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EFFECTS OF HABITAT ALTERATION ON PRODUCTION, STANDING CROPS AND YIELD OF BROOK TROUT IN LAWRENCE CREEK, WISCONSIN

by

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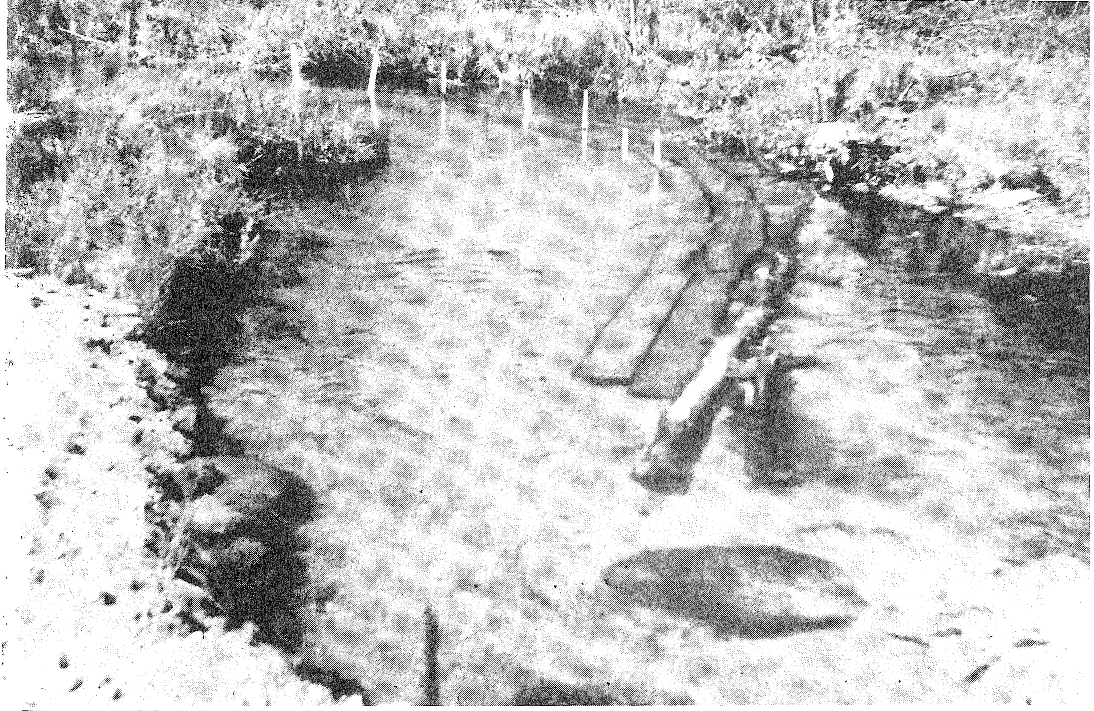
STAGES IN CONSTRUCTION OF STREAM BANK DEVICES



The pattern of the device has been staked out and longitudinal oak plankings installed beneath the surface of the water. The planks are nailed to oak pilings which have been jetted into the stream bottom.

The wooden substructure has been covered with rock, and rock and dirt have also been filled between the device and the old stream bank to form a triangular cover. Grassy sod is then placed over the rock to begin restoration of the aesthetic appearance of the altered stream bank.

The same device two years after installation. Weeds and grasses have restored the natural appearance of the stream bank, and much of the flow now passes through the pool beneath the overhanging bank.

ABSTRACT

The upper mile of Lawrence Creek, designated section A, was intensively altered by the addition of stream bank covers and current deflectors during 1964. These alterations reduced the surface area of section by 50% (3.8 to 1.9 acres), increased the average depth by 60% (5 to 8 inches), increased the number of pools by 52% (188 to 286), and increased the amount of permanent, overhanging bank cover for trout by 416% (719 to 3,709 feet). Alteration reduced the amount of sandy bottom by 40%, silty bottom was reduced by 70%, and gravel bottom was increased by 11%.

The management objective of the habitat alteration was improvement of the sport fishery by increasing the number of naturally produced legal-sized (6-inches or more) trout. Production (total growth) and standing crops (number and/or biomass at census) of trout before and after alteration were also used as comparative indices to assess responses of the trout population to habitat alteration. Food consumption by the trout population and quantitative and qualitative changes in standing crops of benthic invertebrates were also determined.

Data from three years prior to alteration and from three years after alteration compared as follows:

1. The average number of legal-sized trout present when the fishing season began increased by 100% (562 to 1,130 per section) after alteration.

2. Annual production increased by 17% on an absolute basis (261 to 306 pounds/section) and by 140% on a unit area basis (69 to 165 pounds/acre) after alteration. Adults accounted for 66% of annual production after alteration, but only 55% before alteration.

3. The average biomass of trout increased by 40% on an absolute basis (165 to 231 pounds/ section) and by 188% on a unit area basis (43 to 124 pounds/ acre) after alteration. Adults accounted for 87% of the average biomass after alteration but only 78% before alteration.

4. Food consumption increased by 28% on an absolute basis (1,827 pounds to 2,337 pounds/section) and by 162% on a unit area basis (480 to 1,256 pounds/acre) after alteration.

5. Yield increased by 196% on an absolute basis (23 to 68 pounds/section) and by 510% on a unit area basis (6 to 37 pounds/acre) after alteration.

Improvements in the trout population after habitat alteration appeared to be largely the result of increased rates of overwinter survival rather than greater recruitments of young trout to the population or to increased growth rates. Changes in production and standing crops were greater for adult trout than for young-of-the-year trout.

Relationships of production to food consumption, and production to standing crops are also discussed in the paper, as are comparisons of production, standing crops, and consumption in section A versus section B, the unaltered reference zone located immediately downstream for section A.

INTRODUCTION

Estimates of fish production (total growth) are receiving increasing emphasis as biologists see the unique contributions the pioneering studies of production are making to our knowledge of aquatic ecology (Gerking, 1967). However, such studies are still rare in comparison to those based on estimates of standing crops, yields, or catches per unit effort. To estimate production by a population of fish, it is necessary to measure changes in population size and growth during the period of production. With modern electro-fishing gear such data can now be gathered with relative ease for salmonid populations in small streams. Since salmonids are also highly prized as commercial and sport fishes, studies of salmonid production will undoubtedly continue to receive special emphasis and continue to account for a major proportion of all production studies in aquatic biology.

In a previous paper (Hunt, 1966), I reported monthly estimates of production by a wild brook trout (Salvelinus fontinalis) population in Lawrence Creek during 60 consecutive months (1960-64). Production was discussed primarily in relation to concomitant information on the yield (angler harvest) derived from a compulsory creel census. These studies revealed that the pounds of trout grown each year in Lawrence Creek was 2.1 times as great as could be accounted for by measuring the standing crop in April and 1.5 times greater than the standing crop in September. We also found that most of the production by a year class occurred during its first two years of life when natural mortality was also high. Consequently little of the lifetime production accumulated in the standing crop of legal-sized trout, and the yield from the sport fishery represented only 15 percent or less of the weight of trout produced. These examples indicate the kinds of valuable ecological insights production studies can provide.

In this paper, 33 additional monthly estimates of trout production are presented. These data will be used in conjunction with information about standing crops, yield, and food consumption to assess responses of the trout population to alterations of the trout habitat throughout the upper mile of Lawrence Creek. To my knowledge this study represents only the second time production and consumption information have been used to analyze changes in a stock of stream-dwelling salmonids after man's alteration of their habitat, and I believe this study is the first use of such data in an evaluation of what is commonly called "trout habitat improvement".

Warren et al. (1964) reported the results of three detailed field experiments involving production, food consumption and food habits of wild and domestic cutthroat trout (Salmo clarki clarki) stocked in 4 study sections of Berry Creek. The total length of these 4 sections was 1,500 feet. Environmental alterations consisted of the addition of a sucrose enrichment liquid to two sections, and removal of deciduous forest canopy from one of the enriched and one of the unenriched sections, but neither of these alterations has been applied to improve trout streams as a routine management technique.

Descriptions of Lawrence Creek and our research program there have been published by McFadden (1961), Hunt et al. (1962) and Hunt (1966). In the experiment reported here only the upper 2 of the 4 study sections are involved in evaluating changes in the trout population after habitat alteration. During 1964 the trout habitat of section A, the headwater section, was intensively altered by personnel of the Bureau of Fish Management of the Wisconsin Division of Conservation. Section B, the adjacent, unaltered downstream section, was used as a reference ("control") zone.

Our evaluation of this effort, to increase standing crops, production and yield in section A by improving the trout habitat, took two broad approaches:

1. Comparisons of various parameters of the trout population, the trout food supply, physical features of the habitat, and the sport fishery within section A on a prealteration versus postalteration basis. Data from the 3-year period 1961-63 were compared with data from 1965-67.

2. Comparisons of changes in these parameters within section A relative to those occurring in unaltered section B.

The techniques of habitat alteration employed were representative of fairly standardized methods worked out in other trout streams in central Wisconsin. A thorough discussion of these techniques was recently published by White and Brynildson (1967). Our primary research objective at Lawrence Creek was to determine processes by which physical alterations of the environment in Section A were translated into biological changes in the trout population. On the basis of previous evaluations of such habitat alteration in

Wisconsin streams, it was assumed that the alterations would be beneficial and the trout population would improve. Measuring the magnitudes of such improvements was an important but secondary objective. The fundamental question posed was not whether habitat development "works", but "why it works". From a management viewpoint other trout streams in central Wisconsin needed habitat development more than Lawrence Creek. This stream was chosen because of the unique opportunity to integrate an evaluation of habitat alteration into the long-term investigations of brook trout ecology, there, and as a consequence, to quantify and interpret physical and biological changes more throughly than had been previously possible in Wisconsin.

At the time of preparation of this paper, data collections are incomplete, and in a planned final report analyses will be more detailed than those presented here. However, since the additional data to be collected represent only a small proportion of the total, present conclusions should not require drastic alteration. I do hope, however, that participants in this symposium will criticize the validity of these tentative conclusions and suggest additional analyses that would make the final report more useful.

METHODS

Electro-fishing gear was used to make mark and recapture (Petersen method) estimates of the brook trout populations in sections A and B each April, June, and September. Population estimates for each section were made by one-inch groups and summed. Estimates in April included age I and older trout. Peak emergence of age 0 brook trout occurred about February 1, but they were still too small (1-2 inches long) in April to be sampled effectively with our electro-fishing gear. Age 0 stocks were included in June estimates. By then they averaged 2.5 inches long and approximately one-third of the year class was collected during each electro-fishing run. By mid-September, age 0 stocks averaged 4.0 inches long and approximately one-half of the year class was captured on each electro-fishing run.

Age 0 trout collected during June and/or September electro-fishing inventories were permanently marked (fin-clipped) to designate their year of birth and stream section of initial capture. This marking procedure was initiated in 1956 and within 3 years the trout population consisted of predominantly known-age individuals.

Although there is no fish barrier separating section A and section B, recaptures of marked trout have provided us with a measure of the exchange of trout between sections. Previous studies (Hunt, 1965) have also indicated that unmeasured intersectional movement of age 0 trout prior to initial marking in June was probably negligible.

Most of the field data for calculating standing crops, production, age structures, growth rates, mortality rates, and intersectional movements of trout were obtained during the three electro-fishing inventories conducted yearly. Procedures used in this study to derive monthly standing crop and production statistics for each age group were similar to those cited by Hunt (1966). Growth data for trout in sections A and B were collected monthly during 1963 and 1966. Age specific growth curves during 1963 and 1966 were constructed from the 12 point estimates for each year. The 1963 curves were used as guides to derive growth curves for comparable age groups in 1961 and 1962 when only 3 point estimates of growth rates were obtained annually. The 1966 curves were similarly used to estimate monthly growth rates in 1965 and 1967. A computer program was again employed to carry out final mathematical calculations of biomass and production. In this paper production represents the total amount of tissue elaborated by the trout population during a specified period regardless of the ultimate fate of that tissue (Ivlev, 1945).

Yield data were gathered through a compulsory creel census. Anglers obtained free permits at the checking station near the stream before each fishing trip. Anglers could choose any stream section, but permits were issued for only one section per trip. During the 1961-67 trout fishing seasons, experimental angling regulations at Lawrence Creek were more restrictive than the normal statewide regulations and sections A and B received less than normal fishing pressure from fly-fishermen because most of them chose to fish in sections C and D which were reserved for that method.

In the spring of 1963, a year prior to habitat alteration, detailed maps of sections A and B were drawn to scale (1" = 25'). The stream bottom was classified as sand, silt, or gravel. Pools were also drawn to scale and their maximum depths were recorded. Year-round bank cover for trout (arbitrarily defined as 12 inches of water beneath 6 inches of overhanging stream bank) was recorded. Cross-sectional depth profiles of the stream channel (depths measured at 1-foot intervals) were made across transects spaced at 20-foot intervals along the stream. Numbered metal fence posts were installed during the mapping to provide permanent bench marks for later reference.

During the spring of 1966, two years after completion of the habitat alteration, all of section A was resurveyed to quantify some of the physical changes produced by the alteration. Two stretches of section B, representing approximately 13 percent of the section, were also resurveyed to determine how much the unaltered reference zone had changed naturally since 1963.

Prealteration and postalteration mapping was done in the spring before streamflow was confined by the rich growth of aquatic vegetation characteristic of much of sections A and B. Consequently the quantitative summaries of the trout habitat that follow are descriptive of its lowest quality during the year.

Habitat alteration in section A was produced by constructing a series of bank cover and current deflector devices. These devices, placed alternately on each bank, narrowed the stream and the confined flow was guided in a meandering path down the channel. Devices were placed so that the bulk of the flow passed along the face of each structure. The confined flow degraded the stream bed beneath and near the devices to form pools, and in some reaches gravel substrate was exposed after overlying sand and silt had been scoured away. Each device acted as a bank cover wing and a current deflector. Along its upstream end, where the undercut pool was greatest, the device provided overhanging cover for trout. Along its downstream end, the device acted as a current deflector to guide the main flow across to the opposite bank.

The prealteration maps were used in the field to plan the locations and dimensions of the devices. Procedures of construction consisted of:

1. Jetting pairs of 5-foot long oak pilings into the stream bottom to a depth that left their tops below water.

2. Nailing 3-inch-thick oak boards (stringers) to each pair of pilings at a right angle to the stream bank.

3. Nailing 3-inch-thick oak planks to the stringer boards and parallel to the stream bank.

These wooden substructures, completely under water, provided platforms extending 1-3 feet out from the natural stream bank.

4. Covering the substructure platforms with rocks and filling in a wall of rocks between the inner edge of the platforms and the old stream bank.

5. Covering the protruding wood and rock structures with grassy sod to stabilize the devices and restore the esthetic appearance of the stream.

Monthly estimates of food consumption by brook trout in sections A and B during 1961-67 were based on experiments performed by Carline (1968). Individually marked juvenile coho salmon (Oncorhynchus kisutch) held in an aquarium and in an experimental stream were fed known quantities of food (fly larvae). Curves relating growth to food consumption were derived at several water temperature levels. In these experiments growth and food consumption relationships were similar for coho in the aquarium and those in the stream, and Carline concluded that "laboratory derived food and growth relationships can be useful in estimating the food consumption of fish in nature". By referring to these curves, I converted monthly growth rates of brook trout in Lawrence Creek to monthly rates of food consumption per unit weight of trout. Consumption rates were then multiplied by average monthly biomasses of trout of each age to obtain estimates of the weight of food consumed by each age group. Effects of water temperature on growth versus consumption relationships were partially compensated for by selecting the experimental curve derived at a temperature closest to the known monthly mean temperature of Lawrence Creek.

In the Results section that follows, changes in standing crops of trout, food consumption, and production are summarized by 3-year periods before and after habitat alteration. During each period these parameters of the trout populations were calculated monthly and then summed or averaged for various comparisons. Because data for the last 3 months of 1967 were not yet available, I have deleted data for the last 3 months of the prealteration period to make comparisons more valid.

RESULTS

Some of the morphometric characteristics of sections A and B prior to alteration of section A are summarized in Table 1. The trout habitat in section A was judged to be poorer than that in section B which was 40 percent deeper on the average and had 46 percent more pools. Pools occupied 8 percent of the stream bottom in section B but only 4 percent in section A, and section B had twice as much gravel bottom even though its total bottom area was 7 percent less than section A. Section B also had 4 percent more permanent bank cover even though it was one-quarter shorter than section A.

Section B also held a better trout population and supported a better trout fishery than section A during 1961-63. For example, the average biomass of brook trout in section B was 9 percent heavier, annual production was 23 percent greater, angling pressure per season was 88 percent higher, and the number of trout creeled seasonally was 71 percent higher. More detailed comparisons of the trout populations and fisheries in sections A and B will follow. A few brief examples were given here only to indicate why section A rather than section B was chosen as the alteration zone.

Physical Changes

Alteration of trout habitat in section A was intensive in comparison to such work on other Wisconsin trout streams. Approximately one-half of the total length of stream bank was changed. The pattern of installation was such that one stream-edge or the other was altered along most of the section. Materials used in construction were estimated to include 3,650 oak pilings, 38,400 board feet of oak planking, and 6,550 tons of rocks.

Table 1.

Some Morphometric Characteristics of Section A of Lawrence Creek Before and After Habitat Alteration, and of Section B, the Unaltered Reference Zone

Item	Section A			Unaltered
	Before Alt.	After Alt.	% Change	Section B
Surface area in acres	3.81	1.86	- 51	3.15
Avg. width in feet	23.0	14.2	- 48	24.0
Avg. depth in inches	4.9	8.1	+ 65	6.7
Acre - feet of water	1.56	1.25	- 20	1.76
Mid-channel length in feet	5,631	5,710	+ 1	4,525
Number of pools*	188	286	+ 52	275
Number of pools over 2 feet deep	32	56	+ 75	Unknown
Bottom area of pools - sq. ft.	7,288	19,776	+171	10,722
Feet of permanent bank cover**	719	3,709	+416	750
% of stream bottom in pools	4	24	+700	8
% of streambank as perm. cover	5	27	+440	6
Sq. ft. of stream bottom composed of:				
Sand	81,082	48,898	- 40	69,781
Silt	77,559	23,664	- 70	50,914
Gravel	7,489	8,305	+ 11	16,239
% of stream bottom composed of:				
Sand	49	60		51
Silt	46	30		37
Gravel	5	10		12

* Pools were defined as depressions in the bottom wherever there was an abrupt change in bottom slope.

** Permanent bank-cover was arbitrarily defined as 12 inches or more of water beneath 6 inches or more of overhanging bank.

Habitat alteration reduced the surface area of section A by 50 percent and increased its average depth by 60 percent. The cubic configuration (acre-feet) of the altered channel was reduced by only 20 percent. The amounts of sand bottom and silt bottom were reduced by 40 percent and 70 percent respectively. Stream bottom classified as gravel was increased by 11 percent, and gravel accounted for 10 percent of the total bottom area as compared to only 4 percent prior to alteration (Fig. 1). The number of pools was increased by 52 percent, from 188 to 286, but more importantly the area of stream bottom in pools was increased by 170 percent. Pools comprised 24 percent of section A after development as compared to only 4 percent prior to development. Four of the new pools were 30 - 45 inches deep, 45 were 15 - 29 inches deep, and 50 were less than 15 inches deep. The greatest measured change was in the amount of permanent overhanging bank cover which was increased four-fold. Such cover had accounted for only 5 percent of the stream-edge prior to alteration but 27 percent after alteration.

The resurvey of part of section B showed a decrease in surface area by 5 percent and a decrease in average depth from 8.9 inches in 1963 to 8.5 inches in 1966, but the number of pools in the resurvey zone had increased from 24 to 27 and the average depth of pools had increased from 22 inches to 23 inches from 1963 to 1966.

Changes in Standing Crops

After alteration the average biomass of trout in section A weighed 231 pounds, or 40 percent more than the average biomass of 165 pounds for the 3-year period prior to alteration. On an annual basis, standing crops averaged 225, 226, and 243 pounds during 1965-66-67 respectively. All 3 annual averages exceed those for the prealteration years by at least 30 percent. These increases in biomass after alteration of section A were primarily due to gains in age I and older trout (adults) which more than offset declines in biomass of age 0 stocks. The contribution of these age I+ trout to the average biomass increased from 79 percent prior to alteration to 87 percent after alteration. The average monthly biomass of age I+ trout increased from 130 pounds prior to alteration to 202 pounds after alteration, whereas the biomass of age 0 trout decreased from an average of 35 pounds to an average of 29 pounds.

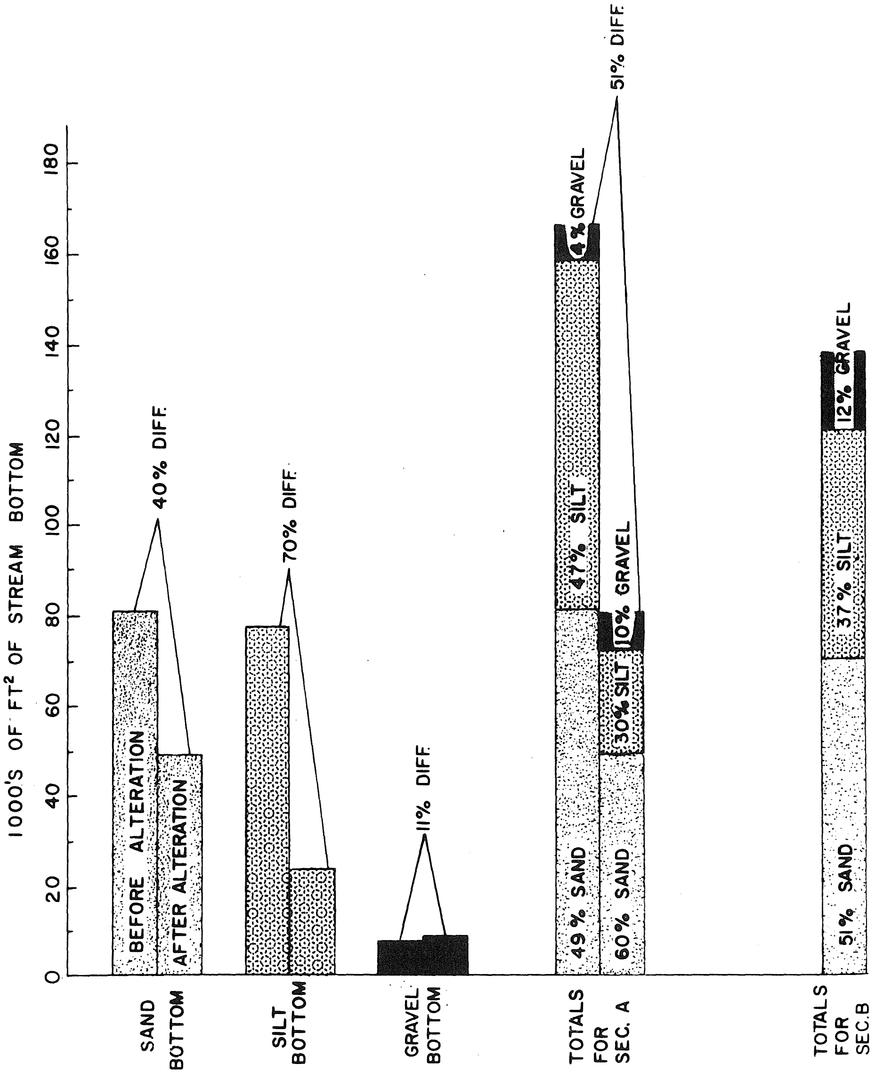


Figure 1. Morphometric characteristics of section A before and after alteration of the trout habitat and section B, the adjacent, unaltered, reference zone.

In section B, the unaltered reference zone, standing crops of brook trout increased in weight by an average of 11 percent during 1965-67 as compared to 1961-63. In this section too, the gain was achieved despite an average decrease of 27 percent in the monthly biomass of age 0 trout (Fig. 2).

During the prealteration years, standing crops were higher in section B than in section A by an average of 8 percent (178 vs. 165 pounds), but during the postdevelopment years monthly standing crops in section A were 17 percent higher (231 vs. 198 pounds) than those in section B. Section B maintained larger biomasses of age 0 trout in all years except 1967 when section A had an average standing crop of 32 pounds and section B an average of 22 pounds (Table 2).

Standing crops of trout in altered section A increased more numerically than they increased in weight. Numerical gains were greatest among the age II and older trout which were 2 to 9 times more abundant after alteration than before. Section A held an average of 1,746 age I+ trout in April, 1961-63 and an average of 3,404 age 0+ trout in September, 1961-63. After alteration the average numbers of trout in April increased to 2,881 (+65%) and the average number present in September increased to 3,740 (+10%). September stocks were numerically higher despite an average decline of 5 percent in the abundance of age 0 trout in section A.

In section B the number of trout present in April also increased during the second 3-year period of study, but the relative gain (38%) was less than the gain in section A. In section B as in section A, age II and older trout showed the most improvement, although in section B the increase in number of older trout was not as great as the decrease in average number of age 0 trout. Section B held 12 percent fewer trout of all ages in September, 1965-67 than it did in September, 1961-63 (Table 3).

Changes in Growth

Growth rates of trout declined slightly in section A during the postalteration period, but so did growth rates in unaltered section B. No cause-effect relationship was evident between changes in growth and changes in environment in one section only. During both 3-year periods, trout of a given age were usually heavier in section A than in section B, but the

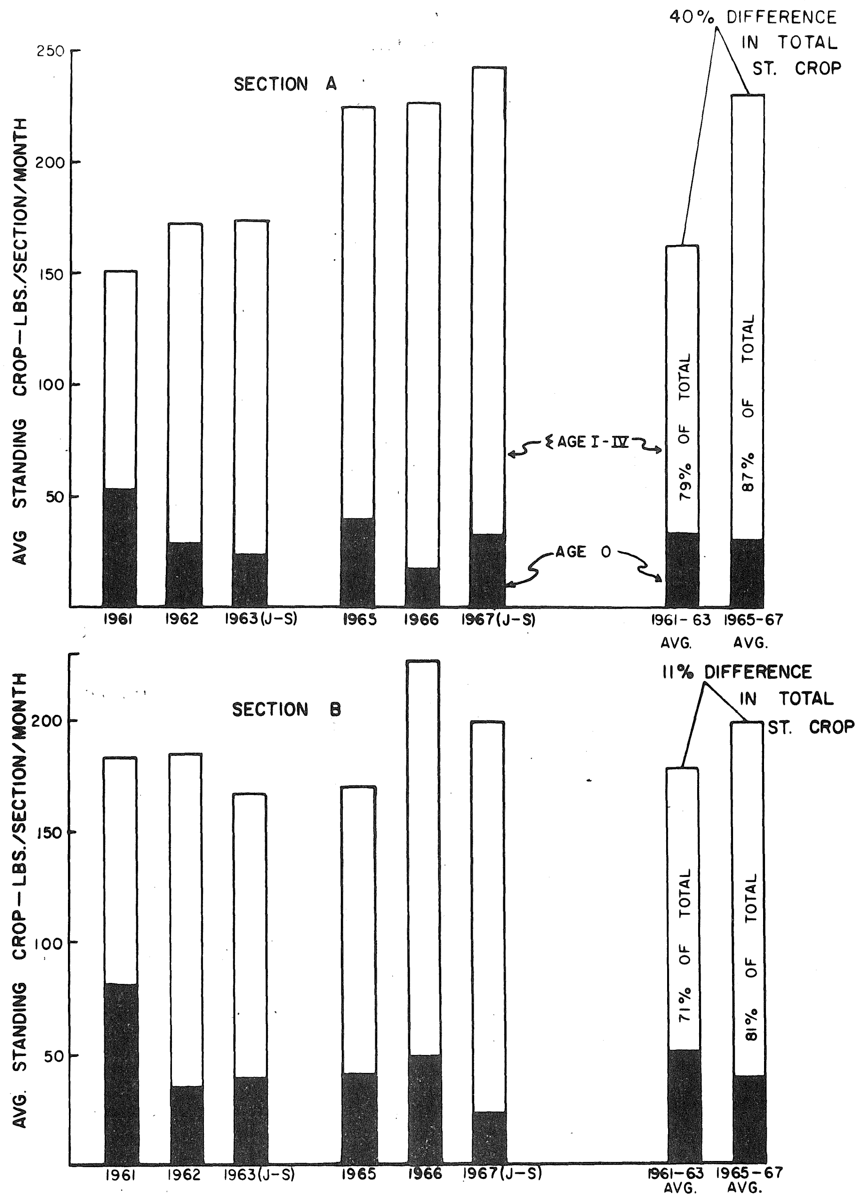


Figure 2. Standing crops of brook trout in sections A and B of Lawrence Creek during 1961-63 and 1965-67. Values for 1963 and 1967 represent 9-month January through September periods.

Table 2.

Standing Crops (Biomass) of Brook Trout in Sections A and B
of Lawrence Creek During 1961-63 and 1965-67

	Average Monthly Biomass in Pounds - By Age Group and Stream Section									
	Section A					Section B				
Year	0	I	II	III	Σ0-IV	0	I	II	III	Σ0-IV
1961	53	81	15	<1	149	80	82	21	<1	183
1962	28	115	26	2	172	34	120	28	3	184
1963*	23	81	64	4	173	38	69	55	4	166
1965	39	116	60	8	225	41	78	45	4	169
1966	17	129	65	15	226	48	132	38	8	227
1967*	32	92	103	15	243	22	81	82	11	198
1961-63 Avg.	35	92	35	3	165	51	90	35	2	179
1965-67 Avg.	29	112	76	13	231	37	97	55	7	198
% Change	-17	+22	+117	+333	+40	-23	+8	+57	+250	+11

* 9-month averages for January - September periods.

Table 3.

Numbers of Brook Trout of Each Age in Sections A and B of Lawrence Creek in April and September of 1961-63 and 1965-67

		Section A					Section B				
Month	Year	0	I	II	III+	Σ	0	I	II	III+	Σ
April	1961		961	67	1	1029		1065	153	3	1221
	1962		2029	192	8	2229		2044	275	14	2333
	1963		1520	444	18	1982		1137	449	16	1602
1961-63 Avg.			1503	234	9	1746		1415	292	11	1718
April	1965		1989	627	55	2671		1391	483	39	1913
	1966		2556	640	129	3325		1992	345	59	2396
	1967		1705	836	107	2648		1955	752	90	2797
1965-67 Avg.			2083	701	97	2881		1779	527	63	2369
% Diff.			+ 39	+200	+908	+ 65		+ 26	+80	+473	+ 38
September	1961	3591	673	48	2	4314	5784	748	45	0	6577
	1962	1968	1036	54	1	3059	2414	1150	43	4	3611
	1963	2077	606	149	6	2838	3676	650	129	5	4460
1961-63 Avg.		2545	772	84	3	3404	3959	849	72	3	4883
September	1965	2834	1060	156	20	4070	2945	623	92	9	3669
	1966	1368	1328	212	14	2922	4542	1286	131	20	5979
	1967	3071	881	250	24	4226	2312	761	174	8	3255
1965-67 Avg.		2424	1090	208	18	3740	3266	890	132	13	4301
% Diff.		- 5	+41	+148	+500	+ 10	- 18	+ 5	+83	+333	- 12

relative changes in weight from year to year within age groups were similar in both sections. Average weights of age 0 stocks in September were highest in both sections in 1966, the year when the numerical density of age 0 trout was also lowest in both sections, but there were no consistent compensatory adjustments of growth rate to numerical density among any of the age groups in either section (Table 4).

Changes in Food Consumption

Food consumption by the brook trout population in section A also increased after habitat alteration but not as much as the biomass of trout increased (28% vs. 40%). An increase of 55 percent in biomass of age I+ trout was paired with an increase of 47 percent in estimated consumption. Biomass of age 0 trout decreased by 17 percent and consumption decreased by 15 percent. The proportion of annual consumption accounted for by age I+ trout increased from 66 percent to 80 percent.

In section B, food consumption declined by 1 percent even though biomass increased by an average of 11 percent during 1965-67. Consumption by age I+ trout (those responsible for the gain in biomass) increased by 19 percent, but decreased consumption by age 0 stocks averaging 30 percent per year reduced total consumption during 1965-67 to a level 1 percent below that for 1961-63. In this section, age I+ trout accounted for 59 percent of annual consumption during 1961-63 and 71 percent during 1965-67 (Fig. 3).

During 1961-63 annual consumption was 12 percent greater in section B than in section A (2,052 pounds vs. 1,827 pounds). During 1965-67, annual consumption was 14 percent higher in section A than section B (2,337 pounds vs. 2,043 pounds).

Changes in Trout Production

Production (total growth) by trout in section A increased by 17 percent following habitat alteration, but it did not improve as much as biomass (40%) or consumption (28%). During 1965-67 annual production by all age groups in section A averaged 306 pounds. Age I+ trout accounted for two-thirds of this total. Prior to alteration age I+ trout accounted for one-half of the total production of 261 pounds per year.

Table 4.

Average Weights (grams) of Age Groups O-III Brook Trout in Sections A and B of Lawrence Creek During 1961-63 and 1965-67

Month	Year	Section A 0	Section A I	Section A II	Section A III	Section B 0	Section B I	Section B II	Section B III
April	1961		24	79	-		20	69	-
	1962		27	83	131		24	79	123
	1963		26	79	122		22	71	105
	1965		22	72	99		19	64	92
	1966		24	77	104		20	73	104
	1967		25	73	100		21	68	100
1961-63 Avg.			26	80	127		22	73	114
1965-67 Avg.			24	74	101		20	68	99
% Change:			-8	-5	-20		-9	-7	-13
September	1961	12	82	155	-	11	73	121	-
	1962	10	57	103	136	9	53	91	170
	1963	12	59	101	144	11	60	92	136
	1965	11	60	91	105	11	55	84	96
	1966	15	54	86	127	13	64	91	114
	1967	12	54	95	109	10	50	86	68
1961-63 Avg.		11	66	120	140	10	62	101	153
1965-67 Avg.		13	56	91	114	11	56	87	93
% Change:		+18	-15	-24	-19	+10	-10	-14	-39

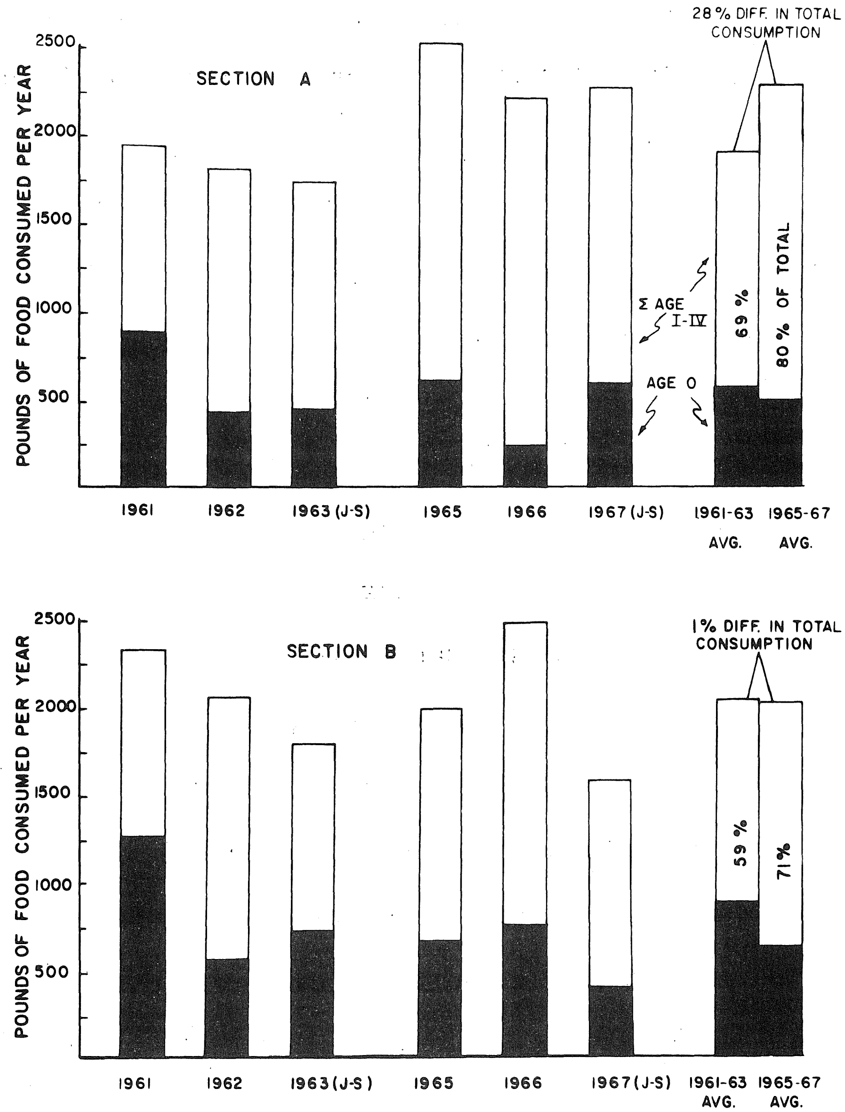


Figure 3. Food consumption by brook trout in sections A and B of Lawrence Creek during 1961-63 and 1965-67. Values for 1963 and 1967 represent 9-month January through September periods.

After alteration of section A, biomass, consumption, and production of age 0 trout decreased by 17 percent, 15 percent, and 11 percent respectively, but among age I+ stocks biomass increased by 55 percent, consumption increased by 47 percent, and production increased by 41 percent.

Average standing crops in section A during the 3 postalteration years were all higher than those for the 3 prealteration years, but annual production during 1966 fell below that recorded in 1961 and 1963. Production by age I+ trout in 1966 was above the 1961-63 levels for these age groups but production by age 0 was exceptionally poor during 1966. An unusual snowmelt flood occurred on February 9, 1966, at about the time when most age 0 trout were emerging. In section A, where the flood was constricted by the narrowed, raised stream banks some redds were known to be destroyed, and when the 1966 year class was first censused in June, it was less than half as strong in section A as was predicted on the basis of egg deposition estimates the previous autumn.

In section B, annual production declined by an average of 9 percent during the latter 3-year period. Although production by age I+ trout increased by 20 percent, this was not enough to offset the 31 percent decrease in average production among age 0 stocks. These proportional changes in section B compare to an average increase in production of 41 percent by age I+ stocks and an average decrease in production of 11 percent by age 0 stocks in altered section A (Table 5 and Fig. 4).

Changes in the Fishery

Both angling effort and yield nearly tripled in section A after habitat alteration. The number of angling trips increased from an average of 149 per season during 1961-63 to an average of 411 during 1965-67. Yield increased from a maximum of 27 pounds per season during 1961-63 to 44, 82, and 79 pounds during 1965-66-67 respectively and the number of trout creeled increased from an average of 103 to an average of 300 (Table 6). The average yield of 23 pounds per season during 1961-63 was equivalent to 9 percent of annual production. During 1965-67 average yield increased to 68 pounds (196% greater than the 1961-63 average) and 23 percent of annual production (Table 7).

Table 5.

Average Biomass (B) of Brook Trout, Annual Food Consumption (C) and Annual Production (P) in Sections A and B of Lawrence Creek During 1961-63 and 1965-67

Year	Age Group	Pounds /Section A			Pounds /Section B		
		B	C	P	B	C	P
1961	0	53	828	161	80	1254	263
	I	81	975	110	82	898	100
	II	15	134	13	21	168	16
	III	< 1	1	< 1	< 1	2	< 1
	Σ0 - IV	149	1939	284	183	2322	378
1962	0	28	421	88	34	557	124
	I	115	1171	129	120	1252	133
	II	26	200	14	28	224	21
	III	2	16	1	2	20	2
	Σ0 - IV	172	1808	232	184	2053	280
1963*	0	23	434	106	38	713	176
	I	81	769	110	69	653	92
	II	64	496	47	55	383	36
	III	4	32	3	4	27	3
	Σ0 - IV	173	1734	266	166	1780	307
1961-63 Avg.	0	35	561	118	51	841	188
	I	92	972	116	90	934	108
	II	35	277	25	35	258	24
	III	3	16	2	2	16	2
	Σ0 - IV	165	1827	261	178	2052	322
1965	0	39	610	128	41	658	139
	I	116	1243	131	78	831	97
	II	60	548	60	45	446	37
	III	8	65	4	4	37	2
	Σ0 - IV	225	2516	324	169	1981	276
1966	0	17	233	50	48	740	157
	I	129	1316	151	132	1366	168
	II	65	543	40	38	314	23
	III	15	118	11	8	48	5
	Σ0 - IV	226	2216	252	227	2472	353
1967*	0	32	585	136	22	393	94
	I	92	855	123	81	719	110
	II	103	733	74	82	490	37
	III	15	95	9	11	64	6
	Σ0 - IV	243	2279	342	198	1185	243
1965-67 Avg.	0	29	476	105	37	597	130
	I	112	1138	135	97	972	125
	II	76	608	58	55	417	32
	III	13	93	8	7	50	4
	Σ0 - IV	231	2337	306	198	1879	291

* 9-month averages or sums for January - September periods

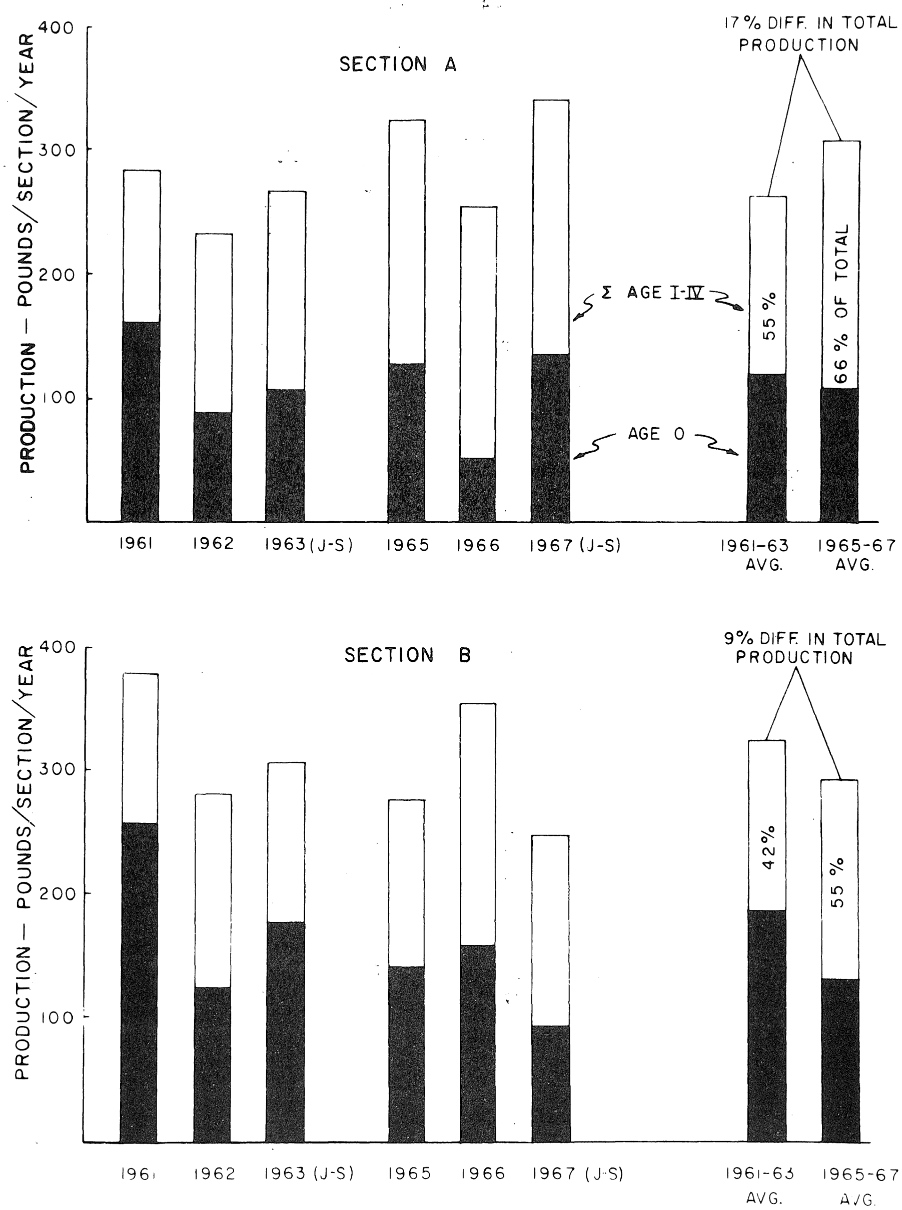


Figure 4. Production by brook trout in sections A and B of Lawrence Creek during 1961-63 and 1965-67. Values for 1963 and 1967 represent 9-month January through September periods.

Table 6.

Some Vital Statistics for The Sport Fishery in Sections A and B of Lawrence Creek During 1961-63 and 1965-67

Item	1961-63 Avg.	1965-67 Avg.	% Change
Angling Trips/Season:			
Section A	149	441	+196
Section B	281	190	- 32
Angling Hours/Season:			
Section A	371	1066	+188
Section B	721	518	- 28
Legal-size Trout (8-inch+) at Beginning of Season:			
Section A	118	303	+156
Section B	103	183	+ 78
Legal-size Trout at End of Season:			
Section A	199	224	+ 13
Section B	145	150	+ 3
Number of Trout Creeled:			
Section A	103	300	+191
Section B	176	217	+ 23
Number of Trout Creeled + Number of Legal Trout Left at End of Season:			
Section A	302	524	+ 74
Section B	321	367	+ 14

Table 7.

Number and Pounds of Brook Trout Harvested from Sections A and B of Lawrence Creek During 1961-63 and 1965-67, and Yield as a % of Annual Production

Year	Section A			Section B		
	Number	Pounds	Yield %	Number	Pounds	Yield %
1961	64	14.4	5.1	123	29.4	7.9
1962	120	26.9	11.6	180	41.3	14.7
1963	124	26.6	9.7	224	39.2	11.6
1965	196	44.2	13.7	224	50.1	18.1
1966	355	81.5	32.3	156	35.8	10.1
1967	348	78.8	23.0	272	60.1	24.7
1961-63 Avg.	103	22.6	8.8	176	36.6	11.4
1965-67 Avg.	300	68.2	23.0	217	48.7	17.6
% Change	+191	+196	+161	+23	+33	+54

In section B, yield increased 33 percent by weight or 23 percent by number but the hours of angling effort declined by 28 percent during the second 3-year period. Yield per season increased from an average of 176 trout, or 37 pounds during 1961-63 to 217 trout, or 49 pounds during 1965-67. Angling trips per season decreased from an average of 281 to an average of 190. During 1961-63 the yield was equivalent to 11 percent of annual production. During 1965-67 this proportion rose to 18 percent in section B (Table 7 and Fig. 5).

Section B received 94 percent more fishing pressure than section A before it was altered (721 hours/season vs. 371) and the yield was 61 percent greater in section B (37 pounds/season vs. 23). After section A was altered, it received twice as much fishing pressure as section B (1,066 hours/season vs. 518) and the yield was 39 percent greater in section A (68 pounds/season vs. 49).

The average number of trout of legal size (8-inch+) in section A at the beginning of the 1961-63 trout fishing seasons was approximately 118. At the beginning of the 1965-67 seasons section A held an average of 303 legal-sized trout, or 156 percent more the prealteration average. In section B the number of legal-sized trout also increased from an average of 103 to an average of 183, or a gain of 78 percent. Section A contained 15 percent more 8-inch+ trout than section B during 1961-63 but 157 percent more during 1965-67. The minimum legal size limit for brook trout in Wisconsin is 6 inches. The number of trout of this size doubled in section A, from a prealteration average of 562 to a postalteration average of 1,130. In section B the number of 6-inch+ trout averaged 468 in April, 1961-63 and 771 in April, 1965-67, a 65 percent increase (Fig. 6).

In summary, then, standing crops, food consumption, production and the sport fishery in sections A and B changed as follows from the first 3-year period to the second:

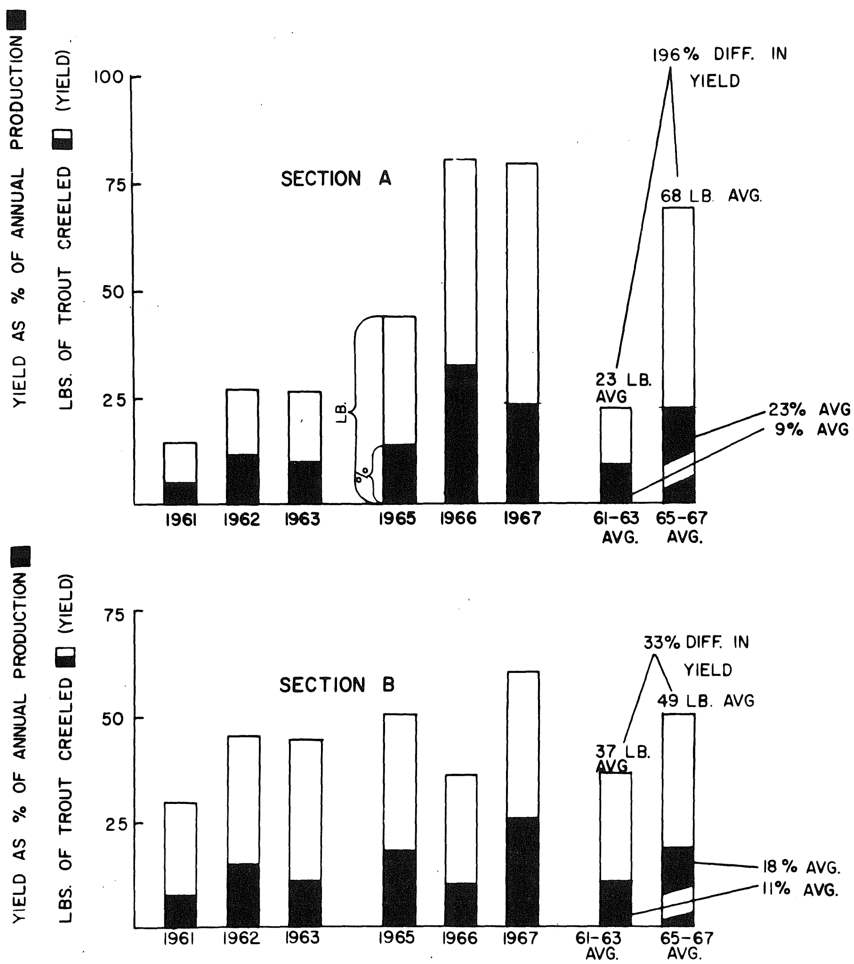


Figure 5. Yield (angler harvest) of brook trout from sections A and B of Lawrence Creek during 1961-63 and 1965-67 and yield as a percentage of annual production those years.

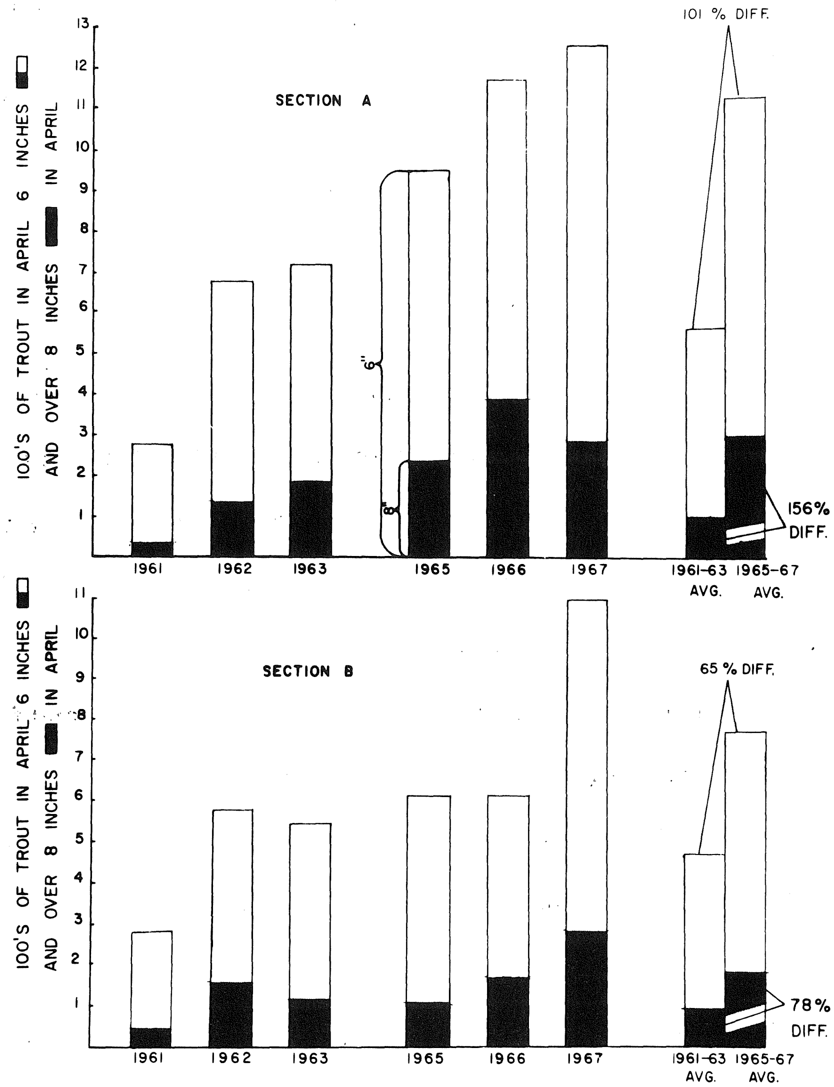


Figure 6. Number of brook trout over 6-inches and over 8-inches in sections A and B of Lawrence Creek in April of 1961-63 and 1965-67.

Item	Percentage Change Section A	Section B
Average biomass (pounds/section)	+40	+11
Average annual consumption (pounds/section)	+28	- 1
Average annual production (pounds/section)	+17	- 9
Angling effort (hours/section/season)	+188	-28
Yield (pounds/section/season)	+196	+32

Annual summaries of the ratios of food consumption to biomass, production to biomass, and consumption to production are listed in Table 9 for each age group. Some implications of the changes in these ratios in relation to the habitat alteration in section A are considered in the Discussion section that follows.

DISCUSSION

As expected, nearly all measured parameters of the trout population and fishery in section A increased after habitat alteration, and most of these improvements were greater in altered section A than those in unaltered section B. Although biomass, food consumption and production did not increase spectacularly, the alterations which initiated them can be categorized as trout habitat improvements.

In the Results section above, the 51 percent decrease in surface area of section A did not enter in to calculations of prealteration - postalteration changes in the trout population or fishery. Data were compared in terms of quantities per section (absolute values) rather than quantities per acre (relative, or unit area values) to maximize the "fairness" of measuring responses to habitat improvement. Obviously reducing the acreage of section A by half automatically doubled the trout biomass per acre and other unit area densities. Nevertheless, despite the initial doubling of trout density the population continued to improve thereafter, and these improvements were usually much greater than those occurring simultaneously in unaltered section B.

Table 9.

Ratios of Annual Food Consumption (C) to Average Biomass (B) of Brook Trout, Annual Production (P) to Average Biomass, and Annual Consumption to Annual Production in Sections A And B of Lawrence Creek During 1961-63 and 1965-67

Year	Age Group	Ratios in Section A			Ratios in Section B		
		C/B	P/B	C/P	C/B	P/B	C/P
1961	0	16	3.0	5.1	16	3.3	4.8
	I	12	1.4	8.9	11	1.2	9.0
	II	9	0.9	10.3	8	0.8	10.5
	III	5	1.0	5.0	7	0.3	10.0
	Σ0 - IV	13	1.9	6.8	13	2.1	6.1
1962	0	15	3.1	4.8	16	3.6	4.5
	I	10	1.1	10.6	10	1.1	9.4
	II	8	0.5	14.3	8	0.8	10.6
	III	8	0.5	16.0	10	1.0	10.0
	Σ0 - IV	11	1.3	7.9	11	1.5	7.3
1963*	0	19	4.6	4.1	19	4.6	4.1
	I	9	1.4	7.0	9	1.3	7.1
	II	8	0.7	10.6	7	0.7	10.6
	III	8	0.7	10.0	7	0.7	9.0
	Σ0 - IV	10	1.5	6.5	11	1.8	5.8
1961-63 Avg.	0	16	3.4	4.8	17	3.7	4.5
	I	11	1.3	8.4	10	1.2	8.6
	II	8	0.7	11.1	7	0.7	10.8
	III	6	0.6	8.0	8	1.0	8.0
	Σ0 - IV	11	1.6	7.1	12	1.8	6.4
1965	0	16	3.3	4.7	16	3.4	4.7
	I	11	1.1	8.9	11	1.2	8.6
	II	9	1.0	9.1	10	0.8	12.2
	III	8	0.5	16.2	9	0.5	15.4
	Σ0 - IV	11	1.4	7.8	12	1.6	7.2
1966	0	14	2.9	4.7	15	3.3	4.7
	I	10	1.2	8.7	10	1.3	8.1
	II	8	0.6	13.6	8	0.6	13.6
	III	8	0.7	10.7	6	0.6	9.6
	Σ0 - IV	10	1.1	8.8	11	1.6	7.0
1967*	0	18	4.3	4.3	18	4.3	4.2
	I	9	1.3	7.0	9	1.4	6.5
	II	7	0.7	9.9	6	0.5	13.2
	III	6	0.6	10.6	6	0.5	10.7
	Σ0 - IV	9	1.4	6.7	6	1.2	4.9
1965-67 Avg.	0	16	3.6	4.5	16	3.5	4.6
	I	10	1.2	8.4	10	1.3	7.8
	II	8	0.8	10.5	8	0.6	13.0
	III	7	0.6	11.6	7	0.6	12.5
	Σ0 - IV	10	1.3	7.8	9	1.5	6.4

* For 9-month January - September periods

Changes in biomass, consumption and production in section A on a unit area basis before and after alteration are summarized in Table 8 and Figures 7-9. Here I will emphasize only 3 of the broadest comparisons.

The average biomass of trout in section A during the 3 years prior to alteration amounted to 43 pounds/acre. After alteration this average increased to 124 pounds/acre, a unit area difference of 188 percent. Annual food consumption increased from 480 pounds/acre to 1,256 pounds/acre, a change of 162 percent. Lastly, annual production increased from an average of 69 pounds/acre to 149 pounds/acre, a 140 percent increase.

Since many of the annual biomass, consumption, and production values were higher during the second and third years of the postalteration period than during the first year, these average values of 124 pounds of trout/acre, 1,256 pounds/acre of food consumed annually, and 149 pounds/acre of production annually are probably not artifacts of the experiment but valid measures of minimal sustainable conditions in the new environment.

Both the relative and absolute changes in biomass, consumption and production in altered section A are summarized in Figure 9. Both indices could be misleading however, since it is not known how much of section A was really a part of the trout environment or, more importantly, whether the productivity of section A was closely related to its surface area. It is conceivable that despite the reduction in surface area of altered section A, the area actually utilized by trout could have increased in the new configuration of the altered mile of stream. The cubic dimension of section A, expressed as acre-feet, decreased only 23 percent despite a 51 percent decrease in surface area. Such an environmental change should benefit the trout, since they rely primarily on passively drifting benthic invertebrates for food (White, 1967). The availability of such a food supply would certainly seem to be improved by an environmental change that confined and speeded up the flow, even if no quantitative increase in food production resulted.

Changes in the trout food supply (what was there and what was eaten) in altered section A and reference section B were measured but the analyses have not been completed. Since food has often been proposed as the most important limiting factor for trout in streams

Table 8.

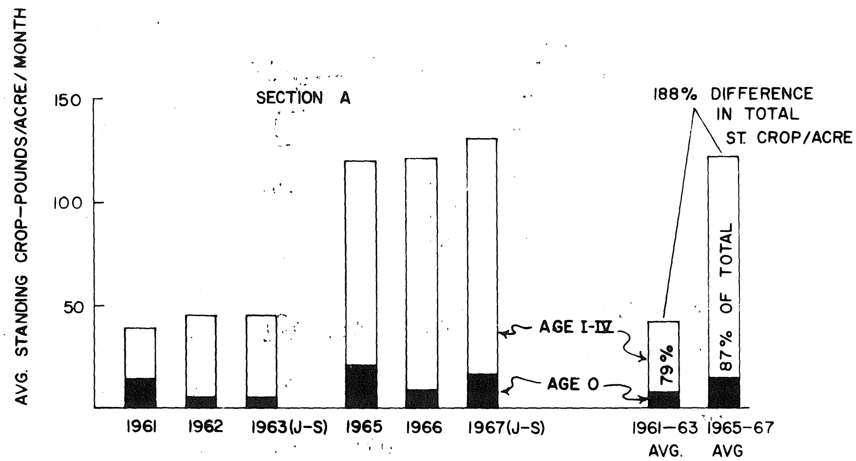
Absolute and Relative Values for Average Biomasses (B) of Brook Trout, Annual Food Consumption (C) and Annual Production (P) in Sections A and B of Lawrence Creek During 1961-63 and 1965-67

	Absolute Values - Pounds/Section						Relative Values - Pounds/Acre*					
	Section A			Section B			Section A			Section B		
Year	B	C	P	B	C	P	B	C	P	B	C	P
1961	149	1939	284	183	2322	378	39	509	75	58	737	120
1962	172	1808	232	184	2053	280	45	475	61	58	652	89
1963**	173	1734	266	166	1780	307	45	455	70	53	565	97
1965	225	2516	324	169	1981	276	121	1353	174	54	629	87
1966	226	2216	252	227	2472	353	122	1191	135	72	785	112
1967**	243	2279	342	198	1675	243	131	1225	184	63	532	77
1961-63 Avg.	165	1827	261	178	2052	322	43	480	69	56	651	102
1965-67 Avg.	231	2337	306	198	2043	291	124	1256	165	63	649	92
% Change	+40	+28	+17	+11	-1	-9	+188	+162	+140	+11	-1	-9

* Section A = 3.8 surface acres during 1961-63 and 1.9 surface acres during 1965-67.

Section B = 3.2 surface acres throughout 1961-67.

** 9-month averages or sums for January - September periods.



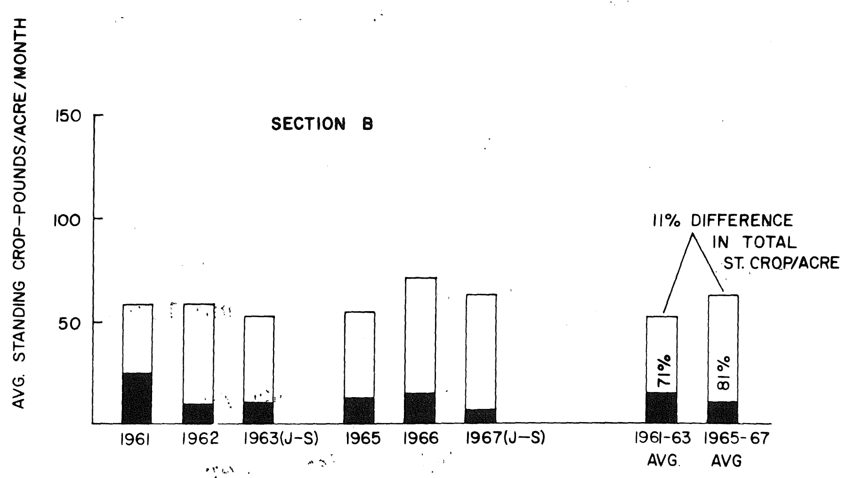


Figure 7. Standing crops per acre in sections A and B of Lawrence Creek during 1961-63 and 1965-67. Values for 1963 and 1967 represent 9-month January through September periods.

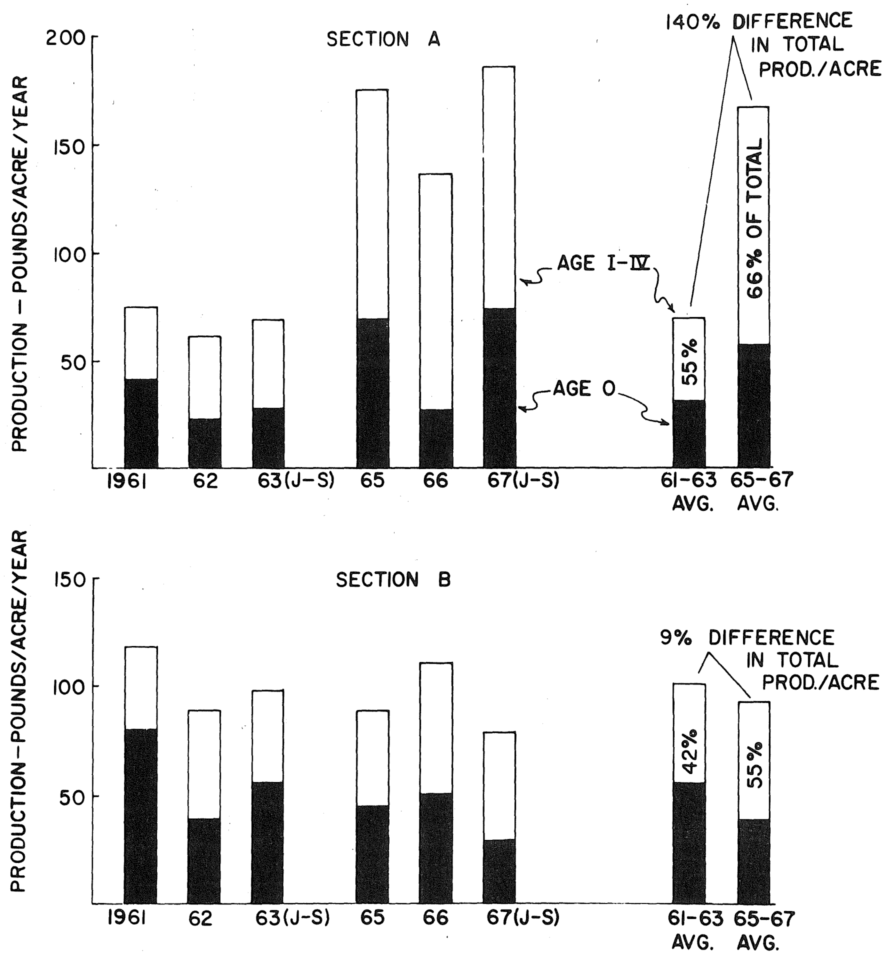


Figure 8. Production per acre in sections A and B of Lawrence Creek during 1961-63 and 1965-67. Values for 1963 and 1967 represent 9-month January through September periods.

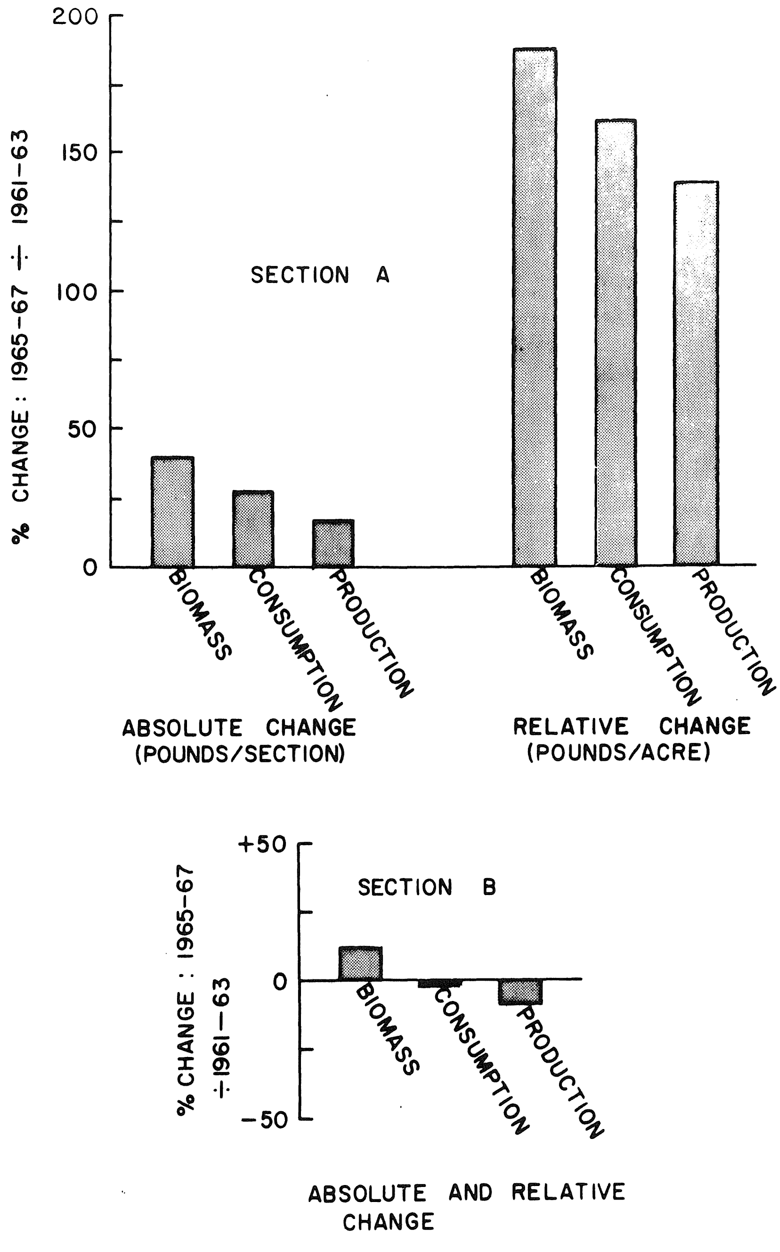


Figure 9. Absolute (pounds/section) and relative (pounds/acre/section) changes in average biomass, annual consumption and annual production in sections A and B during the 3-year period 1965-67 versus the 3-year period 1961-63.

(Chapman, 1966), speculations now about mechanisms responsible for changing the trout population are risky. However, some of these responses did not appear to be primarily food-linked even though changes in the food-supply are not known.

For example, loss of trout in section A during the "winter period" (September 15 to April 1) due to natural mortality and emigration in excess of immigration was greatly reduced after habitat improvement. During the winters of 1961-63 the number of trout in section A declined by an average of 48 percent. During the winters of 1965-67 the decline averaged only 20 percent. Overwinter emigration was reduced by 64 percent despite an absolute increase of 10 percent in the average number of trout present in September. Emigration from altered section A also declined by 11 percent during April to September periods despite an average numerical increase of 65 percent in April standing crops. These reductions in mortality and emigration are believed to represent responses to physical improvements in "space-refuge factors" (protective cover, depth, and pool area) more than responses to changes in food supply.

The results of the food consumption calculations also indicate that independent of any knowledge of changes in the food supply itself, this resource did not seem to become any more limiting after alteration than before. As trout biomass increased in section A food consumption also increased and so did production (Fig. 10A). Food consumption per pound of biomass did decrease slightly (from 11 pounds/pound to 10 pounds/pound) during the postdevelopment period, but this decrease could have resulted from the decreasing proportion of age 0 trout in the total stock rather than size-specific reductions in consumption. The age-specific ratios of food consumed per pound of trout showed little change after habitat improvement (Table 9). Age 0 stocks continued to eat approximately 16 pounds per pound of biomass, age I stocks 10 pounds, age II stocks 8 pounds and age III stocks 7 pounds per pound of biomass.

Warren et al. (1964) found that in the sucrose-enriched sections of Berry Creek trout production (and biomass) increased by 700 percent, but food consumption increased only 200 percent. In these experiments changes in biomass were synonymous to changes in production since few of the stocked trout died. Warren concluded that the change in consumption was the best index of the increase in productivity of the environment due to enrichment.

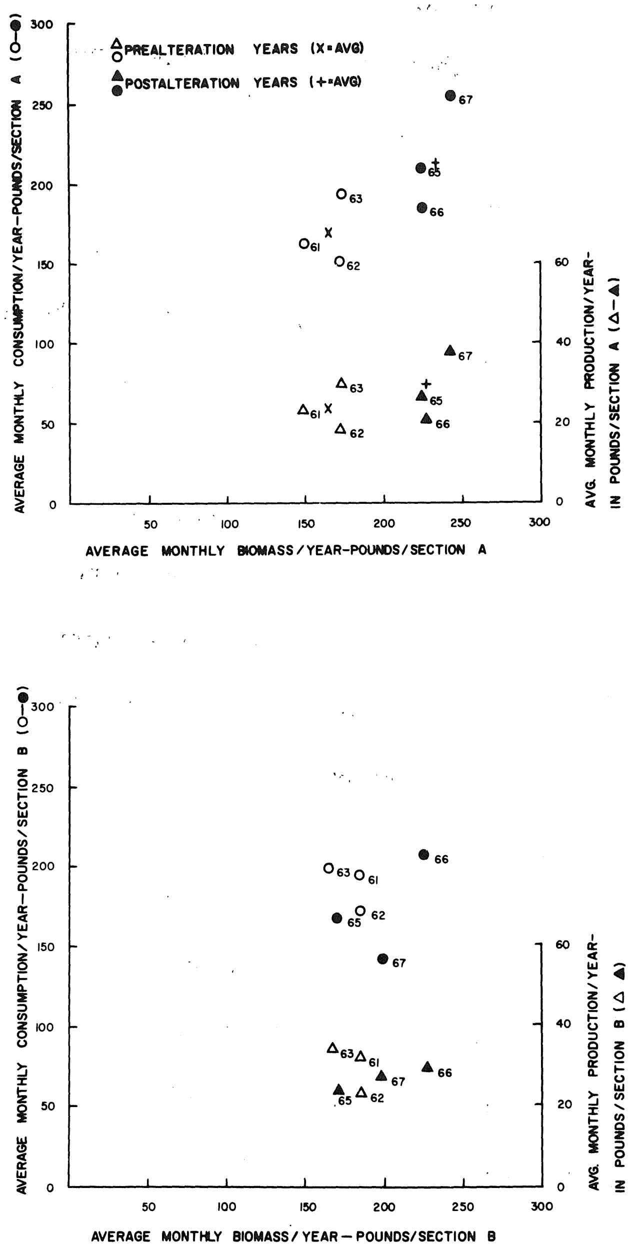


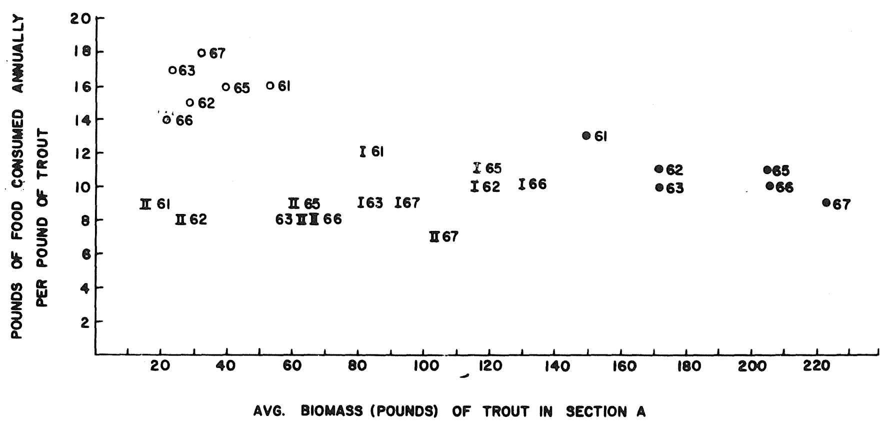
Figure 10. Relationships of average monthly consumption of food and average monthly production to average monthly biomass of brook trout in sections A and B of Lawrence Creek during 1961-63 and 1965-67.

In section A of Lawrence Creek, biomass increased by 40 percent, consumption increased by 28 percent, and production increased by 17 percent in absolute values, or 188 percent, 162 percent, and 140 percent in pounds/acre. In contrast to the experiments in Berry Creek, consumption increased more than production. In Berry Creek environmental manipulations were apparently channeled to the trout population via a temporarily improved food supply, and most of the increased food consumption was converted to growth. In Lawrence Creek transfer mechanisms involved long-term improvements in survival of trout and restructuring of the age composition as well as possible changes in availability of food. Requirements of food for body maintenance must have increased in altered section A because population biomass increased. However, most of the increase in biomass was contributed by adult trout which do not consume as much food or produce as much new body tissue per pound as age 0 trout do. Since age-specific feeding rates did not appear to change, total consumption by the population did not keep pace with rising biomass, and production by the relatively older population did not keep pace with the increase in consumption.

If most of the increase in biomass had been contributed by age 0 rather than age I+ stocks, there is reason to believe that total consumption and total production would have increased proportionately more than total biomass. The actual decrease of 17 percent in average biomass of age 0 trout during 1965-67 was accompanied by decreases of 15 percent in annual consumption and 11 percent in annual production.

In an experiment with mixed lots of panfish (Lepomis sp.) and the black bullhead (Ictalurus melas) stocked in two artificial ponds, Welch and Ball (1966) found that food consumption increased more than fish production as stocking rates were increased, but at the highest stocking rate consumption decreased and production was negative. They concluded that crowding reduced food intake and production.

In section A of Lawrence Creek a two-fold increase in relative density of trout apparently had no crowding effect upon their food consumption (Fig. 11) and only minor effect on production in the improved environment (Fig. 12). This virtual absence of



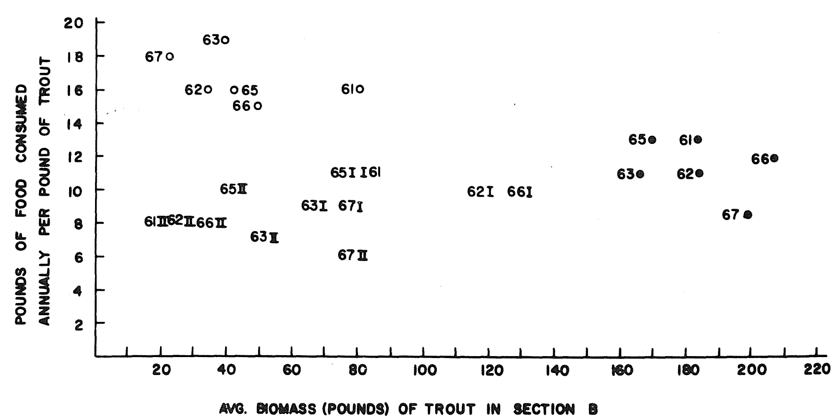
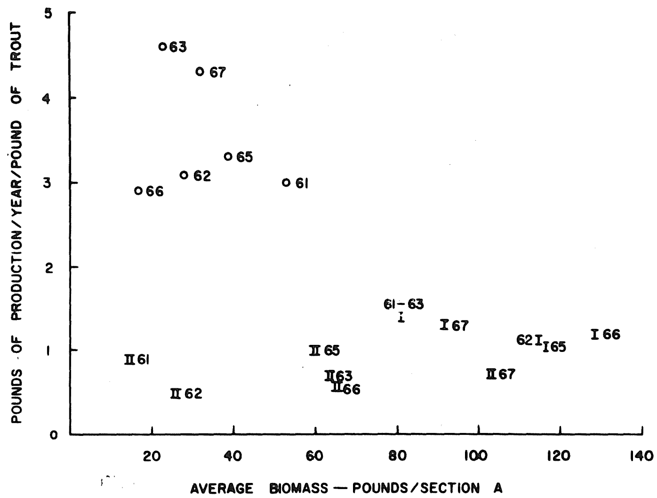


Figure 11. Relationships of annual consumption of food to average biomass for age 0-II brook trout in sections A and B of Lawrence Creek during 1961-63 and 1965-67. Consumption vs. biomass relationships for trout stocks as a whole are also designated by year on the right side of each graph.



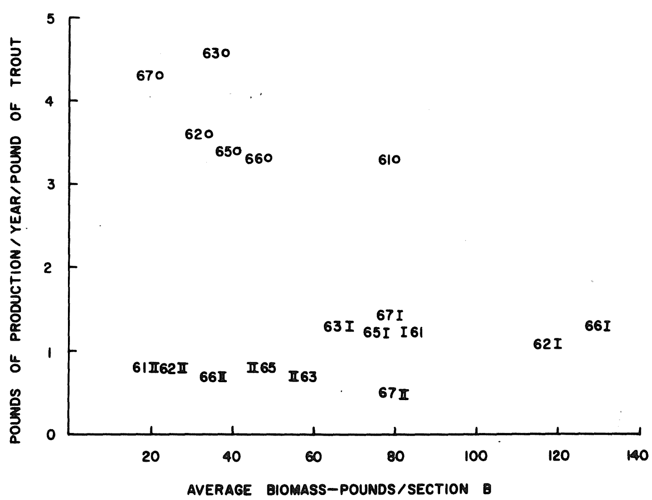


Figure 12. Relationships of annual production to average biomass for age 0-II brook trout in sections A and B of Lawrence Creek during 1961-63 and 1965-67. Production vs. biomass relationships for trout stocks as a whole are also designated by year on the right side of each graph.

compensatory changes in consumption and production suggests that the carrying capacity of altered section A was not exceeded during 1965-67, at least in terms of maintaining existing production efficiencies at even higher biomasses (Table 9).

Annual production in section A surpassed that in section B by 5 percent following alteration, whereas prior to alteration annual production was 23 percent greater in section B. This reversal is chiefly attributable to proportionately larger gains in age I+ stocks and proportionately smaller declines in age 0 stocks in section A.

Average biomass and average production of age 0 stocks in section A during the 3-year postalteration period failed to improve because of inclusion of data from 1966, the year when the age 0 stock was apparently much reduced in strength by the unusual February flood mentioned earlier. If 1966 data are not included in the postalteration average, age 0 production would have been 12 percent greater than the prealteration average.

Biomasses of age I+ trout increased in altered section A, not because they originated from initially stronger age 0 stocks, but because survival was better through the first winter of life and thereafter. Increased production in altered section A was also judged to result from this increase in survival. More trout lived longer and continued to produce at a rate which was primarily determined by their age not their density. Efficiencies of production within age groups did vary from year to year, but difference in efficiencies between age groups were much more prominent (Fig. 12A). Annual production must have been more dependent upon changes in numerical abundance of trout of each age than it was by differences in growth rates within age groups from year to year.

Changes in the sport fishery and numbers of legal-sized trout available for harvest were more dramatic than changes in trout biomass, food consumption, or production in section A. To the fish manager, increases in angler use, yield, and standing crops of legal-sized trout are more significant results of habitat improvement than increases in food consumption and production even though the latter two may be better indices to measure the enhanced productivity of the altered environment.

Habitat improvement in section A produced a stockpiling effect beneficial to the fishery. More trout survived to reach legal size, and as a result of the increase in fishing effort and yield, a better utilization of fish production was achieved. Prior to alteration the angler harvest was equivalent to only 9 percent of annual production. After alteration, the yield represented 23 percent of an annual production that was also greater (Fig. 13).

After alteration the number of trout over 6 inches increased in April stocks by 101 percent, and the number over 8 inches increased by 156 percent. Angling effort increased by 188 percent and yield increased by 196 percent. The catch-rate held at 0.3 trout per hour despite the increase in fishing pressure and despite a probable decrease in average angling skill. During 1961-63 only 18 percent of the angling trips on the entire stream were made to section A. During the 1965-67 fishing seasons 46 percent of the anglers coming to Lawrence Creek chose to fish in section A. The increased preference for fishing is believed to represent in part the easier fishing conditions there after the stream banks had been firmed up, trails for equipment access had been bulldozed along the stream, and much of the streamside brush had been cleared away. Altered section A was the only section that could be conveniently fished without rubber footgear, which many novice anglers did not have.

Substantial but less consistent improvements in yield and recruitment of legal trout also occurred in unaltered section B during the second 3-year period of comparison. There, yield increased by one-third, but the 1966 yield was smaller than yields in 1962 and 1963. Yield amounted to 11 percent of annual production in 1961-63 and 18 percent in 1965-67 and yield increased despite a 28 percent decline in angling effort during 1965-67. The increase in the catch rate from 0.2 trout per hour in 1961-63 to 0.4 in 1965-67 probably resulted mainly from an increase in average angling skill as more of the novices shifted their efforts to section A, although the increase in numbers of legal-size trout must have helped too. A more thorough analysis of factors causing changes in the fishery in sections A and B is planned.

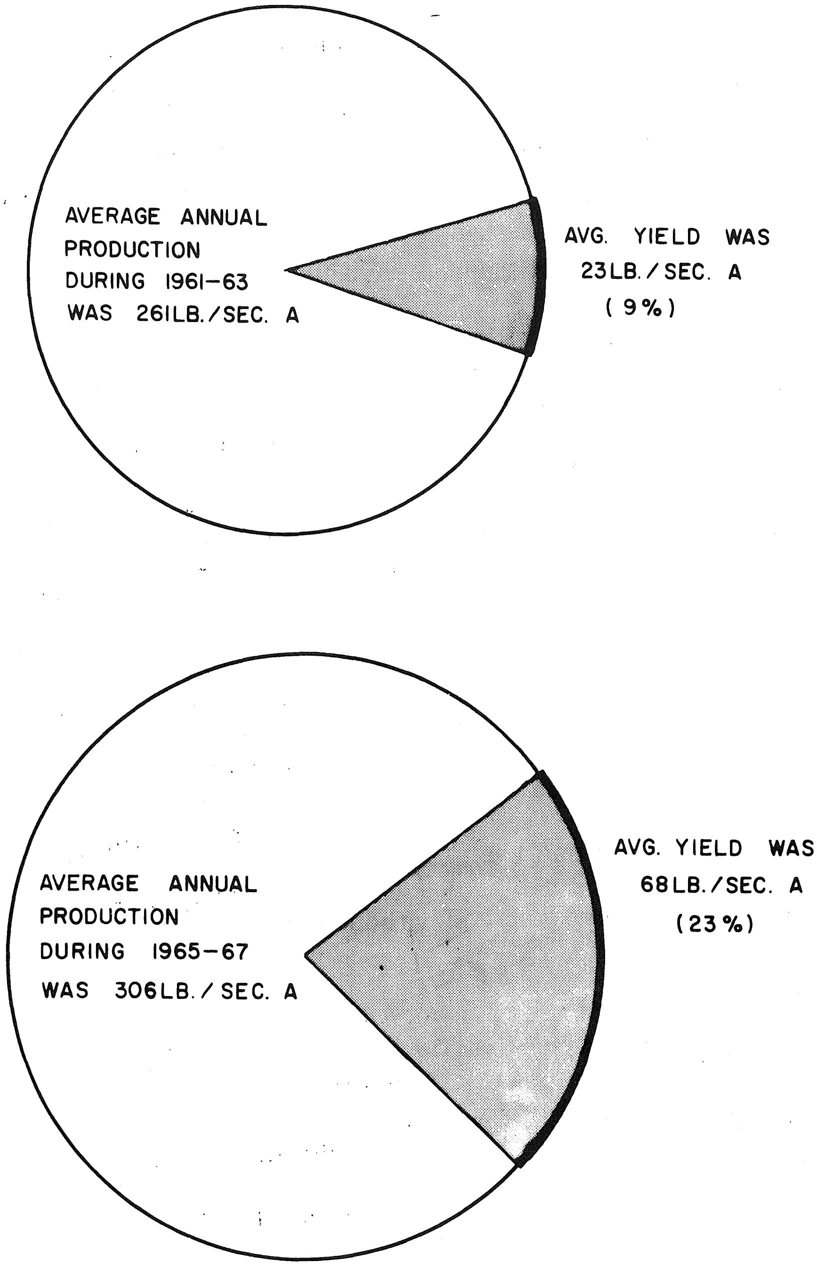


Figure 13. Average annual production by brook trout in section A of Lawrence Creek, and average yield as a percentage of production during 1961-63 and 1965-67.

One aspect of trout population dynamics in sections A and B seems especially worthy of additional discussion independent of any considerations of habitat alteration. This aspect involves the proportional relationships of annual production to biomass. Huet (1964) has stated that in the streams he was familiar with, an approximation of the biomass of fish present could be obtained by doubling the value of annual production derived from his productivity formula. The reciprocal of this relationship would imply that annual production is equivalent to one-half of the average biomass, a quantity which is normally easier to derive in fish sampling studies. The applicability of this conversion factor for estimating trout production in sections A and B during 1961-67 can be judged by examining the biomass and production data plotted in Figure 14. The relationship proposed by Huet is clearly not applicable to the brook trout population in Lawrence Creek. Among 12 pairs of observations annual production ranged from 120 percent to 210 percent of the average biomass. Even after elimination of the highly productive age 0 stocks from the calculations, annual production of age I+ trout was equivalent to at least 100 percent of the average biomass for 9 of 12 pairs of observations and ranged from 85 percent to 130 percent of the average biomass. These latter production vs. standing crop ratios are similar to the type reported by Mann (1965) in his investigation of fish production in the Thames. He concluded that annual production of several species of fish was equivalent to 65 percent of their biomass. His values for annual production (380 pounds/acre) and biomass (588 pounds/acre) are among the highest reported for fish in natural environments, despite the absence of biomass and production data for age 0 fish during their first 6 months of life.

In Lawrence Creek production is high in relation to biomass because brook trout are relatively short-lived in this stream and growth is relatively slow after the second year of life. Only a few live to be four or more years old, and 80 percent or more of lifetime production by a year class normally occurs during the first two years when most of the mortality is also occurring. Consequently, only a small proportion of production accumulates in the standing crop of trout that comprises the sport fishery.

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