A Comparison of Atlantic Salmon Embryo and Fry Stocking in the Salmon River, New York

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Abstract.—To assess the feasibility of restoring an extirpated species, it is crucial to identify the method of reintroduction that optimizes juvenile survival and growth so that adequate adult populations may be established. Because Atlantic salmon Salmo salar fry are relatively expensive to rear, we compared the efficacies of two embryo-stocking methods and one fry-stocking method in producing age-0 Atlantic salmon parr in the Salmon River, New York. As measured by resulting parr densities, there were no differences in survival rates between embryos stocked with and without protective hatching boxes; the mean survival of embryo-stocked fish to late summer was less than 0.01%. Fry stocking produced significantly greater densities of late-summer parr than did embryo stocking, with site-specific survival ranging up to 8%; the mean survival of fry was 2%. Considering the hatchery costs of rearing each life stage, the labor involved in stocking, and the resulting late-summer parr abundances, we recommend planting fry rather than embryos as a method of reintroducing Atlantic salmon. Additional studies are needed to evaluate the success of stocking older life stages of Atlantic salmon in the Salmon River, although factors other than juvenile survival are probably important in establishing and maintaining a spawning population.

Atlantic salmon Salmo salar were historically abundant in northeastern North America, with the Lake Ontario watershed home to perhaps the largest landlocked population in the world (Parsons 1973). Adults inhabited Lake Ontario and utilized tributaries as spawning and nursery areas, ranging as far inland as inlets to the Finger Lakes and Oneida Lake (Webster 1982). Anthropogenic activities implicated in the Atlantic salmon’s extirpation include deforestation, river damming, over-exploitation, and industrial and agricultural pollution (Netboy 1973; Webster 1982; Parrish et al. 1998). An additional hypothesis is that shortly before their extirpation, Atlantic salmon populations began to suffer from chronic reproductive failure associated with a maternally transmitted vitamin deficiency (Ketola et al. 2000). Low thiamine (vitamin B1) levels in maternal and embryonic tissues have been linked to Early Mortality Syndrome (EMS; also known as “Cayuga syndrome”), in which alevins experience nearly 100% mortality before yolk sac absorption (Fisher et al. 1996). During the 1860s, exotic alewife Alosa pseudoharengus became established in the Lake Ontario watershed. Alewife tissue is rich in thiaminase (an enzyme that catalyzes the degradation of thiamine), and consumption of alewives by piscivores has been implicated in EMS (e.g., Fitzsimons and Brown 1998). Ketola et al. (2000) hypothesize that, as dwindling populations of Atlantic salmon began to feed heavily on alewife, subsequent reproductive failure associated with EMS led to extirpation of the Atlantic salmon in the 1890s.

Recently, various academic institutions and state and federal agencies have studied the feasibility of restoring Atlantic salmon populations in the Lake Ontario watershed (Stanfield and Jones 2003; Murphy 2003), including experimental stocking of the fish at various life stages in streams and lakes. However, little if any natural reproduction has taken place in New York’s Lake Ontario tributaries within the last century. Because of the worldwide decline in wild Atlantic salmon populations, and the political and monetary costs associated with obtaining scarce wild progeny, restoration attempts in New York depend largely on the release of hatchery-raised fish to establish self-sustaining populations. Therefore, it is vital to identify the most effective manner of stocking in terms of fish survival, growth, and monetary costs associated with propagation and release.

Atlantic salmon and other stream-spawning salmonines have variable, but usually high, mortality rates associated with early life stages. Within the
redd, the majority of embryos survive to hatching, but heavy mortality is often associated with the emergence process (MacKenzie and Moring 1988). Other sensitive life history periods include the onset of exogenous feeding (Balon 1985) and the first winter (Cunjak et al. 1998). Human rearing and care may nominally increase short-term survival and growth rates by dampening the effects of both density-independent (e.g., temperature variability) and density-dependent (e.g., competition) processes. However, hatcheries may serve to decrease fitness via reduced genetic variability from artificial broodstock selection (Danzmann et al. 1993), although Nielsen et al. (1994) found greater mitochondrial DNA diversity in hatchery steelhead (anadromous rainbow trout) *Oncorhynchus mykiss* than in wild populations. Behavioral modification from hatchery experience (Dickson and MacCrimmon 1984; Norman 1987; Fleming et al. 1997), confounded stream-specific imprinting (Mills 1971), and overall relaxation of various selective pressures (Pettersson et al. 1996) may impede the establishment of self-sustaining populations.

Trade-offs exist among the components of fitness based on the extent of hatchery influence (Norman 1989). For example, salmonines fed to satiation with hatchery pellets and planted as age-0 parr will be comparatively larger than if stocked as swim-up fry, but these larger fish may be behaviorally unsuited for survival in the wild. Such fish, for example, may expend energy on aggressive interactions or suboptimal feeding tactics (Norman 1987). The degree and severity of behavioral modification may be related to time spent under hatchery conditions (Olla et al. 1993), although some behavioral differences between hatchery and wild fish may have a genetic basis (Swain and Riddell 1990). Whether relatively large energy reserves acquired during hatchery tenure serve to offset mortality that results from maladaptive behaviors is still unknown (Whalen and LaBar 1998).

One may predict that salmonines stocked as embryos will probably behave most similarly to wild fish, whereas salmonines stocked as adults possess the greatest energy reserves. The stocking strategy resulting in the highest fitness is somewhere within those bounds. Therefore, a principal biological and management objective when attempting to restore native species with hatchery-raised individuals is to select a life stage for stocking that considers the trade-offs between large body size and retention of “wild” behaviors, based on hatchery residence time and culminating in survival (Letcher and Ter-Rick 2001). The availability of various life stages for stocking, as well as monetary costs associated with hatchery rearing, may also influence management actions.

We are unaware of any published studies that have directly compared the efficacy of embryo stocking and fry stocking or that have estimated the survival and growth of stocked Atlantic salmon in the Salmon River, New York (an important historical spawning and nursery tributary for Atlantic salmon in the Lake Ontario watershed). Therefore, the objective of our study was to compare first-summer survival and growth rates of Atlantic salmon stocked as embryos and as fry in the Salmon River.

**Study Area**

The Salmon River is a 6th-order stream, originating in the Tug Hill Plateau, Lewis County, New York, and emptying into Lake Ontario at Pulaski, Oswego County, New York. The headwaters are heavily forested with mixed hardwood-conifer community and fed by springs and snowmelt; the Tug Hill region annually receives more than 400 cm of snow (Muller 1966). Stream substrate is composed of gravel and cobble interspersed with areas of bedrock and American beaver *Castor canadensis* ponds. The fish community includes eastern blacknose dace *Rhinichthys atratulus*, creek chub *Semotilus atromaculatus*, wild brook trout *Salvelinus fontinalis*, and naturalized resident rainbow trout and brown trout *Salmo trutta*.

A hydroelectric facility and its associated reservoir interrupt the Salmon River approximately 20 km upstream from the mouth. Four kilometers downstream is a natural impassable waterfall, and 2 km below the waterfall is another hydroelectric impoundment. Immediately below the lower hydroelectric facility, the river is seasonally maintained at base flow between 5.2 and 9.5 m³/s, although rainfall events, scheduled recreational discharges, and tributary influxes serve to increase mandated minimum flows. The substrate composition in the 14 km of river below the lower facility averages 20% gravel and 75% cobble mix, with reaches alternating between pools, riffles, and runs. Salmonine spawning habitat (defined by the presence of wild salmonine redds) and juvenile nursery habitat (defined by the presence of age-0 steelhead) predominate and are juxtaposed throughout the river (S. M. Coghlan, personal observation; Coghlan and Ringler, unpublished data).
Our study sites are confined to the 14-km reach below the lower hydroelectric facility (Figure 1).

The New York State Department of Environmental Conservation (NYSDEC) operates a salmonine hatchery on Beaverdam Brook, a small tributary flowing into the Salmon River 2 km below the lower facility. The hatchery raises large numbers of fry and parr of Chinook salmon (*O. tshawytscha*), coho salmon (*O. kisutch*), steelhead, brown trout, and occasionally smaller numbers of Atlantic salmon smolts. These fish are stocked in the Salmon River, several other Lake Ontario tributaries, and the lake proper. Spawning runs of Chinook and coho salmon, steelhead, and occasionally brown trout dominate the accessible reaches of the river.

Although many salmonines return to the hatchery and are utilized for artificial propagation, substantial natural reproduction also occurs. Johnson and Ringler (1981) documented natural reproduction of Chinook salmon, coho salmon, Chinook × coho salmon hybrids, and steelhead in the tributaries of Orwell and Trout brooks; Coghlan and Ringler (unpublished data) also found natural reproduction in the main-stem Salmon River. Atlantic salmon were historically abundant in the Salmon River before their extirpation in the 1890s (Webster 1982). In addition to our experimental embryo and fry stocking, biologists with the U.S. Geologic Survey (USGS) Tunison Aquatic Laboratory, Cortland, New York, occasionally release surplus adult broodstock of Penobscot strain Atlantic salmon into the river. Very rarely, a migratory adult, presumably originating from occasional stocking of surplus smolts (NYSDEC), is observed in the lower reaches of this river (Fran Verdoliva, NYSDEC, personal communication). Other abundant members of the fish community include cutlip minnow (*Exoglossum maxillingua*), fallfish (*Semotilus corporalis*), eastern blacknose dace, longnose dace (*R. cataractae*), and fantail darter (*Etheostoma flabellare*).

**Methods**

We chose 17 study sites based on accessibility via public land and the presence of suitable habitat; we deliberately chose reaches containing seemingly high-quality habitat for early life stages of Atlantic salmon (e.g., riffles with predominately cobble and gravel substrate; Trial 1989) and avoided pools. Sites ranged in length from 100 to 200 m, and adjacent sites were separated by at least 200 m and as much as 750 m (Table 1). Several reaches of the river (Trestle Pool, Schoolhouse Pool, Upper Fly-Fishing Area) were naturally divided into a complex of distributaries, with riverine islands separating channels. In these reaches, we chose multiple study sites with each site con-
TABLE 1.—Site names, life stage, and number of individuals stocked (n). Sites are listed from downstream to upstream. The term “embryo” signifies that embryos were planted directly in artificial redds, the term “embryo (box)” that Whitlock–Vibert boxes were used.

<table>
<thead>
<tr>
<th>Site Code</th>
<th>Life stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compactor Pool</td>
<td>Fry 5,000</td>
</tr>
<tr>
<td>Great Salmon River Wilderness</td>
<td>Fry 4,500</td>
</tr>
<tr>
<td>Pineville</td>
<td>Fry 10,000</td>
</tr>
<tr>
<td>Trestle Pool South Channel</td>
<td>Fry 3,500</td>
</tr>
<tr>
<td>Trestle Pool Main Channel</td>
<td>Fry 8,000</td>
</tr>
<tr>
<td>Trestle Pool North Fork</td>
<td>Embryo (box) 12,500</td>
</tr>
<tr>
<td>Trestle Pool South Fork</td>
<td>Embryo 12,500</td>
</tr>
<tr>
<td>Ellis Cove</td>
<td>Embryo (box) 12,500</td>
</tr>
<tr>
<td>Schoolhouse Pool</td>
<td>Embryo (box) 12,500</td>
</tr>
<tr>
<td>Schoolhouse Pool</td>
<td>Embryo 12,500</td>
</tr>
<tr>
<td>Beaverdam Brook</td>
<td>Embryo (box) 12,500</td>
</tr>
<tr>
<td>Beaverdam Brook</td>
<td>Embryo 12,500</td>
</tr>
<tr>
<td>Pumphouse side channel</td>
<td>Embryo 12,500</td>
</tr>
<tr>
<td>Pumphouse main channel</td>
<td>Fry 11,000</td>
</tr>
<tr>
<td>Upper Fly-Fishing Area</td>
<td>Embryo (box) 12,500</td>
</tr>
<tr>
<td>Upper Fly-Fishing Area</td>
<td>Embryo 12,500</td>
</tr>
<tr>
<td>Upper Fly-Fishing Area</td>
<td>Fry 8,000</td>
</tr>
</tbody>
</table>

Embryo stocking.—On December 17, 1999, we received 125,000 eyed Atlantic salmon embryos from the Ed Weed Fish Culture Station (EWFCS), Grand Island, Vermont. Volunteers from the State University of New York, College of Environmental Science and Forestry, NYSDEC, and Trout Unlimited assisted in the stocking. We estimated numbers of embryos by volumetric displacement, loaded 250 Whitlock–Vibert hatching boxes (Whitlock 1977) with 250 embryos each, and transported 50 hatching boxes to each of five sites (SHP-B, EC, TPNF, UF-B, and BDB-B). After placing 10 hatching boxes in a protective hardware cloth cradle (60 cm long × 60 cm wide × 12 cm high × 1 cm mesh), we excavated a 50-cm-radius, 30-cm-deep pit with shovels and potato rakes in apparent spawning habitat. We drove a section of iron bar (60 cm long × 1 cm in diameter) into the gravel at the head of the pit, attached the cradle to the bar with chain, and buried the hatching boxes under 10–20 cm of gravel. This procedure was repeated five times at each site, with at least 20 m separating adjacent artificial redds. A total of 62,500 embryos (2,500 in each redd, five redds per site, and five sites) were stocked in this manner (Table 1).

The remaining 62,500 embryos were divided evenly among 25 nylon mesh bags, with 2,500 embryos per bag. We transported five bags each to five sites (SHP-E, TPSF, PHSC, UF-E, BDB-E), and excavated pits as described above. Approximately 250 embryos were gently poured into the pit through a section of polyvinyl chloride pipe inserted into the gravel. We piled a small mound of gravel around the base of the pipe, and forcefully exhaled into the top of the pipe as we removed it from the gravel so that the embryos would not be sucked out of the pit by pressure changes. We repeated this process until all 2,500 embryos had been deposited into all nests at each site (Table 1). Discharge at the USGS gauging station (Pineville, New York) at time of stocking was 14.16 m³/s (Figure 2) and stream temperature was 1°C.

Fry stocking.—On June 6, 2000, we received 50,000 Atlantic salmon fry (mean weight, 0.34 g) from EWFCS. Broodstock used to produce embryos and fry for this study were obtained from the same population of hatchery-run fish, and no evidence indicates that any selected genetic variability was present that might lead to consistent fitness differences between the two groups. The fry arrived in bags of water supersaturated with oxygen and packed in beverage coolers. After tempering the fry to ambient river temperature for 60–90 min, we estimated numbers of fry by weight and allotted an approximate density of 2 fish/m² to each site (Table 1). Wading upstream from the arbitrary downstream boundary of each site, we released approximately 10 fry at a time into the
river along bank margins and in eddies behind rocks, making an effort to distribute the fry as evenly as possible. Discharge at the USGS gauging station at time of fry stocking was 7 m³/s (Figure 2) and temperatures ranged from 9°C to 12°C.

Fish sampling.—In March 2000, we fitted five embryo-only redds with fry emergence traps, as described by Porter (1973), and checked the holding boxes for fry at weekly intervals. In May 2000, we placed three traps over known steelhead redds to ensure that our method of deployment was effective at catching emergent fry. Throughout the incubation period, we visited randomly selected redds containing hatching boxes and excavated two boxes biweekly to monitor embryonic survival. Because salmonine embryos and alevis can withstand brief dewatering episodes (Becker et al. 1982), periodic observation would probably not be detrimental to the developing embryos. However, to keep physical damage to a minimum, we did not remove the embryos from the hatching boxes; rather, we simply noted such obvious occurrences as fungal growth or mass mortality. After the emergence period had presumably ended in May 2000, we excavated and recovered all but three hatching boxes. By counting numbers of dead eggs and alevis, we estimated survival from hatching through emergence.

We visited each site twice between June and August and electrofished to estimate population sizes and growth rates. After randomly choosing a 10–20-m reach, we isolated the stream section with two blocking seines (4-mm mesh, sufficiently small to retain juvenile Atlantic salmon of the sizes encountered) and conducted a two-pass removal population estimate (Seber and LeCren 1967). All fish were brought to shore, where they were held in live wells, and their total lengths and wet weights were measured to the nearest 1 mm and 0.1 g, respectively. We shocked two reaches per site, except for UF-F, where we shocked only one reach. We estimated the area of each sampling reach by measuring the length of the reach and multiplying by the average of three width measurements. We also qualitatively surveyed fifteen 50-m reaches of seemingly suitable habitat between study sites for Atlantic salmon parr to document the occurrence of emigration.

Data analysis.—We estimated population size (Seber and LeCren 1967) of age-0 Atlantic salmon parr in the sampled reach as follows:

\[
N = (C_1)^2/(C_1 - C_2) \quad \text{and} \quad S^2(N) = [(C_1)^2 - (C_2)^2 - (C_1 + C_2)]/(C_1 - C_2)^4,
\]

where \(N\) = estimated population, \(C_1\) = number caught on first pass, \(C_2\) = number caught on second pass, and \(S^2(N)\) = variance of population estimator.

Because area (A) of each sampling reach is a constant, the density (fish/m², or d) and associated variance \([s^2(d)]\) were estimated by
Total parr population in each site was estimated by multiplying estimated parr density by the site area; these site estimates were summed over all sites for each stocking method to yield a whole-river estimate of parr production. Dividing whole-river estimates of parr production by initial numbers of fry or embryos stocked yielded overall survival estimates for each stocking method.

We regressed density estimates obtained by using means of two samples per site against those estimates obtained by pooling data from the entire site (i.e., we summed the sampling areas, pass one numbers, and pass two numbers as if the two reaches were actually one contiguous stretch). Because of a highly significant relation between the density estimates from the two methods (df = 12; \( P < 0.0001 \); \( r^2 = 0.9792 \) with \( \beta_0 = 0 \) \( P = 0.04667 \) and \( \beta_1 = 1 \) \( P < 0.0001 \)), but not between variance estimates (df = 10; \( P = 0.9004 \); \( r^2 = 0.0018 \) with \( \beta_0 \neq 0 \) \( P = 0.2229 \) and \( \beta_1 \neq 1 \) \( P = 0.9004 \)), we chose to combine data from two reaches per site rather than the mean of two estimates. In this manner, we are confident that the mean density estimates are both accurate and precise, whereas the higher variance estimates are more realistic, given the range in site-specific catchabilities.

Site-specific parr density estimates were not normally distributed, including many zero values, and associated variances were heterogeneous. Therefore, we used a nonparametric rank-sum procedure (Kruskal–Wallis test; SAS Institute 1998) to test for differences in density among sites with different stocking methods. Because mean densities of embryo-only and hatching-box sites were not significantly different (Kruskal–Wallis test statistic = 1.16; \( P = 0.282 \)), we pooled those data and hereafter consider simply embryo stocking versus fry stocking. Sites were compared during the first (late June–mid-July) and second (mid–late August) sampling periods. Those sites in which no fish were found during the first sampling episode were excluded from the second sampling analysis. We also compared mean parr weights among all sites during each sampling period (one-way analysis of variance [ANOVA]; SAS Institute 1998) as a measure of growth differences, although we acknowledge inherent differences in starting weights and stream residence times between stocking methods. All tests are considered significant at the \( \alpha = 0.05 \) level.

### Results

**Embryo Survival and Emergence**

Periodic winter observations of hatching boxes indicated that embryonic survival to hatching was highly variable. Boxes contained up to approximately 50% fungal-infected embryos, but we found many seemingly healthy embryos among dead masses. No boxes contained dead alevins in the nursery chamber during the period of observation; very few dead embryos (\( n = 7 \)) or alevins (\( n = 3 \)) were encountered while recovering hatching boxes. We also noted that alevin chambers in all boxes were at least 50% full of sediment, and often contained predatory stonefly ACroneuria spp. or dobsonfly Nigronia spp. larvae. Although we collected no Atlantic salmon fry in emergence traps, we did collect numerous steelhead fry in our control traps; in addition, trap collection boxes were effective at holding steelhead fry for at least 1 month with minimal escape. Therefore, we are confident that the absence of salmon fry in the traps represents low emergence success rather than trap inefficacy.

**Fry Survival and Growth**

Parr mean weights in July did not differ significantly among sites, except that PINE fish were significantly heavier than UF-B fish. In August, however, PINE contained significantly larger parr than at all other sites (Student–Newman–Kuels comparison; SAS Institute 1998). All sites in which fish were recovered during both sampling episodes showed a significant increase in mean weight during the summer (Student’s \( t \)-test, SAS Institute 1998; Table 2).

### Table 2.—Temporal variation in age-0 Atlantic salmon parr growth. Mean weight is in grams, and standard errors are given in parentheses. Within columns, values with the same lowercase letter are not significantly different according to the Student–Newman–Keuls test. Sites in which no parr were collected are not shown. See Table 1 for site codes.

<table>
<thead>
<tr>
<th>Site</th>
<th>Midsummer</th>
<th>Latesummer</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>( n )</td>
<td>Weight</td>
</tr>
<tr>
<td>CP</td>
<td>18</td>
<td>0.89 (0.312) ( z )y</td>
</tr>
<tr>
<td>GSRW</td>
<td>20</td>
<td>0.91 (0.378) ( z )y</td>
</tr>
<tr>
<td>PINE</td>
<td>12</td>
<td>1.43 (0.438) ( z )</td>
</tr>
<tr>
<td>TPSC</td>
<td>33</td>
<td>0.73 (0.224) ( z )y</td>
</tr>
<tr>
<td>SH-B</td>
<td>8</td>
<td>1.27 (1.069) ( z )</td>
</tr>
<tr>
<td>SH-E</td>
<td>3</td>
<td>1.26 (1.201) ( z )</td>
</tr>
<tr>
<td>UF-B</td>
<td>20</td>
<td>0.64 (0.146) ( y )</td>
</tr>
<tr>
<td>UF-F</td>
<td>27</td>
<td>0.79 (0.146) ( y )</td>
</tr>
</tbody>
</table>
July densities of Atlantic salmon parr stocked as fry were significantly higher than those of parr stocked as embryos (Kruskal–Wallis test statistic = 4.86, $P = 0.0276$). Parr were completely absent from four embryo-stocked sites (TPNF, TPSF, BHMC, and BDB-B), whereas only one fry-stocked site (TPSMC) was devoid of parr. SH-B yielded the highest embryo-stocked density, 0.12 parr/m$^2$. Densities of fry-stocked parr were highest in UF-F, at 0.49 parr/m$^2$. We estimated that a total of 1,271 (1% survival) and 3,542 (7% survival) of embryo- and fry-stocked fish survived, respectively. August densities of fry-stocked parr were also significantly greater than those of embryo-stocked parr (Kruskal–Wallis test statistic = 8.92, $P = 0.0028$), with no parr recovered at any embryo-stocked site. All fry-stocked sites containing parr in the first sampling period also yielded parr during the second period, albeit at lower densities; UF-F again contained the highest density, at 0.16 parr/m$^2$. Considering all sites, we estimated a late-summer abundance of 1,020 fry-stocked parr (2% survival; Figure 3). In surveying reaches of suitable habitat between study sites, we found no Atlantic salmon parr.

**Discussion**

Embryo-stocking was unsuccessful in producing significant numbers of midsummer parr and failed to produce any late-summer parr. Reported intragravel survival of stocked Atlantic salmon embryos to emergence ranges widely, from 2% (MacKenzie and Moring 1988) to 94% (Marty et al. 1986); Raddum and Fjellheim (1995) consider 20% survival of planted embryos as “normal.” Environmental factors such as winter discharge (Cunjak and Therrien 1998), particle size (Reiser and White 1988), intragravel percolation (Klassen and Northcote 1988), and groundwater influx (Cunjak et al. 2002) significantly affect intragravel salmonine survival, but some of this variation can be attributed to the method of estimation (Harris 1973). Methods that use recovery and enumeration of dead embryos or alevins compared to known numbers of embryos stocked can significantly overestimate survival because of decomposition losses (McDonald 1960; Pauwels and Haines 1994).

The relative efficacy of hatching box versus simple intragravel burial has not been determined conclusively. Harris (1973) compared survivorship of Atlantic salmon embryos stocked with and without hatching boxes and found no significant differences between the two methods. Harshbarger and Porter (1982) reported significantly greater survivorship of brown trout embryos stocked without hatching boxes and attributed this variation to sedimentation of hatching boxes, whereas Garrett and Bennett (1996) reported sedimentation in hatching boxes comparable to that occurring in natural redds. Using juvenile densities as an indicator of intragravel survival, our results correspond with those of Harris (1973). Contradictory results among these studies may reflect regional and microhabitat differences in gravel permeability, water velocity, degree of groundwater upwelling, distance from thalweg, and orientation of artificial redds.

Given the paucity of dead alevins and the absence of fry collected in emergence traps, our results suggest that the highest mortality in young salmonines occurs just before or during the emergence period (McNeil 1969; Gustafson-Marjanen 1982; MacKenzie and Moring 1988). Although density dependence has been shown to strongly influence embryonic survival (Hunter 1959; McNeil 1969; Elliott 1987), the primary mechanism is redd superimposition rather than oxygen depletion from crowded conditions and decaying embryos (Hunter 1959). We rule out significant density-dependent mortality at the embryo stage because the stocking density of 2,500 embryos/m$^2$
of gravel is below the density at which these processes are likely to operate (McNeil 1969). Although embryo density may influence future smolt density through intraspecific competition among fry and parr (Gibson 1995), we also rule out this mechanism for the same reason; rather, physical damage from flooding and ice scour may have been a significant cause of low survival (see discussion below).

We do not consider postemergent active dispersal to be of significance in explaining low densities of embryo-stocked parr. Although emergent fry may move downstream (Beall and Marty 1983), most fry settle within a relatively short distance (<200 m; Beall et al. 1991) from natal redds. Once emerged, Atlantic salmon fry typically occupy very small home ranges during their first summer of life. Stengrimsson and Grant (2003) found that most (64%) wild Atlantic salmon fry did not move out of predefined study areas (10–100 m long); 97% of sedentary fish moved less than 5 m from their previous capture site. Exploratory sampling in suitable habitat reaches between sites yielded no Atlantic salmon parr, offering no evidence for short-distance migration. Applying an estimate of 27% emigration downstream after emergence (Beall et al. 1991) still yields very low survival rates for our embryo-stocked fish through midsummer.

Fry-stocked Atlantic salmon exhibited significantly greater survival than embryo-stocked fish, although estimates were generally lower than those reported in the literature. Survival through the first summer of life is highly variable as well; 20–25% is probably a typical value in moderately productive streams (Bley and Moring 1988), but values have ranged from 0.8% (Mills 1969) to 72% (Cote and Pomerleau 1985). In studies that have evaluated survival of stocked Atlantic salmon fry over several years, high interannual variability is common. Murphy (2003) found that summer survival of fry stocked at a constant density over 4 years varied as much as 10-fold among years; she cites annual variation in abiotic conditions as the probable cause. Similar results were found in studies encompassing 5 years (Knight et al. 1982), 3 years (Orciari et al. 1994), and 2 years (McMenemy 1995). Factors such as stream temperature (Cote and Pomerleau 1985) and discharge at time of stocking (Jensen and Johnsen 1999), available juvenile habitat (Nislow et al. 2000), genetic strain (Orciari et al. 1994; Murphy 2003), and condition of fry (Cote and Pomerleau 1985; but see Whalen and LaBar 1998; Letcher and Terrick 2001) have been shown to influence the survival of Atlantic salmon fry. If these factors vary annually, fry survival probably would vary annually as well. Our survival estimate of 2% is probably on the low end of the range expected for the Salmon River, a stream especially endowed with juvenile salmonine habitat (Stafford-Glasse et al. 1991) that historically supported large populations of Atlantic salmon (Webster 1982). Repeating this study over several years so that stocked fry would encounter a typical interannual range of environmental variables would provide a better estimate of the Salmon River’s potential for rearing juvenile Atlantic salmon.

Severe fluctuations in abiotic conditions between the timing of embryo-stocked fry emergence and the planting of fry may have contributed to the disparity between our two survival estimates. Peak yearly discharge (145 m$^3$/s) at the USGS Pineville gauging station for 2000 occurred on April 5 (Figure 1); this high discharge event may have displaced emerging fry much farther downstream than would have active dispersal alone, with the riverine environment becoming more favorable for later fry stocking. In the Salmon River, significant transport downstream probably would place emergent fry in highly unfavorable habitats. Summer temperatures in the Salmon River routinely reach at least 28°C short distances below the Compactor Pool site (Stafford-Glasse et al. 1991), perhaps in part related to industrial effluent discharge. Farther downstream, the river slows, widens, and grades into estuarine habitat.

We do not believe that the movement of parr between study sites is of any significance in explaining our results. Most sites were located at least 200 m, and as much as 750 m, from adjacent sites. Because juvenile Atlantic salmon (other than those stocked in our study sites) are absent from the Salmon River, and wild steelhead juveniles were found at low densities (Coghlan and Ringler, unpublished data), most of the suitable salmonine habitat in the river is probably unsaturated (sensu Grant and Kramer 1990). It is highly unlikely that parr would emigrate from one study site, move downstream while avoiding long stretches of unsaturated suitable habitat, and finally settle in another study site. In the Trestle Pool, Schoolhouse Pool, and Upper Fly-Fishing Area reaches, both embryo stocking and fry stocking sites were located in long distributary channels separated by riverine islands. Again, we do not consider move-
ment between study sites within any of these reaches as a likely factor affecting our results (namely, that fry stocking outperformed embryo stocking). If a high discharge event did wash many emergent fry downstream from one distributary, large numbers of fry must have swum upstream into a different distributary and colonized a fry stocking site, so as to yield similar results.

It is likely that a flood of the magnitude occurring on April 5 would have been catastrophic for emergent Atlantic salmon, as Letcher and Terrick (1998) demonstrated for age-0 parr. Thus, the most parsimonious explanation is that bed scour or high velocities associated with the April 5 flood killed many embryo-stocked alevins outright or transported them considerable distances downstream; ambient river conditions were more benign for fry stocked later in the year. The effects of this flood may have also compromised the survival of stocked fry several months later (discussed above) by reducing benthic invertebrate abundance (Palmer et al. 1992, 1996; Nislow et al. 2002) or by exposing armored substrate unsuitable for fry habitat. However, this disparity between environmental conditions at the time of each stocking does not invalidate our conclusion that fry stocking was more successful than embryo stocking. For streams in the northeastern USA, spring freshets are the norm, especially in regions with high winter snowfall; discharge in April and May accounts for more than 50% of annual streamflow (Likens et al. 1977). Data from USGS gauging stations on the Salmon River and other Tug Hill streams show a similar pattern, and timing of peak flow occurs usually during March or April, roughly corresponding to emergence times of fall-spawning salmonines. Therefore, any Atlantic salmon restoration program in the Lake Ontario watershed must consider the possibility that spring flooding may prevent recruitment of stocked embryos to the Parr stage.

Although overall Atlantic salmon fry survival was fairly low compared with that in the literature, we identified the most suitable reach of the Salmon River for potential restoration efforts. Based on additional studies in 1999 and 2001 (Coghlan and Ringler, unpublished data), the section of river commonly known as the Upper Fly-Fishing Area consistently produced the greatest density and biomass of Atlantic salmon parr, but only when stocked with fry. This 0.6-km-long reach is characterized by cooler temperatures and a steeper gradient than all other reaches sampled (Coghlan and Ringler, unpublished data; Stafford-Glasse et al. 1991). The fish community here is less diverse than in downstream sections, with only fantail darter common (Coghlan and Ringler, unpublished data). The combination of low temperatures and the virtual absence of potential competitors (i.e., other drift-feeding insectivorous fishes) may characterize this reach as especially favorable for juvenile Atlantic salmon success. Further research is needed to elucidate how the outcomes of competitive interactions with other salmonine species vary along abiotic gradients (i.e., condition-specific competition; Dunson and Travis 1991) if we are to predict juvenile Atlantic salmon success in other Lake Ontario tributaries (S. M. Coghlan and N. H. Ringler, personal communication; embryo stocking failed completely in this study and probably should not be considered as a management tool in the Salmon River. Given hatchery rearing costs of the fry ($6,000), labor-hours required for stocking (28 h at $6.50 per hour), and the Parr abundance at the end of the study (1,020), one age-0 Parr cost approximately $6.06 to produce. These costs likely would vary annually, as would fry survival. In regions where spring floods are not as pronounced and rearing funds are limited, embryo stocking may be preferable, but in most cases fry stocking is probably superior. Stanfield and Jones (2003) found that Parr stocking was consistently more effective than fry stocking in producing Atlantic salmon fall fingerlings in a Canadian tributary of Lake Ontario, although survival estimates associated with each method varied among years as well. Studies comparing the efficacy of stocking older life stages (i.e., Parr or Smolt) to that of fry stocking over several years, similar to the work of Stanfield and Jones (2003), are needed to conclusively determine the best management principle with which to reintroduce Atlantic salmon to the Salmon River. Based on the low survival estimates of this study, neither fry nor embryo stocking appear very promising towards restoration of Atlantic salmon in the Salmon River. However, without a systematic research program that examines the
relative success of stocking various life stages over several years and estimates the contributions of each stocking method to the returning adult stage, we cannot determine conclusively the overall effectiveness of fry stocking. Our results provide a baseline against which future stocking studies may be evaluated. Identifying the most successful genetic strain (e.g., Orciari et al. 1994; Murphy 2003) for survival in the Salmon River and Lake Ontario should also be a high-priority research focus.

During summer 2002, adult Atlantic salmon from a seemingly “wild” origin were observed in low to moderate abundance in the Salmon River (Fran Verdoliva, NYSDEC, personal communication). This influx of migratory adults was coincident with the timing of our initial fry stocking research and needs to be investigated further. A significant increase in the number of Atlantic salmon adults returning to the Salmon River Hatchery or captured by riverine angling over the next several years would suggest successful recruitment of embryo or fry stocked individuals, corresponding to our 1999, 2000, and 2001 stockings. In addition, angling in the Upper Fly-Fishing reach consistently produces smolt-sized individuals (150–270 mm) that have not developed smolt coloration (Fran Verdoliva, NYSDEC, personal communication; S.M. Coghlan, personal observation). Microchemical otolith analyses may be useful in determining the origin of both these large migratory adults and seemingly riverine-resident fish and may yield information on survival and growth in lake and river habitats.

Mortality of embryos and alevins associated with a thiamine deficiency in spawning adults is probably the most serious obstacle to restoring Atlantic salmon populations in the Lake Ontario watershed, and much effort has been directed toward understanding and solving the problem (Fitzsimons et al. 1999). However, adequate recruitment to the spawning adult stage is another critical factor worth study and may in part depend upon first-year survival in tributary streams.

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References


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editor. Symposium on Salmon and Trout in Streams. Institute of Fisheries, University of British Columbia, Vancouver.


Muller, R. A. 1966. Mean seasonal snowfall: New York State. Syracuse University Cartographic Laboratory, Syracuse.


