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MANAGEMENT BRIEF

Performance of Instream Jordan–Scotty Salmon Egg Incubators Under Different Installation and Sedimentation Conditions

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Abstract
Fish stocking, in which natural populations are supplemented with progeny through some unnatural means, is widespread and takes many forms. Long-term benefits of population viability are generally greatest when individuals are subjected to as little artificial rearing as possible. For salmonids, instream incubation enables embryo exposure to natural conditions during a critical developmental period. The Jordan–Scotty incubator is a new tool that facilitates the ability to conduct instream incubation on a semi-large scale. However, the performance of this type of incubator is affected by sedimentation. We quantified sediment accumulation within Jordan–Scotty incubators when installed using four potential methods in a blocked design that eliminated confounding space–time variables. Although sediment accumulation was highly variable, there appeared to be no benefit in taking the extra effort to install the incubators under gravel as recommended by the manufacturer. Incubator exposure to streamflow can be achieved in several ways and reduces sedimentation. We recommend the use of pre-installed plastic milk crates as incubator receptacles.

Many salmonid populations are under threat, often due to low numbers of spawning fish or poor condition of spawning habitat. Supplemental stocking programs are thus widespread. However, the quality of stocked animals (their phenotype) can be influenced by artificial environments. Allowing much of the life cycle to occur under conditions that are as close to natural as possible is beneficial for producing a wild-type individual (Clarke et al. 2016). Exposure conditions are most important in early life due to rapid development and high selection. Fittingly, instream incubation of eggs is a widespread practice used for salmonid populations (Egglishaw et al. 1984; Pauwels and Haines 1994; Donaghy and Verspoor 2000; Venditti et al. 2000).

The Jordan–Scotty salmonid instream egg incubator is a relatively new tool that allows the incubation of eggs in situ under natural temperature and water chemistry cycles. Fry emerge on their own as they would from redds and are not exposed to artificial conditions or handling, thus meeting one of the key recommendations of Clarke et al. (2016). These incubators hold promise for conservation-angling community groups, as they are inexpensive, require little infrastructure, and can be left unattended for months at a time. According to the user's guide for the product, the hatching success for eggs in Jordan–Scotty incubators under ideal conditions can be as high as 65–95%, compared to 5–20% in nature (Scott Plastics 2016).

Salmon typically bury their eggs in gravel, and the manufacturer of the Jordan–Scotty incubators suggests burying the units under gravel. In many areas, this would be desirable, as it would mimic natural conditions and would require no extra infrastructure. However, in some locations, spawning gravels may not be present, either because they are in low supply throughout a watershed or because they do not occur in the exact location where people want to place instream incubators (e.g., expanding fry habitat). In such cases, there are numerous methods that can be devised to physically place the incubators in streams. Minimizing sediment accumulation during embryo development inside incubators is critical because exposure to high levels of sediment during early development is fatal to salmonids (Reiser and White 1988; Lisle and Lewis 1992; Lapointe et al. 2004; Greig et al. 2005; Levasseur et al. 2006). Best practices for installation therefore need to be developed.

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We could find only one source that evaluated different installation techniques for Jordan–Scotty salmon incubators. From 2008 to 2013, a series of technical reports described anecdotal observations of sediment accumulation and hatch success with Atlantic Salmon *Salmo salar* in Ontario streams near the city of Toronto, Canada (see Pritchard 2013). Although the incubators were installed using multiple methods, the incubators were inconsistently deployed among sites and among years, thus confounding the results. Therefore, no unbiased information is available on the performance of these incubators under various deployment methods. Experimentation is needed to determine tradeoffs between installation logistics and hatch success.

While working with the Salmonid Association of Eastern Newfoundland on a reintroduction project for Atlantic Salmon, we tested four potential installation methods. The two objectives of the present study were to (1) monitor hatch success within Jordan–Scotty incubators in relation to sediment accumulation in an urban river and (2) experimentally quantify the amount of sediment trapped in Jordan–Scotty incubators when deployed in the field using different methods. The experiment was conducted under a range of sediment regimes in order to separate the effect of each deployment technique from the confounding effect of the location in which they were deployed.

METHODS

Sediment accumulation and hatching success.— As part of efforts (2012–2018) by the Salmonid Association of Eastern Newfoundland to restock an extirpated Atlantic Salmon population in Rennie's River (St. John's, Newfoundland, Canada), gametes were obtained from wild salmon collected in the Exploits River, central Newfoundland. Fish were removed from a fishway on Grand Falls in early September and were held in flow-through tanks until spawning in November 2014. Gametes were stripped from fish at Grand Falls in the morning and were shipped on ice to Memorial University, St. John's, the same day. This was repeated several times with new fish from November 4 to November 17.

Within 12–16 h of collection, eggs from each female (n = 55) were fertilized using sperm from three to six males in isolation (26 total males) before being remixed by female (creating half-sibling families that were pooled by mother; these specific crosses were created for a different, laboratory-based experiment). Fertilized eggs were allowed to water harden for 8–10 h before being disinfected with Ovadine (100 mg/L for 10 min) following transfer requirements. Approximately 24 h after stripping, disinfected eggs were loaded into Jordan–Scotty incubators, held in containers of water, and then placed at 121 sites in the Rennie's River watershed within the city of St. John's. All embryos were in their incubation locations within 30 h of gamete stripping and within 16 h of fertilization. Incubators were placed inside porous plastic containers (33- × 33- × 28-cm milk crates) that previously had been approximately half-buried into the riverbed (Figure 1). Sites were chosen as locations that were as deep as possible to plant, with good flow rates, and in areas where incubators could withstand natural flows without dislodging in 2012–2013. General conditions of incubation sites used during 2012–2017 were in river sections that were 4 ± 2 m in bank width, with flow rates of 22 ± 16 cm/s, and the tops of the incubators were 33 ± 4 cm below the water surface. No information is available to link specific river conditions to each incubation site for the hatch data reported here.

Each unit contained five incubation plates (Figure 1A, B) that were bolted together to make an "incubator box" (hereafter, "incubator"; Figure 1C). Each plate held 198 eggs in isolated compartments (2 of 200 compartments were used to place tags that identified the mother or a general pool of eggs from several mothers). The incubator was placed such that the plates were oriented parallel to streamflow; thus, there was no upstream or downstream plate. In late May 2015, 58 of the 121 incubators (19 were lost and others were retrieved, but on those particular days, no data were recorded) were removed from the streambed and carefully opened. Once each plate was opened, both sides of all 198 compartments were visually examined for sediments. A subjective assessment of the amount of sediment that had accumulated within all of the egg compartments (i.e., how full the entire plate was) was recorded as low (<25%), medium (25–75%), or high (>75%). Each isolated egg compartment (Figure 1A) was noted as hatched (the assumption if empty) or dead (unhatched egg was still visible). Hatch success of each plate was recorded (percentage of 198 eggs). It is very unlikely that water-hardened, unhatched eggs fell out: over 6 years, we handled many hundreds of filled incubators during transport to the river and did not observe this. It is also unlikely that many eggs were preyed upon over winter, since we observed few invertebrate predators in opened incubators. It was critical that hatch success be quantified before water temperatures warmed substantially (mid-June in Rennie's River) because fungal growth on dead eggs made hatch assessment impossible in July (our personal observations).

We had two resolutions of data available: individual plate level and incubator level. In 29 incubators, the five plates contained eggs from five unique females that were tracked (total of 37 females). Hatch success and sediment accumulation were recorded individually for all 144 plates (5 plates/incubator except that one of the incubators had four tracked plates and one empty plate). Eggs from individual females were present in only one plate per

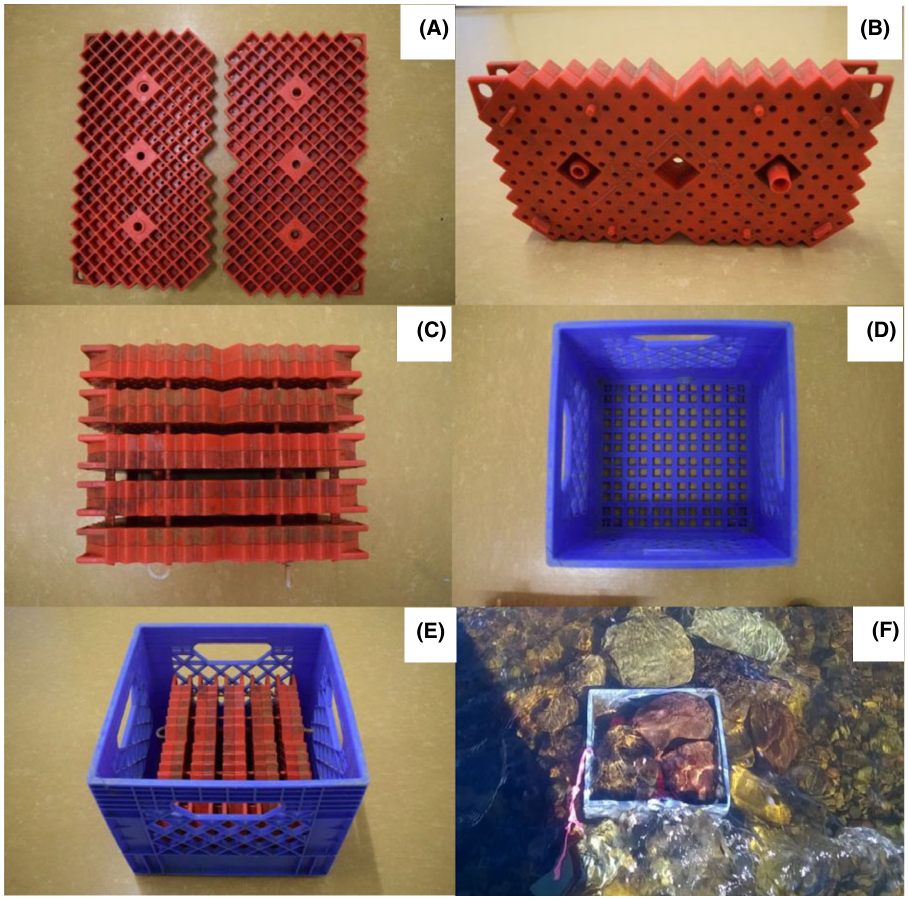

FIGURE 1. Jordan–Scotty salmon incubator setup: **(A)** a single opened incubation plate, **(B)** side view of egg chambers in an assembled plate, **(C)** five plates assembled into an incubation box, **(D)** a plastic milk crate, **(E)** incubation box positioning within the milk crate, and **(F)** recommended river installation technique. [Color figure can be viewed at afsjournals.org.]

incubator (Figure 1) and were used in one to five plates overall. These data (n = 144) were analyzed in a mixed model with sediment accumulation as a fixed effect and female as a random effect. For the incubator-level resolution, 29 incubators (different from those detailed above) contained eggs that were mixed pools of females (typically 5–10) by day (n = 55 total). In such cases, eggs distributed among the five plates within the incubator (and across incubators on a given day) were from the same pooled source, and hatch success and sediment levels were recorded on a per-incubator basis (one datum for all five plates). These data (n = 29) were analyzed using one-way ANOVA with hatch success as the dependent variable and sediment accumulation (low, medium, or high) as the independent variable. Assumptions of parametric statistics were not violated.

Installation techniques and sediment accumulation.— In autumn 2015, an experiment was conducted to determine how installation technique influenced sediment accumulation inside the egg compartments of the Jordan–Scotty incubators. As in much of Newfoundland, spawning-type gravels are very limited in the Rennie's River watershed, which is dominated by bedrock, boulder, and large cobble. A preliminary experiment in September and October provided information that we used to determine the installation treatments to be compared. Subsequently, in each treatment, five plates were bolted together to construct one incubator (1,000-egg equivalent; Figure 1C), and incubators were then installed in one of four treatments:

1. GRAVEL: the incubator was fully buried in the riverbed under gravel as recommended by the manufacturer. For each incubator, a depression in the cobble/boulder riverbed was excavated to approximately 30 cm deep; the incubator was placed in the depression and then covered by gravel (2.5–3.8 mm) that we transported in buckets to those locations. It was the most difficult treatment to implement. There was no direct exposure of river flow on the incubator.

2. CRATE: we preinstalled a plastic milk crate that was approximately half-buried (15 cm) in the cobble substrate, and we surrounded the crate with small boulders. An incubator was inserted into the crate, and several large rocks were placed on top of it (Figure 1F). This was the method used by the Salmonid Association of Eastern Newfoundland for their stocking efforts and mirrored that used for the egg hatching success data described in the previous section (*Sediment accumulation and hatching success*). The incubator was indirectly exposed to river flow, as it was inside the porous crate.
3. STONE PA: an incubator was strapped to a concrete patio stone and was laid on the riverbed parallel to the current. The incubator was totally exposed to river flow in this treatment.
4. STONE PE: an incubator was strapped to a concrete patio stone and was laid on the riverbed perpendicular to the current. The incubator was totally exposed to river flow in this treatment.

Each plate (Figure 1A, B) was filled with plastic beads of the same size and shape as Atlantic Salmon eggs. Ten sites within the watershed were chosen as randomized blocks in the experimental design. These varied in flow rates, water depths, and sediment levels, but we did not record environmental factors at these particular sites. Typical conditions are reported above. Each of the four treatments was installed at each site, thus removing the confounding effects of site differences on the test treatments. The units (40 incubators = 200 plates) were deployed in early December 2015 and removed in late May 2016.

Upon retrieval, a large plastic panel was placed just upstream of the incubator to create a calm zone to reduce sediment disturbance as the incubator was removed from the river. Each incubator was placed in an independent plastic container to contain any sediment that fell out during transport to the laboratory. Sediment from the incubator (and the egg-mimicking beads) was rinsed into this collection container. The sediment was then divided by particle size using a sieve. Only sediment less than 3.35 mm was kept. This resulted in two grain size fractions: 0–1 mm (clay, silt, and very fine to coarse sand) and 1–3.35 mm (coarse sand to fine gravel). The smaller of these size fractions would be of most concern with regard to developing eggs (Julien and Bergeron 2006). Sediment was dried at 60°C for at least 48 h in preweighed aluminum pans. Each pan of sediment was then weighed to determine the total dry mass of each grain size fraction sample for each incubator.

A correlation was run on deposition of both sediment sizes (i.e., 0–1 mm correlated to 1–3.35 mm) across blocks, and data were subsequently analyzed separately for both sediment size fractions. Two of the 40 incubators were lost over the winter, which complicated analyses. Mean sediment accumulation for each block was thus quantified based on all four incubators in eight blocks and based on three incubators in two blocks. Blocks were numbered as ranks of the small size fraction accumulation based on this mean. Statistical analysis of treatment was restricted to the eight blocks that retained all four treatments. To enable standard treatment comparisons across blocks, the dependent variable was the proportion of sediment present in each treatment for a given block (each site)—that is, the proportion of the total mass of a sediment size fraction per block that was found in each treatment. The mixed model contained treatment (fixed) and block (random) as explanatory variables.

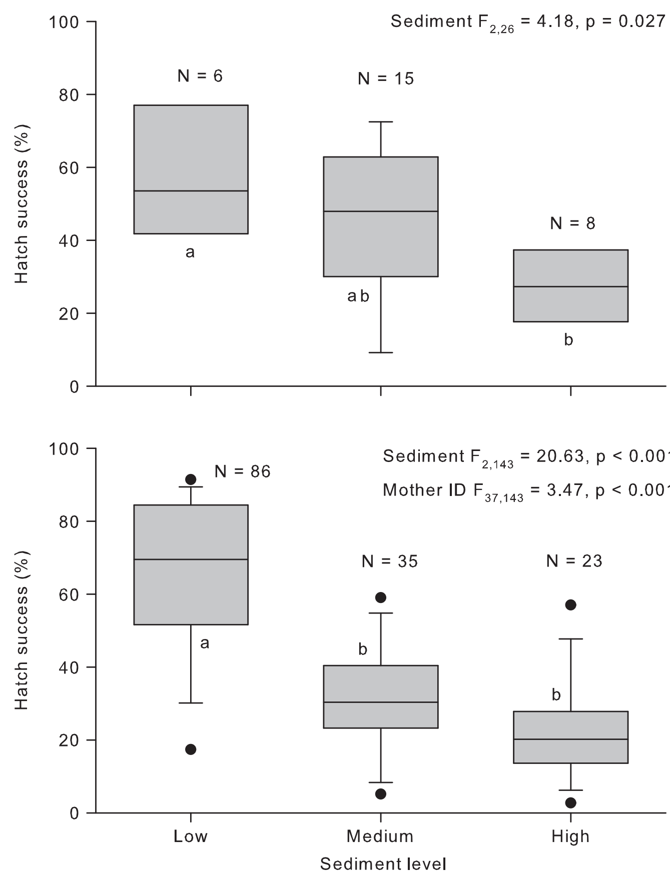

FIGURE 2. Atlantic Salmon hatch success in relation to sediment accumulation within instream Jordan–Scotty incubators: the top panel presents data recorded at the incubator level (29 incubators); the bottom panel presents data recorded at the individual plate level (five plates within each incubator) for a different set of 29 incubators. Shown are the median (line within each box), 25th and 75th percentiles (ends of box), 10th and 90th percentiles (ends of whiskers), and 5th and 95th percentiles (dots) where sample size allows. Means denoted by different lowercase letters are significantly different based on Tukey's pairwise comparisons.

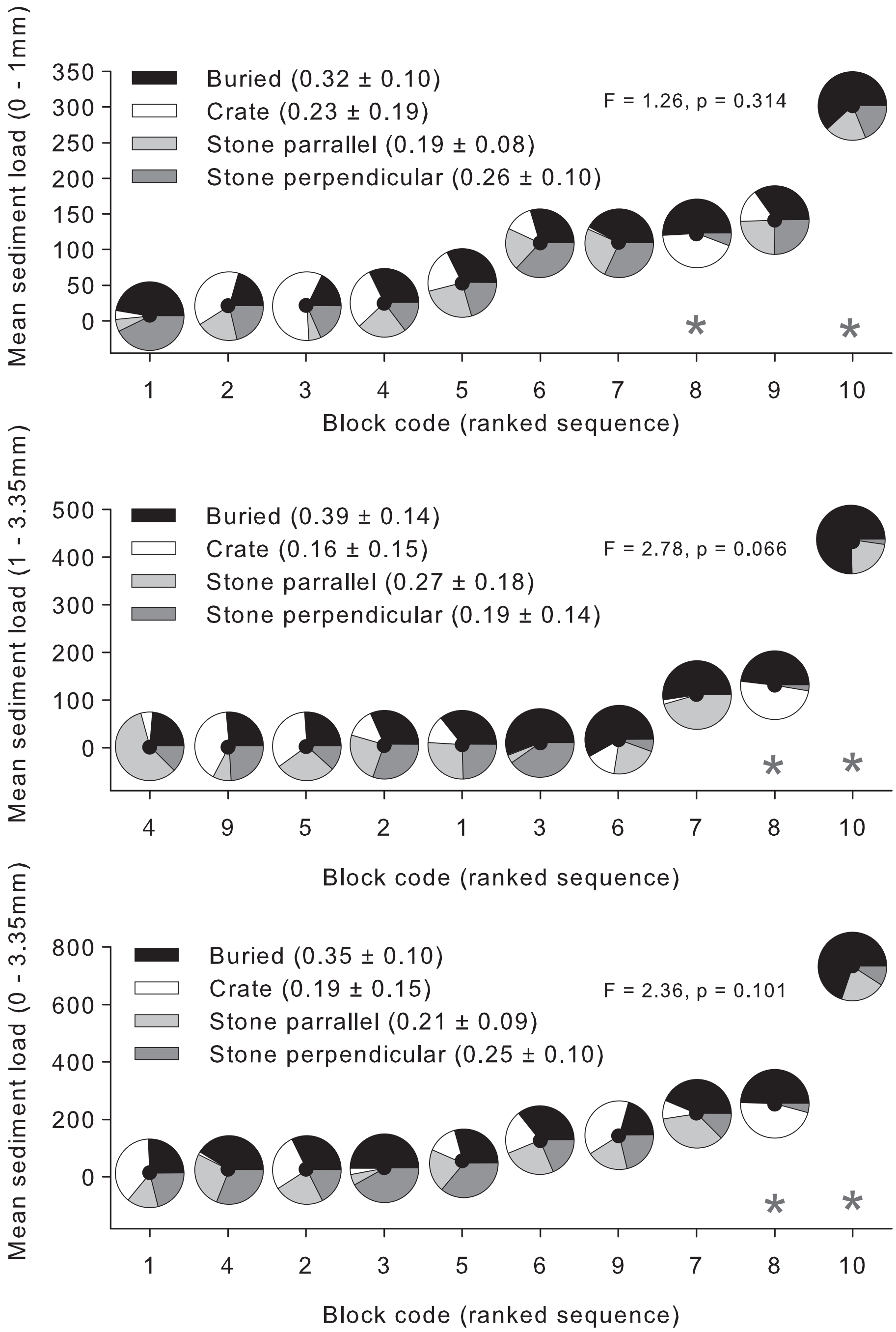

FIGURE 3. Proportion of sediment accumulated by treatment (pie charts) at each block for 0–1-mm (top panel), 1–3.35-mm (middle panel), and 0–3.35-mm (bottom panel) sediments. Vertical location on each panel indicates mean accumulation at each block. One treatment was lost at each of two blocks (8 and 10); pies for all other blocks represent four treatments. Means (±SD) by treatment are given with legends (excluding blocks 8 and 10).

RESULTS

Sediment Accumulation and Hatching Success

Instream incubation from November 2014 to June 2015 resulted in hatch success of groups of Atlantic Salmon eggs ranging from 2% to 94% in the individually quantified plates and from 1% to 80% in the mixed pools of eggs quantified to the incubator-level resolution (five plates). The level of sediment accumulation within the plates was associated with hatching (Figure 2). Units with high sediment loads typically produced 20–30% hatch success (incubator data [mean ± SD]: 29 ± 13.6%; individual plate data: 23 ± 14.2%), whereas those that accumulated low levels of sediment had twice the hatch success (incubator data: 58 ± 16.8%; individual plate data: 65 ± 22.7%; Figure 2). As expected, the effect of female/mother explained a significant amount of variation in egg hatch success ($F_{36,\ 143} = 3.47$, $P < 0.001$).

Installation Techniques and Sediment Accumulation

In the installation experiment, the amount of accumulated sediment of both fractions was correlated across blocks but not tightly so ($r = 0.883$, $P = 0.001$). On average, 85 ± 99.9 g (0–1-mm size fraction; mean ± SD) and 61 ± 170.6 g (1–3.35-mm size fraction) dry weight of sediment accumulated per incubator (five plates). The proportion of sediment accumulated by treatment in each block is shown in Figure 3. There was no consistently large difference in sediment accumulation by treatment. For incubators that were strapped to patio stones, proportionally less material accumulated when parallel to river flow (STONE PA treatment) for fine sediment but perpendicular to flow (STONE PE treatment) for the coarser sediment fraction. Incubators placed inside milk crates (CRATE treatment) accumulated less sediment than those buried in gravel (GRAVEL treatment), but across sites, the data were too variable to be significant (Figure 3).

DISCUSSION

Pritchard (2013) reported substantial sediment accumulation in Jordan–Scotty incubators, and sediment is widely known to negatively affect developing salmonid embryos (Reiser and White 1988; Lisle and Lewis 1992; Lapointe et al. 2004; Greig et al. 2005; Levasseur et al. 2006). Furthermore, our data on Atlantic Salmon from a Newfoundland stream show that high sediment accumulation is associated with poor hatch success in these particular incubators, while sibling eggs can achieve good hatch under low-sediment conditions.

Our experiment provides unbiased information on sediment accumulation based on installation technique because each of the treatments was placed at each site in a randomized block design—something that was missing in previous assessments. Across sites (blocks), there was variation in environmental sediment levels, but each treatment within a block experienced similar conditions. Sediment accumulation data were variable; thus, future work should increase the sample size used in order to provide finer recommendations. It should also include information on how flow rates and ambient sediment levels affect accumulation. Nonetheless, it is clear from our work that there is no benefit to burying incubators in gravel, as on average these contained the highest sedimentation when exposed to river conditions similar to those occurring for other deployment methods. In our study stream, due to a lack of gravels, this was the hardest installation technique to implement. Therefore, under such conditions, we recommend against installing incubators in this manner.

Installing the incubators such that they are more exposed to river flow resulted in less sediment accumulation. Another group working in New Brunswick also concluded that the incubators performed better when they were not buried (Friends of the Kouchibouguacis 2016). We found no consistent difference across sediment size fractions when incubators were installed perpendicular or parallel to flow. Salmon eggs are most sensitive to fine sediments (Julien and Bergeron 2006). On average, parallel installation had the lowest accumulation of fine sediments in our experiment. Our results do not support perpendicular installation as suggested by the manufacturer. Incubators installed within a plastic milk crate (high flow-through capability) had a relatively low accumulation of fine sediments compared to those buried under gravel. The crate method has the added advantage in that the crates can be installed during low summer water levels. They should be dug into the riverbed to about half the depth of the crate height and surrounded by boulders. A large rock placed inside will keep the crates from washing away until the incubator can be placed inside during spawning. Several large rocks placed on top of the installed incubator will typically keep the unit in place until spring (Figure 1). Incubators can be removed after fry emergence, and the crates can be left in place for the following year. Adaptive management would suggest the abandonment of locations with relatively high sediment loadings in subsequent years. Using this strategy while working on the reintroduction project with the Salmonid Association of Eastern Newfoundland, we increased the mean hatch success of approximately 100,000 eggs in Jordan–Scotty incubators from 49% (spring 2015) to 62% (spring 2016) in Rennie's River (poor-quality habitat).

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