1877

Population Dynamics of Trout in Some Streams of the Northern Lower Peninsula of Michigan

Howard Gowing
and
Gaylord R. Alexander

Fisheries Research Report No. 1877
March 12, 1980

MICHIGAN DEPARTMENT OF NATURAL RESOURCES
FISHERIES DIVISION

Fisheries Research Report No. 1877

March 12, 1980

POPULATION DYNAMICS OF TROUT IN SOME STREAMS OF THE NORTHERN LOWER PENINSULA OF MICHIGAN[1]

By Howard Gowing and Gaylord R. Alexander

Abstract

Standing crop, growth rates, and production were computed for trout in 14 streams located in the northern lower peninsula of Michigan. These waters lie in a region with soils which have a high infiltration rate and groundwater recharge. They have the prerequisite flow and temperature regimes, along with carbonate hardness, to be classed as good trout streams. The streams varied in width from 4.7 to 33.9 m and in mean discharge from 0.42 to 4.95 m^3 per second.

One stream contained brook trout only, three contained brown trout almost exclusively, and 10 streams had two or more species of trout. Rainbow trout were present in four of the streams. In 9 of the 10 streams having more than one trout species, brown trout, on the average, comprised 68% of the total standing crop (kilograms per hectare). Of the 10 streams containing brook trout, 3 had fall standing crops of this species no greater than 2.4 kg per hectare. Total fall standing crop of all trout averaged 85.1 kg per hectare. Standing crop per unit area was not related to size of stream based on discharge.

Trends in survival of brown and brook trout differed in that the latter showed better survival the first summer but poorer survival the third year and thereafter. At age 0 and older, brown trout attained a greater length and weight than brook trout with differences tending to increase with age. Brown trout lived longer than brook trout. Relatively few brook trout survived to age IV whereas brown trout commonly survived to age VII. The average annual production of brown trout populations was 81.6 kg per hectare, brook trout populations 24.0 kg per hectare, and rainbow trout populations 8.5 kg per hectare. Production of trout, all species combined and all streams combined, averaged 95.4 kg per hectare. The average P/B ratio, based on the fall standing crop, was 1.04 for brown trout, 1.68 for brook trout, and 1.72 for rainbow trout. For all trout combined it was 1.13.

---

[1] Contribution from Dingell-Johnson Project F-35-R, Michigan.

On six streams censused for angling, the fishing ranged from 160 to 756 hours per hectare or an average of 512 hours per hectare. Anglers cropped between 25 and 378 trout per hectare and from 4.1 to 37.7 kg per hectare. Harvest represented 4-37% of the annual production. Potential production of trout in six streams was also estimated on the basis of natural mortality (M) in the absence of fishing mortality (F). This tended to increase production values, more for brown than brook trout. Streams were ranked on a basis of annual production per unit area (grams per hectare), per unit area per annual discharge (grams per hectare per cubic meter per year), and per unit length per annual discharge (grams per kilometer per cubic meter per year) which indicated a greater efficiency of water use and productivity of trout in small streams compared to large streams.

Introduction

Production is a fundamental element in the assessment of a fish stock. However, some of the basic measurements of a population necessary to estimate production are not readily obtained. Consequently, there is a paucity of information on the production of trout in streams, particularly when the magnitude of this resource is considered.

Our objective in this report is to present the standing crop, growth rates, and production of wild trout in an array of streams considered generally representative of the northern lower peninsula of Michigan. This information will provide a basis for comparison with data from other streams and a framework within which to test new approaches to management.

Study area

The 14 streams involved in this study lie in the northern half of the lower peninsula of Michigan, an area strongly influenced by glaciation. It is an area of rolling hills underlain by deep deposits of permeable outwash containing much sandy till. The soils, therefore, are conducive to high infiltration rates and groundwater recharge. In general, most of the streams of the area have the physical environment necessary to support trout populations, namely relatively cold-water temperature, stable flow, and high carbonate hardness (Hendrickson, Knutilla, and Doonan 1973).

The physical dimensions of the 14 streams vary markedly (Table 1), for example, widths vary from 4.7 m (Williamsburg) to 33.9 m (North Branch Au Sable River). On the basis of mean discharge, the streams were categorized as small, medium, and large. The five small streams--Houghton, Gamble, Hunt, Williamsburg, and Poplar creeks--have mean discharge rates of 0.42 to 0.85 m^3 per second. The medium-discharge streams are the Rifle, Pigeon, Little South Branch Pere Marquette (hereafter designated Pere Marquette), North Branch Boardman, and South Branch Boardman rivers. For these streams the discharge rates range between 1.58 and 2.09 m^3 per second. The large-stream category includes mainstream Au Sable, South Branch Au Sable, North Branch Au Sable, and mainstream Boardman rivers.

The discharge rates for these streams range from 3.25 to 4.95 m^3 per second. In all of these streams the water is hard, varying from 140 to 220 mg per liter of alkalinity and with pH values ranging from 7.9 to 8.5.

The species composition of fish in these streams varies from a comparatively simple association of brook trout (Salvelinus fontinalis) and sculpins (Cottus spp.) as in Hunt Creek, to a complex one where brown trout (Salmo trutta) and brook trout coexist with a variety of warm-water and cold-water fish as in the Rifle River. Trout production more nearly represents total fish production in the former than in the latter. No attempt was made to assess the standing crop or production of fish other than wild trout. In all instances, however, the preponderance of fish production was in trout flesh.

Methods

The streams used in this report were chosen for the availability of data. Four of the 14 streams--Hunt Creek (3.2 km), Pigeon River (9.6 km), Rifle River (8.0 km), and Gamble Creek (1.2 km)--were located at three fisheries research stations where angling was monitored by a complete creel census operated under a daily-permit system (Fig. 1). The period of years selected for these research waters was that just prior to a closure to fishing or termination of creel census.

The second group of streams used was that one where in the late 1950's and early 1960's censuses were conducted on segments of each to assess the impact of special angling regulations on the fisheries. In contrast to statewide regulations, special regulations generally placed greater restriction on lures, increased the size limit, and decreased the creel limit. For example, special regulations on sections of the mainstream Boardman River in 1960-61 were: flies only, 254-mm (10-inch) size limit on all trout, and a creel limit of five trout per day. These regulations were tested against statewide regulations on sections of the Boardman of any lure, 178-mm (7-inch) size limit, and a daily creel limit of 10 fish. Other specific fishing regulations are given in Table 1 of the Appendix. These creel census studies, conducted on a stratified random sampling basis, included the following

streams: mainstream Au Sable River (14 km from Burton's Landing to Wakeley Bridge), North Branch Au Sable River (11.1 km from Otsego-Crawford County line to Eaman's Landing), South Branch Au Sable River (25.9 km from Chase Bridge to mouth), mainstream Boardman River (9.6 km from Fork's Campground to Scheck's Bridge), and the Pere Marquette River (15.9 km from Taylor to Carlson's Bridge). One or more stations were established within these sections to measure the trout populations which were considered representative of the creel census areas (Cooper, Shetter, and Hayne 1959).

The remaining five streams used in the production calculations were those where stream alterations or sediment loading were evaluated but angling was not measured. This group included Houghton Creek, Poplar Creek, Williamsburg Creek, South Branch Boardman River, and North Branch Boardman River.

Semiannual estimates of the brown trout populations in the North Branch Au Sable, South Branch Boardman, Gamble, and Williamsburg were obtained, one in the spring before the trout season opened and again in the fall after the fishing season closed. Similarly, spring and fall estimates of brook trout were obtained in the North Branch Au Sable, Pigeon, Hunt, and Williamsburg. For the other streams, estimates of trout abundance were obtained annually in the fall after the fishing season closed. For trout populations in these streams (single estimate) to show their summer growth, estimates of spring populations were extrapolated. This was accomplished by employing as models populations of brown and brook trout estimated semiannually. For example, from the models the total number of deaths that occurred on the average between two successively older age groups in the fall was determined. The spring estimate was then used to determine the proportion of deaths occurring between fall and spring and spring and fall. In a similar fashion seasonal growth in length, and in turn, weight was determined.

Estimates of the trout populations were derived by the Petersen mark-and-recapture method employing electrofishing gear as a means to

capture trout. For the Rifle River, Gamble and Houghton creeks, estimates were calculated by the Bailey modification of the Petersen formula, but for all other streams the Petersen formula was used as described by Shetter (1957). In either case, estimates differed slightly and the differences were judged to be of little consequence.

The method of determining the age structure of a trout population and the average length of an age group followed the procedure described by Alexander and Ryckman (1976). Formulas were available for the length-weight relationship of trout in the Houghton, Pigeon, North Branch Au Sable, Hunt, Gamble, and Rifle. The Pigeon River formulas were used to assign weight to trout in the mainstream Boardman and tributaries, Williamsburg, and Poplar; formulas for the Platte River were applied to trout in the Pere Marquette River; and the North Branch Au Sable formulas provided the means for assigning weights to trout in the mainstream Au Sable and South Branch Au Sable.

Growth rates were derived from sequential estimates of average weights. Production was computed according to the method of Ricker (1975) and is based on total instantaneous mortality rates (Z). In view of the varying role that angling mortality played in different streams, production was also computed on the basis of only natural instantaneous mortality rates (M), by subtracting fishing (F) from total instantaneous mortality rates (Z). In turn, the new assumed survival rate was the antilog of the natural mortality rate (M). During the fall and winter, when there was no angling mortality, natural mortality (M) was equivalent to total mortality (Z). During the spring and summer fishing season, beginning usually with age-I trout, the earliest age subject to angling mortality, natural mortality rate (M) was used.

Fishing regulations have become generally more restrictive over the 23 years covered by this study. Creel limits diminished and size limits increased, influenced by the continued implementation of special fishing regulations on sections of certain streams that began in the late 1950's. The only liberalization was the gradual lengthening of the fishing season. While some streams were covered by special regulations and others fished under the normal statewide regulations, no attempt was made to separate the two

in terms of their effect on the fishery. This aspect was reported by Shetter and Alexander (1962, 1965, 1966), Alexander and Ryckman (1976), Latta (1973), Shetter (1969), Cooper, Shetter, and Hayne (1959), Cooper, Shetter, and Alexander (1963), and Alexander, Buc, and Schnicke (1979).

The original studies on these streams were for a varying number of years and for different years within the period of 1954-1977. Estimates of trout for a stream were averaged over the number of years of data and compared to other streams, disregarding temporal differences. In most instances, estimates of trout were obtained for two or more stream sections, then pooled and an average determined. This approach also necessitated getting a mean for the anglers' catch of trout over the years covered by the particular study. In these cases where angling was under special and statewide regulations in the same stream, the catch in the two waters was pooled by species and an average obtained. This report rests on a body of data that involves well over 400 separate population estimates.

Results

The fall standing crop of trout in the Rifle, Houghton, and Gamble was comprised almost entirely of brown trout and, in 9 of the 10 streams containing more than one species of trout, brown represented 68% or more of the total standing crop (Table 2). The exception was the Pigeon River where brown trout represented 31% and brook trout 69% of the total. Only in Hunt Creek was the population exclusively brook trout. In most streams young trout comprised the largest portion in number per hectare of the total fall standing crop. For example, in South Branch Boardman young of the year and yearlings (age I) made up about 79% of the total standing crop of brown trout while comparable age brook trout in the Pigeon represent nearly 98% of the total standing crop. (Baseline data on all trout populations by age and length group are given in Appendix Tables 2-8.)

Williamsburg had the largest standing crop of brown trout followed by South Branch Boardman, mainstream Au Sable, and Houghton. They ranged between 112.7 and 171.4 kg per hectare. The smallest standing crops of brown trout occurred in the Pigeon (10.1 kg per hectare) and

and Rifle rivers (24.7 kg per hectare). In the remaining seven streams containing brown trout, the standing crop ranged between 51.2 and 77.2 kg per hectare.

Excluding the Pere Marquette, where only two brook trout were sampled, 10 of the 14 streams contained brook trout, and of these, 3 had standing crops of 2.5 kg per hectare or less. Of the 7 streams having standing crops larger than 6.0 kg per hectare, only 2 had brook trout as old as age V (North Branch Au Sable and Hunt), 3 had trout to age IV, and 5 streams had trout to only age III. By far the largest fall standing crop of brook trout was the 63.4 kg per hectare in Hunt Creek. This was 2.7 times larger than the fall standing crop of brook trout in the North Branch Au Sable and Pigeon rivers and 5.3 times larger than in the mainstream Boardman. Williamsburg, mainstream Au Sable, and South Branch Au Sable were in the intermediate range with standing crops varying between 6.8 and 8.2 kg per hectare.

Rainbow trout (Salmo gairdneri) occurred in only 4 of the 14 streams --Poplar, mainstream Au Sable, Pere Marquette, and Williamsburg. Poplar Creek had a standing crop of 11.2 kg per hectare, about two-fold greater than in the Au Sable River. In the Pere Marquette the fall standing crop was 3.9 kg per hectare while in Williamsburg it was only 0.8 kg per hectare. Streams with anadromous runs of rainbow trout (steelhead) are not adequately represented in this small sample.

There was no relationship between total fall standing crop of trout per unit area and the categories of small, medium, and large streams. Of the 4 streams having standing crops greater than 100.0 kg per hectare, 2 were small (Williamsburg and Houghton), 1 medium (South Branch Boardman), and 1 large (mainstream Au Sable). Where the standing crop ranged between 70.7 and 88.9 kg per hectare, 1 stream was small (Poplar), 2 medium (North Branch Boardman and Pere Marquette), and 1 large (North Branch Au Sable). In the third group where standing crops ranged from 61.5 to 65.7 kg per hectare, 2 small (Gamble and Hunt creeks) and 2 large (South Branch Au Sable and mainstream Boardman) streams were represented.

The two smallest standing crops occurred in the Pigeon River (33.0 kg per hectare) and Rifle River (24.7 kg per hectare), both in the medium-size category. For the 14 streams the average fall standing crop (all trout species combined) was 85.1 kg per hectare.

Survivorship curves for brown and brook trout populations are shown in Fig. 2 (see Appendix for tabulated data). Number of fry was derived from data on maturity, fecundity, and survival in the gravel for brown and brook trout in the North Branch Au Sable River and the literature (Alexander 1974). These survivorship curves were based on average survival rates (S) for brown trout in 13 streams and for brook trout in 10 streams. Brown trout had an average spring population of 24,972 fry per hectare and by age VI in the fall were reduced to less than 1.0 fish per hectare. On the other hand, brook trout had an average population of 14,302 fry per hectare, about 43% smaller than brown trout, and by age IV in the fall were reduced to less than 1.0 fish per hectare. On the average, summer survival of brook trout fry was better than brown trout fry. The trends in survival did not differ significantly again until the third and fourth summers when survival rates for brook trout diminished more precipitously than for brown trout. The diminution of the population coincided with the age and size at which brook trout are subject to high angling mortality.

From age 0 to age V, brown trout growth in length was consistently superior than brook trout in any stream (Tables 3 and 4). Brown trout in the North Branch Au Sable and Pere Marquette rivers maintained the highest level of growth over the first 6 years of life. Growth of age II and age III brown trout in the Pigeon and age IV and age V trout in the South Branch Au Sable ranked highest. Poorest growth occurred in Gamble Creek with trout in the North Branch Boardman and Williamsburg also ranking low. The maximum difference in growth for example was 72 mm at age I and 101 mm at age IV in the fall when comparing the North Branch Au Sable and Gamble Creek.

Among stocks of brook trout in 10 streams, those in the mainstream Boardman, South Branch Au Sable, and North Branch Au Sable ranked highest in growth (length) and those in the South Branch Boardman, North Branch

Boardman, and Hunt Creek ranked lowest (Table 4). The difference in growth, for example between Hunt Creek and the South Branch Au Sable amounted to 36 mm at age I and 66 mm at age III in the fall. At age 0 and older, brown trout attained, on the average, a greater length than brook trout. From age 0 to age III in the fall, the disparity tended to increase with age, with the minimum amounting to about 8 mm and the maximum 45 mm.

For both brown and brook trout growth in weight by age corresponded to growth in length in these streams. For the first 3 years of life brown trout exceeded the weight of brook trout in the fall by as little as 2 g at age 0 to as much as 70 g at age II (see Tables 4 and 5, Appendix). Differences between the two species can be seen in the rates of growth. As maximum growth occurs during the spring-summer period, the instantaneous growth rates (G) of brown trout for the first three summers of life were 4.325, 1.503, and 0.675 respectively, and exceeded slightly those for brook trout which were 4.091, 1.234, and 0.599.

Production of trout in these streams was variable. The largest production of brown trout was 184.4 kg per hectare in Williamsburg, followed by 150.9 kg per hectare in South Branch Boardman River, and 129.2 kg per hectare in Houghton Creek (Table 5). Production was also comparatively large in the mainstream Au Sable (99.5 kg per hectare) and Poplar Creek (88.0 kg per hectare). In 6 of the remaining 8 streams production varied from 53.6 kg per hectare (Gamble) to 73.3 kg per hectare (North Branch Boardman). A relatively small production of brown trout occurred in both the Rifle and Pigeon, 15.4 and 13.2 kg per hectare, respectively.

Production of brook trout was more variable than brown trout production. In Hunt Creek production of brook trout was 89.5 kg per hectare and greatly exceeded the production of this species in any of the other streams (Table 5). It was 2-fold larger than the North Branch Au Sable, 2.4-fold larger than the Pigeon, and nearly 4-fold larger than brook trout production in the mainstream Boardman. The next lower level of production ranged between 10.6 and 14.1 kg per hectare in three

streams--Williamsburg, mainstream Au Sable, and South Branch Au Sable. The lowest level of brook trout production--between 0.6 and 4.2 kg per hectare--was in the North Branch Boardman, South Branch Boardman, and Poplar Creek.

A considerable amount of the total annual production is contributed by the young trout in the population. Growth of brown trout from fry to age I in the fall accounted for 40 to 58% of the total annual brown trout production. For brook trout, which exhibited a shorter life span than brown trout in these streams, these young fish contributed between 67 and 88%.

In the nine streams where brown and brook trout coexisted, only in the Pigeon River did brook trout production exceed that of brown trout. Overall, production of all trout in the 14 streams averaged 95.4 kg per hectare.

As growth is more rapid in summer than in winter and as survival is similar, greater production is gained during the summer than winter. In the 14 streams about 75% of the production occurred during the spring and summer period (mid-April to mid-October) and 25% during the fall and winter period (Table 6).

The relationship of production to standing crop, or P/B ratio, was found to be relatively constant and therefore is of interest to fisheries managers as it provides a means to obtain an approximation of production through knowledge of the standing crop (Waters 1969, 1977). Waters (1977) defined the P/B ratio as total production of a cohort divided by the mean standing crop during the life span of the cohort. It is commonly calculated as annual production divided by mean annual standing crop, regardless of voltinism or life span. However, as used in this report, it is the ratio of total annual production to average fall standing crop. Our application of the P/B ratio stems primarily from the common practice of measuring trout populations annually in the fall when stream conditions are more favorable for sampling fish than in the spring. It is a time when the biomass of the population is near its peak.

In our streams the P/B ratios for brook trout exceeded those for brown trout (Table 7). The average P/B ratio for brook trout in 10 streams

was 1.68 and for brown trout in 13 streams 1.04. The ratio for all trout combined in 14 streams ranged between 0.62 (Rifle) and 1.54 (Pigeon) and averaged 1.13.

Creel census records for six streams are reviewed here and, with one exception, covered the period 1959-1967. The exception is the creel census records for the mainstream Au Sable which were collected in 1976. The 1976 records are judged to be representative of the fishery in the Main Au Sable during 1974-77, the years for which an estimate of average production was obtained. In general, fishing pressure on these streams was intensive, averaging 512 hours per hectare. The most intensive fishing was 756 hours per hectare on the mainstream Au Sable in 1967 whereas fishing pressure was lowest on Gamble Creek, 160 hours per hectare (Table 8). In Hunt Creek, a small stream, anglers cropped 378 brook trout per hectare, the highest for this group of streams. This represented more than 28 kg per hectare which was about 32% of the total annual production. Trout were also cropped heavily in the North Branch Au Sable with nearly 275 fish per hectare or about 38 kg per hectare caught. The weight harvested represented about 37% of the annual production in this large stream. At the other extreme, anglers harvested only 25 trout per hectare or about 5.4 kg per hectare in the mainstream Au Sable, also a heavily fished large stream. This amounted to 4% of the annual production. In Gamble Creek, a small, lightly fished stream, the harvest was only 31 trout per hectare or 4.1 kg per hectare, equivalent in weight to about 8% of the total annual production.

The role of fishing mortality in the foregoing six streams was reviewed with respect to production. Production as compiled in this paper was based on total instantaneous mortality rate (Z) which takes into account deaths from fishing (F) and natural mortality (M). When fishing is removed as a component of total mortality, the survival rate subsequently increases and thereby the population size, or standing crop, increases. Since the total mortality rate is equivalent to the natural mortality rate during the winter, the survival rate during this period is unaltered. The high natural mortality of brook trout is reflected in their comparatively small standing crops and short life span. These factors limit the amount of increased

production based solely on natural mortality rates. On the other hand, brown trout live longer, thus production is accrued on a broader age base of fish. Thus removing angler mortality provides a greater potential for fish production in brown trout.

Production of trout based on instantaneous rates of total mortality (Z) and natural mortality only is shown for six streams in Table 9. Fishing mortality rates for brown trout in the North Branch Au Sable were greater than for brown trout in the Pigeon which in effect increased their survival rates and allowed for greater theoretical production. The difficulty in using natural mortality rates (M) to determine production potential is the assessment of possible but unknown compensatory change in natural mortality with changes in density as a result of angling mortality. Nevertheless, this approach sets an approximate maximum production potential whereas the first method used measures an empirical but lower production. Production in the absence of fishing would undoubtedly fall between values obtained by the two methods.

Discussion

In the array of streams reported here there is perhaps some bias in that infertile and marginal trout streams are underrepresented. Nevertheless, the range in production which varied from about 15.0 to 196.0 kg per hectare and averaged about 95.0 kg per hectare, is fairly representative of the northern lower peninsula of Michigan. There may also be some unique situations in this region of the state where artificial enrichment of a stream has resulted in higher production than reported here. Brynildson and Mason (1975) reported such a case for an enriched zone (polluted) of a stream in Wisconsin where production of brown trout was 396 kg per hectare, which exceeded considerably the production calculated here for Williamsburg Creek. In Williamsburg, South Branch Boardman, Houghton, and North Branch Au Sable--the more productive streams--there are indications of some enrichment through man's activities (Ellis and Gowing 1957; Alexander, Buc, and Schnicke 1979). On the other hand, Cooper and Scherer (1957) reported an annual brook trout production of 300 kg per hectare in a fertile

limestone stream that was not enriched in Pennsylvania. In small streams in Great Britain, Le Cren (1967) found production of brown trout to range between 20-120 kg per hectare. Our category of small streams had production values generally above this range. Brook trout production in Hunt Creek of nearly 90 kg per hectare was of the same magnitude as the 99-109 kg per hectare of brook trout reported for Lawrence Creek in Wisconsin (Hunt 1966). Both of these exceeded the 62 kg per hectare reported for brook trout in Valley Creek, Minnesota (Elwood and Waters 1969).

The data presented here cannot resolve the question of whether greater production can be achieved in a stream by two rather than a single species of trout. Neither can we determine the superiority in production of one species over another if they existed singly in the same stream. Nevertheless, there is some indication that greater production is achieved when two or more species of trout coexist than where only one is present (Bjornn 1972). For nine streams in this study that had at least two species of trout, annual production averaged about 116 kg per hectare whereas in six streams with almost exclusively one species of trout, including one Wisconsin and one Minnesota stream cited earlier, production averaged about 76 kg per hectare. In our streams where brown and brook trout coexisted, the former predominated in eight out of nine cases.

We found a direct relationship between average fall standing crop and annual production ($r = 0.959$, d.f. = 12). As the standing crop increased, production increased at a proportional rate. The average annual production of the trout population was about 1.13 times the fall standing crop. Since the P/B ratio for brook trout was consistently greater than that for brown trout, it appears best to treat them separate when possible (Table 7). The average P/B ratio for brook trout was 1.68 and for brown trout 1.04.

The average brook trout population contains proportionately more young fish than the brown trout population thus a greater proportion of the total population is comprised of the faster growing immature fish. This results in higher P/B ratios for brook trout. In our streams the lowest P/B ratio was 0.62 in the Rifle River. The Rifle is typical of the lower reaches of many large rivers, where a comparatively small standing crop of old

brown trout is recruited largely from upstream areas and/or tributaries. Production in these environments is relatively low.

When the P/B ratio is based on the mean annual standing crop (average of spring and fall estimates), other than just the fall standing crop, the average ratio increases about 10.5% or to 1.16 for brown trout and to 1.84 for brook trout. In a review of the literature on P/B ratios, Waters (1977) found most values slightly above 1.0 for normal stream-dwelling populations of trout and salmon. Chapman (1978) indicated that, in cold-water environments when salmonids dominate, 1.5 could be used as a multiplier to estimate production.

Ranking the 14 streams in order of production measured in grams per hectare, showed that the three small streams--Williamsburg, Houghton, and Poplar--were in the top half of the distribution (Table 10). Rounding out the upper half of the distribution is the South Branch Boardman, a medium stream, and mainstream Au Sable, North Branch Au Sable, and mainstream Boardman, all large streams. For the production values to reflect the inherent capacity of these waters to promote growth of the trout populations, the hatchery concept of relating production to flow rates, or exchange rates, was used to rank the streams. Production was expressed in grams per hectare per cubic meter per year. This increased to five--Williamsburg, Poplar, Hunt, Houghton, and Gamble--the number of small streams in the top half of the distribution. The four large streams dropped in their ranking with none higher than ninth in the array of 14 streams. This suggests in part, greater efficiency of water use in small versus large streams. A third ranking combined the length of stream and related it to discharge on an annual basis. Production then was expressed in grams per kilometer per cubic meter per year. Again, small streams tended to be more productive. Four of the seven streams in the top half of the distribution were small and included Williamsburg, Poplar, Houghton, and Hunt. Part of the difference between the general productiveness of small and large streams is that the former have a comparatively greater rate of allocthonous nutrient input per unit of distance than large streams. The South Branch Boardman, a medium stream, and North Branch Au Sable, a large stream, generally ranked relatively high irrespective of the criteria used for ranking.

It is believed that this report which contains a vast amount of information on trout densities, growth, and production, from an array of Michigan streams, can serve as a standard for making comparisons with data from trout streams elsewhere and serve as a framework for future management.

Acknowledgments

Past members of the staffs of the Pigeon and Rifle River Fisheries Research Stations collected and summarized the original field data for the Pigeon, Rifle, Houghton, and Gamble. District fisheries personnel collected some of the information for the Au Sable rivers. Past and present members of the Hunt Creek Fisheries Research Station were involved in the original studies on nearly all of these streams. Otis H. Williams compiled and summarized much of the data for these studies. Jack D. Rodgers assisted in the field work and tabulation of data for many of these streams. We appreciate the efforts of W. C. Latta in reviewing the manuscript.

Table 1.--Physical dimensions of the trout population study areas on 14 Michigan streams and their mean discharge.

Stream	Length (m)	Mean width (m)	Area (ha)	Mean discharge (m^3/sec)
Mainstream Au Sable River	449.3	28.8	1.27	4.95
South Branch Au Sable River	1036.4	23.0	2.41	4.53
North Branch Au Sable River	1067.5	33.9	3.37	3.25
Mainstream Boardman River	1281.0	12.9	1.64	4.30
North Branch Boardman River	208.9	8.2	0.17	1.75
South Branch Boardman River	167.8	9.6	0.16	1.58
Rifle River	7995.9	13.4	10.67	2.09
Pigeon River	9630.1	12.6	12.05	2.09
Little South Branch Pere Marquette River	1189.5	10.6	1.26	1.75
Houghton Creek	2144.4	6.4	1.29	0.85
Gamble Creek	1224.0	5.8	0.71	0.65
Hunt Creek	3217.4	5.6	1.72	0.57
Williamsburg Creek	827.4	4.7	0.47	0.51
Poplar Creek	3354.1	4.8	1.76	0.42

Table 2.--Average fall standing crop (kilograms per hectare) in 14 Michigan streams.

Stream	Species of trout			
	Brown	Brook	Rainbow	Total
Mainstream Au Sable River	117.5	6.7	5.4	129.6
South Branch Au Sable River	54.4	8.2		62.6
North Branch Au Sable River	51.2	23.3		74.5
Mainstream Boardman River	53.8	11.9		65.7
South Branch Boardman River	149.1	1.5		150.6
North Branch Boardman River	68.2	2.5		70.7
Rifle River	24.7			24.7
Pigeon River	10.1	22.8		32.9
Little South Branch Pere Marquette River	71.4		3.9	75.3
Houghton Creek	112.7			112.7
Gamble Creek	61.5			61.5
Hunt Creek		63.4		63.4
Williamsburg Creek	171.4	6.8	0.8	179.0
Poplar Creek	77.2	0.4	11.2	88.8

Table 3.--Growth in length (millimeters) of brown trout from fry to age VIII based on annual spring (S) and fall (F) measurements in 13 Michigan streams.

Stream	Age and season									
	0		I		II		III		IV	
	S	F	S	F	S	F	S	F	S	F
Mainstream Au Sable R.	23	94	115	175	195	236	254	284	297	343
South Branch Au Sable R.	23	96	121	196	223	279	305	348	378	485
North Branch Au Sable R.	23	97	117	224	236	295	302	341	361	419
Mainstream Boardman R.	23	96	119	185	206	249	274	315	327	371
South Branch Boardman R.	23	81	102	162	180	224	241	267	277	302
North Branch Boardman R.	23	91	109	162	184	229	252	290	306	363
Rifle R.	23	112	134	198	215	251	279	325	341	399
Pigeon R.	23	89	114	188	219	284	320	381	396	447
Little South Branch Pere Marquette R.	23	107	135	216	236	277	302	345	366	439
Houghton Cr.	23	91	112	173	192	231	249	279	294	345
Gamble Cr.	23	84	102	152	162	206	218	254	264	318
Williamsburg Cr.	23	89	117	155	196	221	256	274	287	335
Poplar Cr.	23	84	102	157	182	236	256	290	306	363
Mean	23	93	115	180	202	248	270	307	323	379

(continued, next page)

Table 3.--concluded.

Stream	Age and season							
	V		VI		VII		VIII	
	S	F	S	F	S	F	S	F
Mainstream Au Sable R.	387	442						
South Branch Au Sable R.	530	587						
North Branch Au Sable R.	432	518	544	579	597	605		
Mainstream Boardman R.	438	521	570	597				
South Branch Boardman R.	381	444						
North Branch Boardman R.	404	455						
Rifle R.	435	480	504	518	586	597	647	698
Pigeon R.	480	521	550	566				
Little South Branch Pere Marquette R.	475	521	586	622				
Houghton Cr.	384	432	494	528				
Gamble Cr.	325	353	470					
Williamsburg Cr.	381	386	495	513				
Poplar Cr.	367	373						
Mean	417	464	527	560	592	601	647	698

Table 4.--Growth in length (millimeters) of brook trout from fry to age IV based on annual spring (S) and fall (F) measurements in 10 Michigan streams.

Stream	Age and season											
	0		I		II		III		IV		V	
	S	F	S	F	S	F	S	F	S	F	S	F
Mainstream Au Sable R.	23	81	102	160	177	218	244	292				
South Branch Au Sable R.	23	94	115	173	186	218	245	295				
North Branch Au Sable R.	23	89	107	170	183	209	216	262	254	318	318	343
Mainstream Boardman R.	23	96	113	160	179	224						
South Branch Boardman R.	23	81	95	135	144	165						
North Branch Boardman R.	23	86	97	130	156	216						
Pigeon R.	23	81	102	150	168	211	221	279	236	368		
Hunt Cr.	23	81	91	137	147	180	188	229	224	272	274	318
Williams-burg Cr.	23	79	102	150	162	185	244					
Poplar Cr.	23	86	103	150	164	196						
Mean	23	85	103	152	167	202	226	271	238	319	296	330

Table 5. --Average annual production (kilograms per hectare) of trout in 14 Michigan streams.

Stream and years	Species of trout			
	Brown	Brook	Rainbow	Total
Mainstream Au Sable River 1974-77	99.5	13.9	7.8	121.2
South Branch Au Sable River 1974-77	56.8	14.1		70.9
North Branch Au Sable River 1961-67	57.5	44.6		102.1
Mainstream Boardman River 1960-61	69.2	22.5		91.7
South Branch Boardman River 1973-76	150.9	2.1		153.0
North Branch Boardman River 1973-76	73.3	4.6		77.9
Rifle River 1957-1962	15.4			15.4
Pigeon River 1961-64	13.2	37.6		50.8
Little South Branch Pere Marquette River 1960-61	70.5		10.2	80.7
Houghton Creek 1954-1961	129.2			129.2
Gamble Creek 1961-65	53.6			53.6
Hunt Creek 1959-1964		89.5		89.5
Williamsburg Creek 1975-76	184.4	10.6	1.1	196.1
Poplar Creek 1972-74	88.0	0.6	14.9	103.5

Table 6.--Seasonal production (kilograms per hectare) of trout in 14 Michigan streams.

Stream	Spring-summer	Percent	Fall-winter	Percent
Mainstream Au Sable River	91.5	75.5	29.7	24.5
South Branch Au Sable River	53.1	74.9	17.8	25.1
North Branch Au Sable River	82.5	80.7	19.7	19.3
Mainstream Boardman River	73.2	79.7	18.6	20.3
South Branch Boardman River	114.0	74.5	39.0	25.5
North Branch Boardman River	58.3	75.1	19.3	24.9
Rifle River	9.7	63.0	5.7	37.0
Pigeon River	40.5	79.8	10.3	20.2
Little South Branch Pere Marquette River	61.0	75.7	19.6	24.3
Houghton Creek	97.6	75.6	31.5	24.4
Gamble Creek	43.3	80.8	10.3	19.2
Hunt Creek	77.7	86.8	11.9	13.2
Williamsburg Creek	115.8	59.0	80.3	41.0
Poplar Creek	79.1	76.5	24.4	23.5

Table 7.--Ratio of annual production (kilograms per hectare) to fall standing crop of trout (kilograms per hectare) in 14 Michigan streams.

Stream	Species of trout			All trout
	Brown	Brook	Rainbow	
Mainstream Au Sable River	0.85	2.07	1.45	0.94
South Branch Au Sable River	1.04	1.72		1.13
North Branch Au Sable River	1.12	1.92		1.37
Mainstream Boardman River	1.29	1.89		1.40
South Branch Boardman River	1.01	1.44		1.02
North Branch Boardman River	1.07	1.71		1.10
Rifle River	0.62			0.62
Pigeon River	1.30	1.65		1.54
Little South Branch Pere Marquette River	0.99		2.63	1.07
Houghton Creek	1.15			1.15
Gamble Creek	0.87			0.87
Hunt Creek		1.41		1.41
Williamsburg Creek	1.08	1.57	1.48	1.10
Poplar Creek	1.14	1.41	1.33	1.16
Mean	1.04	1.68	1.72	1.13

Table 8.--Average number of hours fished, number of trout caught by species, and total catch per hectare in six Michigan streams.

Period, stream, and site	Hours fished	Species of trout			
		Brown	Brook	Rainbow	Total
1976					
Mainstream Au Sable River					
Burton-Wakeley	756.2	10.9	13.0	1.4	25.3
1961-67					
North Branch Au Sable River					
County Line-Eaman's	648.0	96.0	178.8		274.8
1960-61					
Mainstream Boardman River					
Fork Forest-Scheck's	443.8	55.4	50.0		105.4
1961-64					
Pigeon River					
Sections A - E	397.6	11.0	64.8		75.8
1961-65					
Gamble Creek					
Mallard Pond--RRA[a]	159.5	31.0			31.0
1959-1965					
Hunt Creek					
Sections Z, A, B, C	667.0		378.2		378.2

[a] North boundary of Rifle River Recreation Area.

Table 9.--Production of trout in kilograms per hectare for six Michigan streams based on total instantaneous mortality rates (Z) and on natural instantaneous mortality rates (M).

Stream and species	Production of trout based on		Percentage increase
	Z	M	
Mainstream Au Sable River			
Brown	99.5	100.7	1.1
Brook	13.9	14.1	1.8
Rainbow	7.8	7.9	1.2
North Branch Au Sable River			
Brown	57.5	96.5	67.8
Brook	44.6	52.2	17.1
Mainstream Boardman River			
Brown	69.2	76.6	10.7
Brook	22.5	23.9	6.0
Pigeon River			
Brown	13.2	16.6	25.5
Brook	37.6	39.4	5.0
Gamble Creek			
Brown	53.6	55.7	3.9
Hunt Creek			
Brook	89.5	103.6	15.7

Table 10.--Annual production of trout in 14 streams ranked on basis of (1) area, (2) area related to mean annual discharge, and (3) length related to discharge.

Stream	Production		
	g/ha	g/ha/m^3/yr	g/km/m^3/yr
Williamsburg Creek	196,123	0.0122	0.0057
South Branch Boardman River	152,993	0.0031	0.0030
Houghton Creek	129,172	0.0048	0.0031
Mainstream Au Sable River	121,213	0.0008	0.0022
Poplar Creek	103,459	0.0078	0.0037
North Branch Au Sable River	102,121	0.0010	0.0034
Mainstream Boardman River	91,761	0.0007	0.0009
Hunt Creek	89,547	0.0050	0.0028
Little South Branch Pere Marquette River	80,682	0.0020	0.0022
North Branch Boardman River	77,587	0.0014	0.0011
South Branch Au Sable River	70,912	0.0005	0.0016
Gamble Creek	53,607	0.0026	0.0015
Pigeon River	50,740	0.0008	0.0010
Rifle River	15,433	0.0002	0.0003

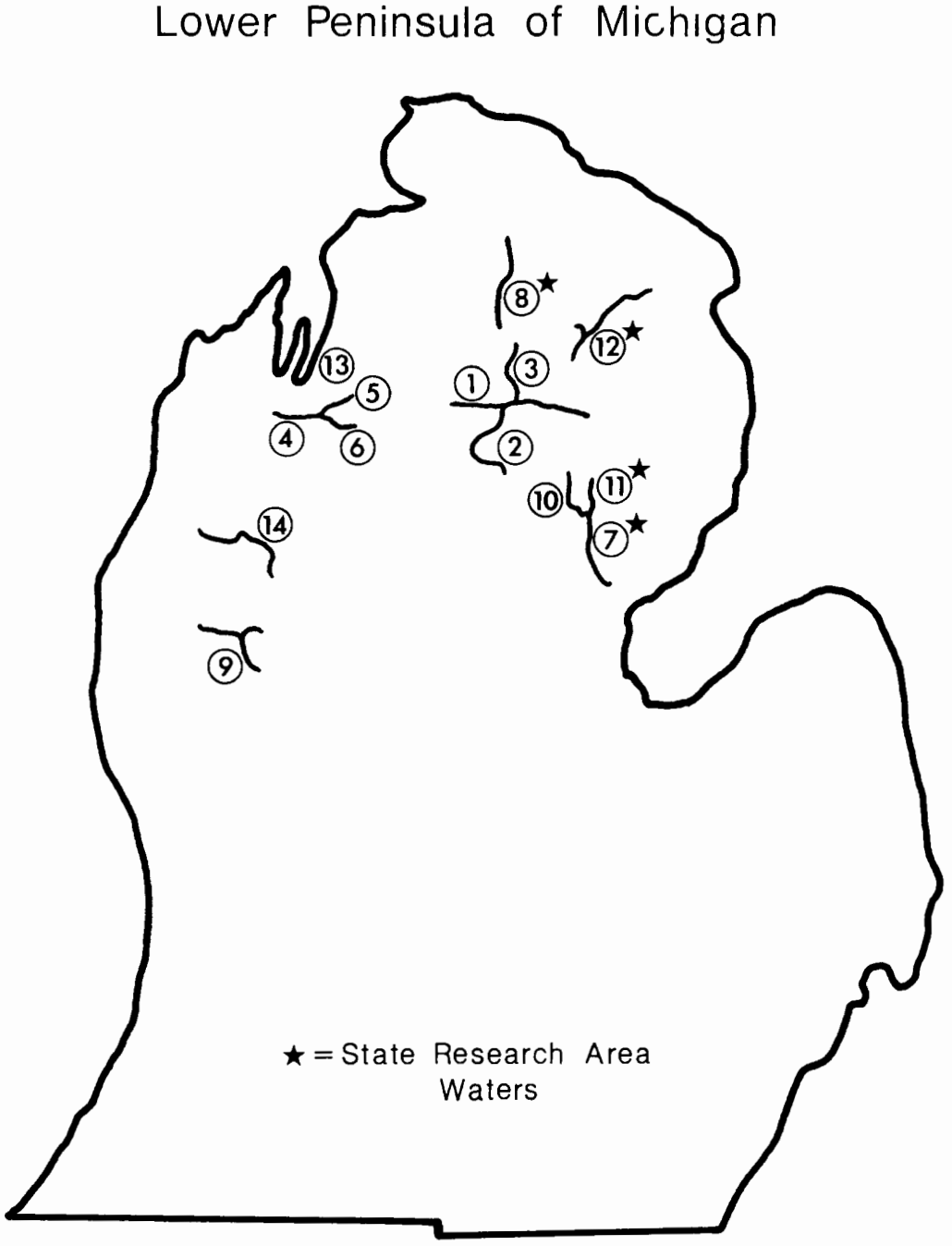

Figure 1.--General geographical distribution of study streams in the northern lower peninsula of Michigan and their identification: (1) Mainstream Au Sable, (2) South Branch Au Sable, (3) North Branch Au Sable, (4) Mainstream Boardman, (5) North Branch Boardman, (6) South Branch Boardman, (7) Rifle River research water, (8) Pigeon River research water, (9) Little South Branch Pere Marquette, (10) Houghton, (11) Gamble Creek research water, (12) Hunt Creek research water, (13) Williamsburg, and (14) Poplar.

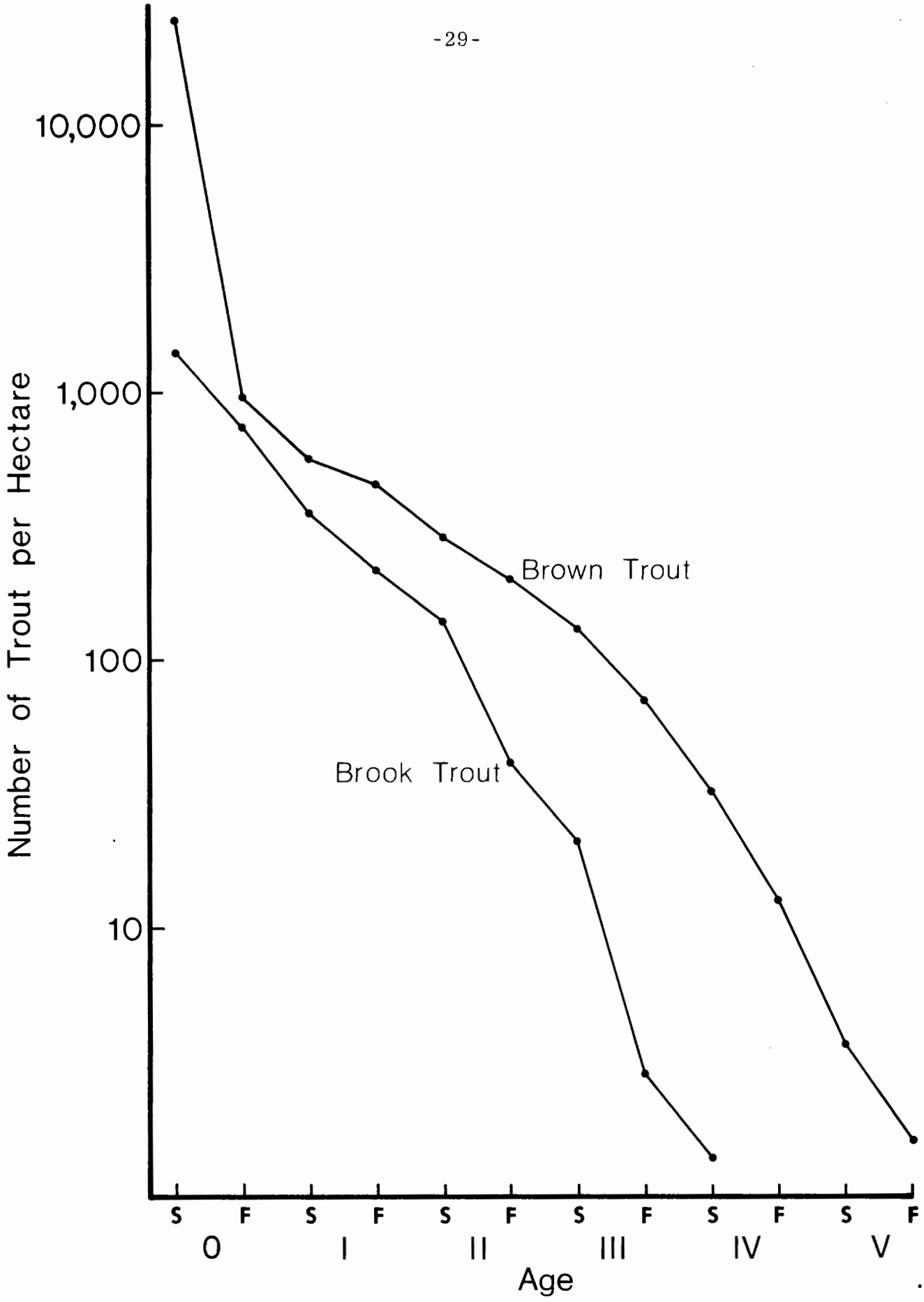

Figure 2. --Survivorship curves based on average spring (S) and fall (F) standing crops of fry-Age V brown trout in 13 Michigan streams and fry-Age IV brook trout in 10 streams.

Literature cited

Alexander, G. R. 1974. The consumption of trout by bird and mammal predators on the North Branch Au Sable River. Mich. Dep. Nat. Resources, Dingell-Johnson Project F-30-R, Final Rep., 40 pp.

Alexander, G. R., and J. R. Ryckman. 1976. Trout production and catch under normal and special angling regulations in the North Branch of the Au Sable River, Michigan. Mich. Dep. Nat. Resources, Fish. Res. Rep. 1840, 14 pp.

Alexander, G. R., W. J. Buc, and G. T. Schnicke. 1979. Trends in angling and trout populations in the Main Au Sable and North Branch Au Sable rivers from 1959-1976. Mich. Dep. Nat. Resources, Fish. Res. Rep. 1865, 59 pp.

Bjornn, T. C. 1978. Survival, production, and yield of trout and chinook salmon in the Lemhi River, Idaho. Idaho Dep. Fish Game, Final Report, Project F-49-R, 62 pp.

Brynildson, O. M., and J. W. Mason. 1975. Influence of organic pollution on the density and production of trout in a Wisconsin stream. Wisconsin Dep. Nat. Resources, Tech. Bull. 81, pp. 1-15.

Chapman, D. W. 1978. Production in fish populations. Pages 5-25 in Shelby D. Gerking, ed. Ecology of freshwater fish production. John Wiley and Sons, New York, N. Y.

Cooper, E. L., and R. C. Scherer. 1967. Annual production of brook trout (Salvelinus fontinalis) in fertile and infertile streams of Pennsylvania. Proc. Pa. Acad. Sci., 41.

Cooper, G. P., D. S. Shetter, and D. W. Hayne. 1959. Results of studies on Michigan trout waters with special angling restrictions (type of lure, size limit, creel limit), 1949-1959. Mich. Dep. Conserv., Inst. Fish. Res. Rep. 1577, 55 pp.

Cooper, G. P., D. S. Shetter, and G. R. Alexander. 1963. Progress report on recent data for trout streams with special regulations Mich. Dep. Conserv., Inst. Fish. Res. Rep. 1577 (4th Suppl.), 16 pp.

Ellis, R. J., and H. Gowing. 1957. Relationship between food supply and condition of wild brown trout, Salmo trutta Linnaeus, in a Michigan stream. Limnol. Oceanogr. 2(4): 299-308.

Elwood, J. W., and T. F. Waters. 1969. Effects of floods on food consumption rates of a stream brook trout population. Trans. Am. Fish. Soc. 98(2): 253-262.

Hendrickson, G. E., R. L. Knutilla, and C. J. Doonan. 1973. Hydrology and recreation of selected cold-water rivers of the St. Lawrence River basin in Michigan, New York, and Wisconsin. U.S. Dep. Interior, Geol. Surv., Water Resources Invest., 73 pp.

Hunt, R. L. 1966. Production and angler harvest of wild brook trout in Lawrence Creek, Wisconsin. Wis. Conserv. Dep. Tech. Bull. 35, 52 pp.

Latta, W. C. 1973. The effects of a flies-only fishing regulation upon trout in the Pigeon River, Otsego County, Michigan. Mich. Dep. Nat. Resources, Fish. Res. Rep. 1807, 28 pp.

Le Cren, E. D. 1969. Estimates of fish populations and production in small streams in England. In T. G. Northcote (ed.), Symposium on salmon and trout in streams. H. R. MacMillan Lectures in Fisheries, Univ. Brit. Col., Vancouver, Canada.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Fish. Res. Board Can. Bull. 191, 382 pp.

Shetter, David S. 1957. Trout stream population study techniques employed in Michigan. Pages 64-71 in Symposium on evaluation of fish populations in warm water streams. Iowa Coop. Fish. Res. Unit, Iowa State Coll. (unpublished)

Shetter, D. S. 1969. The effects of certain angling regulations on stream trout populations. In T. G. Northcote (ed.), Symposium on salmon and trout in streams. H. R. MacMillan Lectures in Fisheries, Univ. Brit. Col., Vancouver, Canada.

Shetter, D. S., and G. R. Alexander. 1962. Effects of a flies-only restriction on angling and on fall trout populations in Hunt Creek, Montmorency County, Michigan. Trans. Am. Fish. Soc. 91(3): 295-302.

Shetter, D. S., and G. R. Alexander. 1965. Results of angling under special and normal trout fishing regulations in a Michigan trout stream. Trans. Am. Fish. Soc. 94(3): 219-226.

Shetter, D. S., and G. R. Alexander. 1966. Angling and trout populations on the North Branch of the Au Sable River, Crawford and Otsego counties, Michigan, under special and normal regulations, 1958-1963. Trans. Am. Fish. Soc. 95(1): 85-91.

Waters, T. F. 1977. Secondary production in inland waters. Pages 91-164 in A. Macfadyen, ed. Advances in ecological research. Vol. 10, Academic Press, London.

Report approved by W. C. Latta

Typed by M. S. McClure

Appendix Table 1. --Trout fishing regulations on the 14 streams during the period of study.

Stream	Years	Size limit (inches) Brown	Rainbow	Brook	Creel limit	Lure
Mainstream Au Sable R.	1974-77	12	12	8	3	Flies
South Branch Au Sable R.	1974-77	10	10	10	5	Flies
North Branch Au Sable R.	1961-67	7	7	7	10	Any
Mainstream Boardman R.[a]	1960-61	10	10	10	5	Flies
		7	7	7	10	Any
South Branch Boardman R.	1973-76	10	10	7	5 plus 5 additional brook	Any
North Branch Boardman R.	1973-76	10	10	7	5 plus 5 additional brook	Any
Rifle River	1957-62	7	7	7	10	Any
Pigeon River[a]	1961-64	7	7	7	5, 10	Any
		9	9	9	5	Any
Little South Branch Pere Marquette River[a]	1960-61	10	10	10	5	Flies
		7	7	7	10	Any
Houghton Creek	1954-61	7	7	7	10	Any
Gamble Creek	1961-65	7	7	7	10	Any
Hunt Creek	1959-64	7	7	7	10	Any
Williamsburg Creek	1975-76	10	10	7	5 plus 5 additional brook	Any
Poplar Creek	1972-74	10	10	7	5 plus 5 additional brook	Any

[a] Two or more regulations in effect on different portions of the stream.

Appendix Table 2.--Average number of brown trout per hectare by age in the spring (S) and fall (F) in 13 Michigan streams. (Figures rounded to closest whole number)

Stream	Age									
	0		I		II		III		IV	
	S	F	S	F	S	F	S	F	S	F
Mainstream Au Sable R.	25,562	1001	528	399	337	310	248	202	77	14
South Branch Au Sable R.	12,970	508	216	136	99	84	58	38	17	6
North Branch Au Sable R.	24,714	421	244	177	141	73	44	16	12	6
Mainstream Boardman R.	25,429	995	448	298	169	113	60	19	8	2
South Branch Boardman R.	47,044	1812	1369	974	732	511	371	169	98	31
North Branch Boardman R.	19,717	772	604	558	287	169	102	51	26	13
Rifle R.	289	11	7	115	76	60	32	11	5	2
Pigeon R.	4,826	189	76	46	21	11	7	4	2	1
Little South Branch Pere Marquette R.	13,867	543	256	177	152	141	82	39	14	2
Houghton Cr.	41,757	1634	995	820	448	285	156	59	25	8
Gamble Cr.	20,367	529	454	435	328	260	185	116	49	17
Williamsburg Cr.	53,280	2929	1327	1177	561	480	217	136	57	51
Poplar Cr.	34,808	1362	748	579	320	206	125	64	29	11
Mean	24,972	977	559	453	282	208	130	71	32	13

(continued, next page)

Appendix Table 2.--continued

Stream	Age							
	V		VI		VII		VIII	
	S	F	S	F	S	F	S	F
Mainstream Au Sable R.	4	1						
South Branch Au Sable R.	2	1						
North Branch Au Sable R.	4	3	1	1	tr	tr		
Mainstream Boardman R.	1	tr	tr	tr				
South Branch Boardman R.	2	1						
North Branch Boardman R.	2	tr						
Rifle R.	1	1	tr	tr	tr	tr	tr	tr
Pigeon R.	tr	tr	tr	tr	tr	tr		
Little South Branch Pere Marquette R.	1	tr	tr	tr				
Houghton Cr.	2	1	tr	tr				
Gamble Cr.	7	2	tr					
Williamsburg Cr.	17	9	5	3				
Poplar Cr.	4	2						
Mean	4	2	tr	tr	tr	tr	tr	tr

Appendix Table 3.--Average number of brook trout per hectare by age in the spring (S) and fall (F) in 10 Michigan streams. (Figures rounded to closest whole numbers)

Stream	Age									
	0		I		II		III		IV	
	S	F	S	F	S	F	S	F	S	F
Mainstream Au Sable R.	9,695	502	189	80	48	7	4	tr		
South Branch Au Sable R.	6,540	338	157	94	54	6	3	1		
North Branch Au Sable R.	21,269	1335	688	244	197	24	16	1	1	tr
Mainstream Boardman R.	11,627	602	261	142	82	7				
South Branch Boardman R.	1,534	79	41	28	19	8				
North Branch Boardman R.	2,069	107	85	77	43	1				
Pigeon R.	23,458	1227	583	378	111	34	7	2	tr	tr
Hunt Cr.	60,777	2705	1432	1125	822	301	171	26	14	1
Williamsburg Cr.	5,708	489	136	78	52	28	2			
Poplar Cr.	348	18	9	6	4	2				
Mean	14,302	740	358	225	143	42	20	3	2	tr

Appendix Table 4. --Growth in weight (grams) of brown trout from fry to age VIII based on annual spring (S) and fall (F) measurements in 13 Michigan streams.

Stream	Age									
	0		I		II		III		IV	
	S	F	S	F	S	F	S	F	S	F
Mainstream Au Sable R.	0.1	7.7	13.9	50.7	70.6	125.0	155.7	219.3	250.2	385.7
South Branch Au Sable R.	0.1	8.4	16.9	70.6	105.8	207.6	270.1	403.3	519.8	1011.4
North Branch Au Sable R.	0.1	8.4	14.9	79.3	125.0	243.8	263.4	377.2	449.4	707.6
Mainstream Boardman R.	0.1	9.2	17.3	63.5	86.4	151.8	202.3	304.5	342.2	493.6
South Branch Boardman R.	0.1	5.5	10.7	43.0	58.5	110.4	138.5	186.1	207.9	269.6
North Branch Boardman R.	0.1	7.8	13.3	43.0	61.0	118.0	156.4	237.4	276.3	464.2
Rifle R.	0.1	14.0	24.4	77.5	102.3	158.1	216.5	340.5	390.4	626.6
Pigeon R.	0.1	7.2	15.0	66.1	100.6	225.3	309.0	534.6	578.9	857.9
Little South Branch Pere Marquette R.	0.1	11.9	23.8	97.5	127.1	205.4	266.0	396.4	473.1	815.8
Houghton Cr.	0.1	7.5	14.0	53.8	76.0	132.7	167.0	238.8	288.2	432.1
Gamble Cr.	0.1	5.6	9.9	33.0	40.0	80.4	96.0	150.2	168.8	291.3
Williamsburg Cr.	0.1	7.2	16.2	37.3	74.4	106.8	166.0	202.3	231.3	366.3
Poplar Cr.	0.1	5.8	10.3	37.5	58.4	127.1	162.2	235.6	276.7	461.6
Mean	0.1	8.2	15.4	57.9	85.5	153.3	197.6	294.3	342.6	552.6

(continued, next page)

Appendix Table 4.--continued

Stream	Age							
	V		VI		VII		VIII	
	S	F	S	F	S	F	S	F
Mainstream Au Sable R.	552.1	830.9						
South Branch Au Sable R.	1446.2	1957.3						
North Branch Au Sable R.	774.5	1344.1	1553.4	1881.4	2061.6	2142.2		
Mainstream Boardman R.	795.0	1347.0	1751.0	2017.0				
South Branch Boardman R.	534.7	843.5						
North Branch Boardman R.	635.2	901.9						
Rifle R.	808.7	1091.0	1253.0	1370.0	1986.0	2090.0	2678.0	3343.0
Pigeon R.	1017.0	1347.0	1506.0	1727.8				
Little South Branch Pere Marquette R.	1033.0	1362.5	1937.7	2316.6				
Houghton Cr.	584.7	825.6	1212.7	1465.0				
Gamble Cr.	312.5	399.1	932.2					
Williamsburg Cr.	534.7	556.0	1162.0	1290.0				
Poplar Cr.	477.0	500.7						
Mean	731.2	1023.6	1413.5	1724.0	2023.8	2116.1	2678.0	3343.0

Appendix Table 5. --Growth in weight (grams) of brook trout from fry to age VI based on annual spring (S) and fall (F) measurements in 10 streams.

Stream	Age 0		I		II		III	
	S	F	S	F	S	F	S	F
Mainstream Au Sable R.	0.1	5.2	10.2	40.4	55.6	103.9	145.1	251.1
South Branch Au Sable R.	0.1	8.0	14.6	51.0	63.2	103.9	145.1	257.8
North Branch Au Sable R.	0.1	6.8	11.8	48.7	60.6	90.0	100.3	179.7
Mainstream Boardman R.	0.1	9.1	14.0	40.3	54.9	107.6		
South Branch Boardman R.	0.1	5.5	8.4	24.3	30.0	44.2		
North Branch Boardman R.	0.1	6.6	9.1	21.7	36.6	97.2		
Pigeon R.	0.1	5.5	10.6	33.2	46.2	90.6	104.0	207.3
Hunt Cr.	0.1	5.2	7.4	25.3	31.4	58.1	65.9	119.3
Williamsburg Cr.	0.1	5.0	10.6	33.2	45.1	62.1	139.0	
Poplar Cr.	0.1	6.6	11.4	33.2	42.2	72.7		
Mean	0.1	6.3	10.8	35.1	46.6	83.0	116.6	203.0

(continued, next page)

Appendix Table 5.--continued

Stream	Age				
	IV		V		VI
	S	F	S	F	S
Mainstream Au Sable R.					
South Branch Au Sable R.					
North Branch Au Sable R.	164.3	323.4	323.4	408.5	
Mainstream Boardman R.					
South Branch Boardman R.					
North Branch Boardman R.					
Pigeon R.	126.6	466.9			
Hunt Cr.	111.5	201.7	207.5	323.4	251.1
Williamsburg Cr.					
Poplar Cr.					
Mean	134.1	330.7	265.5	366.0	251.1

Appendix Table 6.--Average number of brown trout per hectare by inch group in the fall for 13 Michigan streams. (Figures rounded to closest whole number)

Stream	Inch group								
	2	3	4	5	6	7	8	9	10
Mainstream Au Sable R.	185	480	320	53	121	122	95	108	102
South Branch Au Sable R.	52	259	181	18	26	53	45	24	26
North Branch Au Sable R.	44	223	146	10	28	56	66	27	18
Mainstream Boardman R.	60	546	380	22	95	126	77	56	41
South Branch Boardman R.	669	1020	138	334	409	266	282	172	126
North Branch Boardman R.	113	479	200	153	241	132	96	75	25
Rifle R.	0	2	8	4	15	48	55	27	15
Pigeon R.	30	123	36	2	12	22	9	3	3
Little South Branch Pere Marquette R.	6	207	290	44	7	45	66	73	62
Houghton Cr.	298	938	418	176	270	298	188	103	62
Gamble Cr.	81	433	54	199	190	179	141	74	44
Williamsburg Cr.	648	1580	1001	237	366	396	213	108	76
Poplar Cr.	350	930	117	217	222	112	86	75	48
Mean	195	555	253	113	154	143	109	71	50

(continued, next page)

Appendix Table 6. --continued

Stream	Inch group					
	11	12	13	14	15	16+
Mainstream Au Sable R.	59	24	8	2	4	1
South Branch Au Sable R.	33	20	11	10	4	9
North Branch Au Sable R.	23	25	15	6	4	6
Mainstream Boardman R.	10	4	3	3	1	2
South Branch Boardman R.	53	20	2	1	3	8
North Branch Boardman R.	26	14	1	0	3	6
Rifle R.	9	5	4	2	2	3
Pigeon R.	2	3	2	1	1	2
Little South Branch Pere Marquette R.	38	31	16	9	4	5
Houghton Cr.	30	16	4	2	1	3
Gamble Cr.	28	13	3	4	1	2
Williamsburg Cr.	80	40	19	10	5	6
Poplar Cr.	32	19	10	4	2	2
Mean	32	18	8	4	3	4

Appendix Table 7. --Average number of brook trout per hectare by inch group in the fall for 10 Michigan streams. (Figures rounded to closest whole number)

Stream	Inch group								
	2	3	4	5	6	7	8	9	10
Mainstream Au Sable R.	188	268	42	35	33	16	6	2	tr
South Branch Au Sable R.	39	199	93	26	35	30	15	1	tr
North Branch Au Sable R.	282	846	200	64	97	90	21	3	1
Mainstream Boardman R.	64	292	266	29	55	33	7	3	1
South Branch Boardman R.	26	53	6	22	8				
North Branch Boardman R.	7	100	45	25	9	1			
Pigeon R.	435	735	108	163	130	44	15	6	2
Hunt Cr.	984	1638	445	519	336	150	64	16	3
Williamsburg Cr.	212	261	23	47	27	18	6	1	
Poplar Cr.	1	2	1	3	2	1	tr	tr	
Mean	224	439	123	93	73	38	13	3	1

(continued, next page)

Appendix Table 7.--continued

Stream	Inch group					
	11	12	13	14	15	16
Mainstream Au Sable R.	tr					
South Branch Au Sable R.	tr	tr	tr			
North Branch Au Sable R.	tr					
Mainstream Boardman R.						
South Branch Boardman R.						
North Branch Boardman R.						
Pigeon R.	1	tr	tr	tr		tr
Hunt Cr.	1	tr				
Williamsburg Cr.						
Poplar Cr.						
Mean	tr	tr	tr	tr		tr

Appendix Table 8.--Average number of rainbow trout per hectare by inch group in the fall for four Michigan streams. (Figures rounded to closest whole number)

Stream	Inch group 2	3	4	5	6	7	8	9	10
Mainstream Au Sable R.	122	106	4	4	12	14	5	6	4
Little South Branch Pere Marquette R.	16	180	101	6	---	5	9	2	tr
Williamsburg Cr.	0	25	9	9	2	9	2	2	0
Poplar Cr.	604[a]	43	95	78	27	28	22	10	2
Mean	186	88	52	24	10	14	10	5	2

Stream	Inch group 11	12	13	14	15	16+
Mainstream Au Sable R.	2	2	tr	tr		
Little South Branch Pere Marquette R.						
Williamsburg Cr.						
Poplar Cr.	tr					
Mean	tr	tr	tr	tr		

[a] Included 1-inch group.