POPULATION DYNAMICS OF BROOK TROUT (*Salvelinus fontinalis*) DURING MAINTENANCE LIMING OF AN ACIDIC LAKE

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Abstract. Maintenance liming of an acidic lake in the Adirondack Mountains of New York state (Woods Lake) was conducted three times over a 5 yr period in an attempt to establish a self maintaining brook trout population. Various strains and age classes of marked brook trout were stocked annually and the population was inventoried semi annually to evaluate survival, growth, and reproductive success. The Woods Lake brook trout population was dominated by young, stocked fish throughout the maintenance liming period of 1985–89. Based on spring emergent fry trap catches and fall trap net cathces of unmarked fish, only one naturally produced year class (1986) was successfully recruited to the Woods Lake brook trout population. Low annual survival rates (< 20%) of juvenile trout were observed throughout the study period. Although initial growth rates and condition of young trout were satisfactory, increased intraspecific competition for food resulted in declining growth rates and condition of older age classes. Fall standing crops of brook trout remained at relatively low levels of 6 to 10 kg ha^{-1} and both production per unit biomass and growth efficiency decreased over the 5-yr. Repeated whole lake liming and limited spawning habitat improvement were not sufficient to sustain brook trout natural reproduction in Woods Lake. Low productivity, marginal spawning habitat quality, and low survival rates of stocked trout in Woods Lake resulted in the failure to establish a self maintaining, productive brook trout population in Woods Lake.

1. Introduction

The brook trout (*Salvelinus fontinalis*) is the primary game fish indigenous to the Adirondack Mountain region of New York State and although it is still widely distributed, the species is notably absent from many acidic waters in the western drainage basins (Kretser *et al.*, 1989). Several liming studies (Kretser and Colquhoun 1984; Schofield *et al.*, 1986; Gloss *et al.*, 1989) have demonstrated that brook trout populations can be established and maintained by stocking, if circumneutral water quality is maintained after liming and if other physical and chemical conditions are suitable for brook trout survival. However, relatively few self maintaining brook trout populations have been established after liming and stocking acidic Adirondack lakes and the ability of these oligotrophic waters to sustain adequate growth and survival of introduced fish populations for extended periods of time has not been evaluated. Successful natural reproduction was observed in only one of ten small Adirondack lakes that were limed once and stocked annually for a period of 4 yr (Schofield *et al.*, 1986).

Intensive efforts (including liming, stocking, and spawning habitat improvement) to reestablish a self maintaining brook trout population in acidic Woods lake (Porcella, 1989; Gloss *et al.*, 1989) resulted in successful spawning and recruitment of one year class of naturally produced trout the first year after liming and stocking.

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Brook trout growth and production rates were also satisfactory during the first year after reintroduction of trout to Woods Lake, but survival rates of stocked fish were lower than those observed in other limed Adirondack Lakes (Schofield *et al.*, 1989). The latter authors also noted that these relatively short term observations were not representative of equilibrium conditions and that longer periods of observation would be required for evaluation of treatment success.

The management potential of repeated whole lake liming (maintenance liming) for developing and sustaining naturally reproducing brook trout populations in acidic Adirondack lakes is addressed in this study through extended evaluation of survival, growth, and reproductive success of the Woods Lake brook trout population following additional limestone treatments described by Gubala and Driscoll (1990).

2. Methods

Woods Lake was treated by water column additions of $CaCO_3$ in May, 1985 (22.1 t), September, 1986 (34.3 t), and November, 1988 (2 t) to maintain water quality suitable for brook trout survival. The latter small treatment was done to maintain water quality over winter, prior to a planned major watershed limestone treatment in 1989. The first two treatment procedures were described by DePinto *et al.* (1989) and Gubala and Driscoll (1990). Post liming water chemistry of Woods Lake from 1985 through 1988 have been described by Driscoll *et al.* (1989) and Gubala and Driscoll (1990).

Brook trout have been stocked annually in Woods Lake (Table I) since May, 1985, utilizing wild (Temiscamie and Assinica) and hybrid (Domestic × Temiscamie) strains described by Gloss *et al.* (1989) and Webster and Flick (1981). The paired young of year stockings of Assinica and Temiscamie strain brook trout in the spring of 1988 and 1989 were conducted to evaluate factors affecting survival of young of year brook trout in Woods Lake and to evaluate strain differences in survival, growth, and behavior (VanOffelen, 1990). Survival, growth, and reproduction by

TABLE I

Brook trout stocked in Woods Lake: 1985–1989

Period	Year class	Strain	N
SPR 85	1984	Temiscamie	1200
SPR 85	1985	DomesticxTemiscamie	2500
SPR 85	1985	DomesticxTemiscamie (selected)	2500
FALL 86	1986	DomesticxTemiscamie	656
FALL 87	1987	DomesticxTemiscamie	600
SPR 88	1988	Temiscamie	4000
SPR 88	1988	Assinica	4000
SPR 89	1989	Temiscamie	3000
SPR 89	1989	Assinica	3000

the first two year classes of trout introduced to Woods Lake were described by Gloss *et al.* (1989) and Schofield *et al.* (1989).

The Woods Lake brook trout population was assessed each spring and fall from 1985 through 1989 by trap net utilizing procedures described by Gloss *et al.* (1989). Observations were made each year of spawning activity and movement was monitored by outlet trap catches (Gloss *et al.*, 1989). Population size was estimated by the Schnabel procedure (Ricker, 1975) and exponential models of growth and survival were employed to estimate mean annual biomass and production (Chapman, 1967; Schofield *et al.*, 1989). Food consumption was estimated from observed growth and a bioenergetic model of metabolism (Schofield *et al.*, 1989). Reproductive success and recruitment of young of year trout was monitored by trapping emergent fry each spring over near shore spawning sites (Gloss *et al.*, 1989).

3. Results and Discussion

3.1. Population trends and survival

Estimated numbers of brook trout in Woods Lake during fall inventories in 1985 to 1989 (Figure 1) ranged from 930 fish in 1987 (including 600 stocked fall fingerlings) to 3679 fish in 1988. Highest fall population densities occurred during years of spring fingerling stocking (1985, 1988, 1989) when young of year (age 0+) fish were predominant in the fall populations. Young, juvenile fish (≤age 1+) of stocked

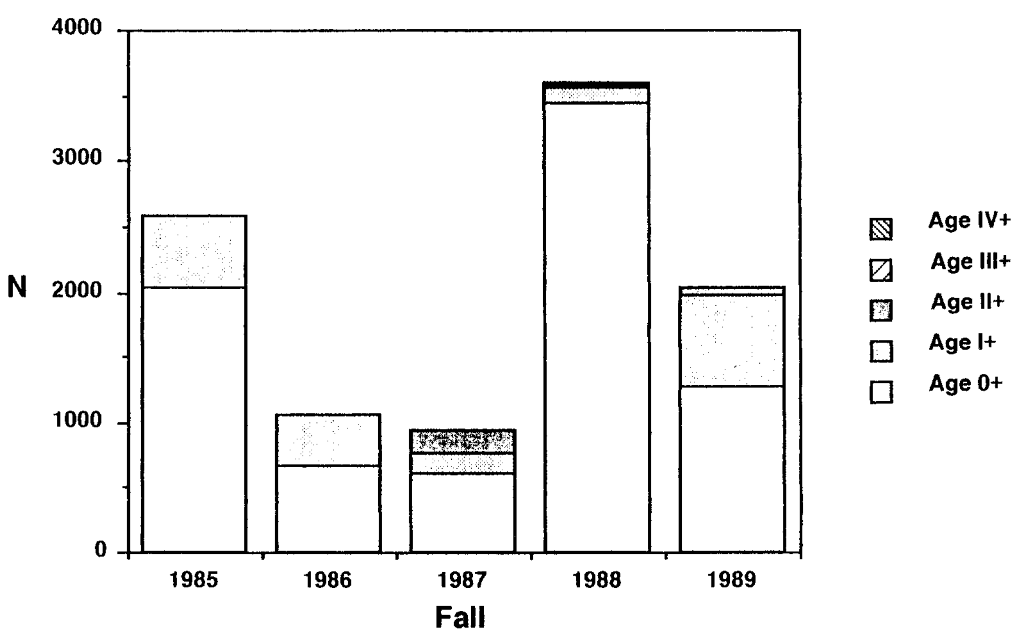

Fig. 1. Brook trout population size and age composition in Woods lake, 1985–1989.

TABLE II

Survival rates (% of number stocked) and 95% confidence intervals for brook trout stocked in Woods Lake

			Years after stocking				
Year Class	Strain	N Stocked	0.5	1.0	1.5	2.0	2.5
1985	DXT	5000	40.7 28.7–60.1	35.0 20.0–67.0	7.7 5.6–12.4		3.4 2.8–5.6
1986	DXT	656		17.1 13.9–21.8		3.4 2.4–5.6	
1987	DXT	600		20.0 15.3–28.8		8.8 4.8–44.2	
1988	Temis	4000	58.7 46.8–78.6		13.3 11.3–16.3		
1988	Assin	4000	27.0 23.5–31.7		4.5 3.7–5.7		
1989	Temis	3000	25.8 20.8–34.0				
1989	Assin	3000	16.4 13.3–21.3				

origin were numerically predominant in the population in all years, suggesting low survival rates of juveniles and little recruitment of naturally produced fish.

Estimated survival rates of young of year fish from stocking to age 1+ ranged from 4.5 to 20% (Table II). A greater proportion of trout stocked as fall fingerlings survived to age 1+ (17.1 to 20.0%) in comparison to spring fingerling plants (4.5 to 13.3%). However, higher stocking densities of spring fingerlings resulted in proportionally greater absolute recruitment of these fish into older age classes in the population. Compared to annual survival rates of 40 to 80% for stocked brook trout of the same strain and year classes in other limed lakes with comparable post liming water quality (Schofield *et al.*, 1986; Gloss *et al.*, 1989), the survival rates observed in Woods Lake are extremely low. The factors responsible for these poor survival rates are not known with certainty. However, acidity did not appear to be a major factor responsible for high brook trout mortality rates in Woods Lake considering the maintenance of relatively high water column pH levels throughout the period (Driscoll *et al.*, 1989; Gubala and Driscoll, 1990). Episodic reacidification of nearshore and winter epilimnetic water (<2 m depth) did occur annually in Woods Lake. However, juvenile and adult brook trout had ample habitat in deeper areas of the lake with suitable water quality during these episodes. Limited comparisons of overwinter versus spring-fall survival rates also suggests that greater mortality was occurring during summer rather than winter periods (Table II). Although emigration is a potential source of population loss, this has been controlled by outlet trapping and replacement of migrants to the lake. Movement associated with increased discharge and spawning activity has been pronounced in Woods Lake during the fall of most years (Gloss *et al.*, 1989), but was noticeably less

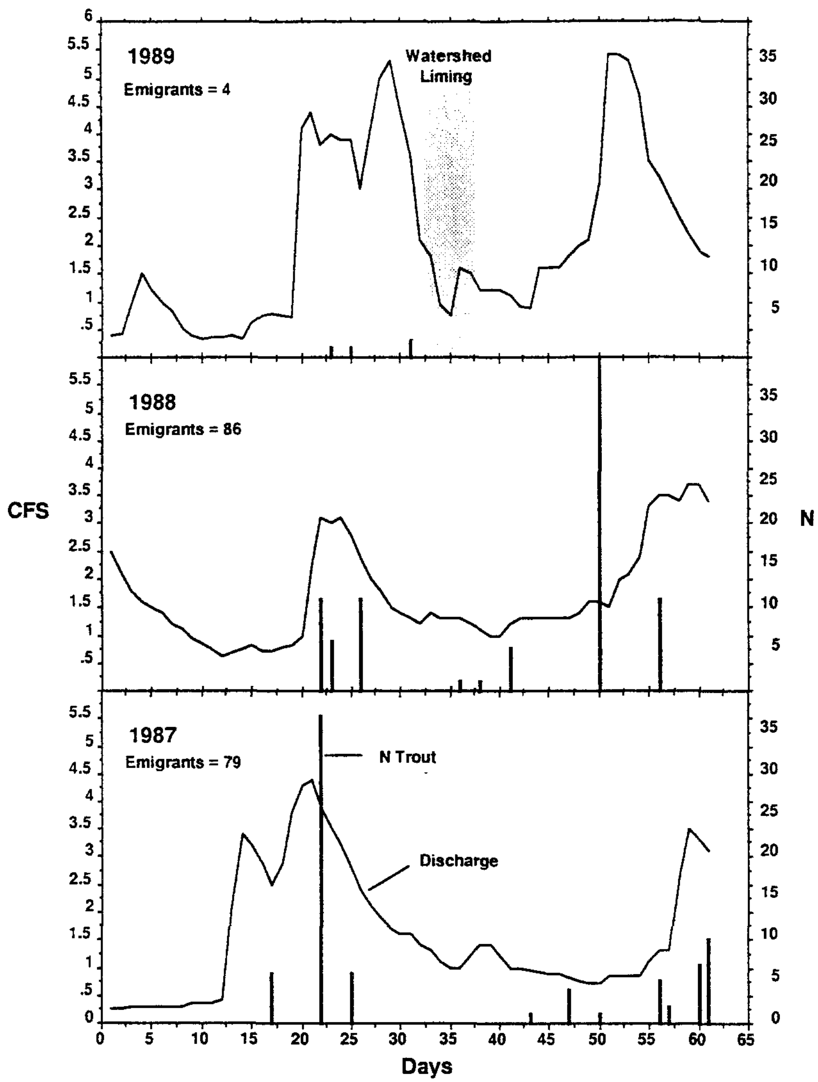

Fig. 2. Daily discharge and outlet trap catch of Woods Lake brook trout during September and October of 1987–1989.

following the recent watershed liming treatment in the fall of 1989 (Figure 2). Relatively high summer epilimnetic temperatures and limited availability of cooler water in deeper areas of the lake could also have resulted in increased thermal stress to the population and higher mortality. Predation by loons and mergansers, which have been observed on the lake with increasing frequency in recent years, is a potentially major source of mortality for young brook trout that has not been quantified. Since relatively few of the surrounding lakes contain fish or have trout populations with densities as high as Woods Lake, it seems logical that these fish eating birds would be attracted to Woods Lake.

3.2. Natural reproduction and recruitment

Spawning brook trout have been observed annually over the redds constructed in nearshore groundwater seepage zones and over artificial spawning boxes installed in 1985 and 1989. The boxes were installed because of limited and poor quality in lake spawning habitat (Gloss *et al.*, 1989). No emergent fry have been captured in traps placed over redds constructed in the nearshore seepage zones each spring from 1986–1989. However, trap catches of emergent fry from the spawning box during the spring of 1986 yielded an estimated recruitment of 700 swim up fry to the population. In 1987 only two fry were captured from traps placed on the spawning box and none were caught in 1988 and 1989. These observations are indicative of the poor physical and chemical quality of the nearshore spawning habitat in Woods Lake.

Although two perennial tributaries to Woods Lake offer potentially better physical spawning habitat than that present in the lake, these streams are highly acidic (Driscoll *et al.*, 1989) and were not utilized by spawning trout. Self maintaining brook trout populations in other Adirondack lakes, at elevations comparable to Woods Lake, utilize both nearshore seepage zones and tributaries for spawning (Schofield, 1990).

Episodic reacidification of the nearshore spawning zone (depths generally <1 m) during snowmelt periods in early spring (Driscoll *et al.*, 1989; Gubala and Driscoll, 1990) is also a potential source of mortality for brook trout larvae present in shallow redds.

Recruitment of brook trout from natural reproduction to the population in Woods Lake was identified by the presence of unmarked brook trout at age 0+ and older in fall trap net inventories. Based on length frequency distributions of unmarked trout (Figure 3), only one year class (1986) from natural reproduction was successfully recruited to the adult brook trout population in Woods Lake. Unmarked fish captured in 1985 were age 0+ Domestic × Temiscamie hybrids stocked in May, 1985 and age 1+ Temiscamies stocked as yearlings (individually marked with jaw tags) at the same time. The unmarked trout captured as age 0+ in the fall of 1988 and again in 1989 as age 1+ fish could have included some trout from natural reproduction. However, a more likely explanation for the occurrence of these fish is missed fin clips on the stocked spring fingerlings from the 1988 year class (Table 1).

3.3. Growth and production

Gloss *et al.* (1989) and Schofield *et al.* (1989) previously reported satisfactory growth and production of the first year class of brook trout (1985) introduced to Woods Lake following liming. Growth in length of the 1985 year class subsequently declined after age 2+ (Figure 4) and subsequent year classes have exhibited significantly lower mean lengths at age 3+ (1986 year class) and age 2+ (1987 year class). Mean lengths at age 0+ and 1+ were not significantly different between year classes (P

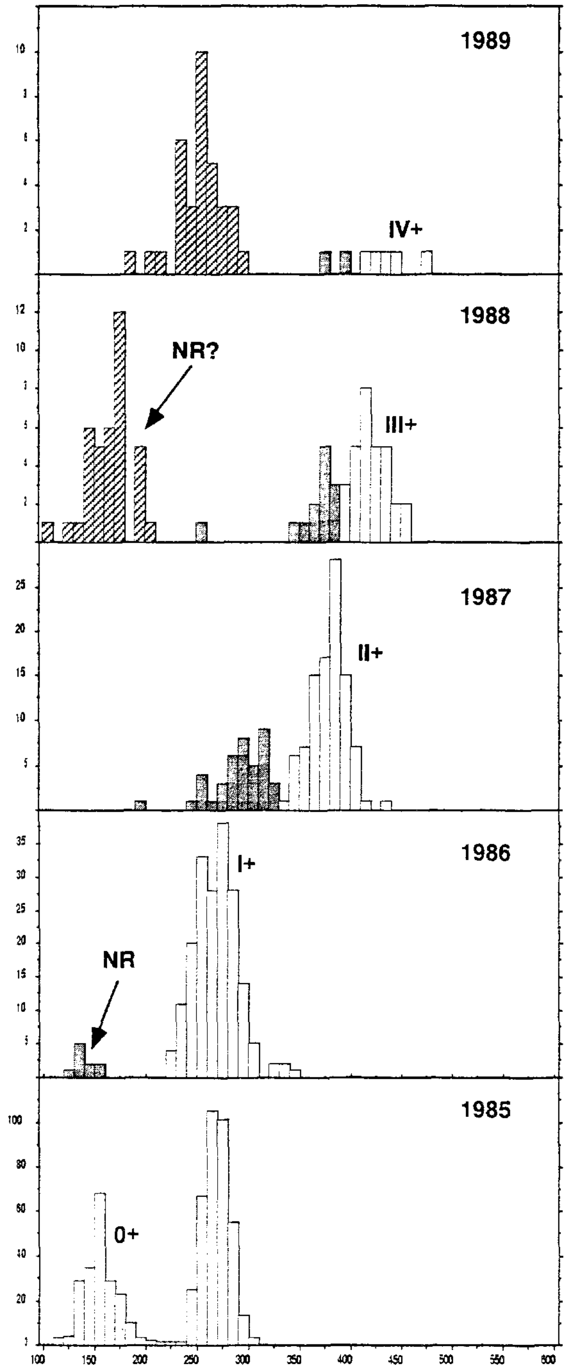

Fig. 3. Length frequency distributions for unmarked brook trout captured in Woods Lake during fall inventories, 1985–1989. NR = natural reproduction. Unshaded bars are fish of stocked origin and known age.

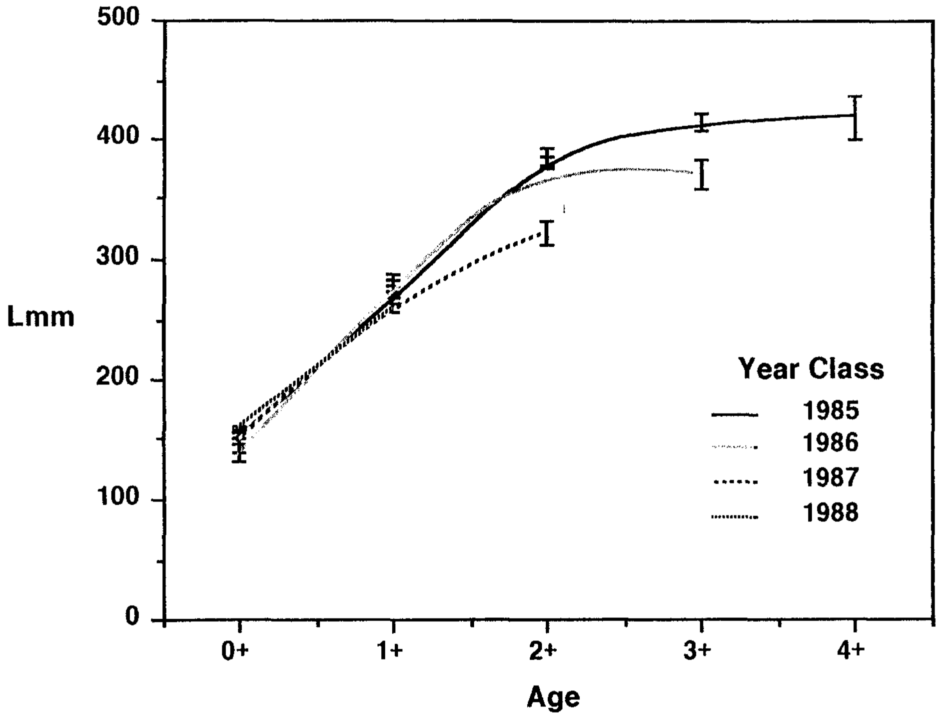

Fig. 4. Mean length at age of Woods Lake brook trout. Error bars are 95% confidence intervals.

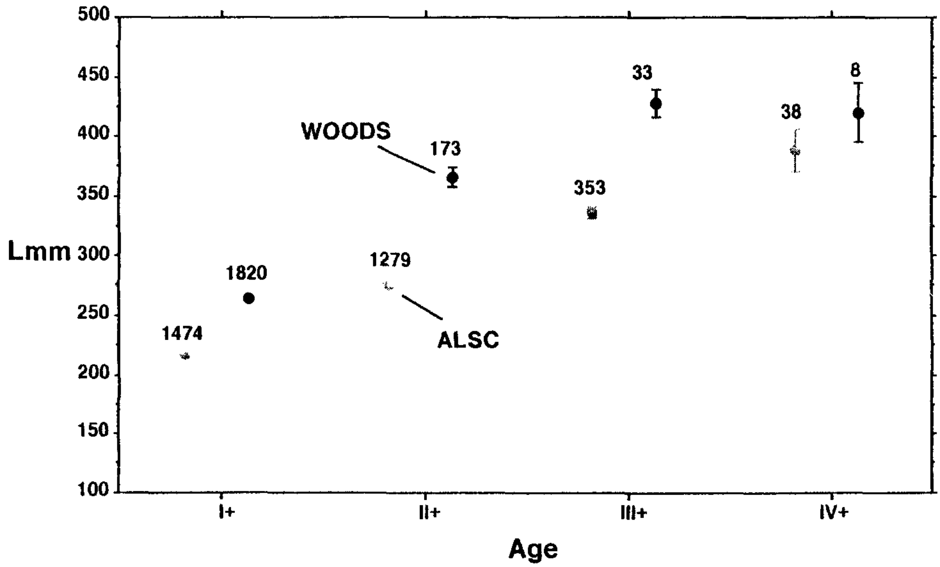

Fig. 5. Mean lengths for brook trout collected from 572 ALSC lakes (1984–1987) and for Woods Lake brook trout (1985–1989). Numbers are sample size and error bars are 95% confidence intervals.

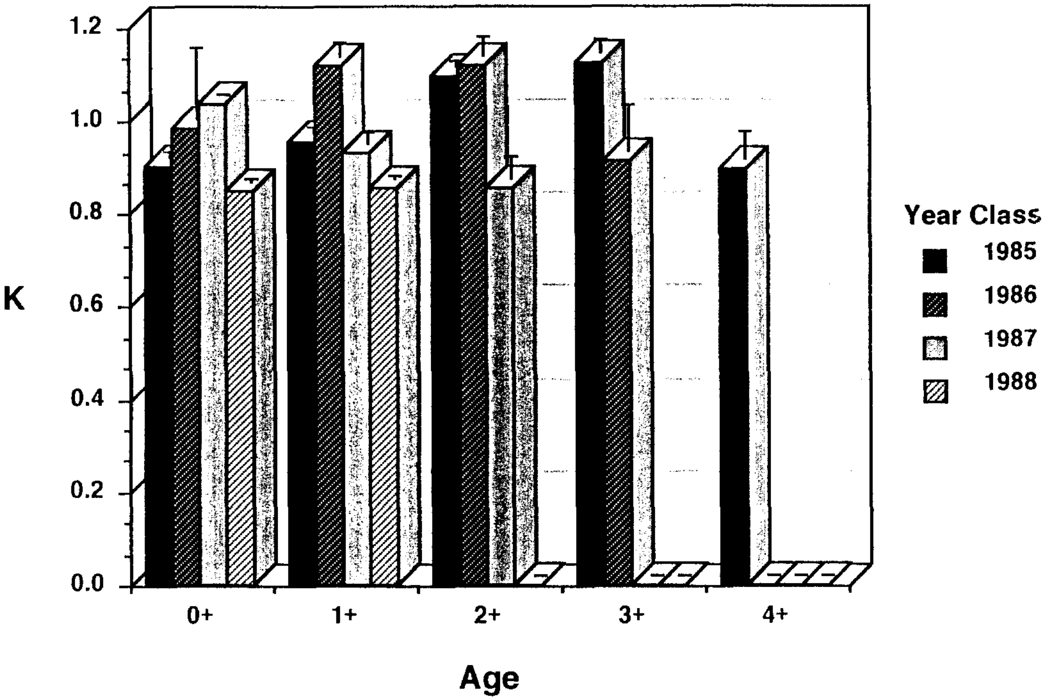

Fig. 6. Mean condition factors for Woods Lake brook trout. Error bars are 95% confidence intervals.

0.05). Although growth rates have declined over time in Woods Lake, mean lengths at age for all brook trout collected from 1985–1989 were still significantly higher than those recorded for brook trout collected in 572 other Adirondack lakes sampled by the Adirondack Lake Survey (Kretser *et al.*, 1989) during the period 1984–1987 (Figure 5).

Mean condition factors ($K = wtg/Lmm^3 \times 10^5$) for Woods Lake brook trout age 0+ to IV+ declined significantly in 1989 (Figure 6) to values < 0.9. These decreases in condition were most pronounced for older age classes and followed substantial increases in population density of younger fish stocked in the spring of 1988 and 1989. Measurements of absolute growth in weight were obtained from individually jaw tagged fish (Figure 7). A marked decline in growth in weight of age II+ trout (change in weight from age 1+ to II+) was observed from 1987 to 1989 and the few older (age 3+ and 4+) tagged fish recaptured in 1989 exhibited significant losses in weight (Figure 7). These observations are indicative of increased intraspecific competition for food among younger age classes and markedly reduced growth efficiency of older age classes.

The potential effects of increased population density of young fish on food availability is reflected by the amount and estimated proportions of food consumed by age classes present in Woods Lake in 1987–88 and 1988–89 (Figure 8). Total food consumption by the Woods lake brook trout population increased from

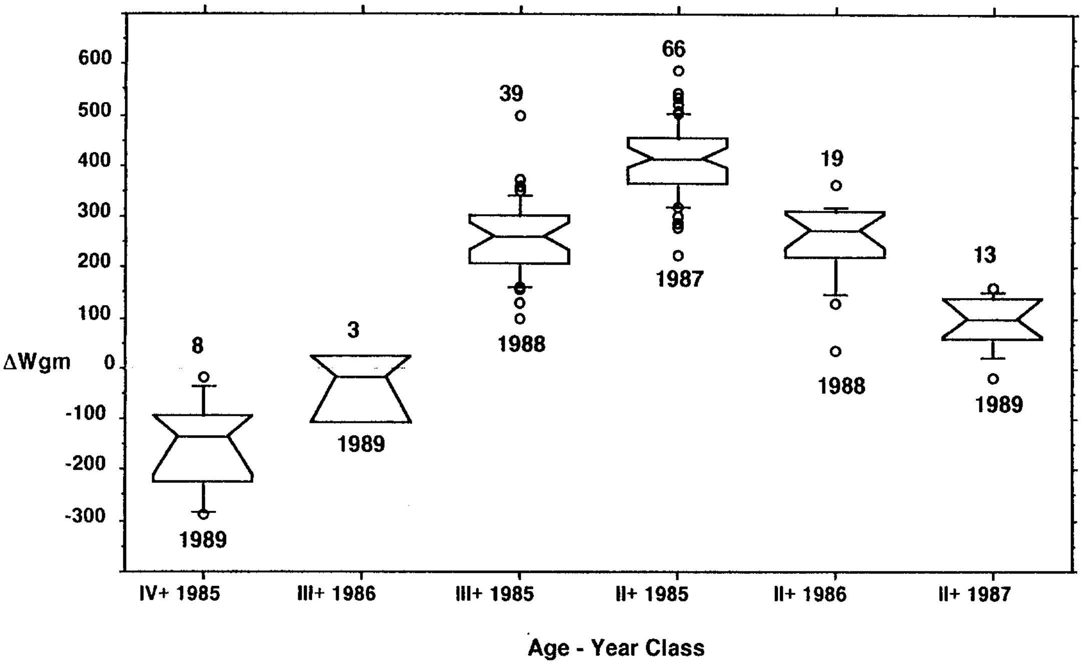

Fig. 7. Notched boxplots of median annual weight change of tagged brook trout captured in Woods Lake. Number of trout in samples and last year captured as shown on graph.

approximately 70 to 80 kg ha^{-1} yr^{-1} in 1985–1987 to 106 kg ha^{-1} yr^{-1} in 1987–1989. Young fish (age 0+ and 1+) consumed 47 to 71% of the total annual ration for the population during this latter period. Comparison of estimated annual growth efficiencies (K = Δweight/ration) between years and age groups (Figure 9) indicates reduced growth efficiency of older age classes during years with high population density (1989 in particular). Although younger fish typically exhibit higher growth efficiency than older fish and the Woods Lake trout population was dominated by these smaller, young fish in the last two years of the study, there was still a decrease in total population growth efficiency (production per unit ration) and production efficiency (production per unit biomass) during this period as a result of an absolute decline in growth rate across all age classes (Table III). Mean annual biomass and total annual production from 1985 through 1989 remained at relatively low levels (Table III) and were at the lower end of the range for these parameters reported for other Adirondack brook trout lakes (Schofield *et al.*, 1989).

4. Summary and Conclusions

The Woods Lake brook trout population has consisted primarily of young, stocked fish throughout the maintenance liming period from 1985–1989. Based on emergent fry trap catches and fall trap net catches of unmarked fish, only one year class

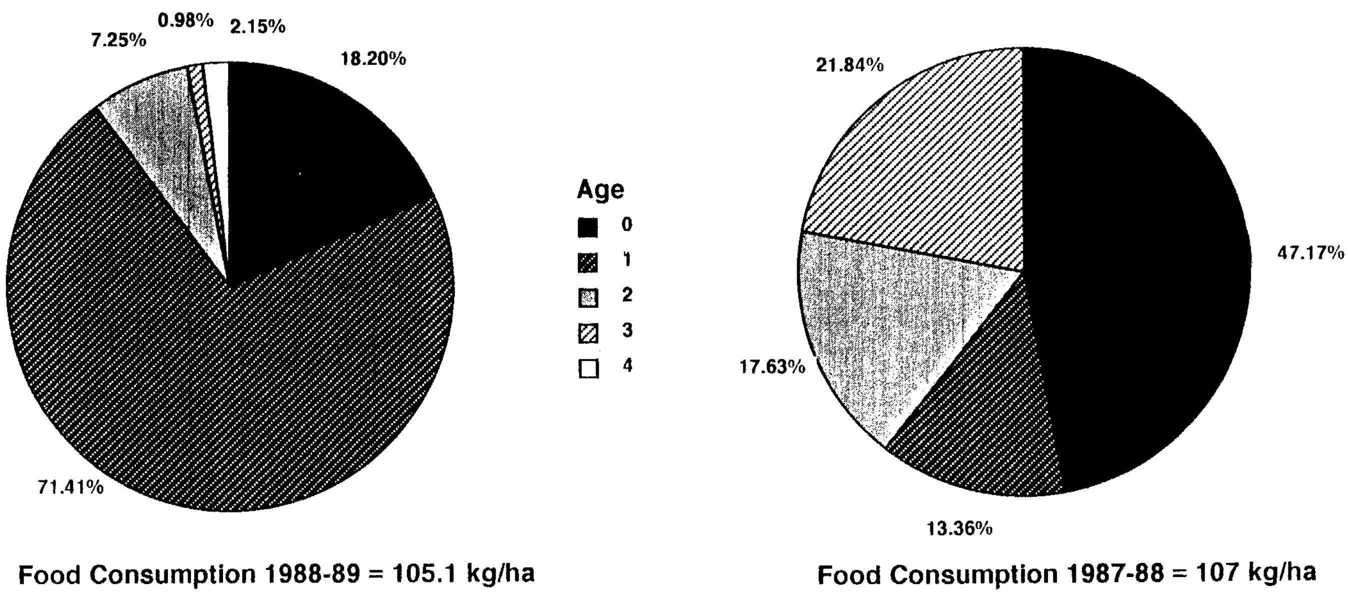

Fig. 8. Estimated proportions of food consumed by age 0–4 brook trout in Woods Lake during 1987–88 and 1988–89.

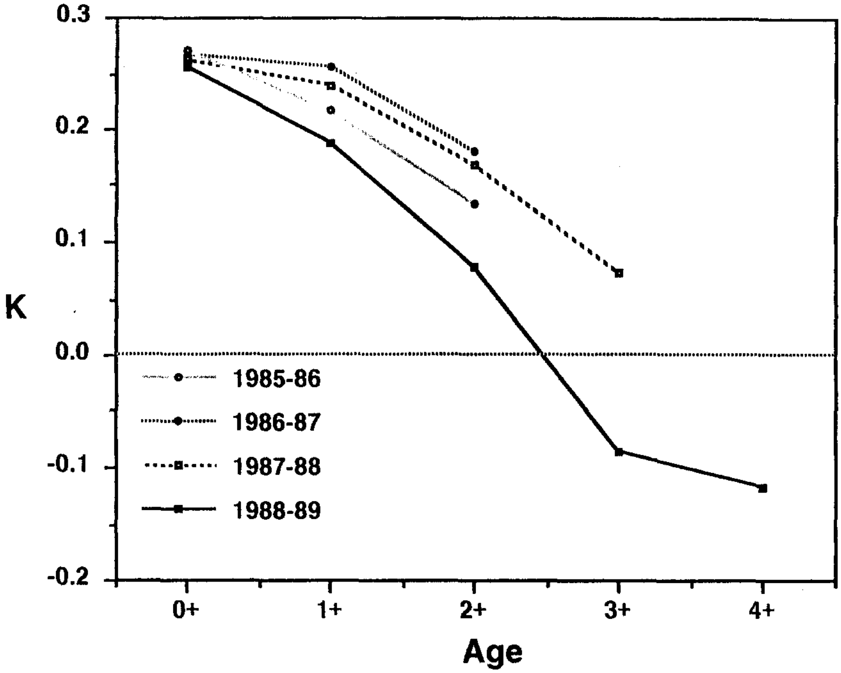

Fig. 9. Estimated mean annual growth efficiency ($K = \Delta W/R$) for Woods Lake brook trout.

TABLE III

Mean annual biomass (B), total production (P), and estimated food consumption (R) for Woods Lake brook trout from 1985–1989

Period	B	P	R	P/B	P/R
	kg ha^{-1}				
10/85 - 9/86	6.9	9.8	80.6	1.4	0.121
10/86 - 9/87	5.1	7.2	71.2	1.4	0.101
10/87 - 9/88	8.4	10.8	107.0	1.3	0.100
10/88 - 9/89	9.0	9.6	105.1	1.1	0.092

(1986) was successfully recruited to the Woods Lake brook trout population. Low survival rates were observed for both spring and fall fingerling trout during the first 2 yr after stocking. Mortality rates were generally higher during summer than winter periods, suggesting that predation (probably avian) and thermal stress may be of primary importance as factors affecting survival. Although initial growth and condition of introduced trout were satisfactory, increased population density resulted in declining growth rates and condition of older age classes. Fall standing crops of brook trout remained at relatively low levels of 6 to 10 kg ha^{-1} during the study period. Total estimated food consumption increased during this period, however both production rate per unit biomass and growth efficiency decreased from 1985–1989. Whole lake liming, repeated stocking, and limited spawning habitat improvements in Woods Lake were not sufficient to sustain brook trout natural reproduction. Poor survival rates and declining growth rates of stocked trout were indicative of marginal habitat quality and low productivity for an Adirondack brook trout lake.

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