Annual Production and Production: Biomass Ratios for Three Species of Stream Trout in Lake Superior Tributaries

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Annual Production and Production: Biomass Ratios for Three Species of Stream Trout in Lake Superior Tributaries

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Abstract.—We made estimates of annual production of stream trout in two Lake Superior tributaries in northeastern Minnesota in 1977-1978. The Caribou River (total alkalinity, 34 mg/L as CaCO₃) drains part of the north shore of Lake Superior in an igneous rock geology. The Blackhoof River (total alkalinity, 83 mg/L) drains glacial drift and lake clay at the western end of Lake Superior. Annual production of brook trout Salvelinus fontinalis in the Caribou River was estimated to be 58.0 kg (wet weight) per hectare, reflecting low water fertility. In the Blackhoof River, annual production was 43.5 kg of brown trout Salmo trutta and 95.7 kg of juvenile rainbow trout Oncorhynchus mykiss per hectare. The total salmonid production of 139.2 kg/hectare in the Blackhoof River appeared to reflect an intermediate level of water fertility. Ratios of annual production: mean standing stock (P/B) were calculated to be 2.2 for juvenile rainbow trout, 1.7 for brook trout, and 0.9 for brown trout. These values suggest an inverse relation between P/B and number of age-groups present (three for rainbow trout, four for brook trout, and six for brown trout).

Estimates of annual production of stream trout have been roughly associated with water quality indices such as alkalinity, hardness, and conductivity, but mechanisms of cause and effect are not readily discernible. Most studies have been of streams that would be characterized as highly productive and have resulted in annual production estimates in the range of 100-300 kg (wet weight) per hectare (reviews by Mann and Penczak 1986; Waters 1988). Studies of streams of obviously lower productive potential are less common (Cooper and Scherer 1967; Whitworth and Strange 1983).

In addition to production rates, of ancillary interest are annual ratios of annual production: mean standing stock (P/B), summarized in reviews by Waters (1977) and Mann and Penczak (1986). Most of the estimates presented in these reviews suggest a fairly consistent level of annual P/B of about 1.0-1.5 for normally growing, stream-resident trout populations, and an inverse relationship between annual P/B and number of age-groups present or maximum age.

Our objectives were to record annual production of stream trout populations from an area of presumed low productivity, the northern Lake Superior drainage (Smith and Moyle 1944; Moyle 1956; Krueger and Waters 1983; Waters 1987), and to examine variations in annual P/B ratio among three salmonine species: brook trout Salvelinus fontinalis, brown trout Salmo trutta, and rainbow trout Oncorhynchus mykiss.

Study Sites

The Caribou River flows southward in the north shore drainage of Lake Superior and empties directly into the lake. The Caribou River drainage is underlain by igneous and metamorphic rock, and its waters are bog-colored and relatively soft, with an alkalinity of 34 mg/L (as CaCO₃). The reach of stream included in our trout production study was 300 m long and had an average width of about 4.5 m, a base-flow discharge of 0.27 m³/s, and an area of 0.135 hectare. The brook trout, nonnative but introduced in this reach of the river, was the most abundant fish, accounting for 70% of total fish standing stock (Krueger 1979; Krueger and Waters 1983).

The Blackhoof River flows from northwest of Lake Superior and empties directly into the Nemadji River, which flows through parts of Minnesota and Wisconsin to empty into the western end of the lake. The Blackhoof River flows through glacial drift in its upper reaches and red-clay glacial lake deposits in its lower reaches. As in the Caribou River, the waters of the Blackhoof River are bog-colored, but have a somewhat higher alkalinity of...
ANNUAL PRODUCTION OF STREAM TROUT

83 mg/L (as CaCO₃). The reach of stream included in our trout production study was 360 m long and had an average width of about 5.2 m, a base-flow discharge of 0.59 m³/s, and an area of 0.186 hectare. Blackhoof River salmonids included mostly the introduced brown trout and rainbow trout. The brown trout occurred as a stream-resident population, although some spawning adults were known to migrate from Lake Superior in autumn. The rainbow trout were anadromous, migrating from Lake Superior to spawn in the spring, typical of Lake Superior populations. Most juvenile rainbow trout remained in the Blackhoof River for 2 years before migrating downstream. Of total fish standing stock, brown trout accounted for 35% and rainbow trout 43% (Doherty 1981; Krueger and Waters 1983).

Methods

Annual production of the salmonine populations was estimated by the instantaneous growth rate method (Ricker 1946; Allen 1949; Waters 1977; Newman and Martin 1983). We made population estimates with the Petersen single-census mark–recapture method (Ricker 1975), using electrofishing as the sampling technique, several times during a year in both streams. Numbers were calculated separately for size-groups to reduce error due to size-related variation in electrofishing efficiency; recapture rates were generally high, ranging from about 0.25 for fish 10 cm in length to near 1.00 for fish 30 cm and longer. Samples of captured trout were weighed and scales were sampled to enable conversion of population estimates by size-group to age-group and thus to year-class. Spawning migratory adults were not included in the production computations. Yearly production was expressed in kilograms (wet weight) per hectare.

Standing stock was determined on each sampling date. Mean annual standing stock was calculated as an average of standing stocks weighted by days in each interval between population estimates. Standing stocks were expressed in kilograms (wet weight) per hectare.

In the Caribou River, population estimates were made on 30 June 1977, 25 October 1977, and 11 July 1978, to cover about 1 year. In the Blackhoof River, estimates were made on 28 July 1977, 28 October 1977, 11 February 1978, and 12 July 1978, also to include about 1 year.

Annual P/B ratios were calculated as annual production divided by mean annual standing stock. Variances of abundance, standing stocks, production, and P/B ratios were calculated according to the methods of Newman and Martin (1983), except for variance of instantaneous growth rate, for which formulas 2 and 3 of Cone and Krueger (1988) were used. Further details of sampling and calculations were similar to those outlined by Waters (1977).

Results

Caribou River

The first population estimate in June 1977 was 625 brook trout for the section; most of these were age 0; fish at ages 1–3 were present in lower numbers. Total numbers of brook trout declined during the year, but subsequent recruitment brought the total up to 1,044 by the July 1978 estimate. Mean annual abundance was 4,242 fish/hectare (Table 1).

Standing stock of brook trout varied from 45.4 kg/hectare in June 1977 (including the 1977 year-class), to 23.9 kg/hectare in October 1977, and 45.0 kg/hectare in July 1978 (including the 1978 year-class). The weighted mean annual standing stock was 34.5 kg/hectare (Table 1). Production of brook trout was estimated at 12.9 kg/hectare for June–October 1977 and 45.1 kg/hectare for October 1977–July 1978. Annual production was 58.0 kg/hectare (Table 1). The annual P/B ratio was thus calculated as 58.0/34.5 = 1.7 (Table 1).

Blackhoof River

The first population estimate for brown trout in the Blackhoof River in July 1977 included five age-groups, except age 0, for a total of 120 brown trout in the section. Age-0 fish were too small to be effectively electrofished in July; they were first sampled in October 1977. Mean annual abundance was 1,024/hectare (Table 1).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Caribou River, brook trout</th>
<th>Brown trout</th>
<th>Rainbow trout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abundance</td>
<td>4,242 (1,238)</td>
<td>1,024 (116)</td>
<td>2,346 (302)</td>
</tr>
<tr>
<td>Standing stock</td>
<td>34.5 (7.4)</td>
<td>47.2 (7.0)</td>
<td>44.0 (10.1)</td>
</tr>
<tr>
<td>Production</td>
<td>58.0 (20.3)</td>
<td>43.5 (11.1)</td>
<td>95.7 (18.2)</td>
</tr>
<tr>
<td>Annual P/B</td>
<td>1.7 (0.7)</td>
<td>0.9 (0.3)</td>
<td>2.2 (0.7)</td>
</tr>
</tbody>
</table>

Values in parentheses are 2 SE.

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Standing stock of brown trout varied from 59.7 kg/hectare in July 1977 to a high of 67.8 kg/hectare in October 1977, when the new year-class was recruited to the sampling gear, and decreased subsequently. Mean annual standing stock was 47.2 kg/hectare (Table 1). Production of brown trout was 24.8 kg/hectare for July–October 1977, 2.9 kg/hectare for October 1977–February 1978, and 15.8 kg/hectare for February–July 1978. Annual production was 43.5 kg/hectare (Table 1). The annual \( P/B \) ratio was 43.5/47.2 = 0.9 (Table 1).

Rainbow trout were considerably more abundant than brown trout in the Blackhoof River. The rainbow trout population never comprised more than three age-groups and usually included only ages 0 and 1. The number of rainbow trout per section varied from 370 in July 1977 to a high of 625 in October 1977 (when the new year-class was recruited) and decreased subsequently. Mean annual abundance was 2,346 fish/hectare (Table 1).

Standing stock of rainbow trout varied from 41.3 kg/hectare in July 1977, to 54.7 kg/hectare in October 1977, then decreased to 47.5 kg/hectare in February 1978 and 25.7 in July 1978. Mean annual standing stock was 44.0 kg/hectare (Table 1). Production of rainbow trout was 35.8 kg/hectare for July–October 1977, 26.4 kg/hectare for October 1977–February 1978, and 33.5 kg/hectare for February–July 1978. Annual production was 95.7 kg/hectare (Table 1). The annual \( P/B \) ratio was 95.7/44.0 = 2.2 (Table 1).

Total salmonine production in the Blackhoof River was 139.2 kg/hectare.

**Discussion**

**Annual Production**

The annual production of 58.0 kg of brook trout per hectare in the softwater Caribou River compared favorably with salmonid production reported for other infertile streams (up to about 60 kg/hectare: e.g., Cooper and Scherer 1967; Whitworth and Strange 1983). In most cases, these estimates were derived from streams in northern or mountainous regions, often in an igneous rock geology. In contrast to the low estimates for softwater streams, much higher estimates (100–300 kg/hectare) have been reported for more southern, hardwater streams, often in limestone geology (e.g., Cooper and Scherer 1967; Lobon-Cervia et al. 1986). Reviews by Mortensen (1977), Waters (1977), Chapman (1978), and Mann and Penczak (1986) list many other production estimates over a wide range, but generally include estimates reflecting the above apparent correlation between alkalinity and production.

The Blackhoof River appeared to be in an intermediate category, with medium alkalinity. In contrast to the Caribou River, the Blackhoof River flows through a more calcareous geology, but still does not have the high alkalinity of a limestone or chalk stream (about 200–250 mg/L as CaCO\(_3\)). Total annual salmonid production of 139.2 kg/hectare was also an intermediate level. However, production was perhaps somewhat higher than expected on the basis of water quality alone, especially considering that invertebrate production was estimated to be only slightly higher than in the Caribou River (Krueger and Waters 1983).

Two explanations for the higher-than-expected production in the Blackhoof River are suggested. First, the presence of two sympatric species may have resulted in greater exploitation of resources, as suggested by Chapman (1978). Second, the relatively high production of juvenile rainbow trout may have resulted from a greater efficiency of food assimilation and higher age-specific \( P/B \) ratios, as is often reported (Hopkins 1971; Elliott 1984). We found the annual \( P/B \) for juvenile rainbow trout to be more than twice as high as that for the brown trout (see succeeding section).

Age-0 fish in the Blackhoof River trout populations presented difficulties in sampling by electrofishing. In this stream, we first sampled age-0 fish in October because age-0 fish were too small in July to be collected effectively. Consequently, the standing stock of age-0 fish in October is given as a minimal estimate of production of this age-group up to that time, which is undoubtedly an underestimate. Similarly, the production of age-0 fish assigned to the period July–October may be overestimated because the standing stock in October includes some production that occurred before July. These two errors, of opposite sign, may cancel each other to some extent, but may in total effect leave some residual error, probably small and probably as an underestimate. We recommend that, in future studies, sampling begin in early spring when age-0 trout can be considered to be absent or at least negligible in biomass; thus, at least the latter error mentioned above will not be present. In contrast, age-0 brook trout in the Caribou River were sampled effectively in June–July and were included in all calculations.

**Annual Production : Biomass Ratios**

Annual \( P/B \) ratios varied among the three species in apparent accordance with age structure: an
inverse relationship existed between annual $P/B$ ratio and the number of age-groups or year-classes in the population (Table 1). This relationship would be expected, given the observations by Mann and Penczak (1986) that annual $P/B$ is inversely correlated with cohort age. The Blackhoof River rainbow trout had two or three age-groups present and an annual $P/B$ of 2.2; the Caribou River brook trout had four age-groups present and an annual $P/B$ of 1.7; and the Blackhoof River brown trout had six age-groups present and an annual $P/B$ of 0.9 (Figure 1; Table 1). On the basis of variances, the $P/B$ ratios for brown trout and rainbow trout were significantly different, whereas the brook trout $P/B$ was intermediate. It appears that the $P/B$ ratio may be correlated with the number of age-groups rather than with species. However, further analysis, including analysis of other kinds of fish populations, will be necessary to assess the validity of this postulated correlation.

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**References**


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