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# Use of Outlet Barriers to Prevent Fall Emigration of Brook Trout Stocked in Adirondack Lakes

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*Abstract.*—Outlet barriers in stocked lakes of the Adirondack Mountains were used to test the hypothesis that preventing fall emigration by adult brook trout *Salvelinus fontinalis* would increase trap-net and angling catch rates as well as the number of large trophy fish. Outlet barriers were maintained during the fall spawning season for 6 years on one lake and 10 years on another lake. We compared prebarrier and postbarrier trap-net and angler catches (1978–1998) in two blocked and two unblocked lakes. Postbarrier availability of brook trout to anglers and trap nets increased significantly in Rock Lake (blocked) but not in Lower Sylvan Pond (blocked) or the two unblocked lakes. However, highly significant increases in angler catches of trophy fish occurred from both blocked lakes. Variables other than emigration, such as number of fish stocked and angling mortality, influenced our ability to detect significant increases in the availability of age-2 and older brook trout in Lower Sylvan Pond. The outlet barriers elicited a population response by stocked brook trout consistent with the hypothesis that emigration losses of mature adults depleted older-aged fish from unblocked lakes. Outlet barriers are a potential management tool; however, managers must consider their specific management goals and the problems associated with seasonally interrupting migratory corridors.

Emigration by mature brook trout *Salvelinus fontinalis* during the fall spawning season can reduce the abundance of adult fish in lakes where fisheries depend on stocking for population recruitment. Fall emigration by stocked brook trout reduced adult populations in two Michigan lakes by 40–90% (Alexander et al. 1990); in Woods Lake, New York, by 21–86% (Schofield and Keleher 1996); and in three lakes in the Adirondack Mountains by 33–69% (Josephson and Youngs 1996). These lakes had little or no spawning habitat, so mature fish presumably emigrated in search of spawning habitat (Warrillow et al. 1997). These studies concluded that fall emigration could seriously deplete populations of mature fish in lakes that lack outlet barriers.

Stocking is essential to maintaining brook trout sport fisheries in the majority of lakes in the Adirondack Mountain region of New York State. Since the early 1800s, human-induced perturbations in this region have resulted in the fragmentation of habitats by dams, logging operations, and acid precipitation, and changes in fish communities have followed introductions of exotic fishes (Schofield 1976; George 1980). These perturbations have eliminated the ability of brook trout to sustain wild populations within most lakes of the region. Most remnant populations of brook trout exist primarily in isolated headwaters of lakes and streams (Keller 1979; Perkins et al. 1993). This constrains reproduction to such an extent that brook trout recruitment in 90% of the lakes depends on stocking (Pfeiffer 1979).

Management of stocked brook trout in the region focuses on individual lakes as the spatial units of management. Lake management practices emphasize stocking and regulations (e.g., seasons, creel limits), and in a few lakes, liming (to neutralize acid precipitation) or chemical reclamation (to remove competitor and predator fish species) to improve conditions for brook trout growth and survival. A fall fingerling stocking program has also been instituted to produce put–grow–take fisheries or to establish self-sustaining wild brook trout populations (Keller 1979). Brook trout may establish self-sustaining populations in some reclaimed lakes (Schofield 1993) but rarely in limed lakes (Flick and Webster 1992), and many of these lakes require routine stocking. The current brook trout management plan for the region does not address the potential effects of emigration losses of adult fish on fisheries in stocked lakes.

We hypothesized that preventing fall emigration of adult brook trout would increase trap-net and angling catch rates and the number of large trophy fish in populations. To examine that hypothesis, we compared indices of population abundance and angling catch of brook trout populations in blocked and unblocked lakes. Comparison of brook trout

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TABLE 1.—Physical characteristics, location, and brook trout stocking history of Goose Lake, Otter Lake, Lower Sylvan Pond, and Rock Lake in the Adirondack Mountains of New York.

| Study site | Drainage area (ha) | Lake area (ha) | Coordinates | Stocked strains of brook trout[a] |
|---|---|---|---|---|
| **Control lakes: no barriers** | | | | |
| Goose Lake | 134.5 | 5.3 | 43°23′N, 74°43′W | 2, 5, 6, 7, 8, 9, 10, 14 |
| Otter Lake | 540.0 | 9.6 | 43°23′N, 74°44′W | 2, 4, 5, 6, 7, 8, 10, 14 |
| **Treatment lakes: with barriers** | | | | |
| Lower Sylvan Pond | 48.7 | 6.5 | 43°37′N, 75°56′W | 4, 5, 6, 7, 8, 9, 10, 14 |
| Rock Lake | 393.6 | 78.9 | 43°57′N, 74°52′W | 1, 2, 3, 4, 5, 6, 10, 11, 12, 13, 14 |

[a] See Table 2 for an explanation of the number code for stocked brook trout strains.

populations before and after installation of fish barriers, as well as to control lakes without barriers, provided direct evidence of emigration effects on stocked brook trout populations.

## Methods

*Study sites*.—Brook trout populations were studied in four lakes located on private lands in the Adirondack Mountains of New York State (Table 1). All four lakes were stocked with brook trout and were drained by outlets. Adult emigration in the fall was previously estimated at 39% of the Lower Sylvan population and 37% of the Rock Lake population (Josephson and Youngs 1996). Spring emigration consisted of small numbers of yearlings, and virtually no emigration occurred in the winter or summer from Lower Sylvan Pond and Rock Lake. Trap-net surveys conducted in these two lakes over a 14-year period (1978–1992) indicated that yearling fish composed 86% of the total population, age-3 fish composing less than 3%. Outlet barriers prevented fall emigration by adult spawning-age brook trout: for 10 years in Lower Sylvan Pond (1989–1998) and for 6 years in Rock Lake (1993–1998). Outlets of the treatment lakes were unblocked before that, and for these preblocked periods, we used 1978–1988 data for Lower Sylvan Pond and 1978–1992 data for Rock Lake. The outlets of two control lakes, Goose and Otter, remained unblocked during the entire study period (1978–1998).

Brook trout populations in three of the study lakes, Goose Lake, Otter Lake, and Rock Lake, originated predominately from stocking; low levels of natural reproduction also contributed but were not sufficient for self-sustaining populations. The wild population in Lower Sylvan Pond originated from spawning in the outlet and was supplemented by annual stocking. Only stocked fish were included in our analyses.

Brook trout fingerlings (age 0) were stocked in the fall at rates of 50 to 125 fish/ha and included a variety of strains (Table 2). All stocked fish were marked by removal of one or more fins to allow for identification of strain and year-class. Most stocked fish were diploid Temiscamie × domestic hybrids. Pure Assinica and Temiscamie strains that originated from northern Quebec have been maintained in Adirondack lakes since the 1960s (Van Offelen et al. 1993). All four study lakes received paired plants of diploid and triploid Temiscamie × domestic brook trout from 1994 to 1996. The mix of strains stocked was similar among the study lakes. Lower Sylvan Pond was stocked with 83% hybrid strains (strains 5, 6, 7, 8, 9, 10, 14; Table 2) in the prebarrier period and 87% in the postbarrier period. Rock Lake was stocked with 37% hybrid strains (strains 6, 10, 11, 14) in the prebarrier period and 84% in the postbarrier period. The fish stocked in Rock Lake in the prebarrier period were predominately wild strains (strains 2, 3, 12). Unblocked Goose Lake and Otter Lake were stocked, respectively, with 100% and 95% hybrid strains (strains 5, 6, 7, 8, 9, 10, 14) before 1990 (an approximate date we used to denote when the treatment lake barriers were put in place—i.e., 1989 and 1993, a spread of 4 years) and 74% and 70% hybrid strains from 1990 to 1998.

Brook trout populations were sampled in October with Oneida-style trap nets (Webster and Flick 1981) at locations selected to capture adult fish moving along shorelines searching for spawning sites, typically near outlets or tributaries. Two trap nets were set for periods of 2–5 nights in each lake except Rock Lake, where three or four nets were set; annual trap-net effort ranged from 4 to 20 trap-net nights per lake. Trap nets were set at the same sites and at approximately the same time throughout the study. In all lakes, one trap net was set near the outlet and the other trap net(s) was set at the opposite end of the lake (near a tributary). The rationale for setting trap nets in this manner

TABLE 2.—Brook trout strains stocked in Goose Lake, Otter Lake, Lower Sylvan Pond, and Rock Lake from 1978 to 1997.

| Number code and strain | Origin | Age at first maturity (years) | Longevity (years) | Information source |
|---|---|---|---|---|
| 1. Assinica | Assinica Lake, Broadkback River system, Quebec | 2–4 | 7 | Webster and Flick 1981 |
| 2. Temiscamie | Temiscamie River (tributary to Lake Albanel) Quebec | 1–3 | 5–6 | Webster and Flick 1981 |
| 3. Horn | Horn Lake, southwestern Adirondacks, New York | 3 | 4 | Keller 1979 |
| 4. Domestic (Cortland or New York) | Domestic strains, New York State hatchery system | 0–1 | 2 | Webster and Flick 1981 |
| 5. Assinica × domestic (F1) | First generation hybrid | 1–2 | 3–4 | File data |
| 6. Temiscamie × domestic (F1) | First generation hybrid | 1–2 | 3–4 | File data |
| 7. Assinica × domestic (F2) | Second generation hybrid | 1–2 | 3–4 | File data |
| 8. Temiscamie × domestic (F2) | Second generation hybrid | 1–2 | 3–4 | File data |
| 9. Assinica × domestic (challenged) | First generation hybrid acid-challenged domestic | 1–2 | 3–4 | File data |
| 10. Temiscamie × domestic (challenged) | First generation hybrid, acid-challenged domestic | 1–2 | 3–4 | File data |
| 11. Temiscamie × domestic (acclimated) | First generation hybrid, acid acclimated | 1–2 | 3–4 | File data |
| 12. Little Tupper | Little Tupper Lake, northern Adirondacks, New York | 2–3 | 5 | Keller 1979 |
| 13. Little Tupper (acclimated) | Little Tupper Lake, acid acclimated | 2–3 | 5 | Keller 1979 |
| 14. Temiscamie × domestic (triploid) | First generation hybrid, from heat-shocked eggs | | | File data |

was to apply an even distribution of the gear around the lakes in areas frequented by spawning brook trout (i.e., outlets and tributaries).

Voluntary angler catch records were used to evaluate angler catch of brook trout from these private, controlled-access lakes. The voluntary angler catch record system provided information on the date, number of anglers, number of fish retained, and number of fish released for each reported trip. Fish boxes with cards and weighing scales were maintained at a lake launch site (Lower Sylvan Pond) or at private camps (Rock Lake, Goose Lake, Otter Lake). The anglers on these private lakes were well-educated in the procedures for recording their angling catches as participants in this established catch record system. Although no independent creel surveys were conducted to verify angler compliance, we assumed a high percentage reported and that this reporting behavior did not change during the period of the study.

*Outlet barriers*.—To prevent adult brook trout emigration during the fall spawning period, outlet fish barriers constructed of 12-mm-square hardware cloth were installed and maintained from early September through early January beginning in 1988 at Lower Sylvan Pond and in 1993 at Rock Lake. Outlet barriers were effective in preventing downstream passage of age-1 and older brook trout (≥200 mm). The barriers were only operated during the fall spawning period because emigration in these two lakes was known to be negligible during the winter, spring, and summer seasons (Josephson and Youngs 1996).

*Population model*.—An age-structured model was developed to characterize the dynamics of brook trout populations in the four study lakes. The model was constructed to test the hypothesis that angler and trap-net catches would increase with an increase in the availability of stocked brook trout, which should increase in lakes with outlet barriers preventing emigration. Unfortunately, in all the lakes examined comparisons of catch rates between prebarrier and postbarrier periods were confounded by variation in stocking levels over time, in the degree of trap-net and angling effort, and by the presence of both wild and stocked trout. These three factors were accounted for in a simple age-structured model by making use of the known number of brook trout stocked, the number of brook trout caught and retained (creeled), and the observed or estimated proportion of stocked fish captured by the two gear types.

Consider a brook trout population in a lake during the periods before and after installation of an outlet barrier. One might expect, under these conditions, that catch rates or catch per unit effort

(CPUE) for a particular gear would increase over the period. In other words, a simple test such as

$$t = \text{CPUE}_{\text{postbarrier}} - \text{CPUE}_{\text{prebarrier}} > 0$$

could be employed. However, if stocking levels and exploitation rates do not remain constant in the prebarrier and postbarrier periods, then catch rates may vary with other causes, as seen when CPUE in the prebarrier period is decomposed into its constituent components,

$$\text{CPUE}_{\text{prebarrier}} = q_{\text{catchability}}(1 - p_{\text{emigration}}) \times (N_{\text{stocked, prebarrier}} - \text{Creel}_{\text{prebarrier}}),$$

and is compared to CPUE in the postbarrier period;

$$\text{CPUE}_{\text{postbarrier}} = q_{\text{catchability}}(1 - p_{\text{emigration}}) \times (N_{\text{stocked, postbarrier}} - \text{Creel}_{\text{postbarrier}}).$$

Availability, or $q_{\text{availability}} = (1 - p_{\text{emigration}})$, is the parameter of interest that changes with installation of a barrier, but the number of stocked or creeled fish must be accounted for in the prebarrier or postbarrier period. Catchability of the angler and trap-net gears ($q_{\text{catchability}}$) can be assumed constant over the entire period and will consequently not affect the estimates. We combined the effects of catchability and availability into a single parameter, $q_{\text{time, gear}} = (q_{\text{catchability}})(q_{\text{availability}})$, that we call availability for each gear and period ($t$) for the purposes of keeping the presentation simple. The remainder of the model follows from age-structured population dynamics theory as might be found in any standard fisheries text (e.g., Ricker 1975, Beverton and Holt 1957, Quinn and Deriso 1999).

Data used in the analysis included initial numbers of brook trout stocked and trap-net and angling catch and effort recorded from 1977 to 1998 (Table 3) for the four study lakes. Initial population size of stocked brook trout was known from stocking records. In the model, $N_{t,0}$ was set to the initial population abundance stocked at time $t$ and age 0, $a$. Population numbers for each cohort at subsequent periods were estimated annually as follows:

$$N_{t+1,\ a+1} = N_{t,a} \cdot S_{t,a}$$

where annual survivorship, $S_{t,a}$, results from a combination of natural mortality, $M$, and time-specific and age-specific angler fishing mortality, $F_{t,a,\text{creel}}$:

$$S_{t,a} = \exp[-(M + F_{t,a,\text{creel}})].$$

Previous evaluations of brook trout strains used in this study indicated a range of annual survivorship rates from 30% to 70% in the absence of fishing (Webster and Flick 1981). For this analysis, $M$ was assumed to be constant and equal to an instantaneous annual rate of 0.7, representing an annual survivorship of 50%.

Observations of trap-net and total retained (creeled) angler catches ($C$) at age ($a$) were represented according to the catch equations (Ricker 1975), shown respectively as

$$C_{t,a,\text{trap}} = \frac{F_{t,a,\text{trap}}}{F_{t,a,\text{trap}} + F_{t,a,\text{creel}} + M} N_{t,a} \times \{1 - \exp[-(F_{t,a,\text{trap}} + F_{t,a,\text{creel}})]\}$$

and

$$C_{t,a,\text{creel}} = \frac{F_{t,a,\text{creel}}}{F_{t,a,\text{creel}} + M} N_{t,a}(1 - S_{t,a}).$$

Only natural mortality and the angler fishing mortality term $F_{t,a,\text{creel}}$ were applied in determining annual survivorship. All fish captured in trap-net samples were measured and released. Trapnet and angler selectivities are assumed to be 0.0 for age-0 fish, and assumed to be 1.0 thereafter. The age of fish caught by anglers was not known; thus, observations and estimates were summarized as totals for each year:

$$C_{t,\text{creel}} = \sum_a {}_{t,a,\text{creel}}.$$

The age of each individual fish in the trap-net catches was known from fin-clips, thereby allowing age-specific comparisons.

Trap-net effort was measured as the number of nights the gear was fished. Angler effort was measured as the number of reported trips. Effort and catch for the two capture processes were related to one another via availability in the following way:

$$F_{t,\text{trap}} = q_{t,\text{trap}} \cdot E_t \quad \text{and} \quad F_{t,\text{creel}} = q_{t,\text{creel}} \cdot E_t.$$

The quantity $F_{t,a,\text{creel}}$ was determined by applying the proportion of creeled fish in the total harvested to total effort. Availability ($q_t$) was represented as a time-dependent variable in the model for both capture processes. Availability was assumed to be constant over the entire period, under the null hypothesis of no change in the system, but under the proposed hypothesis, was assumed to change from one constant value to another for prebarrier and postbarrier periods. Mean percent angling and trap-net availability, with nonsymmetrical back-transformed 95% confidence intervals, were calculated using the instantaneous availability through the formulas $\exp(q_t)\cdot 100$ and $\exp(q_t \pm 2\ \mathrm{SE})\cdot 100$, respectively.

To fit the model and derive the maximum likelihood estimates of $q$ for the trap-net and angler fishing processes, a Gaussian likelihood was formed using a concentrated likelihood formulation (Seber and Wild 1989):

$$L(\hat{q}_{t_1,\mathrm{trap}}, \hat{q}_{t_2,\mathrm{trap}}, \hat{q}_{t_1,\mathrm{creel}}, \hat{q}_{t_2,\mathrm{creel}}, \hat{E}_{\mathrm{trap}}, \hat{E}_{\mathrm{creel}}) = \frac{1}{2}N[\log_{10}(R) + \frac{1}{2}N[\log_{10}(N) - 1],$$

where $\hat{E}_{\mathrm{trap}}$ and $\hat{E}_{\mathrm{creel}}$ are vectors of parameter estimates representing trap and creel effort, respectively, and $R$ is the residual sum of squares of the differences between the logged observations and logged estimates. That is,

$$\begin{aligned} R = & \sum_{t,a} [\log_{10}(C_{t,a,\mathrm{trap}}) - \log_{10}(\hat{C}_{t,a,\mathrm{trap}})]^2 \\ & + \sum_{t} [\log_{10}(C_{t,a,\mathrm{creel}}) - \log_{10}(\hat{C}_{t,a,\mathrm{creel}})]^2 \\ & + \sum_{t} [\log_{10}(E_{t,a,\mathrm{trap}}) - \log_{10}(\hat{E}_{t,a,\mathrm{trap}})]^2 \\ & + \sum_{t} [\log_{10}(E_{t,a,\mathrm{creel}}) - \log_{10}(\hat{E}_{t,a,\mathrm{creel}})]^2. \end{aligned}$$

Note that the observed creel catch, $C_{t,\mathrm{creel}}$, was adjusted downward from the total number of stocked and wild fish creeled by using the proportion of stocked to total fish observed in trap samples. Where no trap samples were available, the average proportion was used. For earlier years on Otter and Goose lakes, when angler effort was not recorded, total effort was set as the average effort in subsequent years, and all fish caught were assumed to be creeled.

For each harvest method we used a simple $F$-test, based on the likelihood-ratio statistic, to demonstrate the significance of the contrast in hypotheses between (1) the full model with separate trap and creel availabilities for each period (prebarrier and postbarrier) and (2) the reduced model with one availability over a period. The $F$-statistic was calculated as

$$F = \left(\frac{\mathrm{SSE}_{\mathrm{reduced}} - \mathrm{SSE}_{\mathrm{full}}}{\mathrm{df}_{\mathrm{reduced}} - \mathrm{df}_{\mathrm{full}}}\right)\left(\frac{\mathrm{SSE}_{\mathrm{full}}}{\mathrm{df}_{\mathrm{full}}}\right)^{-1},$$

where SSE is the sum of squares error and df is the number of observations minus number of parameters for the reduced (one-availability parameter) and full (two-availability parameter) models. The significance test was applied to the results from each study site.

Sensitivity of predicted angling and trap-net CPUE (predicted number fish caught per angler trip) to different parametric model formulations provided another method of exploring the magnitude and direction of the change estimated to have occurred in the blocked lakes. These model formulations were depicted graphically using the one parameter (one $q$) reduced model and the two-parameter (two $q$) full model. The reduced model is the null hypothesis that no change in availability occurs after blocking. The full model is the alternate hypothesis that availability is different after blocking. If the angling or trapnet CPUE predicted by the two-parameter model were greater than the one-parameter model, an increase in CPUE occurred.

*Angling catch of trophy brook trout.*—Angling records allowed for a comparison of the number of large (trophy) brook trout caught and creeled by anglers during the prebarrier and postbarrier periods of the study. Trophy brook trout were those fish 680 g or larger (known to be age-3 or older, based on weight data from stocked, fin-clipped fish captured in fall trap-net samples).We used $t$-tests to examine the hypothesis that preventing fall emigration did not change the angling catch of trophy brook trout in the four study lakes between the prebarrier and postbarrier periods ($\alpha = 0.05$).

## Results

### *Angler and Trap-Net Catch*

Angling and trap-net availability ($q$) of brook trout differed significantly between the prebarrier and postbarrier periods in Rock Lake (blocked) but did not differ in Lower Sylvan Pond (blocked) and the control (unblocked) lakes (Table 4). Percent angling availability ($q_{t,\mathrm{creel}}$; (Figure 1) and percent trap-net availability ($q_{t,\mathrm{trap}}$; Figure 2) significantly increased after the outlet barrier was installed at Rock Lake.

Sensitivity analysis of the two-parameter (pre and postbarrier periods) and one-parameter (entire period) cases indicated changes in angler and trap-net CPUE of age-2 fish in Rock Lake but not in Lower Sylvan Pond. A large increase in the predicted angler CPUE (Figure 3) and a small increase in the trap-net CPUE of age-2 fish (Figure 4) occurred in Rock Lake. In contrast, the predicted

TABLE 3.—Stocking, trap-net, and angling data for Goose Lake, Otter Lake, Lower Sylvan Pond, and Rock Lake from 1975 to 1999. Age-1 to age-4 fish were stocked in the fall as fingerlings. The years 1977–1989 are prebarrier years. Those from 1990 on are postbarrier years for Goose Lake, Otter Lake, and Lower Sylvan Pond; for Rock Lake, the postbarrier years are from 1993 on. Blanks indicate that trap-net samples were not conducted.

| | | Fall trap-net catch | | | | | | Annual angler catch | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Age-0 stocked (*N*) | Age 1 (*N*) | Age 2 (*N*) | Age 3 (*N*) | Age 4 (*N*) | Wild (*N*) | Effort (nights) | Creel (*N*) | Release (*N*) | Total (*N*) | Effort (trips)[a] |
| **Goose Lake (unblocked)** | | | | | | | | | | | |
| 1977 | 300 | | | | | | | | | | |
| 1978 | 1,246 | | | | | | | 1 | 0 | 1 | n/a |
| 1979 | 600 | | | | | | | 0 | 0 | 0 | n/a |
| 1980 | 480 | 66 | 36 | 0 | 0 | 1 | 6 | 9 | 0 | 9 | n/a |
| 1981 | 480 | | | | | | | 23 | 0 | 23 | n/a |
| 1982 | 480 | 69 | 16 | 1 | 0 | 3 | 6 | 5 | 0 | 5 | n/a |
| 1983 | 480 | 169 | 23 | 4 | 2 | 0 | 8 | 39 | 0 | 39 | 21 |
| 1984 | 480 | 114 | 44 | 3 | 0 | 3 | 4 | 1 | 0 | 1 | 2 |
| 1985 | 480 | | | | | | | 62 | 0 | 62 | 13 |
| 1986 | 480 | 69 | 23 | 0 | 1 | 22 | 6 | 26 | 0 | 26 | 8 |
| 1987 | 480 | | | | | | | 8 | 0 | 8 | 6 |
| 1988 | 480 | | | | | | | 0 | 9 | 9 | 4 |
| 1989 | 480 | | | | | | | 1 | 4 | 5 | 4 |
| 1990 | 480 | 63 | 8 | 1 | 0 | 5 | 4 | 1 | 6 | 7 | 5 |
| 1991 | 480 | | | | | | | 12 | 27 | 39 | 17 |
| 1992 | 480 | | | | | | | 5 | 11 | 16 | 10 |
| 1993 | 480 | | | | | | | 8 | 3 | 11 | 11 |
| 1994 | 480 | | | | | | | 2 | 3 | 5 | 12 |
| 1995 | 384 | 107 | 20 | 1 | 1 | 4 | 6 | 0 | 2 | 2 | 5 |
| 1996 | 480 | 51 | 41 | 0 | 1 | 2 | 8 | 8 | 32 | 40 | 11 |
| 1997 | 480 | 58 | 23 | 4 | 0 | 0 | 6 | 3 | 17 | 20 | 14 |
| 1998 | 160 | | | | | | | 7 | 51 | 58 | 15 |
| **Otter Lake (unblocked)** | | | | | | | | | | | |
| 1997 | 500 | | | | | | | | | | |
| 1978 | 480 | | | | | | | 2 | 0 | 2 | n/a |
| 1979 | 600 | | | | | | | 0 | 0 | 0 | n/a |
| 1980 | 810 | 49 | 12 | 2 | 0 | 0 | 6 | 8 | 0 | 8 | n/a |
| 1981 | 480 | | | | | | | 34 | 0 | 34 | n/a |
| 1982 | 480 | 102 | 36 | 0 | 0 | 6 | 6 | 8 | 0 | 8 | n/a |
| 1983 | 480 | 68 | 51 | 10 | 0 | 9 | 4 | 13 | 0 | 13 | 7 |
| 1984 | 480 | 56 | 20 | 8 | 1 | 20 | 4 | 4 | 0 | 7 | 4 |
| 1985 | 480 | | | | | | | 7 | 0 | 7 | 7 |
| 1986 | 480 | 31 | 13 | 1 | 0 | 5 | 6 | 16 | 0 | 16 | 6 |
| 1987 | 480 | | | | | | | 8 | 0 | 8 | 6 |
| 1988 | 480 | | | | | | | 0 | 4 | 4 | 4 |
| 1989 | 480 | | | | | | | 1 | 7 | 8 | 4 |
| 1990 | 480 | 68 | 8 | 0 | 0 | 5 | 4 | 9 | 24 | 33 | 24 |
| 1991 | 480 | | | | | | | 6 | 53 | 59 | 11 |
| 1992 | 480 | | | | | | | 2 | 3 | 5 | 7 |
| 1993 | 480 | | | | | | | 2 | 5 | 7 | 6 |
| 1994 | 480 | | | | | | | 0 | 3 | 3 | 7 |
| 1995 | 384 | 27 | 21 | 4 | 0 | 2 | 6 | 0 | 1 | 1 | 5 |
| 1996 | 480 | 35 | 19 | 1 | 0 | 3 | 8 | 15 | 28 | 43 | 13 |
| 1997 | 480 | 33 | 23 | 6 | 1 | 2 | 6 | 4 | 24 | 28 | 14 |
| 1998 | 1,480 | | | | | | | 19 | 30 | 49 | 11 |
| **Lower Sylvan Pond (blocked)** | | | | | | | | | | | |
| 1975 | 360 | | | | | | | 196 | 17 | 213 | 98 |
| 1976 | 550 | | | | | | | 177 | 4 | 181 | 105 |
| 1977 | 300 | | | | | | | 129 | 6 | 135 | 129 |
| 1978 | 500 | 44 | 6 | 0 | 0 | 341 | 12 | 216 | 41 | 257 | 121 |
| 1979 | 500 | 22 | 6 | 0 | 0 | 236 | 21 | 171 | 16 | 187 | 122 |
| 1980 | 900 | 58 | 4 | 2 | 0 | 260 | 16 | 200 | 29 | 229 | 113 |
| 1981 | 800 | 85 | 11 | 0 | 0 | 316 | 13 | 394 | 94 | 488 | 193 |
| 1982 | 800 | 57 | 4 | 1 | 0 | 123 | 16 | 248 | 49 | 297 | 153 |
| 1983 | 600 | 156 | 30 | 0 | 0 | 451 | 20 | 181 | 25 | 206 | 79 |
| 1984 | 0 | 83 | 35 | 4 | 0 | 519 | 8 | 205 | 26 | 231 | 95 |
| 1985 | 0 | 0 | 57 | 3 | 0 | 404 | 10 | 290 | 122 | 412 | 133 |
| 1986 | 0 | 0 | 0 | 5 | 2 | 267 | 8 | 171 | 24 | 195 | 92 |

TABLE 3.—Continued.

| Year | Age-0 stocked (N) | Fall trap-net catch | | | | | | Annual angler catch | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Age 1 (N) | Age 2 (N) | Age 3 (N) | Age 4 (N) | Wild (N) | Effort (nights) | Creel (N) | Release (N) | Total (N) | Effort (trips)[a] |
| 1987 | 0 | 0 | 0 | 0 | 5 | 379 | 12 | 99 | 51 | 150 | 81 |
| 1988 | 0 | 0 | 0 | 0 | 0 | 349 | 6 | 108 | 99 | 207 | 69 |
| 1989 | 0 | 0 | 0 | 0 | 0 | 177 | 6 | 151 | 150 | 301 | 98 |
| 1990 | 0 | 0 | 0 | 0 | 0 | 279 | 9 | 119 | 112 | 231 | 87 |
| 1991 | 100 | 0 | 0 | 0 | 0 | 111 | 20 | 84 | 82 | 166 | 72 |
| 1992 | 150 | 23 | 0 | 0 | 0 | 61 | 9 | 53 | 57 | 110 | 63 |
| 1993 | 450 | 19 | 5 | 0 | 0 | 83 | 9 | 67 | 51 | 118 | 59 |
| 1994 | 300 | 23 | 7 | 2 | 0 | 45 | 6 | 66 | 94 | 160 | 85 |
| 1995 | 240 | 3 | 0 | 0 | 0 | 5 | 8 | 15 | 28 | 43 | 39 |
| 1996 | 300 | 14 | 2 | 0 | 0 | 20 | 6 | 38 | 66 | 104 | 59 |
| 1997 | 300 | 21 | 8 | 0 | 0 | 111 | 6 | 40 | 102 | 142 | 63 |
| 1998 | 260 | | | | | | | 77 | 162 | 239 | 100 |
| | | | | | **Rock Lake (blocked)** | | | | | | |
| 1981 | 4,000 | | | | | | | | | | |
| 1982 | 3,000 | | | | | | | | | | |
| 1983 | 1,000 | | | | | | | 12 | 0 | 12 | 9 |
| 1984 | 1,000 | 22 | 9 | 0 | 0 | 3 | 16 | 9 | 0 | 9 | 6 |
| 1985 | 576 | | | | | | | 7 | 0 | 7 | 4 |
| 1986 | 1,306 | 31 | 7 | 1 | 0 | 7 | 6 | 5 | 1 | 6 | 5 |
| 1987 | 3,911 | 88 | 10 | 0 | 0 | 20 | 12 | 4 | 0 | 4 | 3 |
| 1988 | 3,954 | 38 | 0 | 0 | 0 | 1 | 12 | 0 | 0 | 0 | 4 |
| 1989 | 9,127 | 117 | 13 | 0 | 0 | 10 | 9 | 2 | 0 | 2 | 10 |
| 1990 | 4,200 | 48 | 7 | 0 | 0 | 0 | 6 | 19 | 0 | 19 | 21 |
| 1991 | 1,338 | 241 | 27 | 2 | 0 | 29 | 18 | 4 | 0 | 4 | 28 |
| 1992 | 2,000 | 94 | 34 | 7 | 0 | 7 | 15 | 14 | 7 | 21 | 15 |
| 1993 | 1,000 | 33 | 30 | 4 | 25 | 0 | 9 | 33 | 96 | 129 | 37 |
| 1994 | 2,000 | 55 | 2 | 1 | 4 | 1 | 9 | 23 | 37 | 60 | 23 |
| 1995 | 1,680 | 57 | 5 | 0 | 0 | 6 | 9 | 16 | 44 | 60 | 16 |
| 1996 | 2,000 | 149 | 42 | 0 | 0 | 231 | 9 | 32 | 28 | 60 | 6 |
| 1997 | 2,000 | 58 | 11 | 4 | 0 | 28 | 9 | 59 | 90 | 149 | 28 |
| 1998 | 2,000 | 123 | 65 | 6 | 1 | 386 | 6 | 4 | 80 | 124 | 21 |

[a] n/a = not measured.

angler CPUE and trap-net CPUE for age-2 fish was visually indistinguishable between the predictions based on the one-parameter or two-parameter models in Lower Sylvan Pond (Figure 4).

The percent composition (by number) of age-2 and older fish in trap-net catches increased in blocked lakes but remained unchanged in the unblocked lakes. The percent composition of fish older than age-2 increased in Rock Lake (from 14.7% to 29.6%) and in Lower Sylvan (from 13.1% to 23.0%) between the prebarrier and postbarrier periods. Few age-3 and age-4 fish were observed in trap-net catches in the prebarrier and postbarrier periods in all the study lakes.

### *Angler Catch of Trophy Brook Trout*

The angling catch of trophy brook trout (>680 g) significantly increased in the blocked lakes but did not increase in the unblocked lakes (Table 5). The catch of trophy fish in Rock Lake increased

TABLE 4.—Results of an *F*-test based on the likelihood-ratio statistic to test for a significant change in availability ($q$) of brook trout to trap nets and anglers between the prebarrier and postbarrier periods in Rock Lake, Lower Sylvan Pond, Goose Lake, and Otter Lake. The reduced model includes one availability ($q$) over a period for each harvest method (i.e., trap and creel) and the full model includes separate trap and creel availabilities ($q$) for prebarrier and postbarrier periods.

| Study site | $SSE_{reduced}$[a] | $df_{reduced}$ | $SSE_{full}$ | $df_{full}$ | *F*-statistic | *P*-value |
|---|---|---|---|---|---|---|
| Rock Lake | 78.79 | 68 | 70.86 | 66 | 3.72 | 0.03 |
| Lower Sylvan Pond | 51.31 | 98 | 51.02 | 96 | 0.273 | 0.76 |
| Goose Lake | 46.16 | 43 | 46.03 | 41 | 0.057 | 0.94 |
| Otter Lake | 35.06 | 43 | 34.43 | 41 | 0.375 | 0.69 |

[a] SSE = error sum of squares.

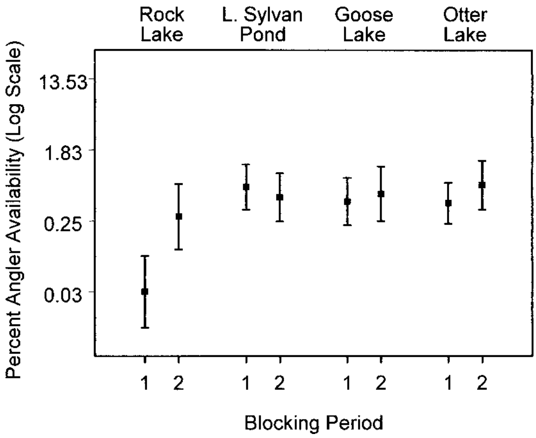


FIGURE 1.—Mean percent availability of stocked brook trout to anglers ($q_{t,\text{creel}}$) and 95% confidence intervals in the prebarrier (1) and postbarrier (2) periods in Rock Lake, Lower Sylvan Pond, Goose Lake, and Otter Lake, based on an age-structured model.

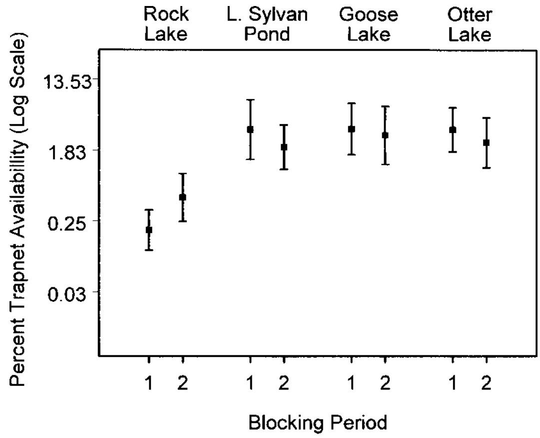


FIGURE 2.—Mean percent availability of stocked brook trout to trap nets ($q_{t,\text{trap}}$) and 95% confidence intervals in the prebarrier (1) and postbarrier (2) periods in Rock Lake, Lower Sylvan Pond, Goose Lake, and Otter Lake, based on an age-structured model.

from 0.0/year in the prebarrier period (0 fish) to 5.5/year in the postbarrier period (33 fish). Similarly, the catch of trophy fish in Lower Sylvan Pond increased from 0.1/year in the prebarrier period (1 fish) to 4.5/year in the postbarrier period (45 fish).

## Discussion

*Model Justification*

A population model was employed to characterize dynamics of the brook trout populations because upon initial examination of our data set, it became apparent that a simple comparison of catch rates in the prebarrier and postbarrier periods would be naïve. Stocking rates changed annually in response to external management actions, whereas retention or creel (as opposed to catch-and-release) rates changed in response to changes in angler attitudes towards keeping their catch. Furthermore, each lake had its own standing stock of wild brook trout. Consequently, catch rates (of either gear) were likely to be influenced by number stocked, number caught and creeled, and the presence (to a greater or lesser degree) of wild fish. Because information was available on each of these factors, it was possible to account for each factor in our data analysis procedure. In the model, stocked brook trout were the population of interest. An appropriate next step in subsequent analyses might be to try to deduce the dynamics of wild brook trout in these systems. Such analyses would be complicated only by the fact that the equivalent of stocking (i.e., recruitment) information for wild

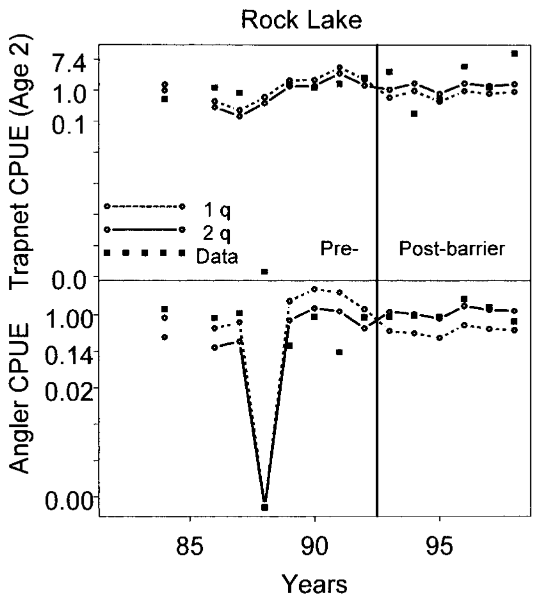


FIGURE 3.—Predicted (circles) and observed (squares) trap-net catch per unit effort (CPUE; number/trap-net night) for age-2, stocked brook trout and angler CPUE (number/angler trip) for all stocked fish in Rock Lake. The one-parameter, reduced model (1q) and two-parameter, full model (2q) lines are shown. The reduced model (solid line) incorporates the null hypothesis that no change in trap-net and angling availability occurs after blocking; the full model (dotted line) is the alternative hypothesis that trap-net and angling availability is different after blocking.

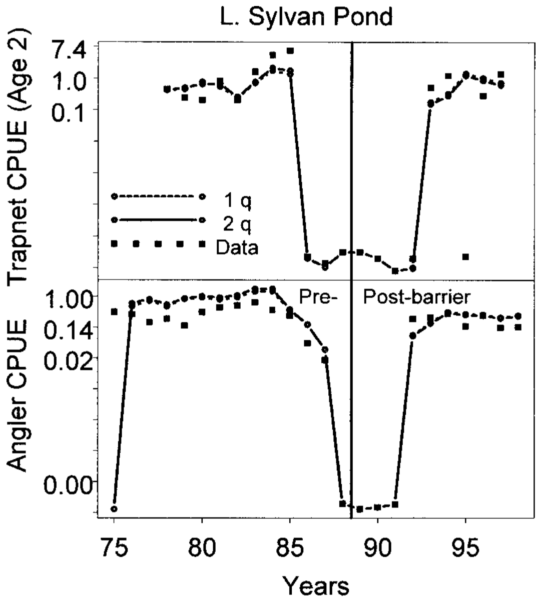


FIGURE 4.—Predicted (circles) and observed (squares) trap-net catch per unit effort (CPUE; number/trap-net night) for age-2, stocked brook trout and angler CPUE (number/angler trip) for all stocked fish in Lower Sylvan Pond. The one-parameter, reduced model (1q) and two-parameter, full model (2q) lines are shown. The reduced model (solid line) incorporates the null hypothesis that no change in trap-net and angling availability occurs after blocking; the full model (dotted line) is the alternative hypothesis that trap-net and angling availability is different after blocking.

brook trout is not available. However, if each population can be assumed to respond to both angler and survey effort in the same way, then trends in wild brook trout abundance could be estimated from the existing data.

*Population Response*

The outlet barriers employed in this study elicited a population response by stocked brook trout consistent with the hypothesis that emigration losses of mature adults were depleting older-aged fish from unblocked lakes. Increases in availability to trap-nets and anglers and the angler catch of large trophy fish indicated a shift to greater absolute numbers of age-2 and older fish in Rock Lake. The population in Lower Sylvan Pond did not fully respond as expected. However, trophy fish exceeding 680 g and the percent (by number) of age-2 and older fish in trap-net catches increased in both blocked lakes. For example, the catch of trophy fish in Lower Sylvan Pond rose from 1 fish in the 10-year prebarrier period to 45 fish in the 10-year postbarrier period.

TABLE 5.—Results of two sample *t*-tests to compare the mean number (±95% confidence intervals) of trophy (>680 g) brook trout caught annually by anglers in the prebarrier and postbarrier periods in Rock Lake (df = 18), Lower Sylvan Pond (df = 22), Goose Lake (df = 22), and Otter Lake (df = 22).

| Study site | Number trophy fish per year (±CI) Prebarrier period | Postbarrier period | *P*-value |
|---|---|---|---|
| Rock Lake | 0.0 (±0.0) | 5.5 (±3.9) | <0.001 |
| Lower Sylvan Pond | 0.1 (±0.2) | 4.5 (±2.7) | 0.001 |
| Goose Lake | 0.0 (±0.0) | 0.7 (±0.8) | 0.06 |
| Otter Lake | 0.9 (±0.0) | 0.3 (±0.7) | 0.20 |

The response of the brook trout population to an outlet barrier in Rock Lake was similar to that noted in Fuller Pond, Michigan, by Gowing (1978). Before installation of a fish trap on the outlet, the Fuller Pond population of stocked brook trout consisted of age-1 and age-2 fish, with a complete absence of age-3 and older fish. In two subsequent studies Fuller Pond outlet was blocked by the fish trap, and the proportion of age-3 and older fish in fall trap-net catches increased to 37% (Gowing 1986) and to 20% (Alexander et al. 1990). Contrary to our expectations, trap-net catch rates of stocked age-3 and older brook trout did not increase in blocked study lakes.

Although the percent composition of age-2 and older fish increased in Lower Sylvan Pond following blocking, variables other than emigration may have reduced our ability to detect significant increases in absolute numbers of these older fish. Initial population sizes from stocking and effects of angling mortality were probably the most important factors affecting test sensitivity. The initial size of the stocked brook trout populations may have affected the detectability of changes in the blocked lakes. To explore this potential, we conducted a simulation analysis (using the Rock Lake model) to determine the effect of initial stocking numbers on the detectability of changes in angling and trap-net availability. Initial numbers stocked in the simulations were decreased incrementally by 10%. When initial stocking numbers dropped below 10% of actual numbers stocked in Rock Lake, differences in angling and trap-net availability were not statistically significant. The 10% percent stocking level in Rock Lake corresponds to about 300 or fewer fish. Mean numbers of fish stocked in Lower Sylvan Pond were 590 fish in the prebarrier and 269 fish in the postbarrier years. According to our simulations, stocking levels used in Lower Sylvan Pond in the postbarrier years would not have been sufficient to detect significant increases in age-2 and older fish.

Angling mortality may have contributed to the lack of age-3 and older fish in trap-net catches in the blocked study lakes. Evidence suggests that angling mortality, before fall trap-net sampling, was a major factor in the depletion of age-3 and older fish from the small initial populations in Lower Sylvan Pond. During the postbarrier period, more fish exceeding 680 g were reported to be retained (total = 45 fish) compared with the prebarrier period (total = 1 fish) in this small (6.5 ha) pond. Spring and early summer angling data from Lower Sylvan Pond proved that large, old-age fish occurred in the lake even though such fish were rarely caught in fall trap-net sampling. Due to the relatively few large fish (total = 33) harvested from Rock Lake, angling mortality had less effect on the numbers of age-3 and older fish in this 78.9-ha lake.

Summer water temperature may also have contributed to the high variability and low fall trap-net catches of age-3 and older fish in the two blocked study lakes. Both blocked lakes were shallow and thermally unstratified during summer months. Brook trout generally seek thermal refugia when temperatures exceed 20°C (Power 1980). Brook trout are known to use a limited thermal refugia inlet stream in Lower Sylvan Pond during summer; however, no known thermal refugia exist in Rock Lake. Water temperatures during this study frequently exceeded 20°C and in some years reached 24–27°C for several days; approaching or exceeding the upper temperature tolerance limit of 25°C for brook trout (Fry et al. 1946). Thermal stress could have been a major source of summer mortality for fish exceeding 680 g because energy demands and thermal stress increase as brook trout increase in size (Schofield et al. 1993). In the Ford River, Michigan, years with cool summer temperature patterns were predominated by age-2 and 3, large brook trout compared with warm years, which were predominated by young age-1, small fish (Drake and Taylor 1996). These studies provide indirect evidence that summer thermal stress could have reduced the abundance of old, large fish in our two shallow, unstratified, barriered lakes.

*Management Implications*

Fall emigration losses of adult brook trout could create an obstacle to achieving management objectives in many stocked lakes in North America. Annual stocking is used to maintain brook trout populations in 90% of the 524 Adirondack lakes managed for recreational fisheries (Keller 1979; Pfeiffer 1979). Similarly, 35% of Ontario's 2,100 brook trout lakes (Fraser 1989) and 47% of Maine's 1,010 brook trout lakes (F. R. Bonney, Maine Department of Fisheries and Wildlife, personal communication) are managed by stocking programs because natural spawning does not sustain wild populations.

Outlet barriers provide a management tool to prevent emigration and to improve the quality of brook trout fisheries in stocked lakes lacking adequate spawning habitat. The positive effects of barriers could be enhanced in lakes that have thermal refugia for summer survival (e.g., thermally stratified) and through regulations that reduce angling mortality (e.g., reduced creel limits, catch and release) and, thus, favor the survival of older, larger fish. Barriers in fish management are most often used for keeping nonnative, colonizing fish from moving upstream in aquatic systems, such as sea lampreys *Petromyzon marinus* out of spawning tributaries of the Great Lakes (Hunn and Youngs 1980; Porto et al. 1999), brown trout *Salmo trutta* out of the high elevation streams of the southern Sierra Nevada to promote golden trout *O. mykiss aquabonita* restoration (Pister 1991), and smallmouth bass *Micropterus dolomieu* out of headwater Adirondack lakes to promote salmonid populations. Usually these barriers only prevent upstream movement of fish. Our study instead focused on keeping fish in a system and preventing downstream movement.

Managers should be aware of potential negative impacts of outlet barriers to prevent emigration by brook trout from lakes. Of special note in our study, the natural population of brook trout in Lower Sylvan Pond decreased in the postbarrier period because fish could not access the historical spawning site in the outlet. Although brook trout did spawn at sites within the lake, those recruits did not compensate for the loss of fish spawned in the outlet. Likewise, it is important that managers consider the life history of other aquatic organisms that may require movements through outlet corridors to maintain their populations. Outlet barriers are a potential management tool to increase numbers of older-aged brook trout in stocked lakes; however, managers must consider their specific management goals, the problems associated with seasonally interrupting migratory corridors, and the potential negative effects on other aquatic organisms.

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