Numbers of Juvenile Salmonids Produced in Five Lake Superior Tributaries and the Effect of Juvenile Coho Salmon on their Numbers and Growth 1967-1974

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Fisheries Research Report No. 1846
May 26, 1977

MICHIGAN DEPARTMENT OF NATURAL RESOURCES
FISHERIES DIVISION

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NUMBERS OF JUVENILE SALMONIDS PRODUCED IN FIVE LAKE SUPERIOR TRIBUTARIES AND THE EFFECT OF JUVENILE COHO SALMON ON THEIR NUMBERS AND GROWTH, 1967-1974 [1]

By Thomas M. Stauffer

ABSTRACT

Annual population estimates in 1967-1974 of age-0 and age-I rainbow trout and age-0 coho salmon were made during August-October in a 305-meter section in each of five Lake Superior tributaries. Annual abundance indices for brook trout were obtained in three of the study streams and in one stream for brown trout. The objectives were to determine the amount of natural reproduction by rainbow trout and coho salmon, estimate the number of adults associated with these juvenile populations and to determine if newly established populations of juvenile coho affect other juvenile salmonid populations.

Natural reproduction by rainbow trout was substantial. I estimated that the average annual densities in November of age-0 and age-I rainbows per 305-m study section were $0.69/m^2$ or 1,072 trout and $0.09/m^2$ or 136 trout, respectively, and that this number of age-0 fish were produced by 16 adult rainbow trout.

Natural reproduction by coho salmon was moderate, but was without trend and was extremely variable. Young were produced by adults of hatchery origin in 1968-1970 and by adults of hatchery and wild origin in 1971-1974. I estimated that the average annual density per study section in November was $0.22/m^2$ or 317 age-0 salmon and that a population of 4-14 adults was associated with this juvenile population.

The newly established populations of juvenile coho salmon did not have a detectable effect on numbers and growth of rainbow trout. Linear regressions of the biomass of age-0 rainbow trout or of age-I rainbow trout biomass on the biomass of coexisting age-0 coho for each study section showed that the populations of rainbow trout were independent of coho populations.

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[1] Contribution from Dingell-Johnson Projects F-31-R and F-35-R, Michigan.

The data are suggestive of a depressant effect by coho salmon on brook and brown trout populations. In the three streams where small numbers of brook trout occurred, their numbers were lower when age-0 coho were abundant than when salmon were absent or nearly so. The same was true for a small population of brown trout in the single stream where they occurred. Additional investigations are needed on the relationship between coho salmon and brook and brown trout.

Introduction

Rainbow trout (*Salmo gairdneri*) and coho salmon (*Oncorhynchus kisutch*) provide a sport fishery of considerable magnitude both in Lake Superior and its tributaries. For example, in Michigan waters the estimated catch of rainbow trout and coho salmon in 1973 was 52, 650 and 33, 030 fish, respectively (Jamsen 1974). Relatively little, however, is known about the numbers of wild young produced of either the rainbow or the coho. Of particular interest is the amount of natural reproduction of the coho salmon which were first introduced into Lake Superior in 1966.

My objective in this research was to answer the following questions:

1. What is the abundance of juvenile rainbow and coho and how many adults are produced?
2. Do newly established populations of juvenile coho affect other juvenile salmonid populations? There has been concern that juvenile coho salmon will compete with established populations of rainbow trout, brook trout (*Salvelinus fontinalis*) and brown trout (*Salmo trutta*).

Answers to these questions were provided by annual population estimates and counts of these juvenile salmonids in 305-m long sections of five Lake Superior tributaries in 1967-1974. The five streams are located on the south shore of central Lake Superior. Four had volumes of 0.05-0.10 m^3/sec and contained abundant spawning habitat for salmonids (Table 1). The fifth stream had a volume of 1.00 m^3/sec and a smaller amount of spawning habitat. All streams have had fair to excellent rainbow trout spawning runs for many years. Adult coho salmon have spawned in varying numbers in the study streams since 1967. A study section was selected on each stream which had an abundance of age-0 rainbow trout and where good population estimates could be obtained. The most abundant salmonids in these sections were rainbow trout and coho salmon. Brook trout were present in much lesser numbers and brown trout occurred in only one stream. Sculpins (*Cottus cognatus* and/or

Table 1.--Physical characteristics of 305-meter study sections in five Lake Superior tributaries, 1967-1974.

Characteristic	Stream and county				
	Union, Ontonagon	Chinks, Baraga,	Little Huron, Marquette	Little Garlic, Marquette	Anna, Alger
Dates of population estimate[a]	8-15 Aug	24 Aug-1 Sep	27 Sep-9 Oct	26 July-7 Aug	20 Sep-9 Oct
Distance from Lake Superior (km)	<1	9	3	2	3
Area (m^2)	1,468	1,201	1,364	1,863	1,891
Average width (m)	4.8	3.9	4.5	6.1	6.2
Average depth (cm)	20	13	19	23	56
Volume of flow (m^3/sec)[b]	0.05	0.05	0.10	0.10	1.00
Bottom type (%)					
Boulders, rubble	25	25	49	59	9
Gravel	61	53	42	35	24
Sand	13	2	9	4	51
Silty-sand	0	15	0	0	3
Detritus	1	5	0	2	13
Conductivity (μmho)	200	180	130	140	200
Temperature (C)					
Minimum[c]	0			0	2
Maximum[d]	25	18	20	20	14
pH[e]	8.2	8.2	7.8	7.8	8.2

[a] Except for the following estimates: Union River, 26-27 August, 1974; Chinks Creek, 14-16 August, 1967 and 8-9 September, 1971; Little Huron River, 6-7 September, 1967 and Anna River, 29-30 August 1967.

[b] Normal low flow at time of estimate as judged by annual measurements.

[c] Winter temperatures from Zimmerman (1968).

[d] Recorded during summer heat waves.

[e] At time of estimate in 1967.

C. bairdi) were abundant; other fish species such as blacknose dace (Rhinichthys atratulus), longnose dace (R. cataractae), burbot (Lota lota) and johnny darter (Etheostoma nigrum) were generally rare to common.

Procedures

The numbers of age-0 and age-I rainbow trout and age-0 coho were determined by annual population estimates in the study sections during 26 July-9 October of 1967-1974. The mark-and-recapture method was used. Salmonids were caught with a d-c shocker, marked and released on one day, and recaptured the next. Population estimates and their variances were calculated by Bailey's (1951) modified Petersen equations as outlined in Ricker (1958, p. 54). A few estimates did not meet the requirement (total second-day catch $\times$ pq >9) for computation of 95% confidence limits. Hence, these limits are less reliable than for the estimates where the requirement was met. With few exceptions, estimates on a given stream were made on nearly the same dates each year (Table 1). Thus, within streams, it was possible to compare numbers and densities among years.

The numbers of age-I coho salmon, brook trout and brown trout and age-II rainbow trout were not sufficient for reliable population estimates. Hence, the numbers of individuals caught during the population surveys were used as indices of abundance.

Ages of juvenile salmonids were determined easily by scale examination and by the virtually discrete length frequencies of age-0 and age-I fish. Average total length was obtained by measuring all salmonids taken on the first day of the estimates. Average weight was derived from the average length, using length-weight relationships given by Stauffer (1975). The weights so obtained were minimal (about 95% of the true weight) because of the curvilinear nature of the relationship. Biomass (grams per square meter) for each estimated population was obtained by multiplying the estimated number by the average weight of the fish, then dividing this product by the area of the study section.

The relationships of various parameters (example, fish size vs. density) were calculated using both untransformed data and a log-log transformation. Whichever produced the higher regression coefficient (*r*) was used in this report.

Results

Age-0 rainbow trout. Substantial numbers of age-0 rainbow trout occurred each year in each study section except for the Union River in 1974, Chinks Creek in 1968 and 1969, and the Anna River in 1973 and 1974. Populations of age-0 rainbow trout ranged from 269 ($0.22/m^2$) to 6,068 ($4.13/m^2$) and biomass from 0.21 to 4.92 g/m^2 (Tables 2 and 3). There was an indication of a 2-year cycle of abundance except for the Anna River. Odd-numbered year populations were larger (usually significantly so) than those of even-numbered years for the Union and Little Garlic rivers. The existence of a 2-year cycle is most evident when the average density and 95% confidence limits for odd and even years are compared (Table 4). In all streams except the Anna River, the average density for odd years was significantly higher than for even years.

There was an indication in three sections that growth of age-0 rainbow trout (Table 2) was inversely related to density. The Union River (r = -0.928, F = 37.53), Chinks Creek (r = -0.571, F = 2.91) and the Little Garlic River (r = -0.511, F = 2.12) had relatively high curvilinear correlation coefficients, but only the coefficient for the Union River was significant. There were no indications of size-density relationships for the Little Huron or Anna rivers.

Age-I rainbow trout. Numbers of age-I trout in the five test sections (Table 5) ranged from 26 ($0.02/m^2$) to 395 ($0.21/m^2$) and biomass ranged from 0.38 to 4.96 g/m^2 (Table 3). Annual numbers of trout within each stream were without trend and quite consistent, with the exception of the Union River in 1967.

At higher densities there was an increasingly depressant effect on growth (Table 5) in Chinks Creek and the Little Huron River as shown

Table 2.--Number, density (number per square meter) and average length (millimeters), including 95% confidence limits, of age-0 rainbow trout in a 305-m section in five Lake Superior tributaries, 1967-1974.

Tributary	Year	Number	Density	Average length
Union River	1967	6,068 ± 364	4.13 ± 0.25	50.8 ± 0.2
	1968	3,329 ± 264	2.26 ± 0.18	54.8 ± 0.4
	1969	5,998 ± 428	4.08 ± 0.29	52.5 ± 0.4
	1970	2,808 ± 207	1.91 ± 0.14	58.0 ± 0.3
	1971	4,247 ± 229	2.89 ± 0.16	52.6 ± 0.2
	1972	2,618 ± 331	1.78 ± 0.22	54.0 ± 0.6
	1973	4,457 ± 218	3.03 ± 0.15	49.9 ± 0.4
	1974	456 ± 47	0.31 ± 0.03	65.3 ± 0.9
Average		3,748 ± 100	2.55 ± 0.07	54.7 ± 0.2
Chinks Creek	1967	1,211 ± 228	1.01 ± 0.19	57.0 ± 0.8
	1968	269 ± 75	0.22 ± 0.06	60.0 ± 1.6
	1969	316 ± 43	0.26 ± 0.04	60.2 ± 0.9
	1970	571 ± 83	0.48 ± 0.07	56.6 ± 1.0
	1971	913 ± 93	0.76 ± 0.08	63.6 ± 0.8
	1972	1,374 ± 199	1.14 ± 0.16	52.9 ± 0.9
	1973	1,545 ± 149	1.28 ± 0.12	50.8 ± 1.0
	1974	1,007 ± 142	0.84 ± 0.12	48.1 ± 1.0
Average		901 ± 50	0.75 ± 0.04	56.2 ± 0.4
Little Huron River	1967	1,788 ± 208	1.31 ± 0.15	51.9 ± 0.6
	1968	644 ± 135	0.47 ± 0.10	54.3 ± 1.1
	1969	1,051 ± 187	0.77 ± 0.14	54.3 ± 0.8
	1970	621 ± 113	0.46 ± 0.08	57.6 ± 1.1
	1971	934 ± 119	0.68 ± 0.09	60.3 ± 0.8
	1972	636 ± 154	0.47 ± 0.11	52.2 ± 1.2
	1973	586 ± 99	0.43 ± 0.07	54.6 ± 1.4
	1974	669 ± 106	0.49 ± 0.08	54.8 ± 1.4
Average		866 ± 51	0.64 ± 0.04	55.0 ± 0.4

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Table 2. --concluded

Tributary	Year	Number	Density	Average length
Little Garlic River	1967	3,405 ± 910	1.83 ± 0.49	50.4 ± 0.8
	1968	2,357 ± 559	1.26 ± 0.30	49.3 ± 0.9
	1969	6,327 ± 672	3.40 ± 0.36	44.5 ± 0.4
	1970	2,845 ± 320	1.53 ± 0.17	48.4 ± 0.5
	1971	3,786 ± 463	2.03 ± 0.25	49.8 ± 0.5
	1972	2,094 ± 371	1.12 ± 0.20	46.6 ± 0.8
	1973	3,995 ± 517	2.14 ± 0.28	42.4 ± 1.0
	1974	1,978 ± 394	1.06 ± 0.21	50.0 ± 0.8
Average		3,348 ± 196	1.80 ± 0.11	47.7 ± 0.3
Anna River	1967[a]	782 ± 569	0.41 ± 0.30	43.0 ± 1.8
	1968	674 ± 185	0.36 ± 0.10	48.3 ± 2.0
	1969	920 ± 369	0.49 ± 0.20	50.6 ± 1.8
	1970[a]	1,348 ± 1,075	0.71 ± 0.57	47.4 ± 1.6
	1971	860 ± 311	0.45 ± 0.16	46.4 ± 1.4
	1972	978 ± 436	0.51 ± 0.23	39.4 ± 1.5
	1973	468 ± 175	0.25 ± 0.09	45.7 ± 2.4
	1974	496 ± 148	0.26 ± 0.08	44.6 ± 2.4
Average		816 ± 176	0.43 ± 0.09	45.7 ± 0.7

[a] The limits for number and density are less reliable than others (see page 5).

Table 3.--Biomass (grams per square meter) and 95% confidence limits of age-0 and age-I rainbow trout and age-0 coho salmon, in a 305-m section in five Lake Superior tributaries, 1967-1974.

Tributary and year	Rainbow trout		Coho salmon	Aggregate
	Age-0	Age-I	Age-0	
Union River				
1967	4.92 ± 0.33	0.86 ± 0.37	0.00	5.78 ± 0.49
1968	3.38 ± 0.28	4.96 ± 0.77	1.34 ± 0.26	9.68 ± 0.86
1969	5.36 ± 0.41	2.92 ± 0.45	0.62 ± 0.17	8.90 ± 0.63
1970	3.41 ± 0.27	2.58 ± 0.42	0.00	5.99 ± 0.50
1971	3.81 ± 0.23	4.38 ± 1.04	0.51 ± 0.15	8.70 ± 1.08
1972	2.55 ± 0.33	4.09 ± 1.24	0.45 ± 0.23	7.09 ± 1.31
1973	3.41 ± 0.20	0.88 ± 0.11	2.60 ± 0.23	6.89 ± 0.32
1974	0.79 ± 0.08	1.46 ± 0.19	0.28 ± 0.06	2.53 ± 0.21
Average	3.45 ± 0.10	2.77 ± 0.24	0.72 ± 0.07	6.94 ± 0.27
Chinks Creek				
1967	1.71 ± 0.33	0.86 ± 0.27	0.00	2.57 ± 0.42
1968	0.44 ± 0.12	1.34 ± 0.55	2.31 ± 0.30	4.09 ± 0.64
1969	0.52 ± 0.07	0.84 ± 0.30	4.18 ± 0.32	5.54 ± 0.44
1970	0.79 ± 0.12	0.75 ± 0.24	0.00	1.54 ± 0.26
1971	1.80 ± 0.19	0.38 ± 0.29	1.55 ± 0.30	3.73 ± 0.46
1972	1.54 ± 0.23	0.62 ± 0.46	2.58 ± 0.46	4.74 ± 0.69
1973	1.52 ± 0.15	1.16 ± 0.39	2.20 ± 0.36	4.88 ± 0.56
1974	0.85 ± 0.12	1.69 ± 0.30	0.94 ± 0.17	3.48 ± 0.37
Average	1.15 ± 0.06	0.95 ± 0.13	1.72 ± 0.12	3.82 ± 0.18
Little Huron River				
1967	1.67 ± 0.20	1.72 ± 0.29	0.00	3.39 ± 0.35
1968	0.69 ± 0.15	2.16 ± 0.54	0.09 ± 0.05	2.94 ± 0.56
1969	1.12 ± 0.20	1.92 ± 0.33	0.15 ± 0.11	3.19 ± 0.40
1970	0.80 ± 0.15	1.73 ± 0.29	0.00	2.53 ± 0.33
1971	1.36 ± 0.18	1.64 ± 0.40	0.31 ± 0.08	3.31 ± 0.45
1972	0.61 ± 0.15	1.68 ± 0.39	0.42 ± 0.11	2.71 ± 0.43
1973	0.64 ± 0.11	1.84 ± 0.28	0.53 ± 0.18	3.01 ± 0.36
1974	0.73 ± 0.12	1.64 ± 0.42	0.00	2.37 ± 0.44
Average	0.95 ± 0.06	1.79 ± 0.13	0.19 ± 0.04	2.93 ± 0.15

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Table 3.--concluded.

Tributary and year	Rainbow trout		Coho salmon	Aggregate
	Age-0	Age-I	Age-0	
Little Garlic River				
1967	2.12 ± 0.57	1.64 ± 0.36	0.00	3.76 ± 0.67
1968	1.37 ± 0.33	3.36 ± 0.72	0.78 ± 0.49	5.51 ± 0.93
1969	2.71 ± 0.30	1.94 ± 0.47	0.22 ± 0.09	4.87 ± 0.56
1970	1.57 ± 0.18	1.69 ± 0.29	0.00	3.26 ± 0.34
1971	2.27 ± 0.29	1.86 ± 0.27	0.77 ± 0.15	4.90 ± 0.42
1972	1.03 ± 0.19	2.03 ± 0.35	1.05 ± 0.29	4.11 ± 0.49
1973	1.47 ± 0.20	2.67 ± 0.93	0.33 ± 0.16	4.47 ± 0.96
1974	1.20 ± 0.24	1.83 ± 0.43	0.11 ± 0.07	3.14 ± 0.50
Average	1.72 ± 0.11	2.12 ± 0.19	0.41 ± 0.09	4.25 ± 0.23
Anna River				
1967	0.29 ± 0.21	0.79 ± 0.21	0.00	1.08 ± 0.30
1968	0.37 ± 0.10	1.90 ± 0.47	0.27 ± 0.07	2.54 ± 0.49
1969	0.58 ± 0.23	1.94 ± 0.36	0.17 ± 0.08	2.69 ± 0.43
1970	0.69 ± 0.55	1.83 ± 0.56	1.42 ± 0.24	3.94 ± 0.82
1971	0.41 ± 0.15	0.91 ± 0.33	3.06 ± 0.35	4.38 ± 0.51
1972	0.28 ± 0.13	1.33 ± 0.92	1.50 ± 0.41	3.11 ± 1.02
1973	0.22 ± 0.08	1.04 ± 0.31	2.14 ± 0.19	3.40 ± 0.37
1974	0.21 ± 0.06	2.07 ± 0.68	1.64 ± 0.24	3.92 ± 0.72
Average	0.38 ± 0.08	1.48 ± 0.19	1.27 ± 0.10	3.13 ± 0.22

Table 4.--Number per square meter and the 95% confidence limits in odd and even years of age-0 rainbow trout in a 305-m section in five Lake Superior tributaries, 1967-1974.

Years	Stream				
	Union River	Chinks Creek	Little Huron River	Little Garlic River	Anna River
Odd	3.53 ± 0.11	0.83± 0.06	0.80 ± 0.06	2.35 ± 0.18	0.40 ± 0.10
Even	1.56 ± 0.08	0.67 ± 0.06	0.47 ± 0.05	1.24 ± 0.11	0.46 ± 0.16

Table 5.--Number, density (number per square meter) and average length (millimeters), including 95% confidence limits, of age-I rainbow trout in a 305-m section in five Lake Superior tributaries, 1967-1974.

Tributary	Year	Number	Density	Average length
Union River	1967[a]	38 ± 15	0.03 ± 0.01	144.6 ± 9.8
	1968	357 ± 55	0.24 ± 0.04	129.6 ± 4.2
	1969	277 ± 42	0.19 ± 0.03	117.6 ± 2.4
	1970	264 ± 43	0.18 ± 0.03	115.0 ± 2.4
	1971	384 ± 91	0.26 ± 0.06	121.3 ± 2.3
	1972	314 ± 95	0.21 ± 0.06	127.1 ± 3.1
	1973	104 ± 14	0.07 ± 0.01	110.0 ± 10.2
	1974	143 ± 18	0.10 ± 0.01	115.8 ± 4.6
Average		235 ± 20	0.16 ± 0.01	122.6 ± 2.0
Chinks Creek	1967[a]	66 ± 20	0.05 ± 0.02	122.2 ± 4.7
	1968	100 ± 41	0.08 ± 0.03	121.1 ± 7.6
	1969[a]	50 ± 18	0.04 ± 0.01	130.4 ± 5.6
	1970[a]	45 ± 15	0.04 ± 0.01	125.4 ± 5.4
	1971[a]	26 ± 19	0.02 ± 0.02	125.8 ± 10.8
	1972[a]	32 ± 23	0.03 ± 0.02	129.9 ± 10.9
	1973	83 ± 28	0.07 ± 0.02	120.5 ± 9.1
	1974	116 ± 21	0.10 ± 0.02	121.3 ± 7.3
Average		65 ± 9	0.05 ± 0.01	124.6 ± 2.8
Little Huron River	1967	159 ± 26	0.12 ± 0.02	115.0 ± 2.5
	1968	215 ± 53	0.16 ± 0.04	112.7 ± 2.3
	1969	185 ± 31	0.14 ± 0.02	113.4 ± 2.4
	1970	202 ± 34	0.15 ± 0.02	107.1 ± 2.4
	1971	130 ± 33	0.10 ± 0.02	120.2 ± 2.7
	1972	179 ± 42	0.13 ± 0.03	111.0 ± 2.9
	1973	231 ± 35	0.17 ± 0.03	104.8 ± 6.4
	1974	144 ± 37	0.11 ± 0.03	116.6 ± 4.4
Average		181 ± 13	0.14 ± 0.01	112.6 ± 1.2

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Table 5.--concluded.

Tributary	Year	Number	Density	Average length
Little Garlic River	1967	219 ± 47	0.12 ± 0.03	113.1 ± 3.1
	1968	395 ± 84	0.21 ± 0.04	119.2 ± 3.0
	1969	236 ± 56	0.13 ± 0.03	116.6 ± 2.6
	1970	263 ± 45	0.14 ± 0.02	108.7 ± 2.5
	1971	256 ± 37	0.14 ± 0.02	112.1 ± 2.2
	1972	263 ± 44	0.14 ± 0.02	115.4 ± 2.3
	1973	308 ± 107	0.17 ± 0.06	118.6 ± 3.5
	1974	269 ± 63	0.14 ± 0.03	111.5 ± 3.0
Average		276 ± 23	0.15 ± 0.01	114.4 ± 1.0
Anna River	1967	120 ± 32	0.06 ± 0.02	112.0 ± 4.4
	1968	256 ± 63	0.13 ± 0.03	115.7 ± 3.3
	1969	210 ± 38	0.11 ± 0.02	123.0 ± 3.2
	1970	232 ± 70	0.12 ± 0.04	117.3 ± 3.1
	1971	111 ± 41	0.06 ± 0.02	117.2 ± 4.9
	1972[a]	133 ± 92	0.07 ± 0.05	126.2 ± 5.3
	1973	160 ± 48	0.08 ± 0.02	111.4 ± 5.2
	1974	204 ± 66	0.11 ± 0.04	125.8 ± 4.4
Average		178 ± 21	0.09 ± 0.01	118.6 ± 1.5

[a] The limits for number and density are less reliable than others (see page 5).

by significant inverse curvilinear relationships (*r* = -0.721, *F* = 6.53; *r* = -0.871, *F* = 18.91, respectively). On the other hand, there was no significant relationship between density and growth in the Union (*r* = -0.334, *F* = 0.76), Little Garlic (*r* = 0.614, *F* = 3.63) and Anna (*r* = 0.224, *F* = 0.38) rivers.

There seemed to be little relationship between the number of age-I rainbow trout and number of age-0 trout present the preceding year. Linear correlation coefficients and corresponding *F* values (*n* = 7) were: Union River, 0.247 and 0.32; Chinks Creek, 0.794 and 8.50; Little Huron River, 0.474 and 1.45; Little Garlic, -0.097 and 0.05, and Anna River, -0.616 and 3.05. Only the regression for Chinks Creek was significant.

Age-0 coho salmon. Moderate numbers of age-0 salmon were present in the study sections of the streams during 1968-1974 except in 1970 (Table 6). In 1968-1970, young were produced by adults of hatchery origin and, in 1971-1974, by adults of hatchery and wild origin. An exception to the pattern of moderate numbers occurred in 1970 when the only stream with significant numbers of salmon was the Anna River which had been stocked in 1968. The other streams were not stocked in 1968, so the near absence of age-0 coho in 1970 could have been caused by the lack of straying into these streams by adults of hatchery origin.

Numbers of coho within the sections were exceedingly variable; they ranged from 0-1,989 at densities of 0-1.66/m^2 (Table 6) and biomass was 0-4.18 g/m^2 (Table 3). The most consistent producers of large numbers of age-0 coho salmon were Chinks Creek and the Anna River which were the only study streams planted with coho salmon. For the non-planted streams, the Union and Little Garlic rivers produced moderate numbers of age-0 salmon but the Little Huron River contained only small numbers.

The limited data (*n* = 5 to 7) suggested that there might be an inverse curvilinear relationship between length of age-0 salmon (Table 6) and density in all streams, meaning that high densities depressed growth.

Table 6.--Number, density (number per square meter) and average length (millimeters), including 95% confidence limits, of age-0 coho salmon in a 305-m section in five Lake Superior tributaries, 1968-1974.

Tributary	Year	Number	Density	Average length
Union River	1968	742 ± 141	0.50 ± 0.10	67.0 ± 1.2
	1969	277 ± 74	0.19 ± 0.05	71.9 ± 2.9
	1970	0	0.00	
	1971	287 ± 82	0.20 ± 0.06	66.0 ± 1.7
	1972[a/]	176 ± 92	0.12 ± 0.06	75.0 ± 1.8
	1973	1,733 ± 147	1.18 ± 0.10	62.7 ± 0.8
	1974	109 ± 23	0.07 ± 0.02	77.1 ± 1.8
Average		475 ± 36	0.32 ± 0.02	70.0 ± 0.7
Chinks Creek	1968	1,254 ± 159	1.04 ± 0.13	62.8 ± 1.0
	1969	1,989 ± 146	1.66 ± 0.12	65.6 ± 0.7
	1970	0	0.00	
	1971	444 ± 86	0.37 ± 0.07	78.2 ± 1.2
	1972	1,275 ± 226	1.06 ± 0.19	64.9 ± 1.0
	1973	1,035 ± 170	0.86 ± 0.14	66.0 ± 1.6
	1974	421 ± 75	0.35 ± 0.06	67.1 ± 1.4
Average		917 ± 53	0.76 ± 0.04	67.4 ± 0.5
Little Huron River	1968[a/]	29 ± 17	0.02 ± 0.01	79.4 ± 4.0
	1969[a/]	55 ± 39	0.04 ± 0.03	75.5 ± 3.8
	1970	0	0.00	
	1971[a/]	78 ± 20	0.06 ± 0.02	84.3 ± 3.3
	1972	179 ± 46	0.13 ± 0.03	71.4 ± 2.2
	1973	239 ± 83	0.18 ± 0.06	69.2 ± 2.2
	1974	0	0.00	
Average		83 ± 15	0.06 ± 0.01	76.0 ± 1.4

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Table 6.--concluded.

Tributary	Year	Number	Density	Average length
Little Garlic River	1968[a]	473 ± 300	0.25 ± 0.16	70.5 ± 1.6
	1969	139 ± 59	0.07 ± 0.03	70.6 ± 2.0
	1970	0	0.00	
	1971	458 ± 91	0.25 ± 0.05	70.4 ± 1.3
	1972	658 ± 182	0.35 ± 0.10	69.7 ± 1.2
	1973	230 ± 110	0.12 ± 0.06	67.9 ± 3.9
	1974[a]	58 ± 35	0.03 ± 0.02	75.1 ± 8.1
Average		288 ± 54	0.15 ± 0.03	70.7 ± 1.6
Anna River	1968	84 ± 22	0.04 ± 0.01	92.1 ± 3.0
	1969[a]	32 ± 16	0.02 ± 0.01	99.3 ± 4.5
	1970	506 ± 85	0.27 ± 0.04	84.5 ± 1.6
	1971	1,227 ± 138	0.65 ± 0.07	81.4 ± 0.7
	1972	732 ± 199	0.39 ± 0.11	75.9 ± 1.5
	1973	871 ± 78	0.46 ± 0.04	81.0 ± 1.8
	1974	527 ± 77	0.28 ± 0.04	87.8 ± 2.1
Average		568 ± 40	0.30 ± 0.02	86.0 ± 0.9

[a] The limits for number and density are less reliable than others (see page 5).

Correlation coefficients and F values were: Union River, -0.906 and 18.51; Chinks Creek, -0.672 and 3.30; Little Huron River, -0.692 and 2.76; Little Garlic River, -0.664 and 3.16; and Anna River, -0.895 and 20.34. However, only the relationships for the Union and Anna rivers were significant.

Salmonids of other age groups and species. Age-II rainbow trout were sparse in the study sections. Average numbers caught per year ranged from 3 (Chinks Creek) to 28 (Anna River). There were no readily apparent trends in abundance within individual streams. The numbers of age-II fish were not correlated with numbers of age-I rainbow trout present the preceding year.

Few yearling coho were found; average numbers caught per year within streams ranged from 3 to 22 individuals. Overall, the streams (Chinks Creek and the Anna River) that contained the largest numbers of age-0 coho seemed to have the largest numbers of age-I salmon. However, when linear regressions for numbers of age-I coho on age-0 coho present the preceding year were calculated for individual streams, only the regression for Chinks Creek was significant ($r = 0.832$, $F = 8.96$).

Brook trout were sparse to common in Chinks Creek, Little Huron River and the Anna River (Table 7) but virtually absent from the Union and Little Garlic rivers. In the former streams, the numbers of brook trout caught during the population estimates ranged from 14-145 individuals.

Brown trout occurred only in the Anna River where there was a small population (Table 7). The numbers of brown trout caught during the population surveys ranged from 19 to 100.

Abundance of Juvenile Salmonids

To compare numbers of juvenile salmonids among the study sections, it was necessary to estimate the populations present at the end of the growing season. Hence, I derived rough estimates of November populations from mortality trends developed from monthly population estimates during much of two growing seasons on the study sections in the Little Garlic River and Chinks Creek (Stauffer 1975).

Table 7.--Numbers of brook and brown trout caught during population estimates in a 305-m section in three Lake Superior tributaries, 1967-1974.

Year	Tributary and fish group[a]							
	Chinks Creek		Little Huron River		Anna River			
	Brook trout		Brook trout		Brook trout		Brown trout	
	<100 mm	≥100 mm	<100 mm	≥100 mm	<100 mm	≥100 mm	<100 mm	≥100 mm
1967[b]	68	77	12	11	14	24	28	72
1968	4	31	14	13	16	23	7	62
1969	31	14	32	27	13	25	12	59
1970	43	37	22	15	6	18	2	48
1971	9	25	12	19	7	12	2	17
1972	25	6	14	6	23	18	22	3
1973	22	37	4	10	3	28	9	27
1974	27	27	41	8	10	6	12	16
Average	29	32	19	14	12	19	12	38
±95% C.L.	16	17	10	6	5	6	7	21

[a] Trout less than 100 mm were mostly age 0 and trout greater than 99 mm were age I and older.

[b] In 1967, only the numbers of brook and brown trout caught during the marking run were recorded. The total number of trout caught during the marking run was divided into the two different size groups on the basis of average percentages for 1968-1974. For the recapture run, the number caught was estimated to be the average number caught during 1968-1974. This number was divided into the two size groups as was done for the marking runs.

Age-0 rainbow trout. The average density of age-0 rainbow trout in the five study sections was 0.69/m^2 (1,072) at the end of the growing season (Table 8). The better producers were the Union River (1.32/m^2) and Little Garlic River (0.86/m^2) followed by the Little Huron River (0.49/m^2), Chinks Creek (0.44/m^2) and the Anna River (0.33/m^2). Higher densities in the Union and Little Garlic rivers were not associated with differences in any of the measured physical characteristics (Table 1). Unmeasured factors are very likely responsible for differences in abundance. For example, the number of spawners and quality of the spawning substrate were unknown. Densities of juvenile rainbow trout in these five Lake Superior tributaries were comparable to, and in some instances greater, than those observed in other streams (Table 8). Density was comparable to that found by Alexander and MacCrimmon (1974) and Miller (1975) but was considerably greater than that described by Taube (1975).

At the time of the estimates (July-October) age-0 rainbow trout showed a 2-year cycle of abundance in that odd-year populations averaged larger than those in even years, except for the Anna River (Table 4). These cycles still persisted at the end of the growing season in November. I believe that this 2-year cycle is unique because the catch of downstream-migrating rainbow trout smolts in Waddell Creek (Shapovalov and Taft 1954) and in Black River (Stauffer 1972) showed no evidence of such a reproductive cycle. Numerous annual counts of age-0 brook trout in September by Shetter (1961), Latta (1965) and Hunt (1974) also did not reveal any evidence of a 2-year cycle.

The cause of the cycle I observed is uncertain but I first thought that it might be density-related because the cycles were especially apparent on the Union and Little Garlic rivers which produced the largest numbers of trout. Also, others (McFadden 1969, Mills 1969) have indicated that yearling trout limit populations of age-0 trout. To test this hypothesis, I examined the density relationship of age-0 and age-I trout for each of the study sections at the time of the surveys. There was no relationship between the two age groups for any stream. However, the

Table 8.--Average density (number per square meter) of juvenile salmonids in various streams and 95% confidence limits (in parentheses).

Reference	Location of sample	Date	Density: Rainbow trout Age 0	Density: Rainbow trout Age I	Density: Coho salmon Age 0
This paper[a]	Union River	Nov 1967-74[b]	1.32	0.08	0.20
	Chinks Creek		0.44	0.05	0.51
	Little Huron R.		0.49	0.14	0.05
	Little Garlic R.		0.86	0.08	0.09
	Anna R.		0.33	0.09	0.24
		Average	0.69	0.09	0.22
Taube 1975	Platte River,[c] Lake Michigan	Sep 1967-72	0.15 (0.01)	0.02 (0.01)	0.01
			0.12 (0.01)	0.02 (0.01)	0.04
			0.19 (0.02)	0.05 (0.01)	0.22
Alexander and MacCrimmon 1974	Bothwell's Creek, Lake Huron	Aug 1970	2.30	0.21	
		Sep 1970	1.80	0.19	
		Nov 1970	1.20	0.16	
Chapman 1965	Three Oregon streams	Aug 1959-62			1.41
		Nov 1959-62			0.96
Miller 1975	Huron River, Lake Superior	Aug 1967, 1969, 1970	0.86 (0.10)	0.10[d] (0.01)	

[a] Density in November estimated from earlier estimates for each year.

[b] Coho salmon averages are for the years 1968-1974.

[c] The three sets of values represent different sections of the river.

[d] Average of 1969 and 1970 only.

effect of yearlings on age-0 rainbow trout may have taken place before the time of the estimates; that is, during the time before many age-I trout migrated out of the study area. To examine this possibility, I tested the relationships (for each stream separately and combined) between age-I rainbow trout numbers in July and age-0 rainbow trout in August. These numbers were estimated from mortality trends established by Stauffer (1975). None of the regressions were significant, again suggesting the absence of any effect of yearlings on populations of age-0 trout. Next, I examined average monthly air temperatures and precipitation records but there were no indications that these meteorological conditions influenced rainbow trout populations. I conclude that my data are inadequate to determine the cause or causes of the 2-year cycle.

Age-I rainbow trout. The average density of age-I rainbow trout in the five sections was about $0.09/m^2$ (136 per section) in November at the end of the growing season (Table 8). I arrived at this approximate average by assuming that the Chinks Creek, Little Huron and Anna river populations had stabilized by the time of the estimates and that the Union and Little Garlic river populations would be reduced by 50% from the time of the estimates to the end of the growing season (Stauffer 1975). The Little Huron ($0.14/m^2$) was the best producer, the Union, Little Garlic and Anna rivers (0.08-$0.09/m^2$) were next best and Chinks Creek produced the least number of age-I rainbow trout ($0.05/m^2$). Subjective observations indicated that abundance was associated with the amount of fish cover. Average annual density for all streams was remarkably consistent. In 1969-1974 it was 0.08-$0.09/m^2$ with the low density ($0.06/m^2$) occurring in 1967 and the high in 1968 ($0.12/m^2$). The density of these yearlings was not usually related to density of age-0 trout the preceding year, which indicated that more than ample numbers of young were produced to populate the study sections with age-I trout. The surplus age-0 trout either died or moved downstream. The densities I found in the five streams were much greater than that observed by Taube (1975); slightly less that that found by Alexander and MacCrimmon (1974); and the same as that determined by Miller (1975) as shown in Table 8.

Age-0 coho salmon. The average annual density per study section of age-0 coho was estimated as $0.22/m^2$ (317 salmon) in November (Table 8). The average density among the streams ranged from $0.05/m^2$ (Little Huron River) to $0.51/m^2$ (Chinks Creek). The Anna and Union rivers had intermediate densities (0.24 and $0.20/m^2$) while the Little Garlic River had a density of $0.09/m^2$. Chinks Creek and the Anna River, where yearling coho salmon had been planted in the watershed, had the highest densities but the Union River, which had never been planted, had a density nearly as high. Among years, average density for all sections ranged from near zero to $0.26/m^2$; it was without trend and extremely variable. I expected that large numbers of age-0 coho at year N would, when they reached maturity, produce large numbers of progeny at year N + 3. However, neither curvilinear (r = 0.086, F = 0.12) nor linear (r = 0.258, F = 1.14) regressions of numbers of age-0 coho at year N + 3 on numbers of age-0 coho at year N were significant (n = 18). Populations of age-0 coho that were subsequently augmented by plants of yearling coho were excluded from this test. No doubt many additional factors such as straying of hatchery salmon, spawning conditions and survival to maturity determined the amount of reproduction. Densities of coho salmon in the five Lake Superior tributaries at the end of the growing seasons were similar to that found by Taube (1975) but considerably less than that observed by Chapman (1965), as shown in Table 8.

Effects of Age-0 Coho Salmon on Trout

If juvenile coho salmon have an adverse effect on juvenile rainbow trout, the biomass of rainbow trout, which reflects both numbers and growth, would decrease as biomass of age-0 coho salmon increased. Such was not the case. Calculations of linear regressions (n = 8) of the biomass of age-0 rainbow trout or of age-I rainbow trout on the biomass of coexisting age-0 coho salmon for each study section produced no significant relationships (Table 9). In fact, r and F values were exceedingly low which indicated that the populations of rainbow trout were independent of

Table 9.--Linear regression coefficients (r) and F values for the relationship between biomass of age-0 or age-I rainbow trout and biomass of age-0 coho salmon in a 305-m section in five Lake Superior tributaries, 1967-1974.

Stream	Age-0 rainbow trout on age-0 coho salmon		Age-I rainbow trout on age-0 coho salmon	
	r	F	r	F
Union River	< -0.001	< 0.01	-0.083	0.04
Chinks Creek	-0.306	0.62	-0.049	0.02
Little Huron River	-0.320	0.68	-0.059	0.02
Little Garlic River	-0.294	0.57	+0.452	1.55
Anna River	-0.170	0.18	-0.314	0.66

coho populations. This conclusion is supported by my field observations and observations of Hartman (1965) which indicated that age-0 coho salmon occupy different microhabitats than rainbow trout. Taube (1975) also found that coho salmon exerted no detectable effect on juvenile rainbow trout in a Lake Michigan tributary.

The addition of coho salmon to a stream rather substantially increased the total biomass of juvenile rainbow trout and coho salmon (Table 10). When age-0 coho salmon were scarce, total biomass of juvenile rainbow and coho ranged from 2.0 to 4.8 g/m^2 but when they were more abundant biomass was 3.0-8.2 g/m^2.

The limited evidence, however, suggested that juvenile coho salmon caused a reduction in the brook trout populations (Table 7). In Chinks Creek, when salmon were absent (1967 and 1970), the average numbers of age-0 and age-I or older brook trout caught were 56 and 57, respectively. In comparison, when salmon were abundant (1968, 1969, 1971-1974), these age groups of brook trout averaged 20 and 23, respectively. In the Little Huron River, when salmon were sparse or absent (1967-1970, 1974), the number of age-0 and age-I or older brook trout caught averaged 24 and 15, respectively, as compared to 10 and 12 for the years (1971-1973) when salmon were more abundant. In the Anna River, when salmon were absent or nearly so (1967-1969), the number of age-0 and age-I or older brook trout averaged 14 and 24, respectively, as compared to 10 and 16 when salmon were abundant (1970-1974). These data are suggestive of a depressant effect by coho salmon on brook trout populations but more evidence is needed.

Comparisons of brown trout numbers caught in the Anna River when salmon were absent with numbers caught when salmon were abundant suggested that coho salmon also had a depressant effect on brown trout populations (Table 7). In 1967-1969, when salmon were absent or nearly so, the number of age-0 and age-I or older brown trout caught averaged 16 and 64, respectively, as compared to 9 and 22 when salmon were abundant (1970-1974). The reality of the decrease in age-0 fish is suspect because of the small numbers involved. However, Taube

Table 10.--Total biomass of juvenile rainbow trout and coho salmon (grams per square meter) and 95% confidence limits when age-0 coho salmon were scarce and when they were more abundant in a 305-m section in five Lake Superior tributaries, 1967-1974. (Number of annual biomass estimates in parentheses.)

Salmon density (Number per square meter)	Stream				
	Union River	Chinks Creek	Little Huron River	Little Garlic River	Anna River
< 0.3	4.8 ± 0.2 (3)	2.0 ± 0.2 (2)	2.9 ± 0.2 (5)	3.8 ± 0.3 (4)	2.1 ± 0.2 (3)
0.3-4.2	8.2 ± 0.4 (5)	4.4 ± 0.2 (6)	3.0 ± 0.2 (3)	4.8 ± 0.4 (4)	3.8 ± 0.3 (5)

(1975) also found a reduction in numbers of age-0 brown trout in the presence of coho salmon in one of the two comparable sections of the stream he investigated. The reduction in numbers of older brown trout when salmon were present in the Anna River appears to be real. On the other hand, Taube (1975) did not find any effect of coho salmon on numbers of older brown trout. Undoubtedly, additional investigations of relationships between coho salmon and brown trout are needed.

Estimated Populations of Adult Rainbow Trout and Coho Salmon

Rainbow trout. I estimated from survival rates in the early life-history stages that 16 adult rainbow trout would be required to produce a November population of 1,072 age-0 trout. Survival of age-0 rainbow from August to November was 44% (Stauffer 1975), so there were 2,436 present in August. To estimate survival from egg deposition to August, I used the data of Miller (1975) who transferred ripe rainbow trout over an impassable barrier and then estimated the number of young produced. From these data, I estimated a survival of 10% from egg deposition to August, therefore some 24,000 eggs were deposited. The average number of eggs per female was 3,000 (Hassinger et al. 1974); thus eight female trout plus an appropriate number of males were required to produce a November population of 1,072 age-0 rainbow trout. The number of adults may be overestimated because the actual survival from egg to August may have been underestimated (all females may not have spawned). Also suggesting that my estimate of adults is high was Miller's (1975) comment that each spawning female should produce 200 fall fingerlings which would require about five females to produce a November population of 1,072 age-0 trout.

Coho salmon. The number of adult coho associated with a November population of 317 age-0 coho was estimated as 4 to 14 fish by two methods. In the first method, I estimated the number of adults by means of survival percentages at various prior life stages of the November populations, using data of Chapman (1965) or Mason (1975).

Data from Chapman (1965) suggested that survival from egg deposition to November was about 9%, so 3,522 eggs were deposited to produce a November population of 317 age-0 coho. Stauffer (1976) determined that egg deposition of Lake Superior salmon averaged 1,736 eggs per female. Hence, two female salmon plus a like number of males were required to produce a November population of 317 age-0 salmon. Stauffer (1975) found that survival from late August to November was 67%, so 473 age-0 coho were alive in August. Mason (1975) estimated survival from deposited eggs to late August as 4%; thus, 11,825 eggs were deposited. Since average egg deposition for each female was 1,736 (Stauffer 1976) seven females plus a like number of males were needed to produce a November population of 317 age-0 salmon.

In the second method, I estimated the number of age-0 coho present in November that would survive to adulthood. Chapman (1965) and Taube (1975) have shown that survival from November to April-May was about 40%. Survival of yearling coho smolts planted in Lake Superior to adulthood has been 6% or greater (Parsons 1973). It seems reasonable to believe that wild smolts would survive at least as well. Application of these two survival figures to a November population of 317 age-0 coho indicated that eight would survive to spawn.

Acknowledgments

J. W. Peck, W. C. Wagner, P. R. Hannuksela and A. Vincent assisted with the field work. Doris S. Greenleaf tabulated the field data and calculated the population estimates and associated parameters. W. C. Latta, M. H. Patriarche, C. M. Taube, J. W. Peck and W. C. Wagner reviewed the manuscript. J. R. Ryckman advised on statistical procedures.

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Report approved by W. C. Latta

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