of 1973, then steady season-to-season declines during the next four years to a record low (for 1970-77) in the fall of 1977 (Table 2). This prolonged decline is reflected in the posttreatment decreases in average depth and channel volume of all study zones and probably disrupted hypothesized improvements in channel shape of the Treatment Zone after brush removal.

**Lunch Creek.** Small changes in channel shape occurred in the Treatment Zone after removal of trees and shrubs. Mean width of the Treatment Zone decreased by 2%. There was no change in mean depth, and surface area and water volume decreased by 2% (Table 1). In the Reference Zone mean width and surface area both increased and mean depth decreased from October 1971 to October 1977. Thus, in comparison to itself, the Treatment Zone did not show major channel-shape improvements, but at least its configuration did not deteriorate as habitat for trout from 1971 to 1977, as was the case in the Reference Zone.

**Spring Creek.** Posttreatment changes in channel configuration of the Treatment Zone were more favorable in Spring Creek than in the other two study streams. Although mean width increased slightly and unexpectedly, mean depth increased by 74% and water volume increased by 86%. Concurrently, there was a 13% increase in mean width of the brushy Reference Zone, a 16% decrease in mean depth and a 4% decrease in water volume (Table 1).

## AQUATIC MACROPHYTES

**Little Plover River.** Abundance of aquatic macrophytes in the Treatment Zone increased from zero for the pre-

**TABLE 2.** *Monthly mean discharge (cfs) at the upper boundary of the Meadow Zone and upper boundary of the Treatment Zone in the Little Plover River during 1970-77.*

| | 1970 | | 1971 | | 1972 | | 1973 | |
|---|---|---|---|---|---|---|---|---|
| Month | Meadow Zone | Treatment Zone | Meadow Zone | Treatment Zone | Meadow Zone | Treatment Zone | Meadow Zone | Treatment Zone |
| Jan | 3.0 | 5.7 | 3.1 | 6.3 | 3.1 | 6.0 | 6.2 | 10.4 |
| Feb | 2.7 | 5.4 | 3.1 | 5.9 | 2.8 | 5.5 | 5.1 | 8.6 |
| Mar | 3.3 | 6.2 | 3.7 | 6.8 | 3.2 | 6.2 | 13.7 | 19.7 |
| Apr | 3.6 | 6.8 | 6.8 | 11.5 | 7.3 | 11.4 | 12.0 | 17.8 |
| May | 6.4 | 10.6 | 5.1 | 9.3 | 5.2 | 9.3 | 13.4 | 21.7 |
| June | 5.7 | 11.1 | 3.9 | 7.3 | 3.8 | 6.8 | 10.5 | 17.9 |
| Jul | 3.7 | 7.1 | 3.7 | 6.7 | 3.2 | 5.8 | 9.4 | 13.8 |
| Aug | 3.3 | 5.9 | 3.7 | 6.7 | 4.7 | 8.3 | 8.1 | 12.1 |
| Sep | 4.0 | 6.9 | 3.2 | 5.9 | 7.5 | 12.5 | 7.5 | 11.4 |
| Oct | 3.7 | 6.9 | 3.5 | 6.5 | 6.6 | 11.2 | 7.0 | 10.1 |
| Nov | 4.4 | 8.4 | 4.0 | 7.4 | 6.7 | 10.7 | 7.6 | 11.0 |
| Dec | 3.5 | 7.1 | 4.0 | 7.5 | 5.8 | 9.6 | 6.6 | 9.4 |
| Annual Mean | 3.9 | 7.3 | 4.0 | 7.4 | 5.1 | 8.7 | 8.9 | 13.6 |

| | 1974 | | 1975 | | 1976 | | 1977 | |
|---|---|---|---|---|---|---|---|---|
| Month | Meadow Zone | Treatment Zone | Meadow Zone | Treatment Zone | Meadow Zone | Treatment Zone | Meadow Zone | Treatment Zone |
| Jan | 5.4 | 7.2 | 3.6 | 5.6 | 2.6 | 5.3 | 1.5 | 3.5 |
| Feb | 5.5 | 7.2 | 3.3 | 5.2 | 2.8 | 5.6 | 1.3 | 3.3 |
| Mar | 7.2 | 10.0 | 3.6 | 5.9 | 6.0 | 9.9 | 2.6 | 5.1 |
| Apr | 8.9 | 14.5 | 6.7 | 10.7 | 6.8 | 11.6 | 3.6 | 7.0 |
| May | 9.1 | 15.1 | 5.6 | 9.9 | 5.3 | 9.9 | 2.6 | 5.5 |
| June | 6.6 | 10.9 | 4.8 | 8.4 | 3.3 | 6.7 | 2.3 | 4.9 |
| Jul | 4.7 | 7.5 | 3.2 | 5.6 | 2.4 | 5.1 | 1.3 | 3.2 |
| Aug | 4.2 | 6.4 | 3.0 | 5.1 | 2.0 | 4.4 | 1.0 | 2.8 |
| Sep | 5.8 | 6.7 | 4.0 | 7.1 | 1.9 | 4.0 | 1.6 | 3.4 |
| Oct | 4.5 | 6.5 | 2.9 | 5.8 | 2.0 | 4.2 | 2.0 | 4.3 |
| Nov | 4.3 | 6.4 | 3.0 | 6.0 | 1.7 | 4.0 | 2.4 | 5.1 |
| Dec | 3.8 | 5.8 | 3.2 | 6.3 | 1.5 | 3.6 | 2.1 | 4.6 |
| Annual Mean | 5.8 | 10.0 | 3.9 | 6.8 | 3.2 | 6.2 | 2.0 | 4.6 |

treatment phase to coverage of 3,426 $ft^2$ of substrate by September 1977 (Table 3). Water buttercup was the pioneering dominant species and maintained that dominance throughout the 1974-77 period. Its proportional contribution to the total aquatic plant assemblage decreased each year, however, from 94% in September 1974 to 76% in September 1977. Speedwell and watercress, the other two prominent species to become established, never accounted for more than 15% of the total quantity of aquatic plants individually nor a maximum of 24% of the total together. Both increased from year to year, watercress more so than speedwell.

In the Reference Zone, abundance of aquatic macrophytes also increased during 1972-77, but not to the degree noted in the Treatment Zone (Table 3). The increase from 295 $ft^2$ in 1972 to 920 $ft^2$ in 1977 was entirely confined to the upper half of the Reference Zone. The increase there was probably due to increased solar radiation as a result of death of several streamside elm trees due to Dutch elm disease. In the lower half of the Reference Zone no aquatic plants were observed throughout the study period.

Water buttercup was the dominant species in the Reference Zone also, but it was never as abundant there as it was in the Treatment Zone.

Although channel lengths and substrate areas of the Treatment and Reference Zones were about the same, by the last year of the study the quantity of aquatic vegetation in the Treatment Zone was 272% greater than in the Reference Zone (3,426 $ft^2$ vs 920 $ft^2$), even though prior to brushing there was no such vegetation in the Treatment Zone but 295 $ft^2$ in the Reference Zone.

**TABLE 3.** *Annual abundance and species composition of aquatic macrophytes in the Treatment and Reference Zones of the Little Plover River before (1972) and after (1974-77) removal of woody vegetation in the Treatment Zone.*

| | | Species | | | | | | | | Zone Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Veronica connata* | | *Ranunculus longirostris* | | *Nasturtium officinale* | | Misc. Species** | | | |
| Study Zone | Year (Sept.) | ft² | % of Total | ft² | % of Total | ft² | % of Total | ft² | % of Total | ft² | % of Zone Bottom |
| Treatment | 1972* | | | | | | | | | 0 | 0.0 |
| | 1974 | 29 | 2 | 1,490 | 94 | 65 | 4 | 5 | 1 | 1,589 | 4.7 |
| | 1975 | 86 | 6 | 1,179 | 87 | 65 | 5 | 23 | 2 | 1,352 | 4.0 |
| | 1976 | 237 | 7 | 2,936 | 87 | 201 | 6 | Tr. | 1 | 3,374 | 10.0 |
| | 1977 | 321 | 9 | 2,590 | 76 | 515 | 15 | Tr. | 1 | 3,426 | 10.2 |
| Reference | 1972* | | | | | | | | | 295 | 1.8 |
| | 1974 | 68 | 32 | 119 | 55 | 15 | 7 | 13 | 6 | 215 | 1.3 |
| | 1975 | 74 | 38 | 115 | 60 | 4 | 2 | Tr. | 1 | 193 | 1.2 |
| | 1976 | 293 | 54 | 231 | 43 | 14 | 3 | Tr. | 1 | 538 | 3.9 |
| | 1977 | 342 | 37 | 439 | 48 | 139 | 15 | Tr. | 1 | 920 | 5.6 |

* Species composition not defined in 1972.

** Other macrophytes noted were water starwort (*Callitriche* sp.), tape grass (*Vallisneria americana*) and smartweed (*Polygonum* sp.). These were usually present in scattered stands too sparse to measure quantitatively with the methods used.

## STREAM DISCHARGE

**Little Plover River.** During the 1970-72 pretreatment years, average annual discharge at the upper boundary of the Treatment Zone was quite stable, varying by only 19% (7.3 cfs in 1970, 7.4 cfs in 1971 and 8.7 cfs in 1972). Within-year flow patterns, based on monthly means, were also more similar during the pretreatment phase than in the posttreatment phase (Fig. 2). Monthly means varied from 5.4 to 10.6 cfs in 1970, 5.9 to 11.5 cfs in 1971 and 5.5 to 11.4 cfs in 1972.

During the 5-yr posttreatment period, stream flows reached peak monthly and annual high discharges but also record low monthly and annual discharges for the entire 8-yr study period. Stream flow during 1973 was particularly unusual. Every monthly mean was a record monthly high for the study period; March through June of that year were also the 4 months of greatest monthly discharge among 96 such values, and the mean annual discharge of 13.6 cfs was 76% greater than the pretreatment 1970-72 mean (Table 2).

In contrast, the 1974-77 period was one of generally declining seasonal flow. At the upper boundary of the Treatment Zone, mean annual flow for 1974 (10.0 cfs) was 28% greater than the 1970-72 pretreatment mean; but during the last three years of the study, average annual flows were all less than the 7.8 cfs pretreatment mean — 13% less in 1975, 21% less in 1976 and 41% less in 1977. The August 1977 average discharge of 2.8 cfs was the lowest monthly rate during the study. Only one monthly discharge value in 1977, that for April, exceeded any of the 36 monthly means for the pretreatment period at this recording site.

For the entire 8-yr study period of continuous monitoring of stream discharges and converting of these records to monthly mean rates, discharges varied from a high of 21.7 cfs in May 1973 to a low of 2.8 cfs in August 1977, a difference of 675%. Variations in stream flow from season to season and year to year had profound impacts on trout carrying capacity.

**Lunch Creek.** Discharge of Lunch Creek was measured on four occasions in 1976 and 1977. At the upper boundary of the Treatment Zone, discharge was 8.4 cfs in October 1976, 14.6 cfs in March 1977, 9.0 cfs in August 1977 and 10.7 cfs in October 1977. Discharge at the lower end of the Treatment Zone on these same four days was always less, by 2 to 14%. At the lower boundary of the Reference Zone, 0.78 mile farther downstream, some increase in stream discharge was detected on each occasion, a less than 3% gain on the first three dates but a 14% greater flow for the October 1977 sampling (Table 4).

These flow data are too sparse to correlate with other biological or physical data gathered, but they do suggest a tendency for stream flow to decrease in volume as it passes through the Treatment Zone and then increase slightly in volume through the Reference Zone due to groundwater recruitment.

**Spring Creek.** Baseflow discharge of Spring Creek at its junction with Sand Creek was measured on two occasions and was calculated to be 3.6 cfs in September 1971 and 3.2 cfs in October 1976. At the upper boundary of the Treatment Zone (0.89 mile upstream), discharge on the same dates was 14% less on both occasions.

Based on both subjective year-to-year observations during several visits to the stream each year and the four measured discharge calculations, Spring Creek appeared to have a more stable base flow than did Lunch Creek or the Little Plover River. Discharge was less in the fall of 1976 than in the fall of 1971, but not nearly to the degree that characterized the discharge regime of the Little Plover River.

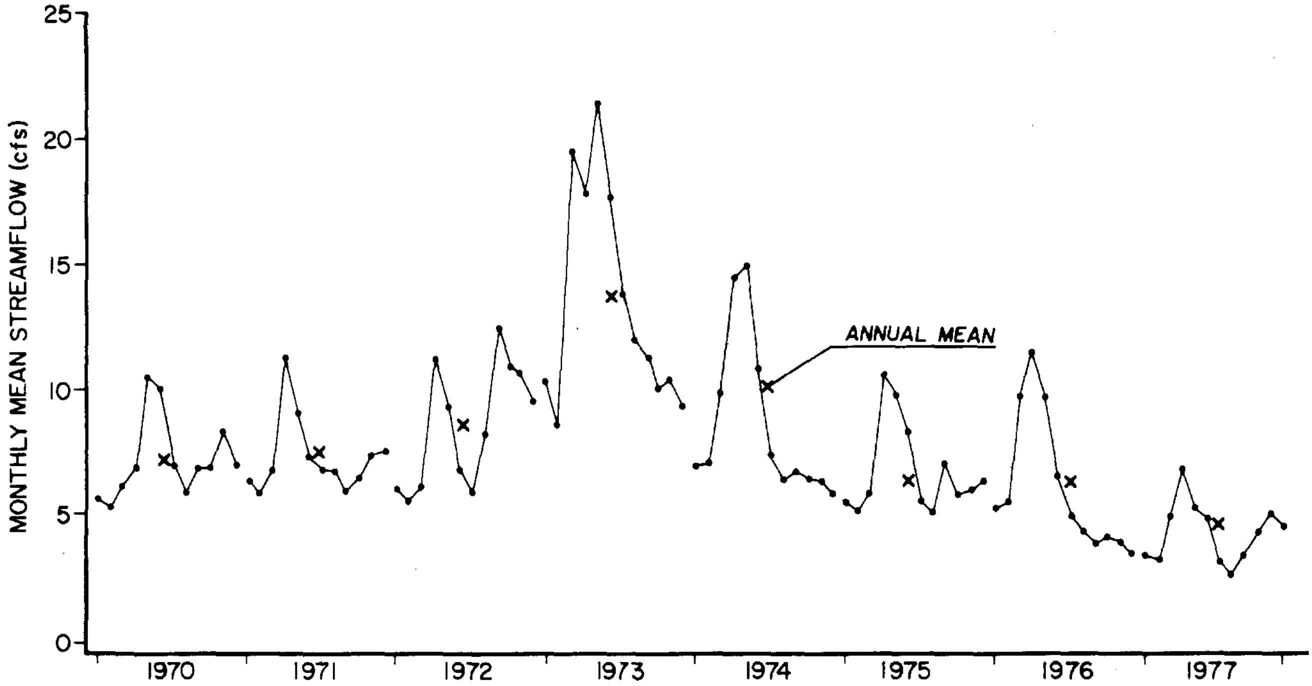



**FIGURE 2.** *Monthly mean discharge (cfs) at the upper boundary of the Treatment Zone in the Little Plover River during 1970-77. Annual mean discharges are indicated by an x located at mid-year points.*

## STREAM TEMPERATURES

**Little Plover River.** During the pretreatment phase, maximum water temperatures recorded at the upstream boundary of the Treatment Zone were 75°F in 1971 and 72°F in 1972. Approximately 1,200 yd downstream, at the lower boundary of the Reference Zone, maximum temperatures of 74°F and 72°F were recorded in 1971 and 1972, respectively (Table 5).

During the summer of 1973, the first summer after shade canopy removal, maximum water temperature at the upper boundary of the Treatment Zone was only 63°F, a reflection of a generally cooler summer and much higher than normal base flow during most of the year. On the same date, at the downstream boundary of the 800-yd Treatment Zone a summer maximum of 68°F was observed. This 5°F maximum increase through the brush-cleared Treatment Zone was dissipated by the time stream flow had passed through 400 yd of unbrushed Reference Zone where the maximum temperature at its lower boundary was also 63°F.

The impact of increased solar heat on the water mass passing through the Treatment Zone tended to decrease each summer after brushing. The 5°F gain noted in 1973 was followed by maximum incremental increases on any one day of 3.5°F in 1974, 2°F in 1975, 2°F in 1976 and 1.5°F in 1977. However, the coincident tendency toward higher temperature regimes of incoming water to the Treatment Zone in successive posttreatment summers

**TABLE 4.** *Discharge at both boundaries of the Treatment Zone and the lower boundary of the Reference Zone in Lunch Creek.**

| | Discharge (cfs) | | |
|---|---|---|---|
| Date | Treatment Zone Upper Boundary | Treatment Zone Lower Boundary | Reference Zone Lower Boundary |
| Oct 1976 | 8.4 | 8.0 | 8.2 |
| Mar 1977 | 14.6 | 14.4 | 14.7 |
| Aug 1977 | 9.0 | 8.5 | 8.7 |
| Oct 1977 | 10.7 | 9.2 | 10.5 |

*Measurements made at 1-ft cross-channel intervals with a Gurley pygmy current meter.

**TABLE 5.** *Maximum annual water temperature (°F) at three recording sites in study zones of the Little Plover River during pretreatment (1971-72) and posttreatment (1973-77) phases.*

| Study Phase | Maximum Stream Temperature (°F) Upper Boundary of Treatment Zone | Lower Boundary of Treatment Zone* | Lower Boundary of Reference Zone** |
|---|---|---|---|
| Pretreatment | | | |
| 1971 | 75.0 | —[1] | 74.0 |
| 1972 | 71.5 | — | 72.0 |
| Posttreatment | | | |
| 1973 | 63.0 | 68.0 | 63.0 |
| 1974 | 73.5 | 77.0 | 75.0 |
| 1975 | 75.0 | 77.0 | 75.0 |
| 1976 | 76.0 | 78.0 | 75.5 |
| 1977 | 85.0 | 86.5 | 87.0 |

*Located 800 yd below upper boundary of Treatment Zone.

**Located 400 yd below lower boundary of Treatment Zone.

[1] No record at this site in 1971-72.

**TABLE 6.** *Monthly mean water temperatures (°F) at the boundaries of the Treatment Zone and lower boundary of the Reference Zone in the Little Plover River.*

| Month | Upper Boundary of Treatment Zone 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | Lower Boundary of Treatment Zone 1973 | 1974 | 1975 | 1976 | 1977 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | —* | 33.0 | 35.7 | 33.8 | 33.4 | 32.3 | 30.7 | — | 34.0 | 33.7 | 32.9 | 32.4 |
| Feb | 36.5 | 36.6 | 35.0 | 33.0 | 35.5 | 37.9 | 34.6 | — | 33.9 | 33.6 | 37.1 | 33.4 |
| Mar | 39.7 | 40.2 | 40.3 | 38.2 | 39.1 | 39.1 | 42.6 | — | 38.6 | 38.8 | 39.5 | 42.1 |
| Apr | 48.1 | 41.4 | 43.8 | 47.3 | 45.0 | 48.3 | 51.4 | — | 46.3 | 44.7 | 49.1 | 51.0 |
| May | 54.8 | 52.9 | 47.1 | 50.5 | 55.6 | 53.5 | 61.5 | — | 51.1 | 57.3 | 54.7 | 61.5 |
| Jun | 61.1 | 56.0 | 49.7 | 54.0 | 55.8 | 61.6 | 61.1 | 53.8** | 55.4 | 57.8 | 62.7 | 61.8 |
| Jul | 59.9 | 59.6 | 52.6 | 58.8 | 62.1 | 62.8 | 67.5 | 56.8 | 61.2 | 63.6 | 64.5 | 68.1 |
| Aug | 59.4 | 57.0 | 51.3 | 57.2 | 59.6 | 60.3 | 62.6 | 55.3 | 58.9 | 58.5 | 61.7 | 62.8 |
| Sep | 51.5 | 52.4 | 47.5 | 50.3 | 52.4 | 53.4 | 57.6 | 51.9 | 50.9 | 52.3 | 54.5 | 57.5 |
| Oct | 50.3 | 44.6 | 44.4 | 45.3 | 49.1 | 45.0 | 49.3 | 48.6 | 46.1 | 50.8 | 45.5 | 49.4 |
| Nov | 40.1 | 40.0 | 35.5 | 38.2 | 45.1 | 36.0 | 41.2 | 39.3 | 38.6 | 42.9 | 36.6 | 41.8 |
| Dec | 36.4 | 33.8 | 33.3 | 33.2 | 37.8 | 32.0 | 35.3 | 34.9 | 32.7 | 36.1 | 32.7 | 36.2 |
| Avg. of Monthly Means | 48.9[1] | 45.5 | 43.0 | 45.0 | 47.5 | 46.8 | 49.6 | | 45.6 | 47.5 | 47.6 | 49.8 |

| Month | Lower Boundary of Reference Zone 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 |
|---|---|---|---|---|---|---|---|
| Jan | 33.0 | 33.2 | 35.8 | 35.3 | 34.1 | 32.5 | 31.8 |
| Feb | 35.2 | 33.5 | 35.4 | 35.2 | 33.1 | 36.9 | 32.8 |
| Mar | 40.0 | 38.5 | 41.5 | 40.3 | 36.5 | 37.7 | 40.4 |
| Apr | 47.9 | 46.0 | 42.2 | 48.8 | 44.3 | 48.8 | 49.7 |
| May | 55.5 | 55.9 | 45.0 | 53.6 | 58.7 | 54.3 | 61.5 |
| June | 60.8 | 57.2 | 50.5 | 57.7 | 62.1 | 62.3 | 62.2 |
| Jul | 59.9 | 56.8 | 52.8 | 62.8 | 67.7 | 64.4 | 68.4 |
| Aug | 58.9 | 56.1 | 51.6 | 60.4 | 64.1 | 61.7 | 63.3 |
| Sep | 52.1 | 51.4 | 47.5 | 53.0 | 52.8 | 55.3 | 57.1 |
| Oct | 51.0 | 44.7 | 43.9 | 47.7 | 48.1 | 45.6 | 47.9 |
| Nov | 40.3 | 38.6 | 35.2 | 41.2 | 45.6 | 36.6 | 40.2 |
| Dec | 36.8 | 35.2 | —* | 36.2 | 35.2 | 32.5 | 33.7 |
| Avg. of Monthly Means | 47.6 | 45.6 | 43.8[1] | 47.7 | 48.4 | 47.4 | 49.1 |

*Insufficient data.

**Recorder installed at completion of brush removal in mid-May.

[1] 11-month average.

**TABLE 7.** *Annual maximum, minimum and mean water temperatures (°F) at the upper and lower boundaries of the Treatment Zone on Lunch Creek during the pretreatment (1972-73) and posttreatment (1974-77) phases.*

| Study Phase | Annual Maximum | | Annual Minimum | | Annual Mean | |
|---|---|---|---|---|---|---|
| | Upper | Lower | Upper | Lower | Upper | Lower |
| Pretreatment | | | | | | |
| 1972 | 74 | 69 | 34 | 31 | ** | ** |
| 1973 | 71 | 68 | 34 | 32 | 51.6 | 48.9 |
| Posttreatment | | | | | | |
| 1974 | 72 | 70 | 35 | 32 | 51.2 | 49.0 |
| 1975 | 72 | 70 | 36 | 32 | 51.7 | 48.3 |
| 1976 | 73 | 71 | 35 | 31 | 50.3 | 47.0 |
| 1977 | 73 | 72 | 34 | 30 | 51.8 | 49.5 |

*Removal of woody vegetation in Treatment Zone was done during November-December, 1973.

**Records incomplete for entire year.

**TABLE 8.** *Maximum annual water temperatures (°F) at the upper and lower boundaries of the Treatment Zone on Spring Creek during the pretreatment (1972-73) and posttreatment (1976-77) phases.**

| Study Phase | Annual Maximum Temperature (°F) | |
|---|---|---|
| | Upper Boundary | Lower Boundary |
| Pretreatment | | |
| 1972 | 66 | 68 |
| 1973 | 62 | 62 |
| Posttreatment | | |
| 1976 | 76 | 78 |
| 1977 | 64 | 64 |

*Removal of woody vegetation in Treatment Zone was done during November-December 1973.

**TABLE 9.** *Average net radiation values at the water surface of the Treatment Zone and Reference Zone of the Little Plover River before and after removal of woody streamside vegetation in April-May, 1973.*

| Date | Gram calories/cm$^2$/minute | |
|---|---|---|
| | Treatment Zone | Reference Zone |
| 28 Aug 1972 | 15 (35)* | 14 (17) |
| 19 Aug 1974 | 59 (34) | 14 (16) |
| 17 Aug 1976 | 58 (33) | 11 (21) |

*Measurements/zone at randomly selected sites indicated by number in parentheses.

resulted in attainment of a record high maximum of 86.5°F in July 1977 at the lower boundary of the Treatment Zone (Table 5).

Average water temperatures for the summer period (June-August), as well as the annual maximum temperature, also tended to increase steadily during the posttreatment period at all three recording sites. At the upper boundary of the Treatment Zone, for example, mean water temperatures for June-August periods were 51.2, 56.7, 59.2, 61.6 and 63.7°F, respectively, during 1973-77. Fortunately this upward trend, independent of canopy removal, was paralleled by a downward trend in the amount of additional solar heating through the Treatment Zone. The difference between 3-month summer means at its upper and lower boundaries was 4.1°F in 1973, 1.8°F in 1974, 0.8°F in 1975, 1.4°F in 1976 and only 0.5°F in 1977 (Table 6). Both the maximum daily incremental increases in water temperature as the water mass passed through the Treatment Zone and the differences just cited in monthly mean temperatures at the upper and lower boundaries of the Treatment Zone indicate that by the end of the fifth posttreatment summer, natural shading of the stream channel by the meadow community of vegetation was sufficient to largely negate any additional increase in water temperature due to brushing.

**Lunch Creek.** As stream flow passed through the 950-yd Treatment Zone, water temperature tended to decrease regardless of time of year (Table 7). During the two summers prior to shade canopy reduction, maximum water temperatures were 5°F and 3°F lower, respectively, at the downstream boundary. Following reduction of shading, maximum water temperatures were 1-2°F lower at the downstream boundary. Annual minimum temperatures were 3°F and 2°F lower at the downstream boundary of the Treatment zone prior to cutting and 2-4°F lower after cutting during the four posttreatment winters.

Over the course of six consecutive years, annual water temperature regimes were quite stable in Lunch Creek as compared to temperature patterns from year to year in the Little Plover River. Annual high water temperatures differed only 3°F (71-74°F range) at the upper boundary of the Treatment Zone on Lunch Creek and only 4°F at its lower boundary (68-72°F range). By comparison the spread in annual highs was 13°F (63-85°F range) at the upper boundary of the Treatment zone on the Little Plover River.

**Spring Creek.** Based on the sparse accumulation of water temperature data on this stream, brush removal along both banks of the 604-yd Treatment Zone appeared to have little impact on altering stream temperatures by the third and fourth summers after shade reduction (Table 8). During the 1976 posttreatment summer, a 2°F higher reading was obtained at its downstream boundary, but during 1977 the same maximum of 64°F was recorded at both Treatment Zone boundaries (during the first week in July). During the two pretreatment summers, similar temperature differences were observed, a 2°F increase one summer and no heat gain through the Treatment Zone the other.

## NET RADIATION

In August 1974, 16 months after removal of streamside canopy on the Little Plover River, net radiation measurements in the Treatment Zone averaged 59 g cal/cm²/min, a 293% increase over the prebrushing average for this zone (Table 9). In the Reference Zone there was no detectable change in the net radiation index from August 1972 compared to August 1974. Forty months into the posttreatment phase (August 1976), the average net radiation index for the Treatment Zone was 58 g cal/cm²/min, based on 33 random in-channel measurements. The average of 21 random readings in the Reference Zone the same date was 11 g cal/cm²/min,, an indication that shade canopy over the stream channel in this unbrushed zone had increased since August 1974.

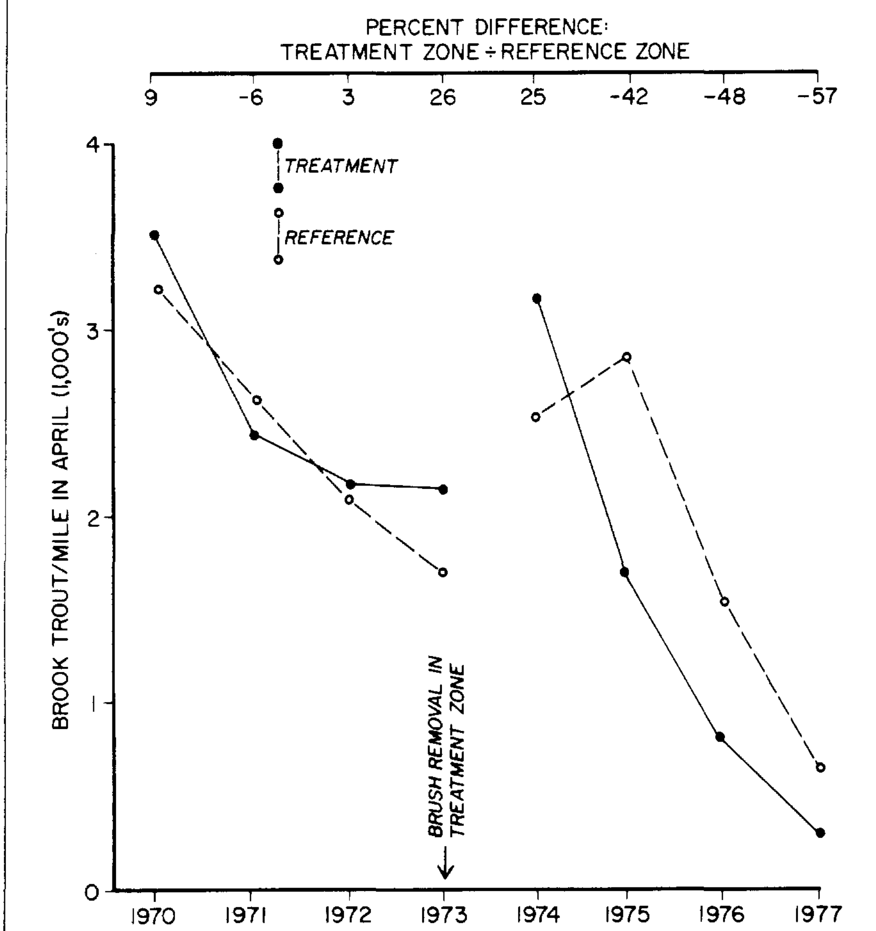



**FIGURE 3.** *Number of brook trout/mile in April in the Treatment and Reference Zones of the Little Plover River before (1970-73) and after (1974-77) removal of woody vegetation in the Treatment Zone.*

## TROUT ABUNDANCE AND BIOMASS

**Little Plover River.** Trends in numbers of trout/mile (Figs. 3-4), pounds of trout/mile (Figs. 5-6) and legal-sized trout/mile (Figs. 7-8) were similar in the Treatment and Reference Zones before and after brush removal. During the first year after brushing, all six indexes of the trout stocks in each study zone increased in comparison to pretreatment mean values. During the remaining posttreatment years, however, stock indexes for successive spring or successive fall inventories generally declined dramatically in both study zones. Moreover, stock declines in the Treatment Zone were usually more precipitous than declines in the unbrushed Reference Zone.

Mean number of brook trout/mile in April was 42% less in the Treatment Zone and 21% less in the Reference Zone during the posttreatment phase than in the pretreatment phase (Table 11, Append.). A similar comparison of mean biomass/mile in April for the two study periods showed a 19% decrease in the Treatment Zone and a 2% decrease for the Reference Zone. Legal-sized trout/mile in April increased by an average of 8% in the Treatment Zone after brushing, but during the same posttreatment period there was a 37% average gain in the unbrushed Reference Zone. In both zones the 1974-75 values were the ones that boosted the posttreatment average to a positive percentage over the pretreatment means. Lowest density of legal-sized trout occurred in both zones in April 1977, the last year of evaluation.

September indexes for the Treatment Zone showed an average posttreatment changes of 24% fewer trout/mile, 8% more pounds/mile and 15% more legal trout/mile. For two of the three indexes, however, average changes in the Reference Zone were more favorable in comparison to pretreatment averages: a 16% decrease in mean number of trout/mile, a 1% increase in mean biomass/mile and a 29% increase in legal trout/mile (Table 11, Append.).

**Lunch Creek.** In both study zones the number and biomass of brown trout tended to decline during the posttreatment period (1974-77). Patterns of decline were not as steady as in the study zones of the Little Plover River, but in both zones of Lunch Creek the poorest trout stocks in terms of number/mile, biomass/mile and trout over 10 in./mile occurred during 1977, the last year of the study (Figs. 9-14).

The Treatment Zone held an average of 45% fewer brown trout/mile in April after streamside clearing (1,437/mile) than before (2,634/mile). Concurrently, in the Reference Zone, a natural marsh-meadow habitat, there was an average decline of 24% in number/mile in April (from 850/mile during 1971-73 to 647/mile during 1974-77). April biomass declined from an average of 279.1 lb/mile in the Treatment Zone before brushing to 128.8 lb/mile after brushing, a 54% decrease. In the Reference Zone average April biomass decreased by 37% (from 126.8 lb/mile to 80.5 lb/mile) when comparing the same yearly groupings of data (Table 12, Append.).

Of the six stock parameters measured each year in each study zone, only two (number/mile in September and number/mile over 10 in. in September) showed less decline in the Treatment Zone than in the Reference Zone. The Treatment Zone held an average of 98% more brown trout/mile in September than the Reference Zone held during pretreatment years but 128% more during the posttreatment years (Fig. 11). In the same relative terms, independent of absolute declining trends in both zones, the Treatment Zone contained 49% fewer trout/mile over 10 in. in September than the Reference Zone during the pretreatment phase. During the postreatment phase there were 31% fewer trout/mile of this size in the Treatment Zone in September than in the Reference Zone; i.e., there still were fewer trout/mile in the Treatment Zone than in the Reference Zone in absolute terms but the difference was less than it was for the prebrushing phase (Fig. 14).

**Spring Creek.** Trends in the abundance and biomass of brook trout in the Treatment Zone of this stream were markedly different than corresponding trends in the downstream Reference Zone during the two evaluation phases of brush removal along the banks of the Treatment Zone (Figs. 15-20). Number/mile, biomass/mile and legal trout/mile tended to increase from spring to spring and fall to fall in the Treatment Zone after brushing despite downward trends in these three stock indexes in the unbrushed Reference Zone during 1974-77.

Mean number of brook trout/mile was 2,335 in the Treatment Zone before brushing but 2,818 after brushing, a 21% improvement (Table 13, Append.). Comparable means for the Reference Zone were 1,834 vs 1,521/mile, a 17% decrease. Average April biomass of brook trout in the Treatment Zone increased from 162.3 lb/mile to 193.6 lb/mile, a 19% improvement following brushing. Concurrently there was an average decrease of 20% in April biomass in the Reference Zone (from 142.3 to 114.9 lb/mile).

Legal-sized trout in April increased from an average density of 813/mile prior to brushing to 1,023/mile after brushing in the Treatment Zone, a 26% gain. Corresponding changes in the Reference Zone resulted in a 17% average decline.

October-October comparisons for pretreatment vs posttreatment phases provided even more impressive support for the hypothesis that brush removal tends to increase trout-carrying capacity: For trout of all sizes: 35% average increase in the Treatment Zone; 20% average decrease in the Reference Zone. For trout biomass: 54% average increase in the Treatment Zone; 24% average decrease in the Reference Zone. For legal-sized trout: 53% average increase in the Treatment Zone; 22% average decrease in the Reference Zone.

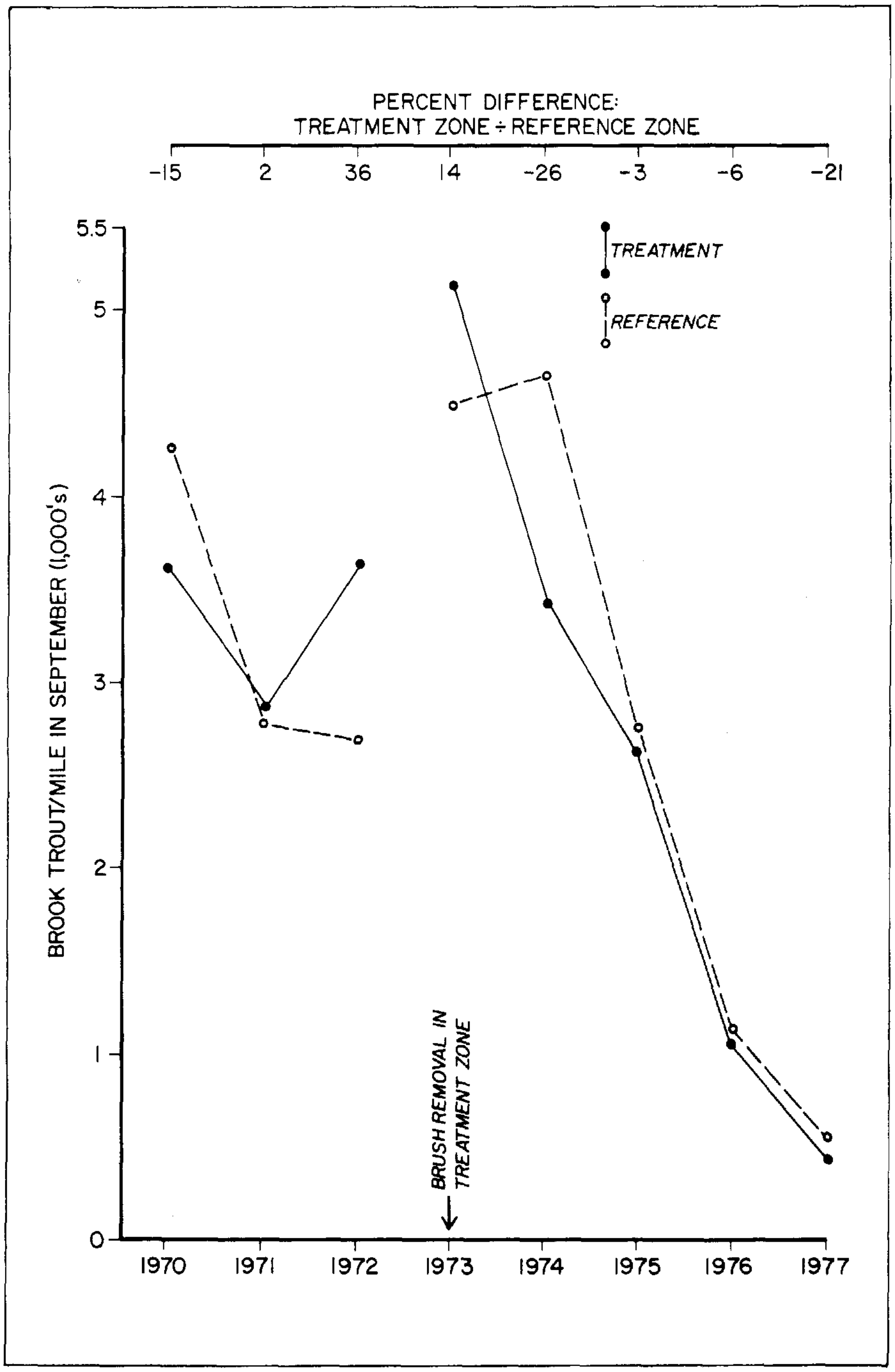



**FIGURE 4.** *Number of brook trout/mile in September in the Treatment and Reference Zones of the Little Plover River before (1970-72) and after (1973-77) removal of woody vegetation in the Treatment Zone.*

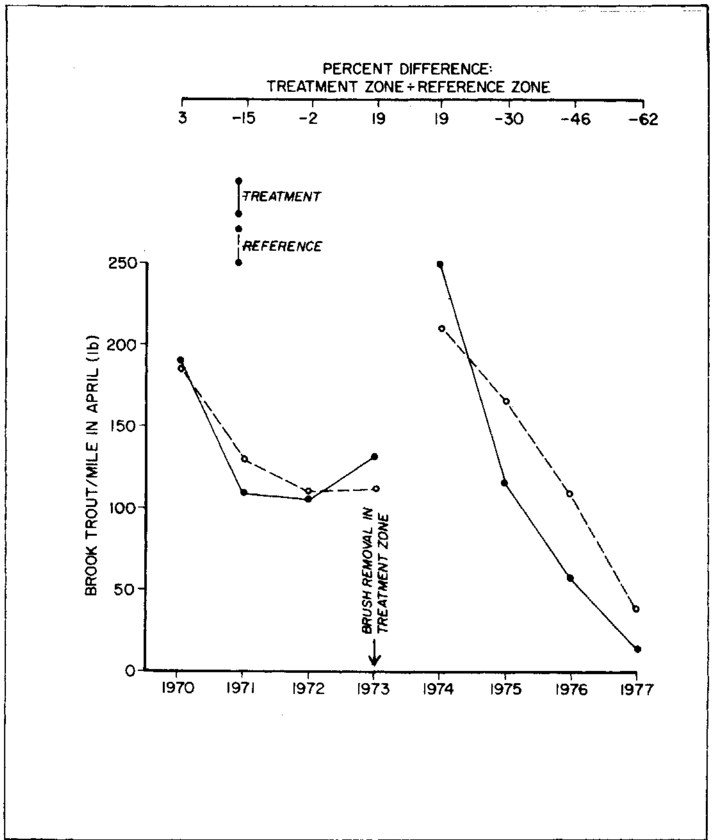



**FIGURE 5.** *Pounds of brook trout/mile in April in the Treatment and Reference Zones of the Little Plover River before (1970-73) and after (1974-77) removal of woody vegetation in the Treatment Zone.*

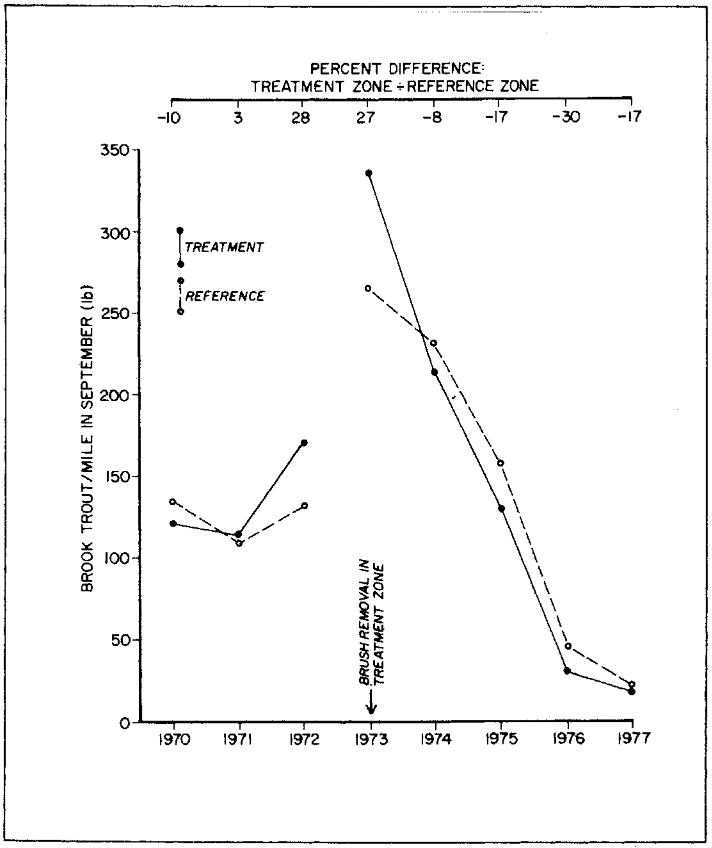



**FIGURE 6.** *Pounds of brook trout/mile in September in the Treatment and Reference Zones of the Little Plover River before (1970-72) and after (1973-77) removal of woody vegetation in the Treatment Zone.*

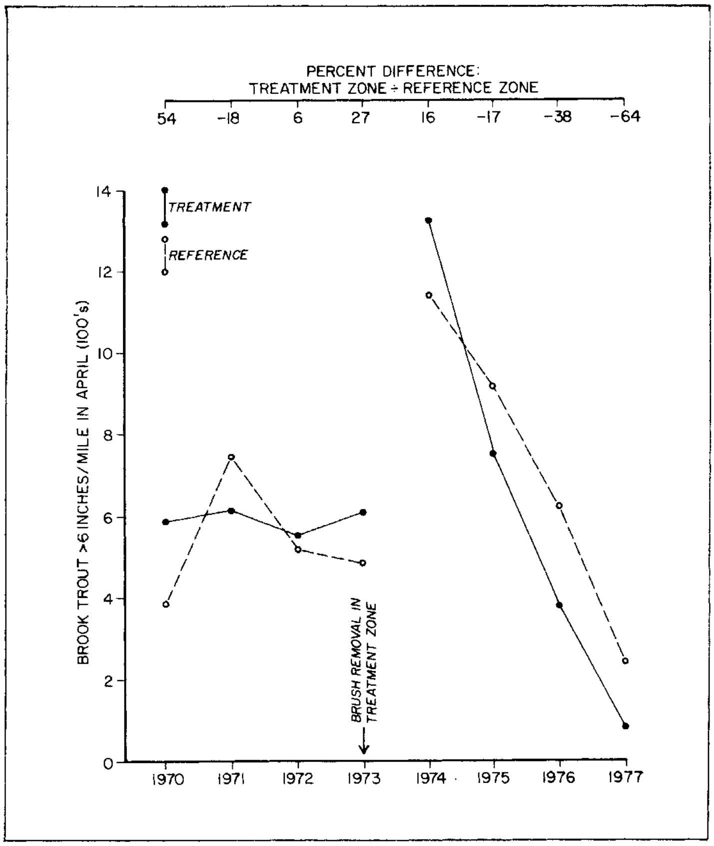



**FIGURE 7.** *Number of brook trout over 6 in. long/mile in April in the Treatment and Reference Zones of the Little Plover River before (1970-73) and after (1974-77) removal of woody vegetation in the Treatment Zone.*

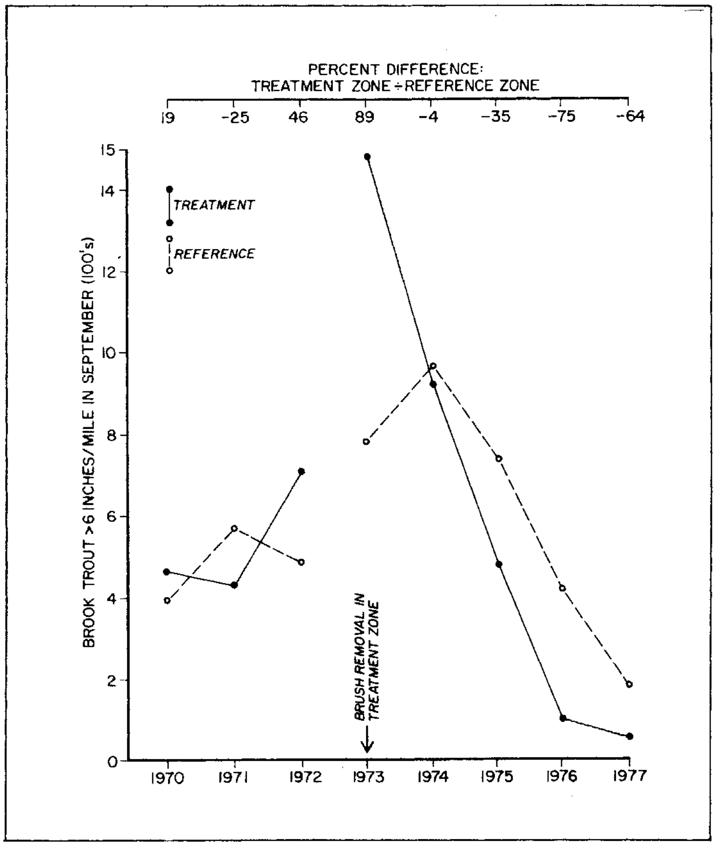



**FIGURE 8.** *Number of brook trout over 6 in. long/mile in September in the Treatment and Reference Zones of the Little Plover River before (1970-72) and after (1973-77) removal of woody vegetation in the Treatment Zone.*

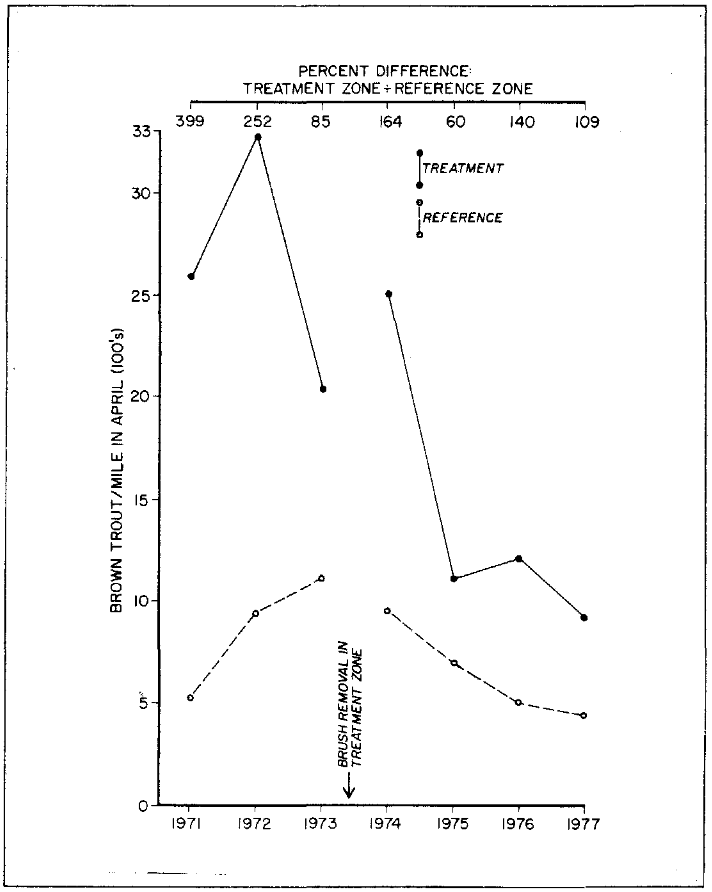



**FIGURE 9.** *Number of brown trout/mile in April in the Treatment and Reference Zones of Lunch Creek before (1971-73) and after (1974-77) removal of woody vegetation in the Treatment Zone.*

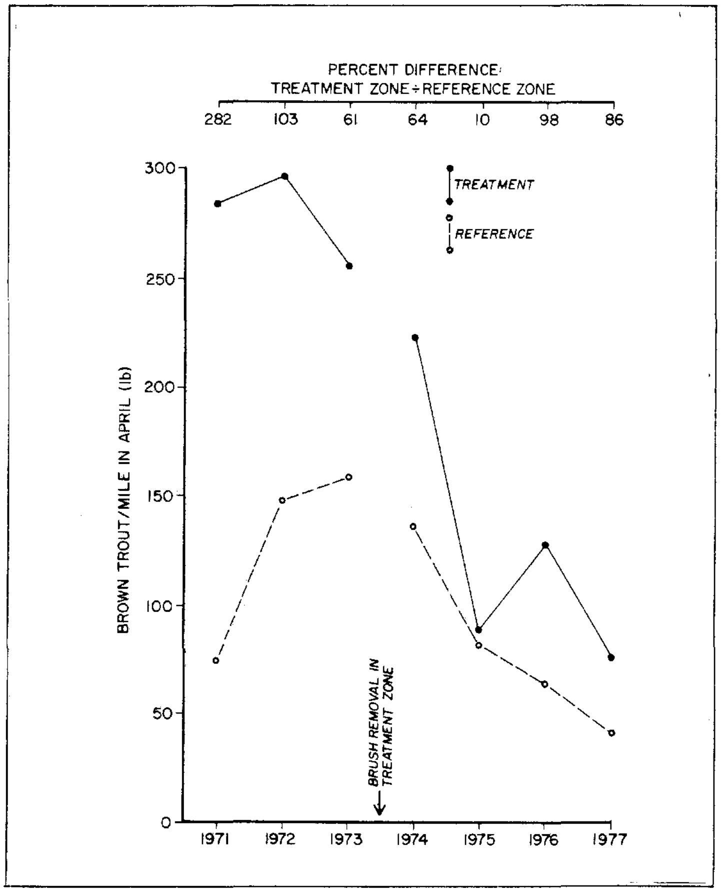



**FIGURE 11.** *Pounds of brown trout/mile in April in the Treatment and Reference Zones of Lunch Creek before (1971-73) and after (1974-77) removal of woody vegetation in the Treatment Zone.*

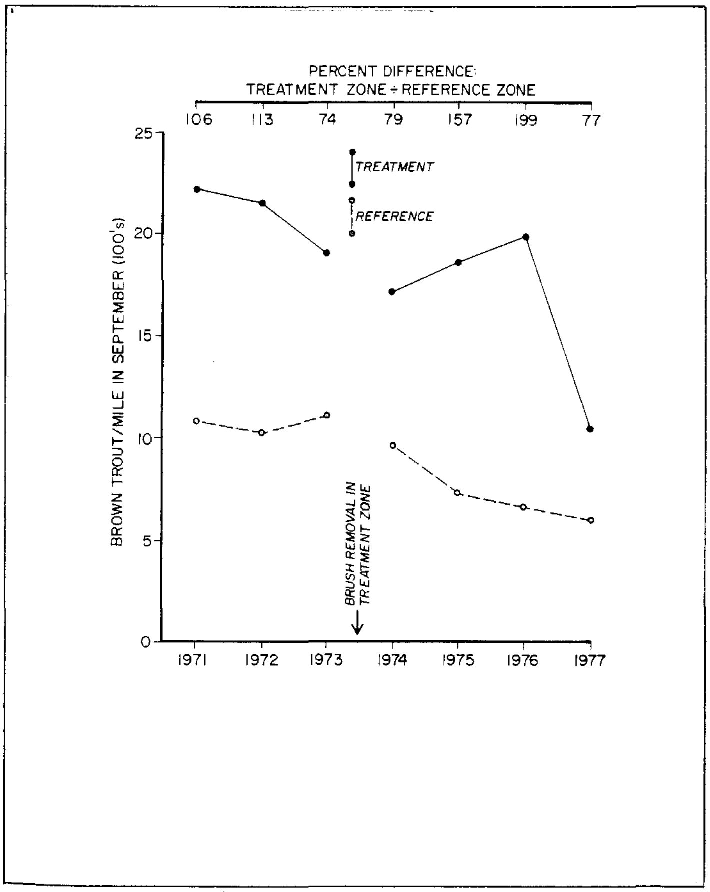



**FIGURE 10.** *Number of brown trout/mile in September in the Treatment and Reference Zones of Lunch Creek before (1971-73) and after (1974-77) removal of woody vegetation in the Treatment Zone.*

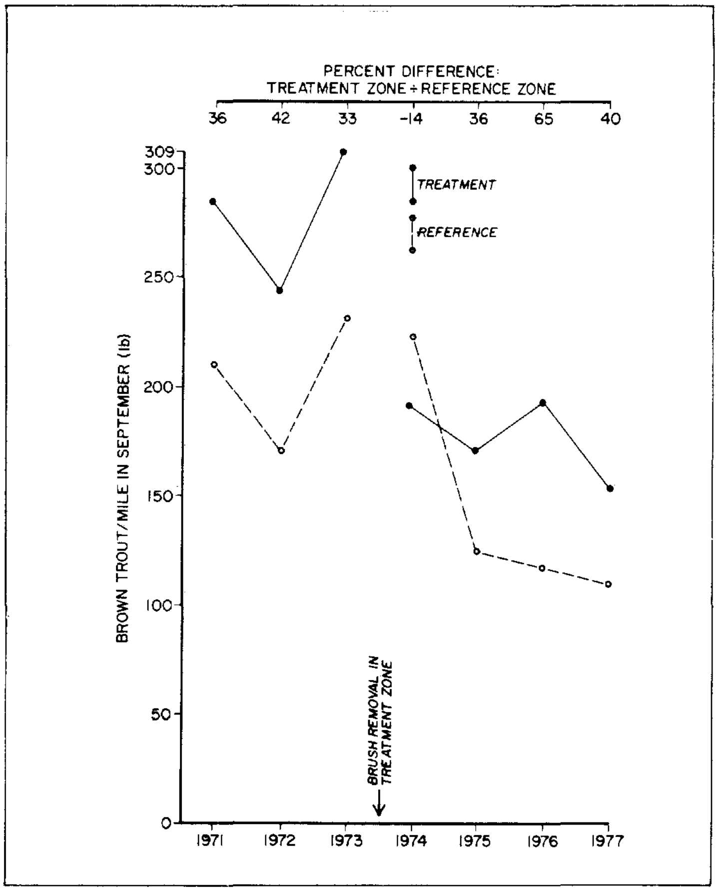
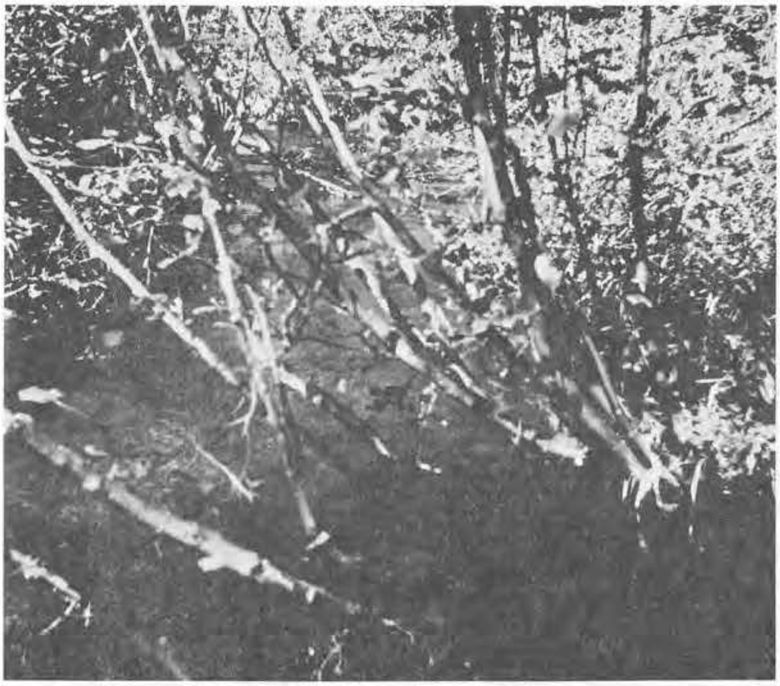



**FIGURE 12.** *Pounds of brown trout/mile in September in the Treatment and Reference Zones of Lunch Creek before (1971-73) and after (1974-77) removal of woody vegetation in the Treatment Zone.*



*Brushy invasion of trout habitat—a blessing or a curse in its impact on trout-carrying capacity. Still a blessing for trout in the condition shown, as it provides midchannel and underbank cover combined with adequate water depth for legal-sized trout. Within another few years, however, habitat quality for trout will begin to steadily diminish in such a reach of stream.*

*Speckled alders along this stream bend have now become a curse—greatly reducing trout-carrying capacity. The bank has slumped in, a shallow silt bed has accumulated among the prostrate branches and maximum water depth has been displaced to midchannel, where there is no associated hiding cover for trout.*

*During the process of removing woody streamside vegetation, trees and brush along the stream edge were carefully cut to fall away from, not into, the stream. Cut material was removed and piled along the border distal from the stream edge.*

*When woody vegetation is removed along both stream banks, as was done in this study, the cutover landscape appears shockingly barren until grassy vegetation has had an opportunity to grow for a few weeks.*

*Silt flats exposed to the air as stream discharge normally declines during the summer are soon stabilized by grassy vegetation, thus helping to permanently narrow the stream channel. When stream flow again increases the next fall and spring, it will have greater eroding power within the confined channel to scour new pools, enlarge existing ones and expose greater areas of streambed gravel where such substrate is present.*

*A portion of the 600-yd Treatment Zone on Spring Creek, three summers after removing woody vegetation. A lush turf of grasses and weeds has become established. Aquatic macrophytes also flourished throughout this Treatment Zone, as hypothesized, to the benefit of its trout-carrying capacity.*

*Stumps and sprouts were sprayed with an herbicide to retard regrowth. Another, much less intensive, cutting and spraying effort to suppress regrowth of woody vegetation was not necessary until five growing seasons after the initial removal.*

*Another view of the marsh-meadow habitat established in the Treatment Zone of Spring Creek as a result of the removal of woody vegetation three years previously. Both stream edges now provide nearly continuous hiding cover for trout throughout most of the open water period of the year.*

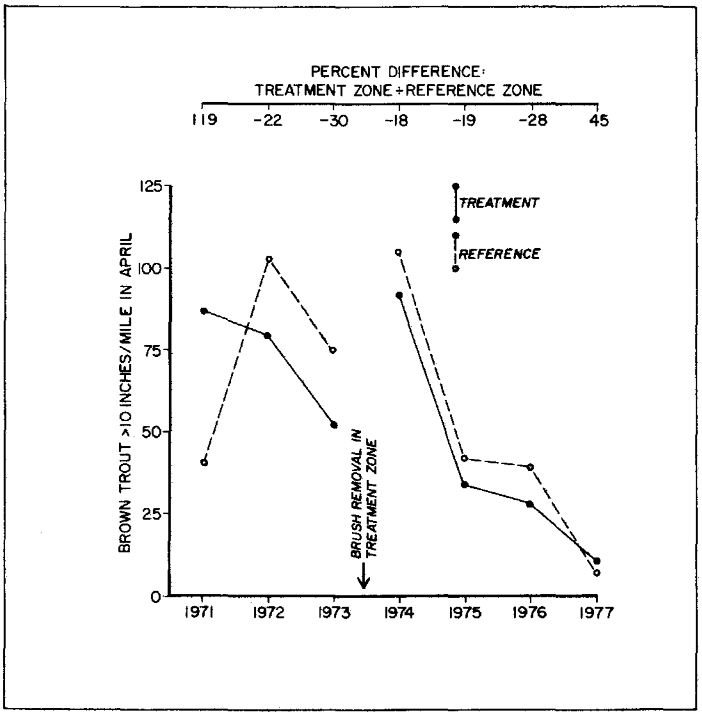



**FIGURE 13.** *Number of brown trout over 10 in./mile in April in the Treatment and Reference Zones of Lunch Creek before (1971-73) and after (1974-77) removal of woody vegetation in the Treatment Zone.*

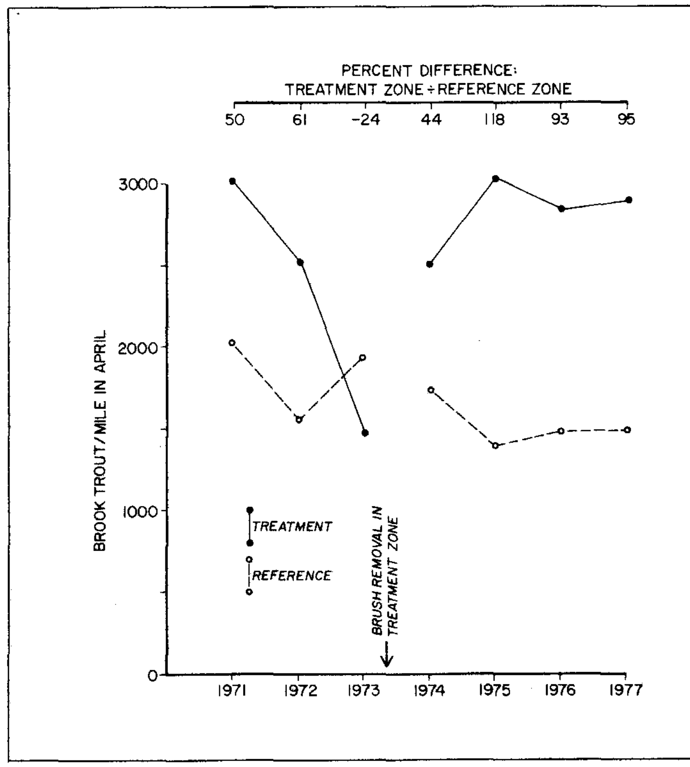



**FIGURE 15.** *Number of brook trout/mile in April in the Treatment and Reference Zones of Spring Creek before (1971-73) and after (1974-77) removal of woody vegetation in the Treatment Zone.*

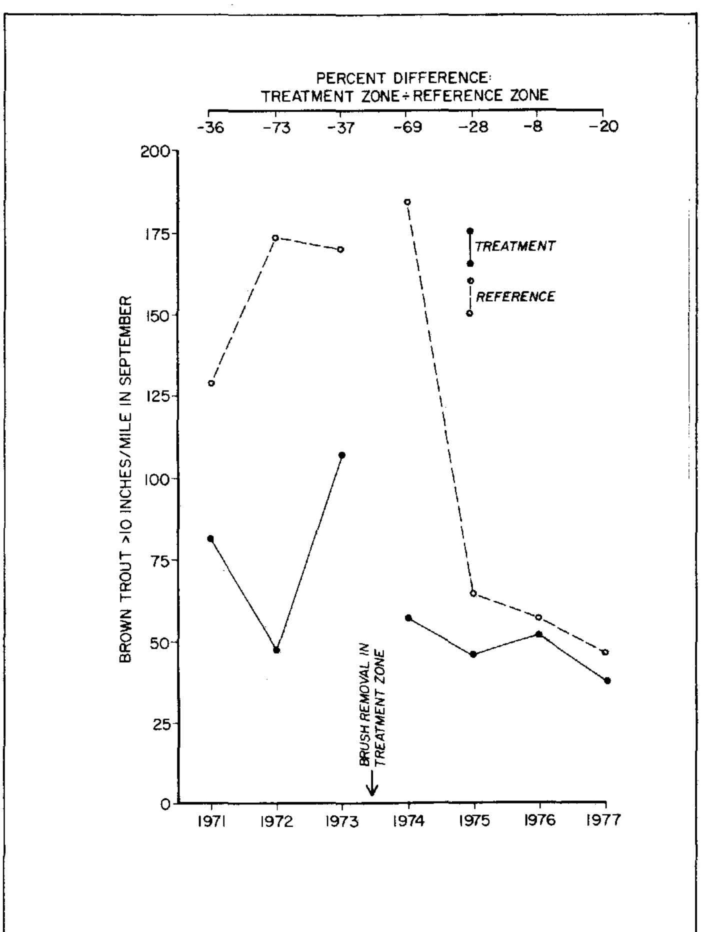



**FIGURE 14.** *Number of brown trout over 10 in./mile in September in the Treatment and Reference Zones of Lunch Creek before (1971-73) and after (1974-77) removal of woody vegetation in the Treatment Zone.*

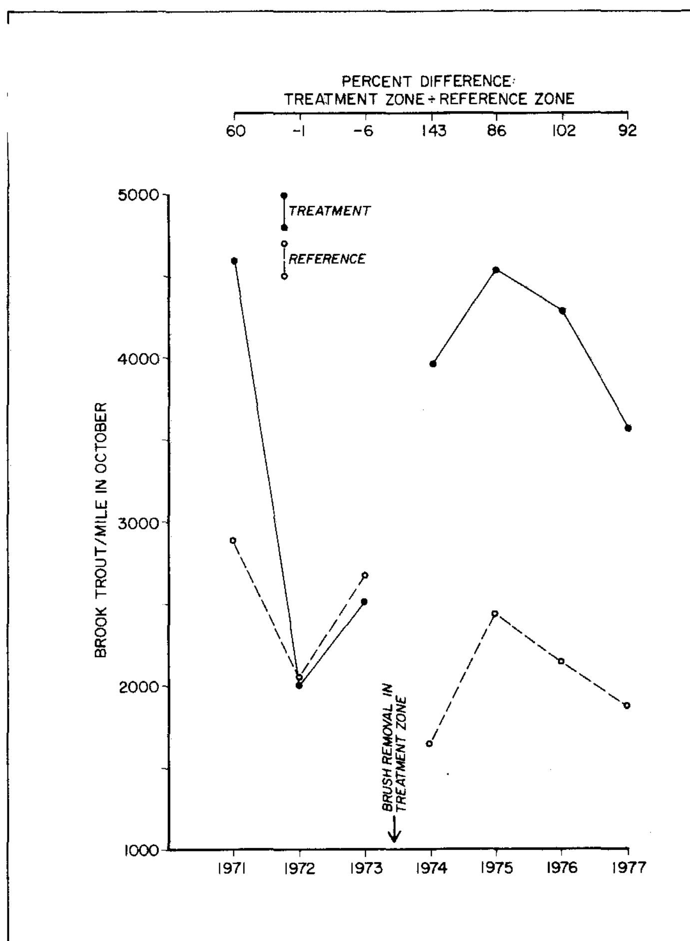



**FIGURE 16.** *Number of brook trout/mile in October in the Treatment and Reference Zones of Spring Creek before (1971-73) and after (1974-77) removal of woody vegetation in the Treatment Zone.*

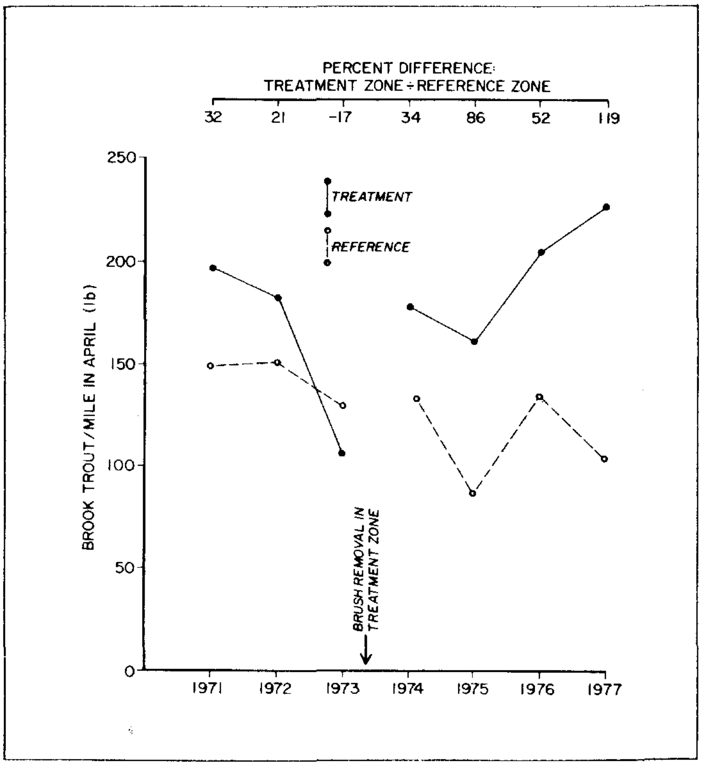



**FIGURE 17.** *Pounds of brook trout/mile in April in the Treatment and Reference Zones of Spring Creek before (1971-73) and after (1974-77) removal of woody vegetation in the Treatment Zone.*

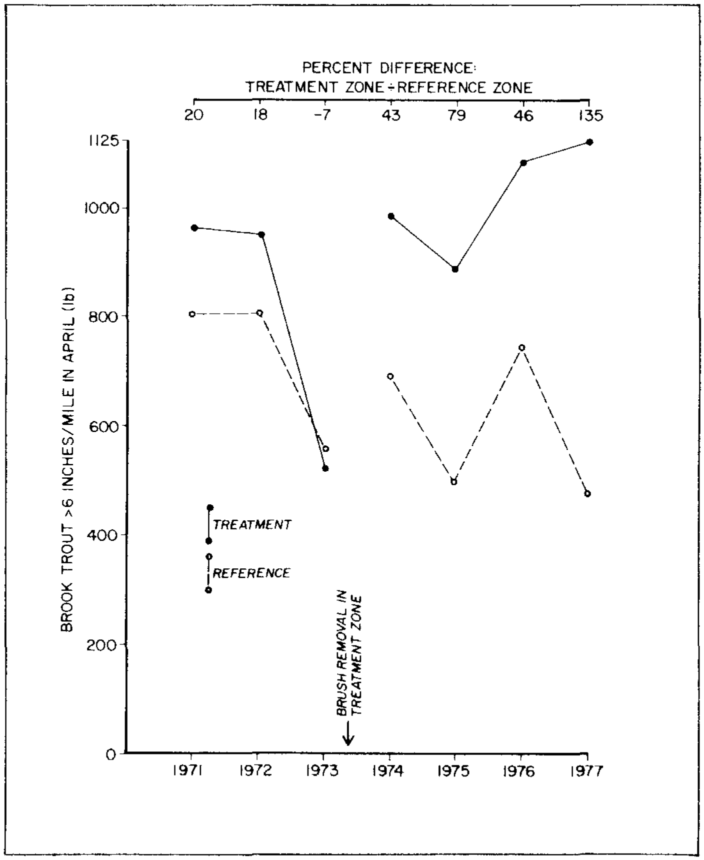



**FIGURE 19.** *Number of brook trout over 6 in. long/mile in April in the Treatment and Reference Zones of Spring Creek before (1971-73) and after (1974-77) removal of woody vegetation in the Treatment Zone.*

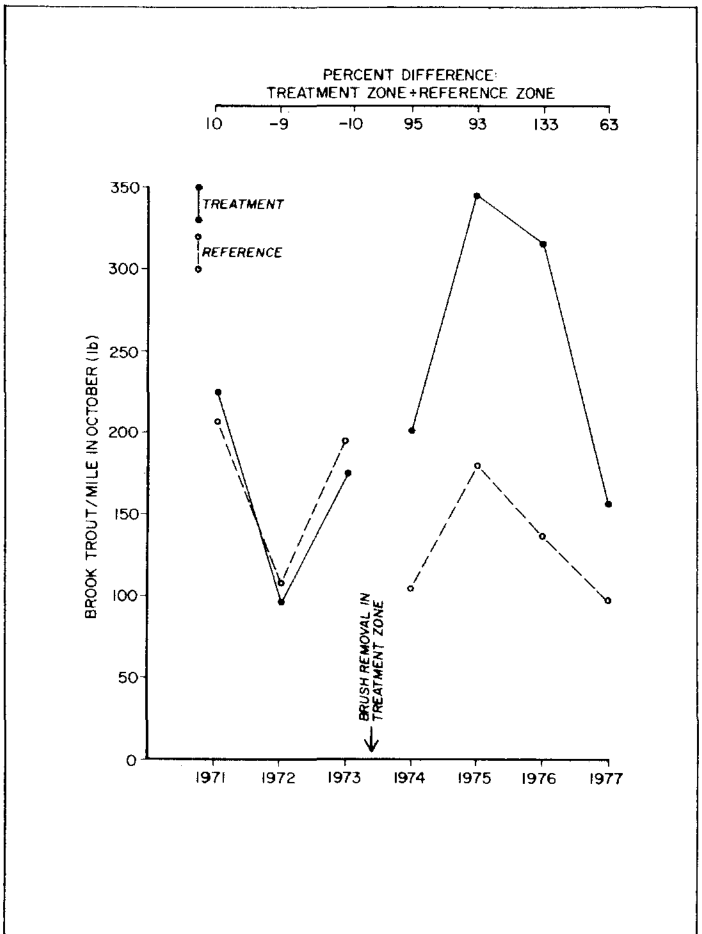



**FIGURE 18.** *Pounds of brook trout/mile in October in the Treatment and Reference Zones of Spring Creek before (1971-73) and after (1974-77) removal of woody vegetation in the Treatment Zone.*

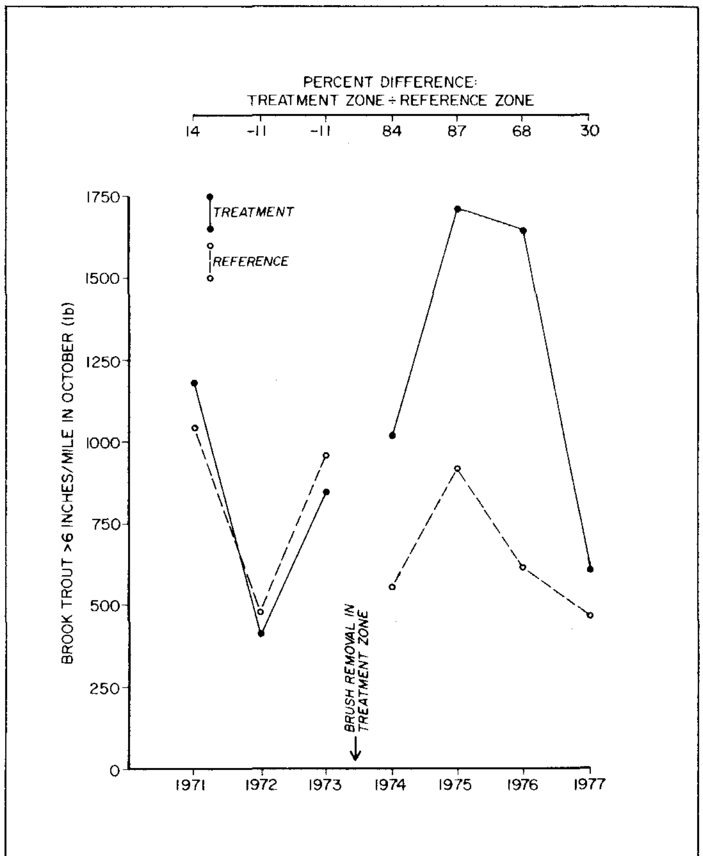



**FIGURE 20.** *Number of brook trout over 6 in. long/mile in October in the Treatment and Reference Zones of Spring Creek before (1971-73) and after (1974-77) removal of woody vegetation in the Treatment Zone.*

## TROUT GROWTH RATES

In all three streams, growth rates of most age groups of trout improved slightly in Treatment Zones after brush removal relative to concomitant growth rates in Reference Zones (Tables 14-16, Append.). In the Little Plover River growth rates of age groups 0-III were compared for average April-September incremental changes in length in each zone and each study phase (Fig. 21). Mean April-September growth of age 0 stocks was 4% better in the Treatment Zone than in the Reference Zone during the pretreatment phase but 14% better for the posttreatment phase. For age I stocks, the change was from no difference to a 23% difference in favor of the Treatment Zone. Ages II and III stocks also reflected comparatively better growth for the posttreatment phase.

In Lunch Creek, incremental growth of ages 0-III stocks of brown trout was better in the Reference than in the Treatment Zone for all four age groups during the pretreatment phase, but during the posttreatment phase ages 0 and III grew equally well in the zones and the difference in growth of ages I and II stocks was less between zones although still better in the Reference Zone (Fig. 22).

In Spring Creek, three of the four age groups showed improved growth in the Treatment Zone relative to that in the Reference Zone during the posttreatment period (1974-77). For age 0 stocks incremental growth changed from 3% less in the Treatment Zone than in the Reference Zone to 4% better; for age I stocks from 5% less to 21% more; for age II stocks from 15% less to no difference (Fig. 23).

## THE SPORT FISHERY

**Little Plover River.** During the 130-day 1970 trout fishing season, periodic counts of angler vehicles and on-site interviews were made on 94 days. Based on an assumed season-long "fishing day" of 15 hr, the census effort covered 72% of the total days and 39% of the total fishing hours. Interviews were made with 206 anglers, and 485 creeled trout were examined.

The 1972 fishing season lasted 125 days, of which 69% were included in the creel census covering 36% of the total fishing hours. Interview data were obtained from 190 anglers who had kept 415 brook trout, all of which were measured for length and examined for known-age marks.

During the 1976 posttreatment fishing season of 140 days, 70% of the days and 41% of the fishing hours were censused. Contacts were made with 400 anglers who had kept 361 brook trout.

Seasonal estimates of nine characteristics of the sport fisheries for 1970, 1972 and 1976 are summarized in Table 10 for three study zones. In addition to the Reference and Treatment Zones referred to in other segments of the evaluation study on the Little

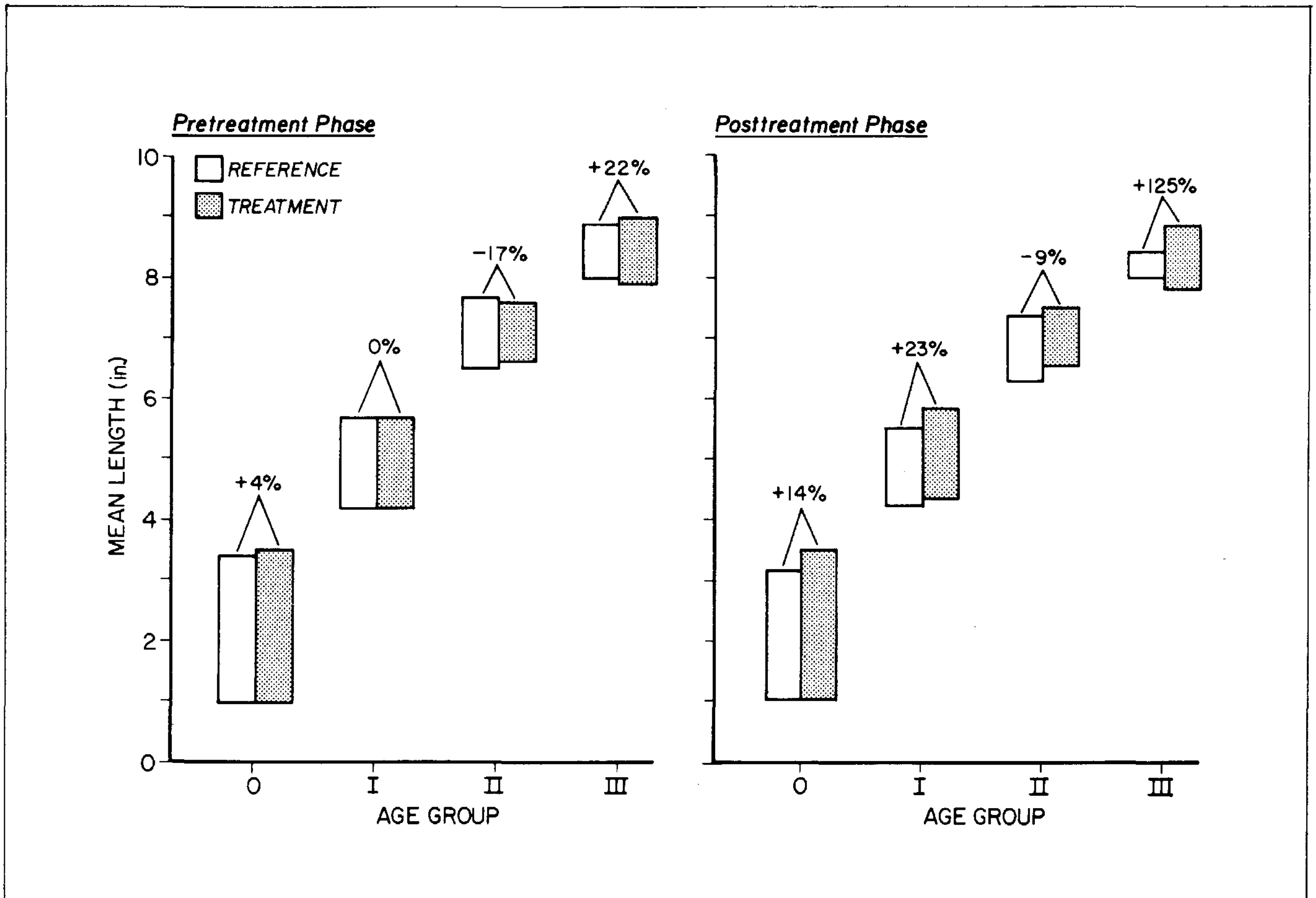



**FIGURE 21.** *Mean April-September increments of growth of brook trout in the Treatment and Reference Zones of the Little Plover River before (1970-72) and after (1973-77) removal of woody vegetation in the Treatment Zone. Percent values cited equals Treatment Zone increment divided by Reference Zone increment.*

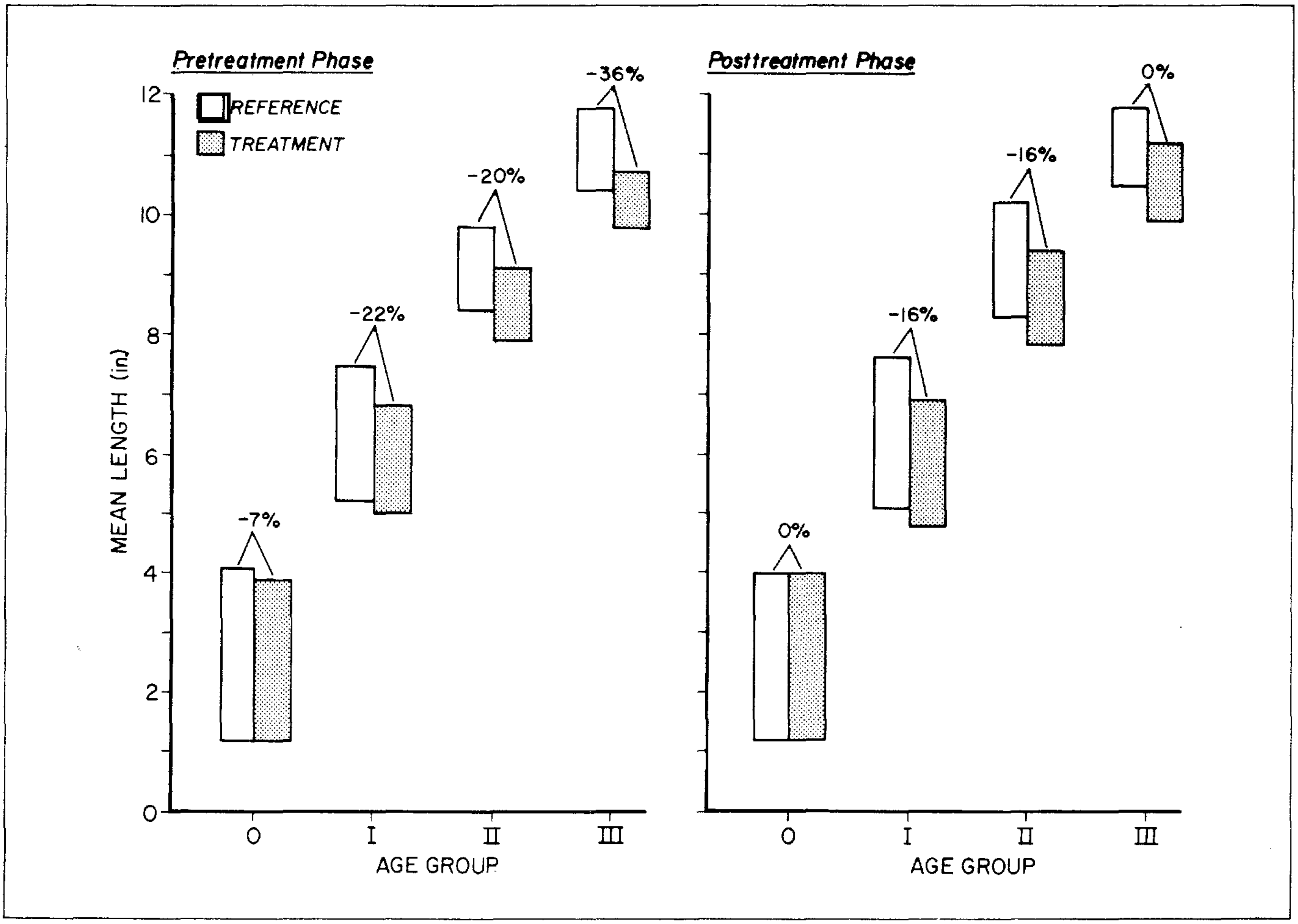



**FIGURE 22.** *Mean April-September increments of growth of brown trout in the Treatment and Reference Zones of Lunch Creek before (1971-73) and after (1974-77) removal of woody vegetation and the Treatment Zone. Percent value cited equals Treatment Zone increment divided by Reference Zone increment.*

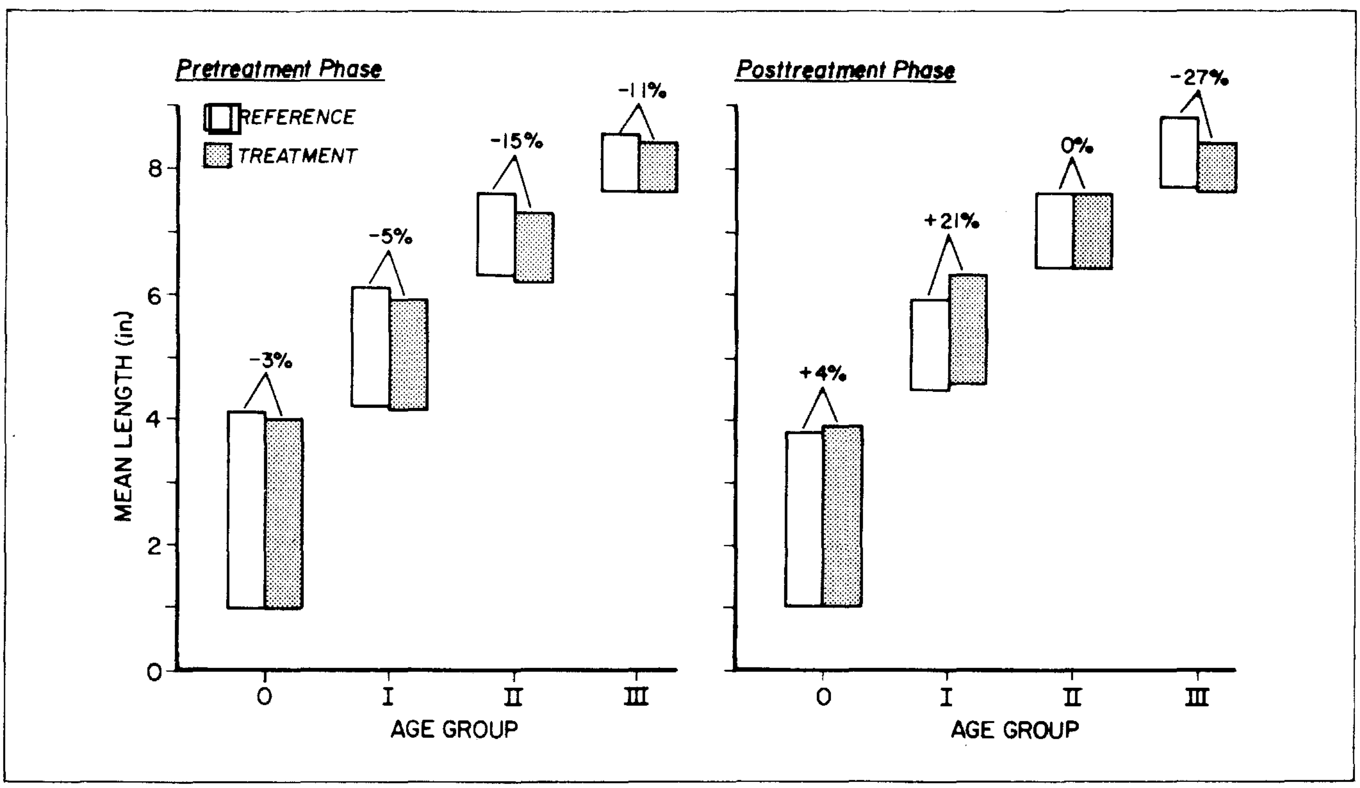



**FIGURE 23.** *Mean April-October increments of growth of brook trout in the Treatment and Reference Zones of Spring Creek before (1971-73) and after (1974-77) removal of woody vegetation in the Treatment Zone. Percent value cited equals Treatment Zone increment divided by Reference Zone increment.*

**TABLE 10.** *Selected creel census indexes for the sport fishery for brook trout in three study zones of the Little Plover River before (1970-72) and after (1976) removal of woody vegetation in the Treatment Zone.*

| Item | Meadow Zone* | | | Reference Zone** | | | Treatment Zone | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1970-72 Avg. | 1976 | % Change | 1970-72 Avg. | 1976 | % Change | 1970-72 Avg. | 1976 | % Change |
| Angling trips/mile | 254.7 | 458.8 | 80 | 132.4 | 696.3 | 425.9 | 132.4 | 530.4 | 300.6 |
| Angling hours/mile | 372.0 | 792.9 | 113 | 237.5 | 676.3 | 184.8 | 237.5 | 674.2 | 183.9 |
| Yield: | | | | | | | | | |
| Number/mile | 395.3 | 855.9 | 117 | 414.0 | 607.6 | 46.8 | 414.0 | 438.0 | 5.8 |
| Pounds/mile | 53.3 | 111.0 | 108 | 66.2 | 85.5 | 29.2 | 66.2 | 61.8 | -6.7 |
| Avg. length (in.) | 7.2 | 7.2 | 0 | 7.7 | 7.5 | -2.6 | 7.7 | 7.5 | -2.6 |
| Trout released/mile | — | 912.1 | — | — | 316.4 | — | — | 438.0 | — |
| Catch Rate: | | | | | | | | | |
| Creeled/hour | 1.23 | 0.96 | -22 | 1.71 | 0.92 | -46.2 | 1.71 | 0.63 | -63.2 |
| Released/hour | — | 1.01 | — | — | 0.93 | | — | 1.17 | |
| Exploitation Rate (%) | 9.8 | 27.3 | 178.6 | 15.6 | 39.6 | 153.8 | 10.4 | 54.5 | 424.0 |

*Meadow Zone = 0.75-mile portion beginning 0.23 miles above the Treatment Zone.

**Reference Zone = Two 0.23-mile portions bounding the 0.45-mile Treatment Zone.

Plover River, sport fishery data for the Meadow Zone are also included.

Creel census data (other than exploitation rate) for the Reference and Treatment Zones had to be combined for the 1970 and 1972 fishing seasons even though this was not the intent of the original experimental design. The change was necessitated by the fact that most anglers could not distinguish where the Reference Zone ended and the Treatment Zone began because the zones looked similar prior to brushing of the Treatment Zone. Consequently sport fishing indexes for 1970 and 1972 provided no insights into potential differences in angling between these two zones, except that separate exploitation rates were calculated (Table 10).

Assuming equal harvest/mile in the Reference and Treatment Zones, but known and differing standing stocks (derived from April electrofishing inventories), angler exploitation was estimated to average 15.6% in the Reference Zone and 10.4% in the Treatment Zone for the 1970 and 1972 fishing seasons. In the Meadow Zone (whose boundaries anglers could easily recognize), average angling exploitation was only 9.8%. Angling effort and catch rate were highest in this zone, but relative yield (both number creeled/mile and pounds cropped/mile) was less than in the Reference and Treatment Zones.

Angling effort increased substantially in all three study zones during 1976, the first season after terminating the 3-year refuge status for these zones and the first year of fishing since brush removal in the Treatment Zone. Among comparisons of 1976 fishery statistics between the Treatment Zone and Reference Zone, trips/mile, hours of fishing/mile, trout creeled/mile, pounds cropped/mile and catch rate of trout creeled/hour were all higher for the Reference Zone fishery. Only two indexes, trout released/mile and catch rate/hour for trout released, were higher for the Treatment Zone. In both zones mean length of trout kept was 7.5 in., a 3% decline from the 1970-72 average of 7.7 in. Angler exploitation rates in 1976 were up considerably over the pretreatment average. In the Treatment Zone, harvest was equivalent to 54.5% of the preseason stock. In the Reference Zone the number of trout kept by anglers equalled 39.6% of the preseason stock.

In terms of hours fished/mile/zone the Meadow Zone was again the hardest-fished zone in 1976, as it had been in 1970 and 1972. Yield in 1976 was also proportionately greatest in the Meadow Zone, but angling exploitation was the lowest of the three zones, 27.3% — a reflection of the greater standing stock of trout in this zone in April than in the Treatment or Reference Zones, but a much higher rate of exploitation than the 9.8% average for the 1970 and 1972 fishing seasons.

# DISCUSSION

Unanticipated variations in stream flow proved to be a major confounding influence in meeting the original objectives of this study — to assess the impact of removing woody streambank vegetation on trout populations, trout habitat and the sport fisheries. However, in terms of new ecological knowledge about trout streams and their management, this influence of stream flow may prove to be a particularly valuable bonus: an unexpected dividend in resolving escalating societal conflicts over the "best uses" of fluvial waters, and a warning to fishery biologists and researchers to give more attention to the importance of stream flow when managing or investigating trout stream ecosystems. Although abnormally high discharges can be hazardous for trout, particularly during incubation and the first few weeks after emergence, abnormally low flows usually constitute more serious threats. Such conditions increase the hazards of undesirable stream temperatures for trout, reduce trout living space and access to hiding and escape cover, reduce availability of invertebrate drift — their primary source of food — and may prevent access to spawning grounds (Wesche 1973; White 1973).

Reliable discharge data were obtained over the course of this study for the Little Plover River only. However, annual discharges of all monitored streams in Wisconsin support the conclusion that a statewide pattern of progressively worse stream flows characterized the 1974-77 period encompassing most of the posttreatment phase (U.S. Geological Survey 1970-77). Discharge of the Wisconsin River, for example, which has the largest drainage in the state, reached a 63-year record low in the fall of 1976. That of the Chippewa River, another major drainage, fell to a 60-year record low for the same season (U.S. Geological Survey 1976). Of the three streams involved in this study, the Little Plover River was the one most intensively studied and was probably the most severely influenced by variation in discharge. The initial increase in the standing stock of brook trout in the Treatment Zone in 1973 as compared to 1970-72, and subsequent declines in seasonal abundance and biomass during 1974-77, were closely paralleled by changes in stream discharge (Fig. 24). Highest biomass, in September 1973, was associated with the summer of greatest average discharge. Lowest biomass, in September 1977, was associated with the summer of lowest average discharge. In the first posttreatment summer of 1973, average discharge at the upper boundary of the Treatment Zone increased by 108% over the pretreatment summer of 1972. This change was accompanied by a 97% increase in fall biomass. From 1973 through 1977, average summer discharge declined by 75% in the Treatment Zone and fall biomass declined by 95%, from a study period maximum of 337.3 lb/mile to a study period minimum of only 17.8 lb/mile. There appears to be no environmental correlate other than discharge that could have altered trout-carrying capacity so dramatically — and by responding to shade canopy removal by first improving carrying capacity and

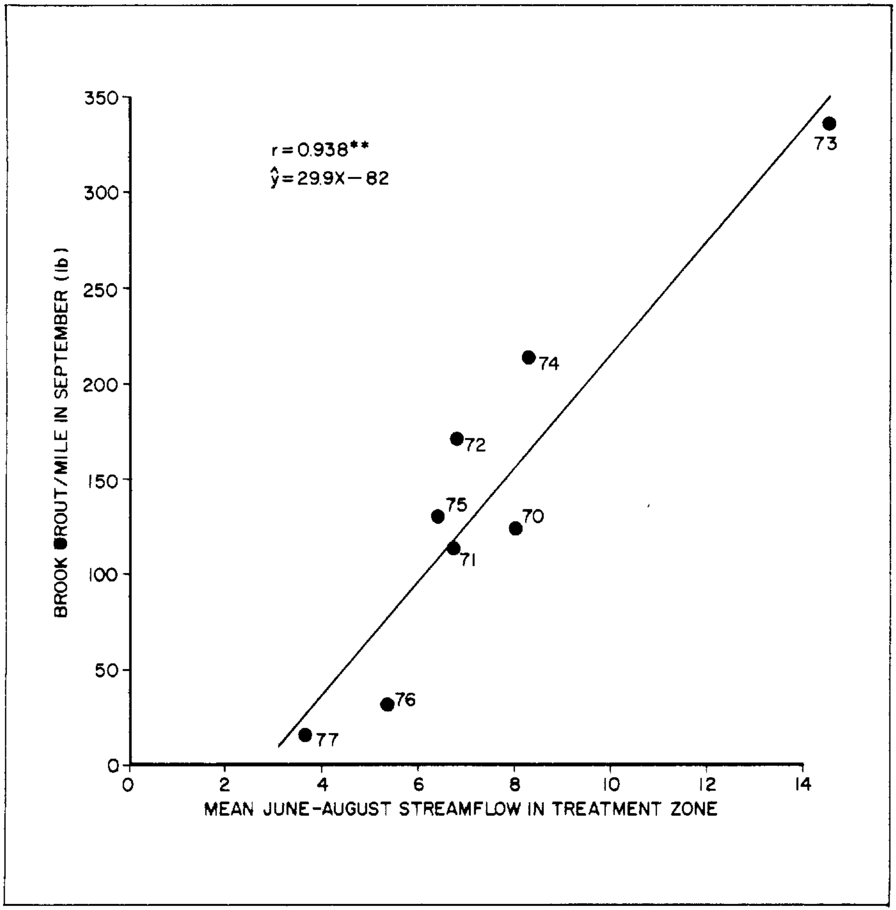



**FIGURE 24.** *Relation of summer discharge to fall trout-carrying capacity in the Treatment Zone in the Little Plover River during 1970-77.*

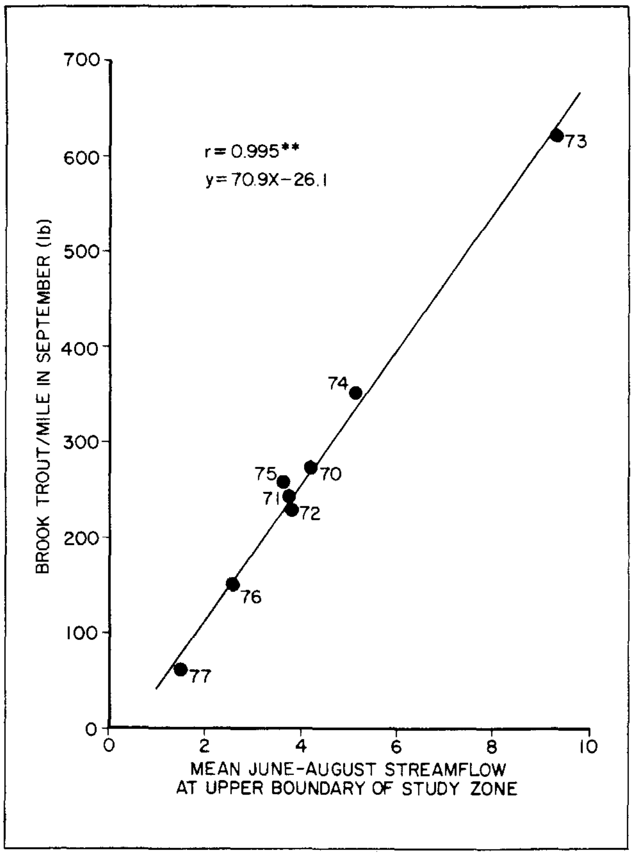



**FIGURE 25.** *Relation of summer discharge to fall trout-carrying capacity in the Meadow Zone of the Little Plover River during 1970-77.*

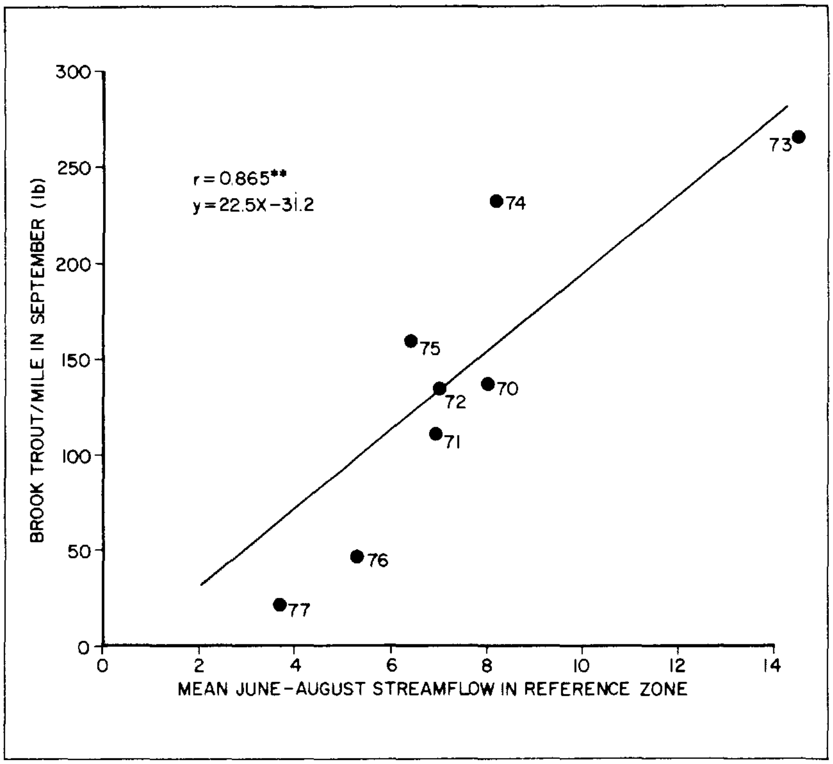



**FIGURE 26.** *Relation of summer discharge to fall trout-carrying capacity in the Reference Zone of the Little Plover River during 1970-77.*

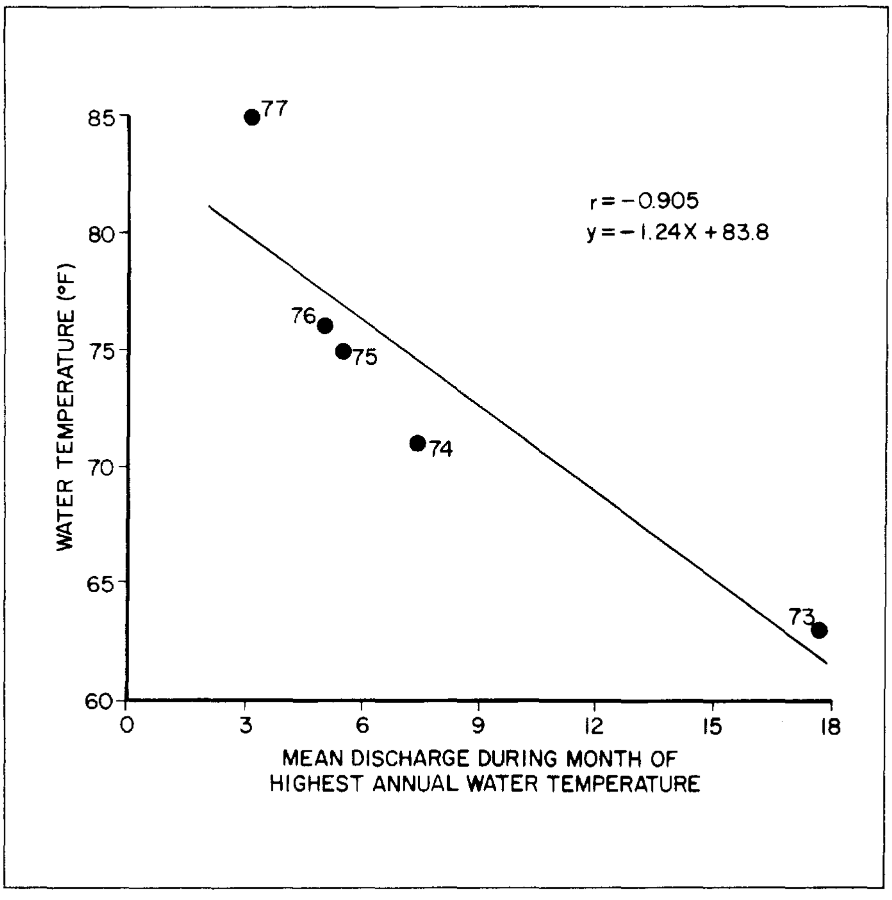



**FIGURE 27.** *Relation of annual maximum water temperature in the Treatment Zone of the Little Plover River and mean monthly discharge at the upper boundary of the Treatment Zone for the month in which maximum temperature occurred during 1973-77.*

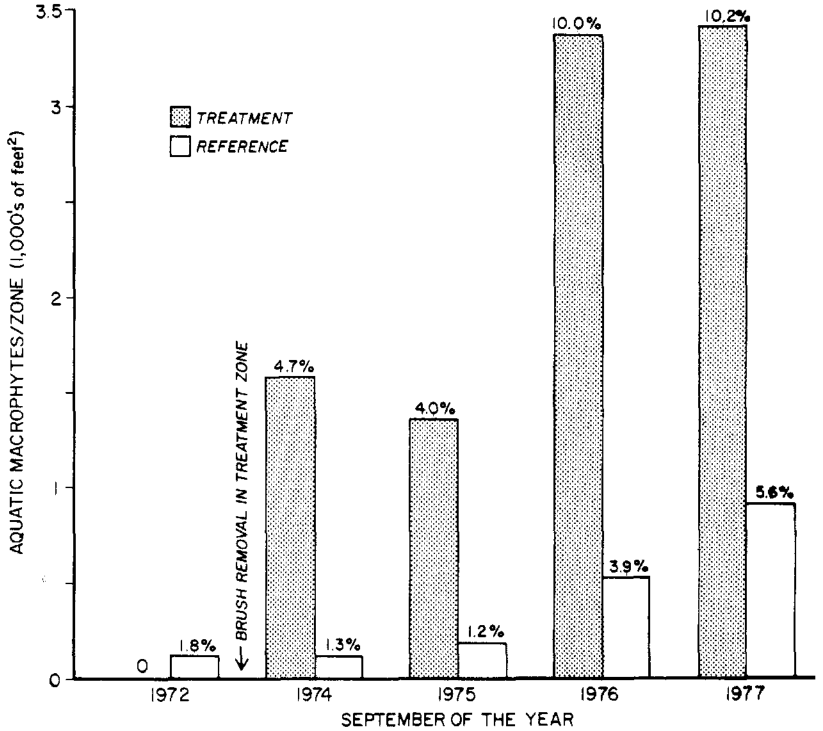



**FIGURE 28.** *Abundance of aquatic macrophytes in the Treatment and Reference Zones of the Little Plover River before (1972) and after (1974-77) removal of woody vegetation in the Treatment Zone. The proportion of Zone bottom occupied by macrophytes is shown by percentage on top of each bar.*

then increasingly constricting it for 4 successive years.

Additional evidence that streamflow regime was a critical physical variable limiting abundance of trout in the Little Plover River during the study period is seen in the even stronger correlation ($r$ = 0.995**) between summer discharge and fall biomass in the Meadow Zone where there was no deliberate reduction in shade canopy (Fig. 25), and the highly significant correlation ($r$ = 0.865**) that also characterized summer discharge and fall biomass in the Reference Zone where net radiation measurements indicated a slight increase rather than decrease in channel shading during the study (Fig. 26).

White et al. (1976) found similar significant correlations between mean summer flow and fall biomass of brook trout for Big Roche a Cri Creek (in central Wisconsin) for the 1957-65 period and for Hunt Creek (north central tip of lower Michigan) for the 1966-75 period. Stream flow also proved to be the most important of six physical environmental variables influencing standing stocks of brook trout in the experimental sections of Black Tail Creek in Montana studied by Kraft (1972).

Variation in stream flow also had a profound impact on maximum summer water temperatures of the Little Plover River (Fig. 27). At the upper boundary of the Treatment Zone, for example, the lowest summer maximum of 63°F occurred in June 1973, the summer of highest average discharge. The highest water temperature at this recording site was 85°F in July 1977, the summer of lowest average discharge. Both the discharge and temperature data summarized in Figure 30 are independent of influences due to brush removal, which was done downstream from this recording site. Weeks and Stangland (1971) also concluded that variations in stream flow of the Little Plover River had a significant influence on summer water temperatures during the 1964-67 period of their studies.

Despite water temperatures of 85°F in the Meadow Zone, 86.5°F in the Treatment Zone and 87°F in the Reference Zone during July 1977, temperature-induced mortality of trout was not observed even though such temperatures are considered to be well in excess of upper tolerance limits for brook trout (Brasch et al. 1973; Bridges and Mullan 1958; Cherry et al. 1975; McCormick et al. 1972). If such mortality did occur, it was not noticed by DNR personnel during weekly visits to service temperature recorders, and none was reported by anglers.

Perhaps in a stream like the Little Plover River, where inputs of groundwater seepage are nearly continuous throughout the study zones (Weeks et al. 1965), trout are able to survive by seeking out tolerable microhabitats within the larger temperature-intolerable water mass. Regardless of such speculation, however, there were still substantial numbers of trout in all zones just two months later when the September electrofishing inventory was conducted. Stock abundance was the lowest on record at that time in all zones, but understandably low in relation to the scarcity of living space and related decrease in usable underbank hiding cover due to low flow. Stream flow reached a record low in August 1977 for the 8-year study period (Table 2).

The combination of low flow and abnormally high water temperatures could have triggered emigration of trout from the 1.66-mile study area on the Little Plover River, thus accounting for the low standing stocks there in the fall of 1977; but if such movement had occurred, migrants would have encountered worse temperature conditions in the main stream above the Meadow Zone (shallower, wider and heavily silted due to cattle pasturing) and in the stream or shallow impoundment below the Reference Zone.

Abnormally low stream flow throughout most of the posttreatment phase is also believed to be a principal cause for failure of the sport fishery to improve in the Treatment Zone of the Little Plover River, and in the other study zones as well.

Abundance of trout in the Treatment Zone when the 1976 fishing season began was only one-fourth that present at the beginning of the 1970 and 1972 pretreatment seasons censused. Angler use in terms of seasonal trips and hours increased 301% and 184% respectively in the Treatment Zone after brush removal, but these increases probably reflected angler anticipation of improved fishing after three years of refuge status. As measured by catch/hour and yield, angling in 1976 was better in the brushy Reference Zone than in the brush-cleared Treatment Zone.

One sport fishery objective of brush removal was attained despite complications of low flow. Exploitation rate increased from 10% in the Treatment Zone prior to brushing to 55% after brushing.

In retrospect, more useful information on a sport fishery for a brush-cleared stream would have been gathered if the same amount of creel census effort had been expended at Spring Creek. There, there would have been no bias in the fishery due to temporary imposition of a fish refuge, and trout population responses were positive, as hypothesized, despite decreased stream flow. However, financial limitations prevented operation of more than one creel census effort.

The importance of normal stream flow in attaining study objectives was also evident in relation to postulated changes in morphometry of Treatment Zones after brushing. Failure of these zones to both narrow and deepen, particularly in Lunch Creek and the Little Plover River, would seem to be a logical result of decreased discharge during most of the posttreatment phase.

Despite a 28% decrease in channel width of the Treatment Zone on the Little Plover, the channel's average depth decreased by 7%. At Lunch Creek, average depth of the Treatment Zone did not change after brush removal despite a modest 2% reduction in channel width. If posttreatment discharge had been normal or similar to that in 1973, average depth should have increased in both Treatment Zones due to channel constriction, and in the Little Plover as an additional consequence of flow constriction caused by increased abundance of aquatic plants.

Concomitant changes in channel shape of Reference Zones in the Little Plover River and Lunch Creek reflected even greater deterioration of trout habitat quality during the study period, a factor that lends some indirect credence to the management concept of brush removal: trout habitat quality in Treatment Zones probably would have been even worse in 1977 in comparison with 1971 if they had not been brushed, just as it was in the unbrushed Reference Zones. Once channel constriction has been accomplished by means of establishment of a grassy turf and undercut banks, brush removal, like more intensive renovation of stream channels with bank covers and current deflectors, may prove to be more beneficial in sustaining trout-carrying capacity in years of low flow than in years of normal or above normal flow (White 1972).

Average depth and channel volume of the Treatment Zone on Spring Creek increased after brushing, despite a slight increase in average width and the probability that discharge was below normal.* I suspect that these seemingly incompatible changes after brushing were the consequence of prolific but unmeasured growth of aquatic vegetation, vegetation that became abundant enough to cause both increased scouring of the substrate and substantial damming-flooding effects even at lower than normal flow.

Such effects caused by lush growth of aquatic macrophytes are viewed as a common management problem rather than as desirable habitat change in many fertile streams of England (Dawson 1978), Germany (Krause 1977) and Denmark (Dawson and Kern-Hansen 1978). While mechanical removal of aquatic weeds to reduce the risk of flooding is still the conventional management solution in these countries, it is relevant to my study to note that all three investigators have proposed "biological management" schemes based on reducing aquatic weeds by planting streamside shade trees. Kern-Hansen and Dawson (1978) also collaborated in an investigation demonstrating that the abundance of aquatic plants was limited primarily by terrestrial shade, not dissolved nutrients, in a series of some 19 lowland streams of Denmark. Undesirable heavy growths of aquatic plants that subsequently impede flow and increase the risk of flooding along such lowland streams could not be practically prevented by management schemes to reduce concentration of the major chemical nutrients.

Failure of the brown trout population in Lunch Creek to respond positively to brush removal may have been due in part to failure of aquatic macrophytes to become a dominant feature of the Treatment Zone environment, in contrast to the situation at Spring Creek. A few sparse beds of water buttercup were observed to be developing in 1976-77, but these vegetational stands probably never accounted for coverage of more than 1-2% of the substrate area.

Aquatic macrophytes responded as hypothesized in the Treatment Zone of Little Plover, increasing from nearly total absence prior to brushing to coverage of 3,426 ft$^2$ of substrate by the fall of 1977 (Fig. 28).

Responses of the brook trout stock in the Treatment Zone of Spring Creek were quite supportive of the primary hypothesis of this study, especially when viewed against concomitant stock declines in the unbrushed Reference Zone. Success in this stream as opposed to failures on the Little Plover and Lunch Creek probably reflects a combination of synergistic factors: more stable discharge during the posttreatment phase, greatly increased abundance of aquatic plants, greater scouring and deepening of the stream channel and continued good recruitment of age 0 stocks. The standing stock of brook trout in the Treatment Zone was at its best in comparison with the stock in the Reference Zone in April 1977, four years after brushing, when biomass was 119% greater (Fig. 17) and density of legal-sized trout was 135% greater (Fig. 19) in the Treatment Zone than in the Reference Zone. Increased abundance of trout in the Treatment Zone of Spring Creek could have reflected wholly or in part a volitional movement of trout from the Reference Zone. Trout were not marked differently in the two study zones, so such movement could be neither refuted nor confirmed. Whether the habitat changes in the Treatment Zone improved the survival rate of the resident stock or whether trout moving into the altered zone preferred it to the habitat they vacated, it seems logical to conclude that in either case streambank brushing accomplished a major purpose — production of a larger stock of legal-sized trout.

*Depth to water level in an irrigation well about 15 miles north of Spring Creek was monitored continuously by the USGS during the study period. Average annual depth varied by only 2.8% during that seven-year period, but the pattern of fluctuations was similar to that for stream discharge for the Little Plover River, i.e., highest in 1974 (43.2 ft below ground surface) and steady decline in successive years to a record low in August 1977 (45.1 ft below ground surface) (USGS record for M. F. Mommsen well located east of Cameron, Wisconsin).

## OTHER BRUSH REMOVAL PROJECTS IN WISCONSIN

Since initiation in 1970 of the experimental brush removal study reported here, DNR fish managers have carried out at least a dozen similar cutting and clearing projects on trout streams. Of necessity, none of these projects has been evaluated as extensively as this study and for a variety of reasons only three of these projects to date have yielded data that permitted assessments of changes in trout numbers and/or biomass.

Woody vegetation, including many large box-elder trees *(Acer negundo)*, was removed from 30-ft strips paralleling banks of four densely shaded study zones on the Kinnikinnic River, St. Croix Co., during the winters of 1973-74 (Bert Apelgren, pers. comm.). Total length of the cleared zones was 0.84 mile. Average increases in abundance and biomass of wild brown trout in April, based on one pretreatment estimate/zone and three posttreatment estimates/zone were as follows: 45% increase in number/mile (from 4,806 to 6,988); 32% increase in legal trout/mile (from 2,497 to 3,094); 86% increase in biomass for all sizes (from 193 lb/acre to 359); 80% increase in biomass for trout over 6 in. (from 167 lb/acre to 300). Channel width of the cleared zone at the time of brushing averaged 28 ft, the widest stream channel along which reduction of shade canopy has been attempted to date in Wisconsin. The increase in rooted aquatic vegetation, primarily *Ranunculus* sp. and *Elodea* sp., was judged to be "dramatic" by the fish manager in charge of the project.

In September 1976, trout population estimates were made in four study zones of McCann Creek in Chippewa Co. Two of the zones totalling 0.35 miles had been brushed during the winters of 1974-75, while two zones totalling 0.17 miles of stream were not brushed. Brushed and unbrushed zones alternated. Speckled alder was the dominant shade species removed from 30-ft strips along both stream banks. Prior to brushing, the four zones were environmentally similar (Stuart Hagen, pers. comm.).

*During the first summer of streambank brushing along McCann Creek, lush beds of watercress developed, helping to rapidly narrow the channel, meander stream flow and provide cover for trout.*

No quantitative information was collected on the wild brook trout stocks in the study zones prior to brushing. However, approximately 16 months after completion of cutting and clearing, the two cleared zones in comparison to the two unbrushed zones contained an average of: 33% more brook trout/mile (9,296 vs 6,970); 69% greater biomass/acre (233 lb/acre vs 138). Average width was 10% less (16.0 vs 17.8 ft) and average depth 33% greater (14.8 vs 11.1 in.) in the cleared zones than in the unbrushed zones at the time of the electrofishing inventory of the trout stocks. Exceptionally lush growths of watercress developed in the Treatment Zones of McCann Creek during the first summer after brushing, greatly enhancing both the quantity of hiding cover for trout and its esthetic appearance.

Dense growths of speckled alder were removed along two portions of Behning Creek, a small (avg. width 6.0 ft) brook trout stream in southwest Polk County. Approximately 727 ft of both stream banks were cleared during the winter of 1975-76 in Zone 1 and 555 ft of both stream banks were brushed in the winter of 1976-77 in Zone 2 (Richard Cornelius, pers. comm.). Width of the cleared strips averaged approximately 20 ft. In Zone 1 the number of brook trout (age I or older) in the spring decreased after brushing: by 25% after one year (from 360/acre to 270; by 56% after two years (from 360/acre to 160). In Zone 2 there was an increase of 45% in the number of brook trout during the first posttreatment year (from 470/acre to 680).

No rooted aquatic vegetation was observed in either zone prior to brushing. During the first posttreatment summer, sparse stands of watercress and tape grass *(Vallisneria americana)* became established, and both species increased slightly in abundance during the second summer in Zone 1. No posttreatment data have as yet been obtained to assess physical changes in channel morphometry.

# MANAGEMENT CONSIDERATIONS

1. This report covers evaluation of only one management approach to improving trout habitat by reducing shade canopy — an approach that involved nearly 100% removal of woody vegetation from both stream banks. Primarily on the basis of habitat and trout population responses in the Treatment Zone of Spring Creek, the stream least influenced by below-normal discharge, supplemented by data from two less intensive management investigations, I conclude that deliberate shade canopy removal has enough management potential to merit further application.

Optimism about the merits of streambank brushing based on the success of management along Spring Creek, the Kinnikinnic River and McCann Creek should continue to be tempered with caution until results of several more experimental treatments have been adequately evaluated.

Three such experimental approaches worth evaluation are:

(a) Removal of shade canopy from one bank only at any given point along the proposed treatment sector.

(b) Removal of shade canopy from both stream banks but for shorter distances than I tested; i.e., exposure of the stream channel to enough increased solar radiation to stimulate proliferation of aquatic macrophytes and establishment of grassy turf banks, but with interspersed retention of woody shrubbery where it still provides good hiding cover for trout and will continue to have a buffering impact on summer water temperatures.

(c) Removal of shade canopy from one or both streambanks for several hundred yards, as was done in my evaluation, but only after half-logs (Hunt 1977) have been installed to provide in-channel hiding cover for trout to replace and augment hiding cover removed by brushing. This combination of management practices would potentially produce immediate gains in hiding cover and fishability, and more gradual improvements in channel shape, trout food production and bank stabilization.

2. Although the findings of this study are not conclusive, the degree of likely increase in aquatic macrophytes may be especially important in determining the degree of improvement in trout-carrying capacity. A decision to proceed with shade removal should include assessment of the potential for pioneer establishment of aquatic plants where none exist or for expansion of existing stands. Consider whether desired plants are already present in sparsely shaded reaches and whether suitable substrates for plant colonization are present in reaches to be brushed.

3. Cost of the cutting and removal operation along the Little Plover River was approximately $450/acre cleared or $3,000/mile of stream (1973 prices). About 75% of the expense was for manual labor, estimated at 90 hr/acre. (No volunteer labor was involved in this project.) Cost of the herbicide and its application accounted for approximately 20% of the total. The remaining 5% involved purchase of seed and seeding. Time and money devoted to seeding cutover areas with a mixture of grasses, as was done along the Little Plover River, are probably not necessary inclusions in brushing projects if natural areas of desired vegetation already exist along part of the stream. Desirable marsh-meadow habitats developed just as rapidly along Lunch Creek and Spring Creek, where no artificial seeding was done, as along the Little Plover.

4. Herbicide suppression of regrowth of woody vegetation is highly recommended. The procedure used in this study worked adequately. Herbicide (Ammate X-NI is recommended) was sprayed on all cut stumps as soon as day-long air temperatures were in the recommended range for the herbicide used. A few weeks later a touch-up cutting and second spraying was performed to suppress regrowth missed on the first spraying. No additional cutting and herbicide application was needed until 5 years later, at which time approximately 10 hr/acre were expended on the first areawide maintenance operations in the Treatment Zones.

5. Chances are good that brush removal projects will trigger increased recreational use and greater angler harvest, desirable consequences for most stream fisheries where such removal is contemplated. Where budgetary constraints permit, a creel census to document changes in angler use and exploitation is desirable, to determine if greater use and exploitation do occur and to evaluate whether potential increases in trout numbers and biomass are being suppressed by increased exploitation resulting from easier fishing conditions.

6. Growth rates of most age groups of trout should improve following brushing.

7. Pretreatment water temperature data should be gathered during one or two June-August periods. Two factors to consider when evaluating such water temperature data prior to a decision on brushing are these:

(a) Were temperature observations taken during a summer when stream discharge was about normal, above normal or below normal? Since variations in stream flow can have significant influence on summer water temperatures, especially on small streams which are the most likely candidates for streambank brushing in Wisconsin, consideration of streamflow regimes is particularly critical. If on-site data on normalcy of summer flow are not available to correlate with data obtained on maximum summer water temperatures, projections of departures from the normal in summer flow should be made based on data available for the nearest similar stream.

(b) Was the summer air temperature regime normal, above normal or below normal during the period of collecting water temperature data? The combination of below normal air temperatures and above normal summer flow could be particularly deceptive in providing data that would more strongly support a decision to proceed with a brushing project than would data obtained when both air temperature and streamflow during the summer were normal.

8. Reduction of shade canopy as a technique to improve trout stream habitat is one that is particularly adaptable to use of volunteer labor during cutting and clearing phases. Such work can be done at almost any time of the year. If volunteer cooperators are used, discuss with them the ecological hypotheses of such management. They should be told that this technique is still in the experimental phase: applications to date have been successful in situations where changes in stream discharge have not interfered, but more varied testing is still needed before definitive guidelines are established for choosing the severity of shade removal to carry out and for predicting the degree of improvement to expect in the trout habitat, trout populations and sport fisheries.

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**TABLE 11.** *Standing stocks of brook trout in the Treatment and Reference Zones of the Little Plover River, April and September, 1970-77.*

| Study Zone | Item | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | Pretr. Avg.** | Posttr. Avg.** | % Difference[1] | "t" value[2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Treatment | No/mile in April | 3,518 | 2,451 | 2,160 | 2,144 | 3,153 | 1,698 | 804 | 287 | 2,568 | 1,486 | -42 | |
| Reference | | 3,215 | 2,610 | 2,093 | 1,706 | 2,520 | 2,918 | 1,535 | 660 | 2,406 | 1,908 | -21 | |
| | Remainders* | 303 | -159 | 67 | 438 | 633 | -1,220 | -731 | -373 | 162 | -423 | | 1.41, n.s. |
| Treatment | No/mile in Sept. | 3,602 | 2,851 | 3,660 | 5,129 | 3,440 | 2,662 | 1,076 | 451 | 3,371 | 2,552 | -24 | |
| Reference | | 4,259 | 2,782 | 2,696 | 4,484 | 4,646 | 2,756 | 1,141 | 572 | 3,246 | 2,720 | -16 | |
| | Remainders | -657 | 69 | 964 | 645 | -1,206 | -94 | -65 | -121 | 255 | -372 | | 0.56, n.s. |
| Treatment | lb/mile in April | 191.3 | 109.8 | 106.2 | 133.1 | 250.4 | 116.0 | 58.9 | 15.1 | 135.1 | 110.0 | -19 | |
| Reference | | 185.4 | 129.6 | 108.3 | 111.7 | 210.2 | 166.3 | 108.5 | 40.2 | 133.8 | 131.3 | -2 | |
| | Remainders | 5.9 | -19.8 | -2.1 | 21.4 | 40.2 | -50.3 | -49.6 | -25.1 | 1.4 | -21.2 | | 0.98, n.s. |
| Treatment | lb/mile in Sept. | 122.7 | 114.7 | 171.3 | 337.3 | 214.9 | 132.0 | 31.6 | 17.8 | 136.2 | 146.7 | +8 | |
| Reference | | 135.8 | 110.9 | 134.4 | 266.6 | 232.6 | 158.3 | 45.4 | 21.5 | 127.1 | 144.9 | +1 | |
| | Remainders | -13.1 | -3.8 | 36.9 | 70.7 | -17.7 | -26.3 | -13.8 | -3.7 | 24.6 | -15.4 | | 0.29, n.s. |
| Treatment | Legal-sized trout/ | 590 | 616 | 549 | 618 | 1,332 | 760 | 387 | 87 | 593 | 642 | +8 | |
| Reference | mile in April | 382 | 748 | 518 | 488 | 1,149 | 918 | 626 | 241 | 534 | 734 | +37 | |
| | Remainders | 208 | -132 | 31 | 130 | 183 | -158 | -239 | -154 | 52 | -92 | | 1.27, n.s. |
| Treatment | Legal-sized trout/ | 464 | 424 | 712 | 1,485 | 927 | 486 | 104 | 67 | 533 | 614 | +15 | |
| Reference | mile in Sept. | 391 | 566 | 486 | 784 | 968 | 742 | 424 | 188 | 481 | 621 | +29 | |
| | Remainders | 73 | -142 | 226 | 701 | -41 | -256 | -320 | -121 | 214.5 | -184.5 | | 0.23, n.s. |

*Remainders = Treatment Zone values minus Reference Zone values.

**Pretreatment averages = April 1970-73 but September 1970-72; posttreatment averages = April 1974-77 but September 1973-77. Cutting and clearing in the Treatment Zone was done in late April and May 1973, after the spring electrofishing inventory.

[1] Posttreatment average ÷ pretreatment average.

[2] "t" value = Test for difference between average "remainder" for pretreatment phase and average "remainder" for posttreatment phase.

**TABLE 12.** *Standing stocks of brown trout in the Treatment and Reference Zones of Lunch Creek in April and September, before (1971-73) and after (1974-77) removal of woody vegetation in the Treatment Zone.*

| Study Zone | Item | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | Pretr. Avg.** | Posttr. Avg.** | % Difference[1] | "t" Value[2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Treatment | No/mile in April | 2,591 | 3,268 | 2,044 | 2,500 | 1,106 | 1,209 | 932 | 2,634 | 1,437 | -45 | |
| Reference | | 519 | 929 | 1,103 | 947 | 690 | 504 | 446 | 850 | 647 | -24 | |
| | Remainders* | 2,072 | 2,339 | 941 | 1,553 | 416 | 705 | 486 | 1,784 | 790 | | 2.10,p<.10 |
| Treatment | No/mile in Sept. | 2,229 | 2,159 | 1,918 | 1,724 | 1,868 | 2,000 | 1,071 | 2,102 | 1,666 | -21 | |
| Reference | | 1,083 | 1,015 | 1,104 | 965 | 728 | 668 | 605 | 1,067 | 742 | -30 | |
| | Remainders | 1,146 | 1,144 | 814 | 759 | 1,140 | 1,332 | 466 | 1,035 | 924 | | 0.45, n.s. |
| Treatment | lb/mile in April | 283.5 | 297.6 | 256.2 | 223.5 | 88.5 | 127.4 | 75.9 | 279.1 | 128.8 | -54 | |
| Reference | | 74.2 | 146.9 | 159.2 | 136.2 | 80.8 | 64.2 | 40.8 | 126.8 | 80.5 | -37 | |
| | Remainders | 209.3 | 150.7 | 97.0 | 87.3 | 7.7 | 63.2 | 35.1 | 152.3 | 48.3 | | 3.06,p<.05 |
| Treatment | lb/mile in Sept. | 285.0 | 241.8 | 309.1 | 192.1 | 169.7 | 193.5 | 154.1 | 278.6 | 177.4 | -36 | |
| Reference | | 210.3 | 170.8 | 231.9 | 223.1 | 125.0 | 117.6 | 109.9 | 204.3 | 143.9 | -30 | |
| | Remainders | 74.7 | 71.0 | 77.2 | -31.0 | 44.7 | 75.9 | 44.2 | 74.3 | 33.5 | | 1.52,p<.20 |
| Treatment | No. over 10 inches/ | 87 | 80 | 52 | 93 | 33 | 28 | 9 | 73 | 41 | -44 | |
| Reference | mile in April | 40 | 103 | 74 | 105 | 41 | 39 | 6 | 72 | 48 | -33 | |
| | Remainders | 47 | -23 | -22 | -12 | -8 | -11 | -3 | -1 | -7 | | 0.38, n.s. |
| Treatment | No. over 10 inches/ | 82 | 46 | 107 | 57 | 46 | 52 | 37 | 78 | 48 | -38 | |
| Reference | mile in Sept. | 128 | 173 | 169 | 185 | 64 | 56 | 46 | 157 | 88 | -44 | |
| | Remainders | -46 | -127 | -62 | -128 | -18 | -4 | -9 | -79 | -40 | | 0.96, n.s. |

*Remainders = Treatment Zone values minus Reference Zone values.

**Pretreatment averages = April 1970-73 but September 1970-72; posttreatment averages = April 1974-77 but September 1973-77. Cutting and clearing in the Treatment Zone was done in late April and May 1973, after the spring electrofishing inventory.

[1] Posttreatment average ÷ pretreatment average.

[2] "t" value = Test for difference between average "remainder" for pretreatment phase and average "remainder" for posttreatment phase.

**TABLE 13.** *Standing stocks of brook trout in the Treatment and Reference Zones of Spring Creek in April and October before (1971-73) and after (1974-77) removal of woody vegetation in the Treatment Zone.*

| Study Zone | Item | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | Pretr. Avg.** | Posttr. Avg.** | % Difference[1] | "t" Value[2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Treatment | No/mile in April | 3,026 | 2,504 | 1,474 | 2,498 | 3,041 | 2,845 | 2,886 | 2,335 | 2,818 | +21 | |
| Reference | | 2,022 | 1,553 | 1,928 | 1,738 | 1,393 | 1,470 | 1,482 | 1,834 | 1,521 | -17 | |
| | Remainders* | 1,004 | 951 | -454 | 760 | 1,648 | 1,375 | 1,404 | 501 | 1,297 | | 1.74,p<.20 |
| Treatment | No/mile in Oct. | 4,618 | 2,021 | 2,515 | 3,973 | 4,555 | 4,309 | 3,582 | 3,051 | 4,105 | +35 | |
| Reference | | 2,883 | 2,046 | 2,665 | 1,634 | 2,446 | 2,138 | 1,864 | 2,531 | 2,020 | -20 | |
| | Remainders | 1,735 | -25 | -150 | 2,339 | 2,109 | 2,171 | 1,718 | 520 | 2,085 | | 2.94,p<.05 |
| Treatment | lb/mile in April | 196.8 | 182.9 | 107.3 | 178.5 | 161.4 | 205.6 | 228.7 | 162.3 | 193.6 | +19 | |
| Reference | | 148.9 | 151.5 | 129.2 | 133.0 | 86.8 | 135.4 | 104.5 | 143.2 | 114.9 | -20 | |
| | Remainders | 47.9 | 31.4 | -21.9 | 45.5 | 74.6 | 70.2 | 124.2 | 19.1 | 78.7 | | 2.26,p<.10 |
| Treatment | lb/mile in Oct. | 228.8 | 96.8 | 178.2 | 202.9 | 350.0 | 319.8 | 159.4 | 167.9 | 258.0 | +54 | |
| Reference | | 208.5 | 105.9 | 196.9 | 103.8 | 181.4 | 137.1 | 97.7 | 170.4 | 130.0 | -24 | |
| | Remainders | 20.3 | -9.1 | -18.7 | 99.1 | 168.6 | 182.7 | 61.7 | -2.5 | 128.0 | | 3.69,p<.05 |
| Treatment | Legal-sized trout/ | 965 | 953 | 521 | 988 | 891 | 1,088 | 1,124 | 813 | 1,023 | +26 | |
| Reference | mile in April | 807 | 809 | 558 | 691 | 498 | 745 | 478 | 725 | 603 | -17 | |
| | Remainders | 158 | 144 | -37 | 297 | 393 | 343 | 646 | 88 | 420 | | 3.12,p<.05 |
| Treatment | Legal-sized trout/ | 1,188 | 421 | 850 | 1,018 | 1,718 | 1,659 | 609 | 820 | 1,251 | +53 | |
| Reference | mile in Oct. | 1,042 | 475 | 956 | 553 | 918 | 620 | 469 | 824 | 640 | -22 | |
| | Remainders | 146 | -54 | -106 | 465 | 800 | 1,039 | 140 | -4 | 611 | | 2.56,p<.05 |

*Remainders = Treatment Zone values minus Reference Zone values.

**Pretreatment averages = April 1970-73 but September 1970-72; posttreatment averages = April 1974-77 but September 1973-77. Cutting and clearing in the Treatment Zone was done in late April and May 1973, after the spring electrofishing inventory.

[1] Posttreatment average ÷ pretreatment average.

[2] "t" value = Test for difference between average "remainder" for pretreatment phase and average "remainder" for posttreatment phase.

**TABLE 14**. *Average growth of ages 0-III brook trout in the Treatment and Reference Zones of the Little Plover River during the pretreatment (1970-72) and posttreatment (1973-77) phases.*

| Study Phase | Treatment Zone Avg. Length in inches | | | | Reference Zone Avg. Length in inches | | | |
|---|---|---|---|---|---|---|---|---|
| Pretreatment (1970-72): | 0 | I | II | III | 0 | I | II | III |
| April | 1.0* | 4.2 | 6.6 | 7.9 | 1.0* | 4.2 | 6.5 | 8.0 |
| September | 3.5 | 5.7 | 7.6 | 9.0 | 3.4 | 5.7 | 7.7 | 8.9 |
| Increment | 2.5 | 1.5 | 1.0 | 1.1 | 2.4 | 1.5 | 1.2 | 0.9 |
| Posttreatment phase (1973-77): | | | | | | | | |
| April | 1.0* | 4.3 | 6.5 | 7.9 | 1.0* | 4.2 | 6.3 | 8.0 |
| September | 3.5 | 5.9 | 7.5 | 8.8 | 3.2 | 5.5 | 7.4 | 8.4 |
| Increment | 2.5 | 1.6 | 1.0 | 0.9 | 2.2 | 1.3 | 1.1 | 0.4 |

*Length of age 0 in April is an arbitrary estimate. Age 0 stocks were not sampled in April.

**TABLE 15**. *Average growth of ages 0-III brown trout in the Treatment and Reference Zones of Lunch Creek during the pretreatment (1971-73) and posttreatment (1974-77) phases.*

| Study Phase | Treatment Zone Avg. Length in inches | | | | Reference Zone Avg. Length in inches | | | |
|---|---|---|---|---|---|---|---|---|
| Pretreatment (1971-73): | 0 | I | II | II | 0 | I | II | III |
| April | 1.2* | 5.0 | 7.9 | 9.8 | 1.2* | 5.2 | 8.4 | 10.4 |
| September | 3.9 | 6.8 | 9.1 | 10.7 | 4.1 | 7.5 | 9.9 | 11.8 |
| Increment | 2.7 | 1.8 | 1.2 | 0.9 | 2.9 | 2.3 | 1.5 | 1.4 |
| Posttreatment (1974-77): | | | | | | | | |
| April | 1.2* | 4.8 | 7.8 | 9.9 | 1.2* | 5.1 | 8.3 | 10.5 |
| September | 4.0 | 6.9 | 9.4 | 11.2 | 4.0 | 7.6 | 10.2 | 11.8 |
| Increment | 2.8 | 2.1 | 1.6 | 1.3 | 2.8 | 2.5 | 1.9 | 1.3 |

*Length of age 0 in April is an arbitrary estimate. Age 0 stocks were not sampled in April.

**TABLE 16**. *Average growth of ages 0-III brook trout in the Treatment and Reference Zones of Spring Creek during the pretreatment (1971-73) and posttreatment (1974-77) phases.*

| Study Phase | Treatment Zone Avg. Length in inches | | | | Reference Zone Avg. Length in inches | | | |
|---|---|---|---|---|---|---|---|---|
| Pretreatment (1971-73): | 0 | I | II | III | 0 | I | II | III |
| April | 1.0* | 4.1 | 6.2 | 7.6 | 1.0* | 4.2 | 6.3 | 7.6 |
| October | 4.0 | 5.9 | 7.3 | 8.4 | 4.1 | 6.1 | 7.6 | 8.5 |
| Increment | 3.0 | 1.8 | 1.1 | 0.8 | 3.1 | 1.9 | 1.3 | 0.9 |
| Posttreatment (1974-77): | | | | | | | | |
| April | 1.0* | 4.6 | 6.4 | 7.6 | 1.0* | 4.5 | 6.4 | 7.7 |
| October | 3.9 | 6.3 | 7.6 | 8.4 | 3.8 | 5.9 | 7.6 | 8.8 |
| Increment | 2.9 | 1.7 | 1.2 | 0.8 | 2.8 | 1.4 | 1.2 | 1.1 |

*Length of age 0 in April is an arbitrary estimate. Age 0 stocks were not sampled in April.

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