A Performance Evaluation of In-Stream Hatchboxes and Streamside Incubators for Chinook Salmon

By

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Meghan Z. Howell **May 18, 2021**

Abstract

Hatcheries are used to produce salmon to augment the number of fish available for harvest, and to supplement wild populations that may be threatened with extinction. Although traditional hatchery rearing methods can produce many fish, they can pose risk to wild populations because they tend to produce salmon with lower fitness than wild counterparts. As wild salmon populations continue to decline, researchers and managers continue to explore alternative methods with potential to affordably produce large quantities of salmon with higher fitness and survival to adulthood.

In this study, we evaluated two devices designed to artificially boost juvenile salmon abundance with limited rearing cost: instream hatchboxes and streamside incubators. We installed these devices into four artificial stream channels at the Oregon Hatchery Research Center, then supplied them with a total 30,000 fertilized Chinook salmon (*Oncorhynchus tshawytscha)* eggs. We compared egg-to-fry survival rates, cost per fry and fry size for the two methods. Our results suggest that hatchboxes delivered higher egg-to-fry survival (79.8%) than incubators (68.1%). We also found that hatchboxes and incubators produced fry at similar costs ($0.064 and $0.056 per fry, respectively). Finally, we found that fry produced with hatchboxes were 21.4% heavier than those produced with incubators. We suggest that managers and conservationists consider benefits and limitations to the application of these methods as tools for conservation or fisheries augmentation.

1 Introduction

Salmon are important to the ecology, economy and traditional cultural of the Pacific Northwest region of the United States. They serve as nutrient transporters between the ocean, estuaries and freshwater environments, directly benefiting at least 138 different species (Cederholm et al., 2000). Salmon carcasses cause as much as a 65-fold increase in nitrogen and phosphorus loading within streams after salmon spawn (Munn et al., 1999). In 2016, the Oregon commercial salmon fishery brought in a combined harvest value of $8.3 million (ODFW, 2017). In addition, salmon play an essential role in some Native American religious ceremonies and are a traditional food source. It has been estimated that tribes surrounding the Columbia River once consumed around 18 million pounds of salmon annually (Craig & Hacker, 1940).

Habitat degradation and barriers to migration have significantly contributed to the decline of wild salmon populations throughout the Pacific Northwest (Dauble et al., 2011; Yoshiyama et al., 1998). To mitigate effects from habitat loss, hatcheries are often used to increase the abundance of naturally reproducing fish populations (i.e. supplementation; see Cloud & Thorgaard (1993)). Hatchery rearing improves survivorship during early life stages, and can therefore produce more juvenile fish than wild populations can, under many circumstances (Waples et al., 2007). Oregon hatcheries released more than 42 million salmon in 2019 alone (ODFW, 2020). For this reason, hatcheries are considered to be a useful tool for population rebuilding, especially when combined with other conservation efforts such as habitat restoration (Cloud & Thorgaard, 1993).

Despite their utility, controversy surrounding supplementation programs exists for several reasons. Artificial conditions experienced during early life stages can induce lifelong divergence in vital phenotypic traits that may contribute to substantially lower levels of fitness, which may even carry over into future generations (Christie et al., 2012; Clarke et al., 2016). Moreover, captive-rearing until the smolt stage relaxes natural selection on traits necessary for in-stream survival (Christie et al., 2012; Fraser, 2008) and subsequent interbreeding between hatchery and wild fish can transfer maladaptive traits to the wild population, potentially impacting productivity (Chilcote et al., 2011)

Accordingly, continued population declines have prompted conservationists and managers to consider alternative approaches to supplementing salmon populations. Onsite (in-stream or streamside) incubation of artificially fertilized salmon eggs could offer a low-cost alternative to hatchery rearing (Conley et al., 2020) that might even improve adaptation to local natural conditions and fitness, as conferred through reduced exposure to artificial rearing conditions (Thériault et al., 2010). However, uncertainties associated with onsite incubation methods should be addressed before broadscale use. For instance, there is a general lack of knowledge surrounding the costs and egg-to-fry survival rates associated with producing fry with incubators or hatchboxes. The relative performance of these technologies, in terms of fish quality, also warrants investigation.

In this study, we address these uncertainties by evaluating the performance of two artificial egg incubation devices: Jordan-Scotty © (Sidney, BC, Canada) hatchboxes and the Reddzone Streamside Incubators. We estimated and compared cost per fry (i.e., marginal gain), egg-to-fry survival, and the mean size of fry produced with both technologies.

2 Methods

We conducted our study at the Oregon Hatchery Research Center (OHRC) located near Alsea, Oregon, alongside Fall Creek. This facility is a cooperative research project between the Oregon Department of Fish and Wildlife (ODFW) and the Oregon State University Department of Fisheries and Wildlife.

Figure 1. An aerial photo of the four artificial stream channels at the Oregon Hatchery Research Center. Only the two leftmost streams contain water in this image, but all four were operating during our study.

Approximately 30,000 fall Chinook salmon eggs were artificially fertilized on December 1, 2020 at the Elk River Hatchery, near Port Orford, Oregon by ODFW staff and transported to the OHRC on December 10th, 2020. Fertilized eggs were disinfected with 10ppm iodophor solution for 10 minutes, then distributed among four artificial stream channels at the OHRC on the next day. Artificial stream channels at the OHRC are designed habitat replicates, consisting of four pools and five riffles. Water is drawn from nearby Fall Creek, moved across a settling pond to minimize the amount of suspended sediment, and finally pumped into the channels. After traveling through the artificial streams, the water passes through a series of fine screens before it returns to the creek.

Treatments were alternated in the stream channels to minimize potential effects from variable sun or shade exposure. Streams 2 and 4 contained 7 and 8 hatchboxes, respectively, while streams 1 and 3 contained incubators plumbed into the second pool from the top (Figure 1). The stream channels were checked daily by ODFW personnel for vegetation buildup around the incubator pumps, fry mortality and other irregular occurrences.

2.1 Hatchboxes

For our study, we used Jordan-Scotty hatchboxes, which are plastic incubation units designed to eliminate or minimize some sources of mortality associated with natural spawning (*Scotty | Jordan / Scotty Fish Egg Incubator*, n.d.). Each hatchbox is comprised of five plates bolted together with nylon tie bolts. Each plate holds 200 eggs for a total of 1,000 eggs per hatchbox. Its design allows each egg to sit within its own chamber, separated from the rest of the eggs, with an additional hole for alevins to exit after absorbing most of their yolk sac. Each 1,000 egg hatchbox costs $45.

The installation methods recommended by the manufacturer lead to high rates of sedimentation in the hatchboxes (Purchase et al., 2018). Because factors like sediment accumulation can cause embryo mortality (Sear et al., 2017), we took extra precautions to avoid suffocation from water-borne silt when we installed the Jordan-Scotty hatchboxes. We placed the hatchboxes into plastic milk crates to achieve high flow-through and lessen fine sediment accumulation, following the approach of Purchase et al. (2018). We buried the milkcrates in the gravel and secured the hatchboxes inside the crates by placing a large rock on top.

We installed 15 milkcrates between two artificial streambeds at the OHRC prior to filling the channels with water. Because water depth had to be assumed at this stage in the experiment, most of the crates were in low-flow areas of the pools and some of them were moved prior to hatchbox installation. Accordingly, we were able to collect data for individual hatchbox mortality in a variety of depths and flows.

The manufacturer provides a white loading tray, but the chambers proved to be too small to hold the Chinook salmon eggs used in our study. For this reason, we used a drill press to widen the diameter of chambers in the loading tray. The eyed eggs were then transferred to the hatchboxes and all five plates of each hatchbox were assembled using the provided ties and nuts. We estimated embryo and alevin mortality for individual hatchboxes by counting the number of unhatched eggs, embryo and alevin carcasses upon removal from the streams.

2.2 Streamside Incubators

We installed Reddzone Streamside incubators in two of the OHRC stream channels. Each unit was installed on a gravel bank next to the stream, rather than within the stream. Incubators contain a mesh bag filled with plastic substrate, providing space for alevins to develop beneath a slotted grate. Eggs develop on top of the grate. Then, after hatching and absorbing some of their yolk sacs, alevin swim down through the grate and into the mesh below. After absorbing their yolk sacs, the juvenile salmon swim up through the grate as fry and travel out of a pipe near the top of the incubator. Each of the 0.61m (24”) wide streamside incubators used in our study costs $1,877.00 and holds up to 100,000 eggs.

We filled each of the incubators with only 7,500 eggs, due to egg and resource availability. We installed incubators atop 0.61m × 0.61m wooden bases to ensure the units stayed level throughout the experiment, and we plumbed them into the second pool of their respective stream channels. While this method can be used with freshly fertilized eggs, we filled each incubator with eyed eggs, which are relatively hardy and tolerant of handling.

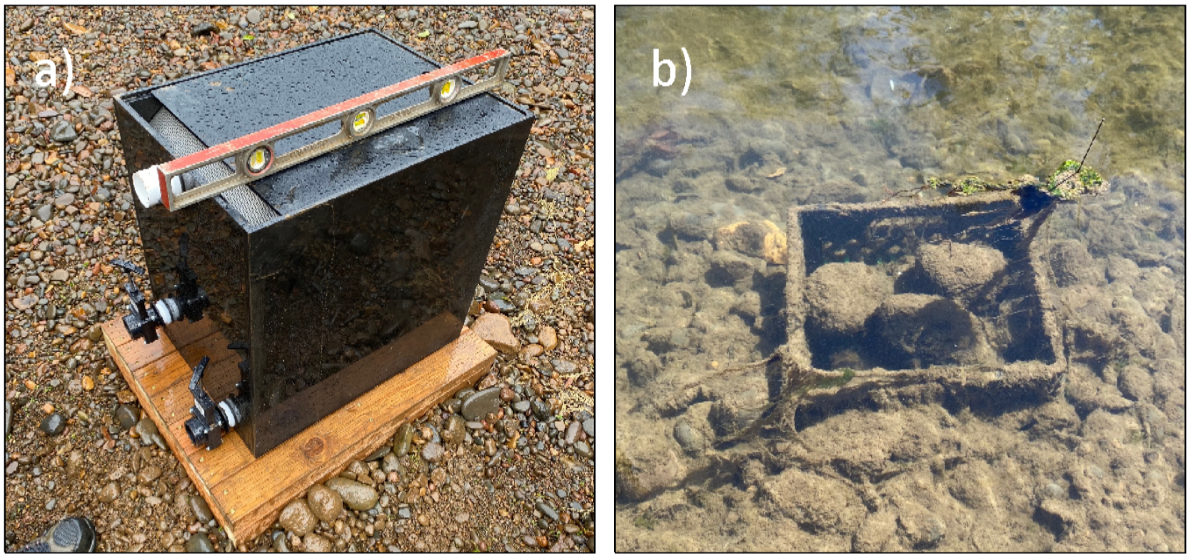

Figure 2. Photos of a) an incubator on a wooden base we made to keep it level and prevent sliding from any erosion throughout the experiment and b) a hatchbox installed within a milkcrate, buried in an artificial stream channel at the OHRC. We placed rocks atop the hatchboxes to prevent them from floating.

2.3 Abundance Estimation

No fish sampling method is 100% effective, so we used a mark recapture approach to estimate fish abundance. In brief, we used a dipnet to randomly capture 10 fry from each pool for marking (total n = 40 per channel). As fry at this age have small fins, we chose to mark them by clipping a portion of the lower lobe on the caudal fin (Figure 4). Fry that have been stressed due to capture and handling show distinct behavioral changes (i.e. seeking cover, remaining inactive) (Mesa & Schreck, 1989) that could bias mark recapture estimates. To avoid these potential biases, we returned fry to their original channels and allowed 24 hours of recovery time and mixing before electrofishing.

The following day we electrofished each channel using a Smith-Root LR-20 backpack electrofisher operating at 400V for 10 minutes from bottom to the top, removing all captured fish. We repeated this process again for a total of 2 passes in each channel. We counted marked and unmarked fry from each pass in all four channels. Finally, we measured fork length (mm) and weight (g) for 40 randomly selected fry from each channel.

We estimated our capture efficiency and fry abundance and survival using an integrated Bayesian model (Figure 3). Mark and recapture data were used to estimate capture probability, which was used to simultaneously estimate fry abundance. The latter and the number of eggs in each raceway were used to simultaneously estimate survival. We also calculated the difference in mean estimated survival of the incubators minus the hatchboxes. Differences were considered significant if the 95% confidence intervals of the survival difference did not include zero.

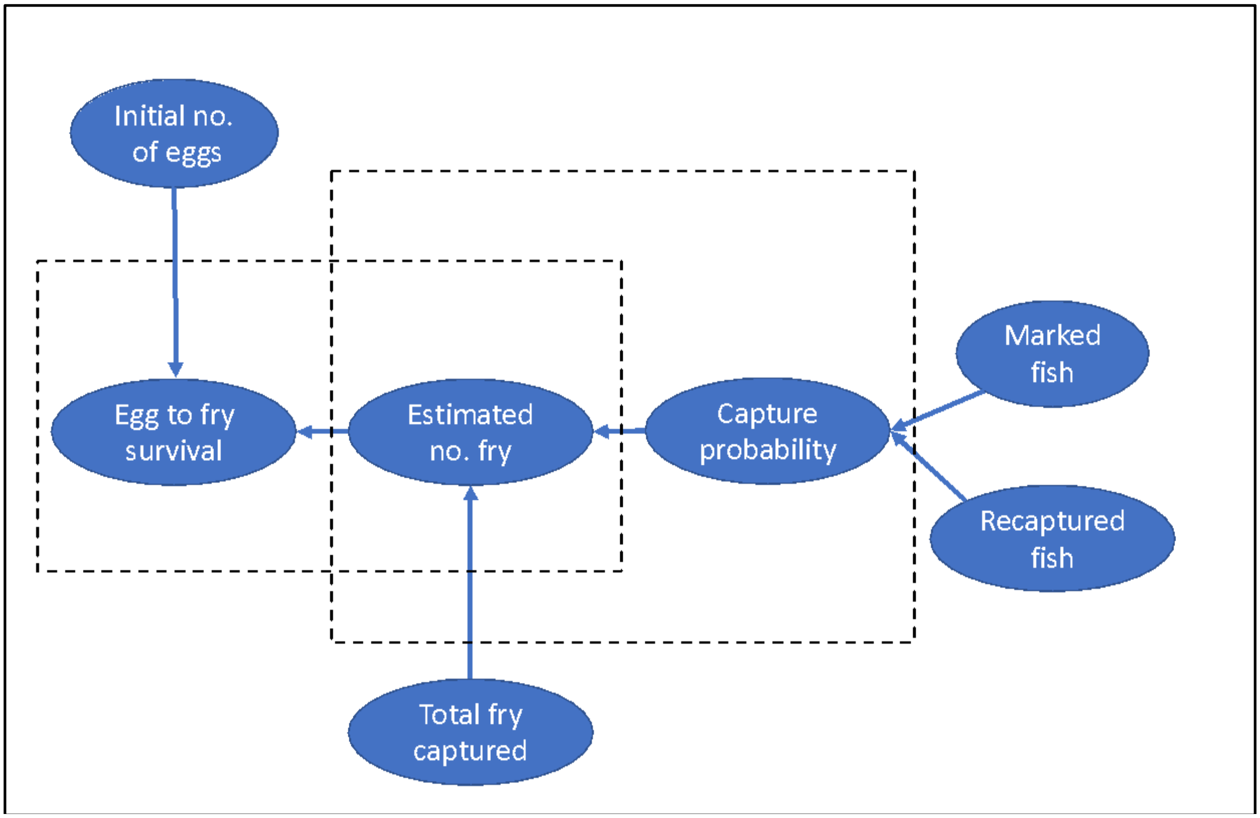

Figure 3. Directed Acrylic Graph (DAG) depicting the Bayesian approach used to estimate fry abundance and egg-to-fry survival.


Figure 4. A marked fry with a clipped lower caudal fin lobe.

2.4 Marginal Gain

We estimated the costs per fry, also known as marginal gain, for both devices used. We used an hourly wage of $12/hr to calculate costs associated with installing and maintaining the incubators and hatchboxes. We did not include travel time to the OHRC or costs of the pipes, electricity or milkcrates. These costs can vary widely, and some supplies were donated to our study. After determining our estimated costs for each device, we divided our estimated abundances to determine cost per fry. For the incubators, we used our calculated survival rate to convert estimated abundance to a value out of 100,000, as the costs to install and run the incubators are the same regardless of the quantity of eggs inside, and these devices would likely be filled to capacity in field settings.

2.5 Size of Fry

Finally, we measured fork length (mm) and weight (g) for 40 randomly selected fry from each channel. We based this number of fish on a a power analysis we performed using a dataset of fork lengths from 950 *O. tshawytscha* fry, collected from spawning areas ranging from the Willamette River to the Clackamas River mouth in 2011-2013. We estimated that 40 randomly selected fish from each stream channel would offer sufficient data to obtain a precision +/- 2.5% (with 95% confidence) for length and weight measurements. We performed t-tests to determine if the mean lengths and weights for fish from the incubators and hatchboxes were significantly different. Potential raceway effects were evaluated by examining one-way ANOVA residual plots ordered by raceway.

3 Results

3.1 Raceway Sampling

We first observed fry in the stream channels approximately 15 weeks after the eggs had been fertilized. ODFW personnel reported observations of larger schools of fry in channels with hatchboxes than in channels with incubators. Average water temperatures in the stream channels ranged between 7.2 °C and 8.3 °C. The first incubator (channel 1) was consistently 0.5-3.0 °C warmer than other channels.

Power was lost three times throughout this study in the incubator channels. The installation of alarms alerted ODFW personnel immediately, and staff quickly used a 5-gallon bucket to fill the incubators with stream water, while resetting the power to the pumps. ODFW personnel monitored the incubators after each event to ensure normal function continued. No significant loss of fish was observed as an immediate result from these events.

From a random sample of 100 fish from each hatchbox stream, 3.5% of the fry produced with the hatchbox method presented a deformity, whereby the top lobe of the caudal fin was folded downward (Figure 5a). We found an average of 62 dead fish (6.16% of the eggs) in each hatchbox when we removed them from the streams. Many of these were stuck partially inside the hatchbox (Figure 5b).

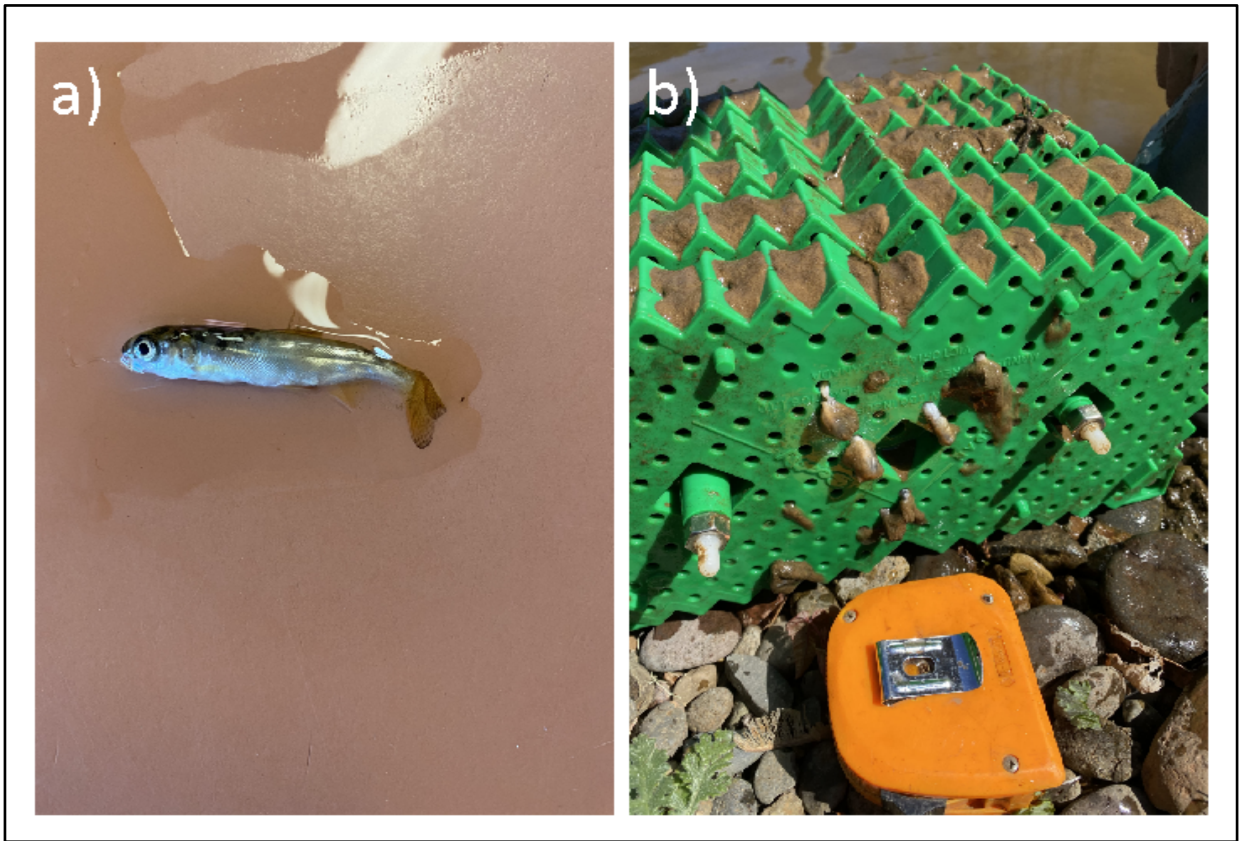

Figure 5. Shown here are a) a photo of a deformed Chinook salmon produced by the Jordan-Scotty hatchbox and b) a photo of dead fry stuck partially inside the device.

3.2 Capture Efficiency

The probability of capturing a single fry in each channel ranged from 21.46% to 47.65% (Table 1).

Table 1. Estimated capture probabilities, abundance and egg-to-fry survival in each stream channel (INC= incubator, HB=hatchbox); 95% confidence intervals are presented in parentheses next to the means. Total number of eggs supplied to each channel is also given.

Stream Channel Number	Eggs Supplied	Capture Probability	Abundance Estimate	Egg-to-fry Survival
Stream 1 (INC1)	7500	33.29% (20.0%, 48.1%)	5772 (5136, 6348)	76.95% (68.41%, 84.68%)
Stream 2 (HB1)	8000	33.33% (20.0%, 48.1%)	5143 (4554, 5698)	73.47% (64.96%, 81.43%)
Stream 3 (INC2)	7500	47.65% (32.8%, 62.7%)	4441 (3870, 5009)	59.21% (51.52%, 66.85%)
Stream 4 (HB2)	7000	21.46% (10.6%, 34.9%)	6827 (6159, 7403)	85.33% (76.96%, 92.56%)

3.3 Egg-to-fry Survival

We estimated egg-to-fry survival rates to be 76.95% and 59.21% in the incubator streams and 73.47% and 85.33% in the hatchbox channels (Table 1). Egg to fry survival in the hatchboxes was 11% greater than stream side incubators and the 95% confidence limits 3-19% indicated that the difference was statistically significant.

3.4 Abundance Estimation

We estimated abundance for the first incubator channel, the first hatchbox channel, the second incubator channel and the second hatchbox channel to be 5772, 5143, 4441 and 6827, respectively (Table 1, Figure 6).

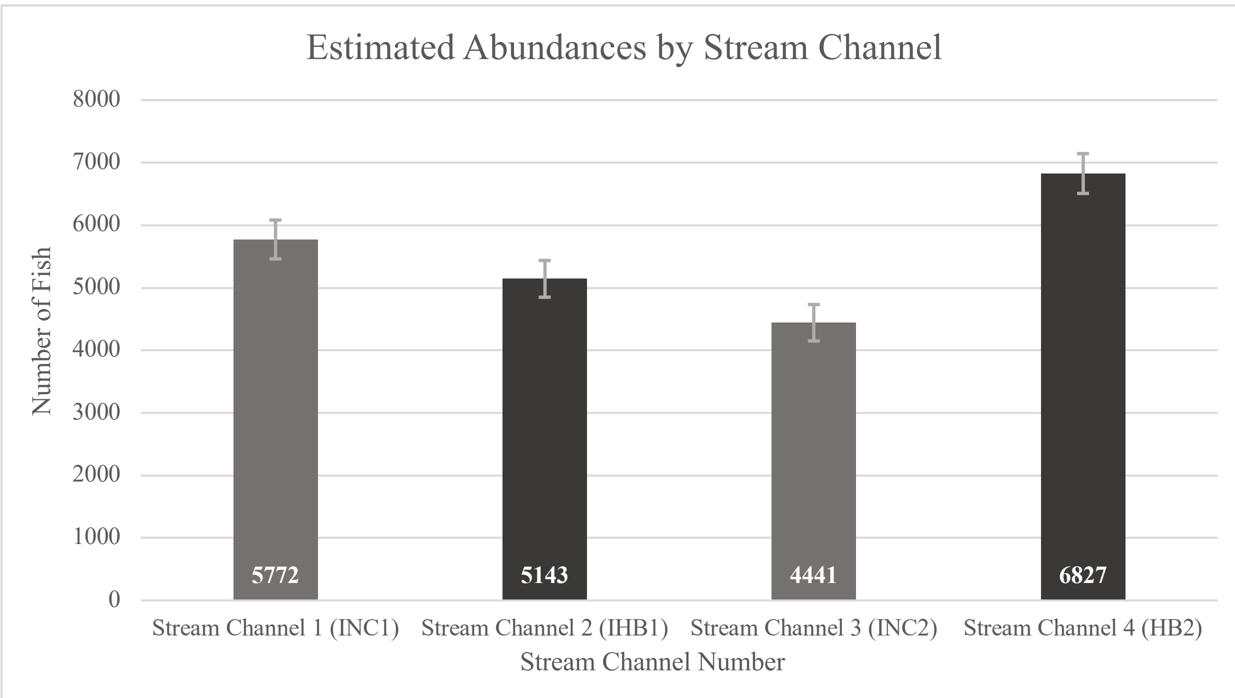

Figure 6. Estimated abundance of Chinook salmon produced in simulated stream channels with incubators (light gray bars) and hatchboxes (black bars). Error bars are one standard deviation from the estimated abundance.

3.5 Marginal Gain

We estimated the cost per fry for hatchboxes at $0.065, and $0.056 for incubators (Table 2) These costs included the purchase price, maintenance costs and installation time. We then used our estimated survival rate to determine an approximate cost per fry.

Table 2. Total costs consisting of purchase price, maintenance costs, and installation costs.

Device Type	Purchase Price	Maintenance	Installation	Total Costs	Survival Rate	Cost per Fry
Hatchbox	$675	0	$103.00	$778	0.7981	$0.065
Incubator	$3,754	$6	$42.80	$3,802.80	0.6809	$0.056

3.6 Size of Fry

We found no evidence of raceway effects based on one-way ANOVA residual plots ordered by raceway; therefore, we pooled data for replicate hatchbox and incubator streams. The t-tests indicated that the fry produced in the hatchboxes were 21.4% heavier ($p < 0.001$) and 6.79% longer ($p < 0.001$) than fry produced in the incubators (Figure 7a and 7b).

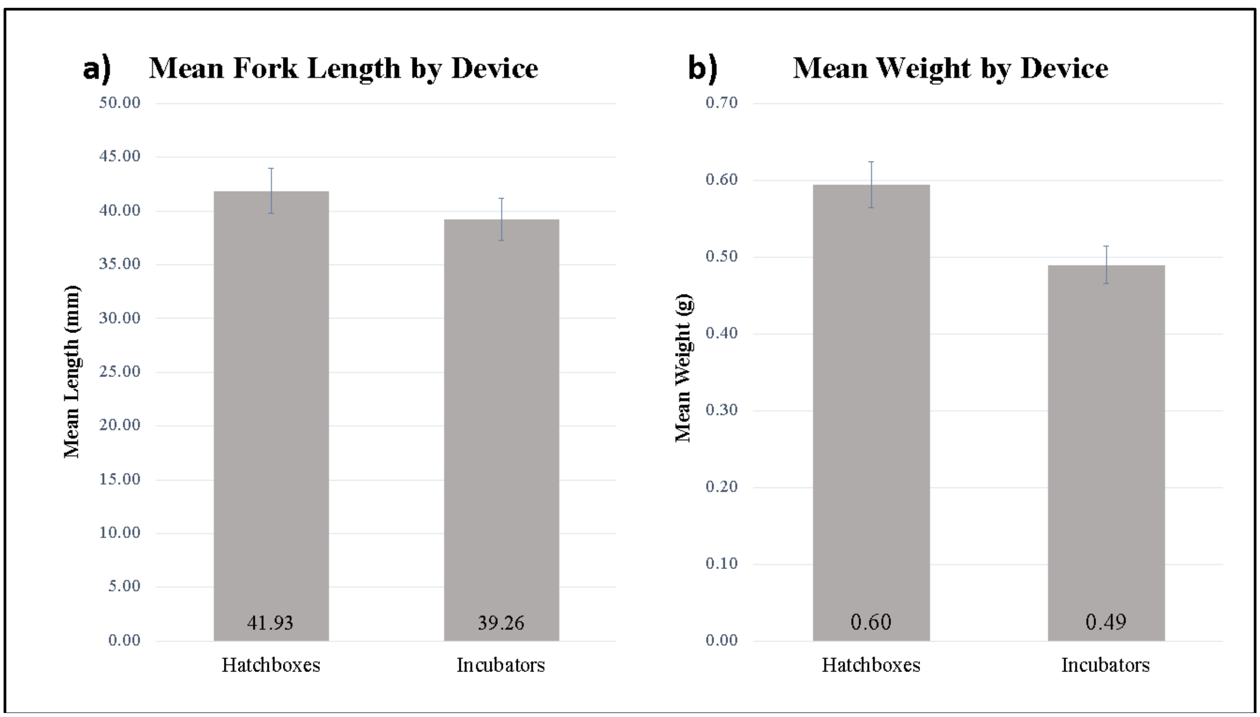

Figure 7. Shown here are a) mean fry fork length and b) mean weight for hatchbox and incubator treatments. The mean lengths and weights for each treatment are within each bar. Each graph has 95% confidence intervals.

4 Discussion

We found that both Jordan-Scotty hatchboxes and Reddzone Streamside incubators can produce meaningful quantities of fry from fertilized eggs at apparently low costs. Our findings offer information that can be used by fisheries and conservation biologists when making decisions about implementing similar methods.

Although streamside incubators can hold many more eggs than a single hatchbox, we found that hatchboxes had a significantly higher egg-to-fry survival rate (11% higher) (Table 1). The hatchboxes also produced fry that were 6% longer and 21.4% heavier than their incubator counterparts (Figure 7). While statistically significant in our experiment, this size difference of only a few millimeters might not have profound effects on survival and adult return rates.

The Reddzone Streamside Incubator requires constant water flow, and for our study we used an electrical pump to move water through the device. But this approach posed additional risk to performance. Namely, we lost power to our pumps three times throughout the study, which caused all the water to flow out of the incubators. On-site alarms and the constant presence of staff prevented mass mortality for our study. However, similar power loss incidents in situations without supervision would likely result in mass mortality of most fry. Gravity fed systems might mitigate this issue, but even pumpless systems cannot be expected to be immune to plumbing issues.

We also observed problems with the Jordan-Scotty Hatchboxes. At the end of our study, we found an average of 62 dead fish (6.16% of the installed eggs) in each box. These fish appeared to be trapped inside the boxes, unable to exit through escape holes that were too small for their size. We used the hatchboxes Jordan-Scotty manufactures for Chinook salmon, but the exit holes were still too small. This issue not only brought down the success rate of this technology, but also raises ethical concerns. The live fry we found stuck in the hatchboxes had absorbed their yolk sacs, indicating they had been stuck for as many as 4 weeks, unable to swim or find food.

Since supplementation programs aim to restore the natural production of salmon populations (Cloud & Thorgaard, 1993), efforts to produce juvenile fish are only meaningful if they lead to the return of adult spawners. For this reason, managers should consider the use of these devices if they can effectively produce adult salmon and also not harm naturally produced fish. Here we found that Chinook fry can be produced for approximately \$0.06 using streamside or in-stream incubation. That said, Thériault et al. (2010) found survival to adulthood of unfed coho salmon (*Oncorhynchus kisutch*) fry (0.09%) to be nearly 30-fold less than that of yearling smolts (2.55% survival to adulthood). Accordingly, although the cost to produce a Chinook salmon smolt by traditional hatchery methods (mean \$0.743/smolt; National Marine Fisheries Service, 2014) may be 10-fold greater than than the cost to produce an unfed fry, the return on investment – in terms of adult production – may still be greater for the hatchery smolt if relative survival to adulthood for Chinook fry and smolts resemble those of coho salmon. Assuming similar differential survival between smolts and fry of both species, we estimate the cost to produce a single adult return for hatchbox or incubator methods at \$66.67 (1,111 fry) and \$29.14 (39 smolts) for traditional hatchery methods.

Even though streamside and in-stream incubation methods may produce adult returns at twice the cost of conventional hatchery methods, we encourage managers to also consider potential tradeoffs between cost and quality. Minimized exposure to artificial conditions by juvenile salmon might allow for the selection of beneficial traits (Christie et al., 2012), and therefore lead to adult salmon with greater fitness than salmon released from hatcheries as smolts. Accordingly, onsite incubation methods may be a preferable alternative for supplementation programs that intentionally produce fish to boost natural production, albeit at higher cost of production than traditional hatchery methods.

However, these potential benefits must be weighed against risks that artificially-produced juvenile salmon may have on naturally-produced juveniles reared in the same stream. Although onsite incubation methods can likely contribute large quantities of juveniles, this approach may not be effective at producing more adults if stream carrying capacities are surpassed. Carrying capacity is described as the maximum population size that could be indefinitely sustained without degrading the ecosystem's future productivity or suitability (Odum, 1997). Fisheries yield is directly related to carrying capacity since there is a maximum fish production rate associated with the highest possible yield (Vasconcellos & Gasalla, 2001). As example, Uusitalo et al., (2005) estimated carrying capacity of rivers flowing into the northern Baltic Sea to be between 4-24 Atlantic salmon (*Salmo salar*) parr per 100 m^2 . While carrying capacity varies depending on factors such as river size, habitat quality and species, we can use such estimates to consider the application limits of methods used. If a river can only sustain 4-24 parr per 100 m^2, it might not be able to support as many as 100,000 fry or the large quantities of parr those fry will eventually become in addition to naturally produced juveniles.

Carrying capacities of marine environments are also important to consider as a growing body of evidence suggests that salmon compete for food in the ocean, leading to reduced growth, delayed age at maturation and reduced survival (Ruggerone & Irvine, 2018). High abundances of salmon in marine environments alter the biomass of zooplankton and phytoplankton, which is reflected in diet, growth and overall salmon survival (Ruggerone & Irvine, 2018). In a study by Amoroso et al. (2017), increasing quantities of pink salmon (*O. gorbuscha*) produced in hatcheries were shown to adversely affect the survival of naturally produced pink salmon in the Prince William Sound.

As populations approach carrying capacity of their environment, resource availability decreases and competition between individuals increases (Ward et al., 2006). Because of this, increased competition between artificially produced juveniles and naturally produced juveniles is inevitable as population sizes increase. This increase in competition could mean that fewer naturally produced fish are able to survive to adulthood and return to spawn. While contributions from on-site incubation methods like those considered in this study could produce large quantities of juveniles with potentially higher levels of fitness, managers should carefully consider possible consequences for wild populations.

Managers should also recognize that hatchbox and incubator methods might not be suitable for many harvest augmentation programs, as the adipose fin of fish produced with onsite devices cannot be clipped before seaward migration. Salmon produced with on-site incubators might be distinguishable from wild fish using genetic markers, but such methods are not reasonably applicable for fishermen.

It is also important to note that despite their success in producing many fry, hatchboxes and incubators likely do not address the underlying reasons for decline of most salmon and steelhead populations. While they might be useful for increasing juvenile production in locations where wild populations are critically endangered, they don't correct underlying issues surrounding habitat degradation, overexploitation, or migratory route blockage. In fact, concerns surrounding supplementation, such as genetic contamination, disease transmission and competition between hatchery and wild fish, might even be exacerbated by these methods.

We acknowledge that estimates for the production cost of a single fish can vary tremendously, depending on what expenses are included. Differences can arise through both costs calculated in our study and in hatchery methods. Due to space and resource availability, we were only able to use Chinook salmon in our study. Similar designs using other salmon species might result in variable egg-to-fry survival rates, costs per fry or fry sizes. While our devices were protected at the OHRC, we did not account for costly losses associated with theft, vandalism or destruction by wildlife that could occur in real world applications.

Although our work has demonstrated the usefulness of onsite incubation devices for juvenile salmon production, we suggest that future research be designed to compare adult return rates for salmon produced by these and traditional hatchery methods. We also recommend that the cause of the deformation to the upper caudal fin lobe and its implications on the survival of fry be explored. Lastly, more information surrounding the ramifications of such large contributions on wild salmon productivity is needed.

With the decline of important salmon and steelhead species, conservationists and managers should consider the applications of alternative rearing methods like in-stream hatchboxes and streamside incubators. Although these methods cannot fully mitigate the root causes for salmon population declines, such as habitat degradation or migratory route blockage, they may represent a useful conservation tool under some circumstances. For example, they could be useful to reintroduce juvenile salmon to areas where wild populations have been extirpated. Using in-stream hatchboxes and streamside incubators for supplementation may help alleviate some of the fitness related risks that hatchery fish pose to wild populations, through reduced juvenile exposure to hatchery conditions. All these points considered, our results still suggest that traditional hatchery methods are likely more cost effective at producing adult returns, and we suggest that managers carefully consider artificial production methods in terms of program goals and cost-benefit analyses.

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