AN ANALYSIS OF MIXED-CELL CONTAINERS TO REAR STEELHEAD AT DWORSHAK NFH IN 2009-2010

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Introduction

Currently, steelhead *Oncorhynchus mykiss* at Dworshak National Fish Hatchery (DNFH) are reared in rectangular circulation ponds, also known as Burrows ponds. The primary design features of the Burrows pond are a central divider wall and the introduction of inflow at high velocity at opposite corners of the pond. The intent is to create circulating flow through the pond that gradually moves towards the middle wall and exits grated floor drains, to more evenly distribute fish through the ponds and facilitates removal of waste (Piper et al. 1982). The current design has some inherit weaknesses. For example, the central wall makes crowding and moving fish difficult. While flow circulates as intended, velocities are not sufficient to move most particulate debris, requiring ponds to be frequently hand-cleaned. Buildup of fish waste and uneaten food creates conditions that can promote diseases outbreaks.

One alternative to the Burrows design is a mixed-cell pond which uses opposing inflow jets to create multiple counter-rotating flow fields (cells), each around a central drain (no central wall). The intent with this design is to mimic conditions of a circular tank within a rectangular pond. Water circulates and moves inward to the central floor drain and creates a vortex effect that carries away waste and uneaten food (see Watten et al. 2000; Ebeling et al. 2005; Oca and Masalo 2007). Potential benefits are a container that is easier to maintain and fish with higher condition from swimming in higher velocity flow. In one example, there is preliminary evidence that Chinook salmon *O. tshawytchsa* reared in mixed-cell ponds were leaner, had higher initial survival (during downstream migration) and lower precocial rates than fish reared in standard raceways (Brian Vinci, Freshwater Institute, *pers. comm*.).

Here, a trial of the use of a mixed-cell design was undertaken at Dworshak National Fish Hatchery (NFH) by comparing various metrics associated with rearing steelhead in two Burrows ponds modified with cells with those reared in unmodified Burrows ponds over several rearing cycles.

Dworshak NFH is located at the confluence of the North Fork and the main stem of the Clearwater River near Ahsahka, Idaho, approximately 811 km from the Pacific Ocean. Construction of the hatchery was included in the authorization for Dworshak Dam and Reservoir (Public Law 87-847, October 23, 1962) to mitigate for losses of steelhead from the North Fork Clearwater River caused by the dam and reservoir.

The hatchery was designed and constructed by the U.S. Army Corps of Engineers. Starting in 1969, the hatchery had 25 Burrows ponds on a single reuse system and 59 Burrows ponds on single-pass water. In 1972, a second phase of construction placed all these ponds on three reuse systems with the option of operating on either reuse or single-pass. In 1986, the oldest system (25 ponds) was taken off reuse and put on single-pass.

The North Fork Clearwater River (NFCWR) steelhead stock maintained by Dworshak NFH is unique. At maturity, males and females of this particular stock of "B" run steelhead average about 91 cm (36 inches) and 82 cm (33 inches) in length, respectively. Spawning stock is comprised of three age classes; 1-, 2-, and 3-ocean fish. This nomenclature refers to the number of complete years fish have spent rearing in the ocean. Fish are actually two years older than this

system indicates, as they are reared for one year in the hatchery and spend another year migrating to and from the ocean.

Goal

Evaluate the effectiveness of using modified mixed-cell ponds to improve rearing conditions and adult returns for steelhead at Dworshak NFH.

Objectives

1. Evaluate growth, condition and survival of juvenile steelhead reared in a modified mixed-cell pond.

2. Evaluate efficiency of use of a modified mixed-cell pond to rear juvenile steelhead.

Methods

In 2008, two existing Burrows ponds were modified by removing the central wall and replumbing intake jets and outflow drains to produce mixed-cell-raceways. Approximate dimensions of each raceway were 22.9 m x 5.1 m x 0.76 m. Each cell received water from four vertical pipes located at the corners of the raceway and at the intersections of adjacent cells (Figure 1). The inflow pipes were fitted with four discharge ports spaced nearly even from the surface to the floor of the raceway. Water pumped through these ports established rotary circulation in the individual cells; three of the inflow pipes supplied two cells simultaneously. Adjacent cells rotated in opposite directions. Each cell had a centrally located bottom drain through which biosolids and other waste were collected and discharged.

The modified ponds were initially tested holding rainbow trout and coho salmon *O. kisutch*. Initial concerns regarding use of the new pond design were that cleaning and removing of fish mortalities would be more difficult because of the greater pond width. Subsequently, the mixed-cell ponds, and two adjacent Burrows pond, were surfaced coated to make cleaning easier and retard algal growth. Longer nets, cleaning brooms, and crowding screens were used to care for the mixed-cell ponds.

Experiments were carried out in the two mixed-cell ponds (MC 64 and MC 66), two resurfaced Burrows ponds (BP 60 and BP 62), and two adjacent Burrows ponds with their original coarse concrete finish (BP 58 and BP 68). A schematic of the pond layout is provided in Figure 2.

The study ponds were stocked on August 5 and 6, 2009 and fish were reared until time of release on April 21, 2010 at an average of 28,497 Brood Year 2009 NFCWR steelhead per pond. All ponds were fed at the same ratio and similarly maintained according to standard operating procedures at Dworshak NFH. Fish in ponds 60, 62, 64, and 66 were marked with approximately 5,000 passive integrated transponder (PIT) tags per pond. Follow-up sampling for tag retention found an average of 4,933 PIT tags per pond. Stocking details are summarized in Table 1.

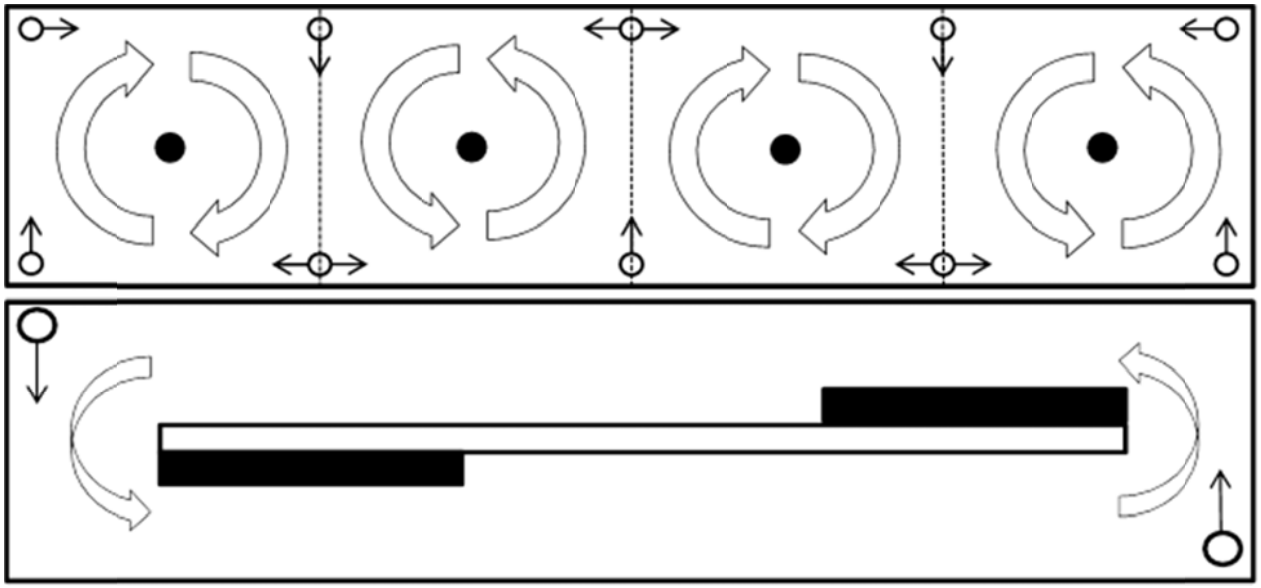


Figure 3. Mixed-cell-raceway (top) and standard Burrows pond (bottom) designs and flow patterns. Open circles represent inflow pipes. Solid circles and rectangles represent outflow floor drains.

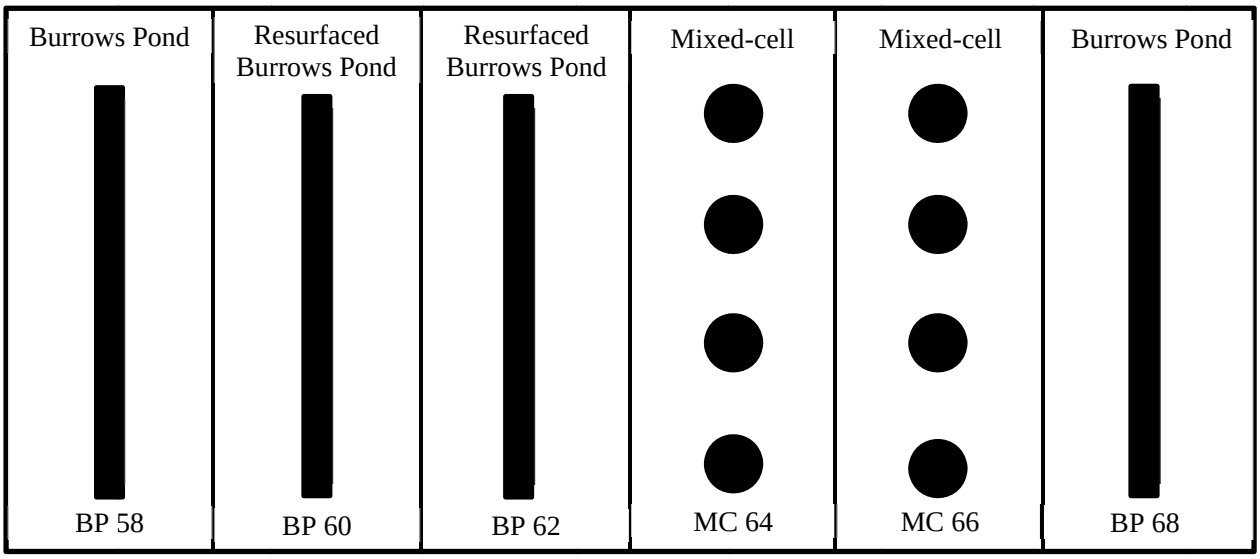


Figure 4. Mixed-cell and Burrows evaluation ponds layout at Dworshak NFH.

Mixed-cell ponds were evaluated by comparing environmental and biological variables between the two pond types. Water quality was monitored by monthly measurements of temperature, pH, dissolved oxygen, nitrite, and ammonia levels. Fish growth and condition factor was assessed by measuring length and weight from 100 fish from each pond monthly. Specific growth rate (SGR) was calculated as $(\ln(W_t) - \ln(W_i)) * 100/t$, where W_i is mean weight at the start of a measuring period, W_t is the weight at the end of that interval, and t is the number of days elapsed. At release, 30 fish from each pond were collected and sent to the Wildlife Habitat Laboratory at Washington State University for conducting proximate analysis, including measures of whole body percent moisture, ash weight, and percent lipids, and calculation of

crude protein percentage. Normal fish health assessments were also made for fish from each pond type at release.

Table 1. Mixed-cell evaluation stocking details.

Pond	Treatment	Stocking Level	PIT tags
BP 58	Uncoated Burrows	27,990	0
BP 68	Uncoated Burrows	28,231	0
BP 60	Coated Burrows	28,233	4853
BP 62	Coated Burrows	28,149	4977
MC 64	Mixed-cell	29,441	4964
MC 66	Mixed-cell	28,938	4938

Water velocities and particle removal rates in mixed-cell and Burrows ponds were measured by researchers from the University of Idaho and their results are summarized below.

Following release, time to migrate from Dworshak NFH to Lower Granite Dam, Ice Harbor Dam and Bonneville Dam was compared based on detections of PIT tagged steelhead at juvenile fish facilities at those projects. Those same detections were used to calculate survival estimates using Cormack-Jolly-Seber methods for single release events using the program SURPH 3.5.2 (Lady et al., 2013). Detections were adjusted by collection and detection probabilities associated with spill and bypass operations ongoing at the time.

Growth and condition were compared using repeated measure analyses of variance and regression; regressions were compared using analysis of covariance (ANCOVA). Proximate composition and survival were compared using multivariate analysis of variance (MANOVA). Cumulative travel time curves were compared using the Kolmogorov-Smirnov test. Travel times were compared using the Mann-Whitney U test; confidence intervals calculated using 10,000 bootstrap iterations. Survival was compared between treatments using Chi-square analyses of SURPH 3.5.2 estimates (Lady et al., 2013). All tests were significant at the alpha = 0.05 level.

Results

Water Quality

Overall water quality was relatively consistent across all study ponds and remained within levels considered safe for juvenile steelhead. Temperatures (Figure 3) ranged from a high of 10.5° C on November 17, 2009 to 5.2° C on March 11, 2010 and varied across ponds by no more than 0.8° C at any time.

Dissolved Oxygen (Figure 4) levels ranged from 9.6 mg/L to 11.1 mg/L and varied across ponds by no more than 0.5 mg/L on any sampling date.

pH levels (Figure 5) predominantly ranged from 7.0 to 7.4. Two small spikes were noted in Burrows ponds; 7.6 in BP 58 on January 21, 2010 and 7.8 in BP 60 on February 25, 2010.

Total ammonia (Figure 6) levels were 0.1 mg/L or lower at all samples save one, a reading of 0.43 mg/L in BP 68 on November 17, 2009. At no other time did total ammonia levels differ by more than 0.1 mg/L across ponds.

Nitrite concentrations (Figure 7) were typically at 0.02 mg/L or lower during the majority of the study. Nitrite levels briefly peaked at 0.06 mg/L in BP 68 on December 12, 2009, 0.07 mg/L in BP 58 on December 21, 2009, and 0.05 mg/L in BP 62 on February 25, 2010.

Mean cleaning times were not significantly different across treatments ($P = 0.24$). Mean cleaning times were 20 minutes 11 seconds, 19:02, and 20:22 for mixed-cells, newly coated Burrows ponds, and uncoated Burrows ponds, respectively.

Growth

Steelhead smolts reared in mixed-cell raceways had a mean length (Table 2) significantly smaller than smolts reared in the uncoated Burrows ponds in six of the seven months ($P < 0.0035$), and a mean length significantly shorter than smolts reared in newly coated Burrows ponds in all months ($P < 0.0003$). Mean weight (Table 3) of smolts reared in mixed-cell raceways was significantly smaller than smolts reared in coated Burrows ponds ($P < 0.003$) but not in the uncoated Burrows ponds ($P > 0.071$). Specific growth rate (Table 4) and condition (K) (Table 5) were equivalent across treatments in all months.

Table 2. Mean length (mm) of juvenile steelhead.

Pond type	10/27/2009	11/24/2009	12/23/2009	1/27/2010	2/22/2010	3/25/2010	4/21/2010
Burrows[a]	145	155	161	173	178	184	197
Burrows coated[b]	144	155	168	171	178	185	195
Mixed-cell[ab]	139	149	162	167	170	180	191

Different superscripts ($p<0.05$) indicate significant differences.

Table 3. Mean weight (g) of juvenile steelhead.

Pond type	10/27/2009	11/24/2009	12/23/2009	1/27/2010	2/22/2010	3/25/2010	4/21/2010
Burrows	32	38	43	53	57	62	72
Burrows coated[a]	32	38	48	47	57	63	70
Mixed-cell[a]	30	35	44	46	50	60	67

Different superscripts ($p<0.05$) indicate significant differences.

Figure 3. Water temperature in Burrows ponds (BP 58/68), coated Burrows ponds (BP 60/62), and mixed-cell raceways (MC 64/66), November 2009 – March 2010.

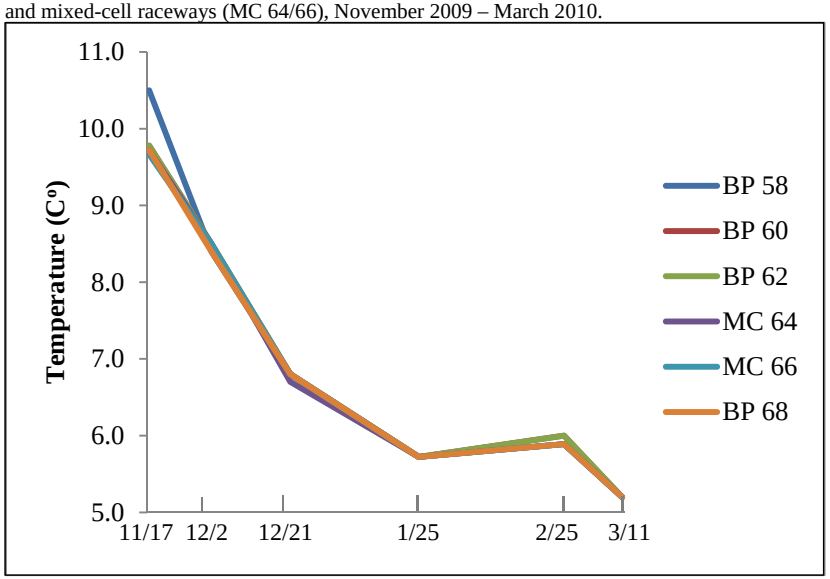


Figure 4. Dissolved oxygen in Burrows ponds (BP 58/68), coated Burrows ponds (BP 60/62), and mixed-cell raceways (MC 64/66), November 2009 – March 2010.

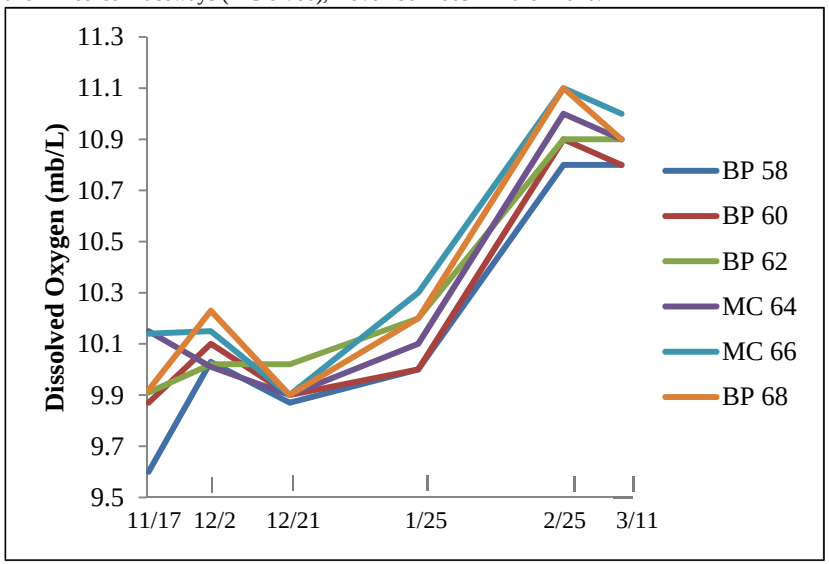


Figure 5. pH in Burrows ponds (BP 58/68), coated Burrows ponds (BP 60/62), and mixed-cell raceways (MC 64/66), November 2009 – March 2010.

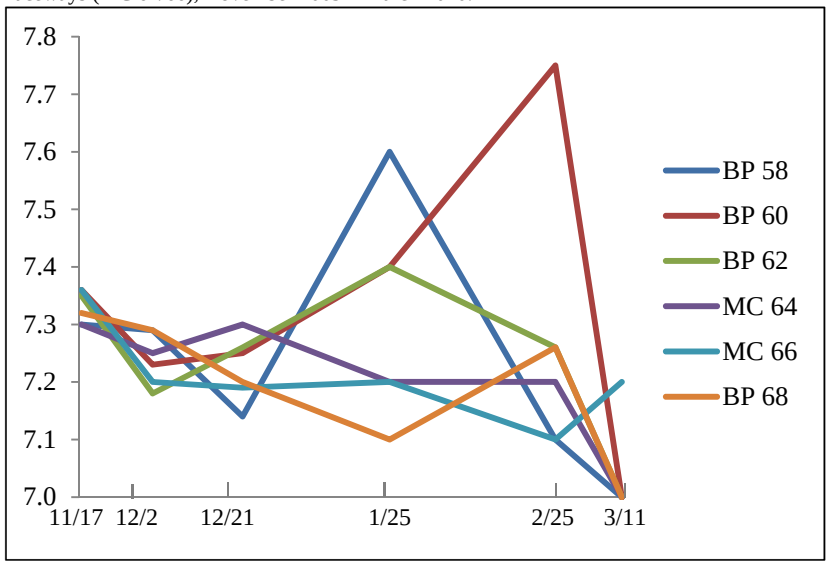


Figure 6. Total Ammonia in Burrows ponds (BP 58/68), coated Burrows ponds (BP 60/62), and mixed-cell raceways (MC 64/66), November 2009 – March 2010.

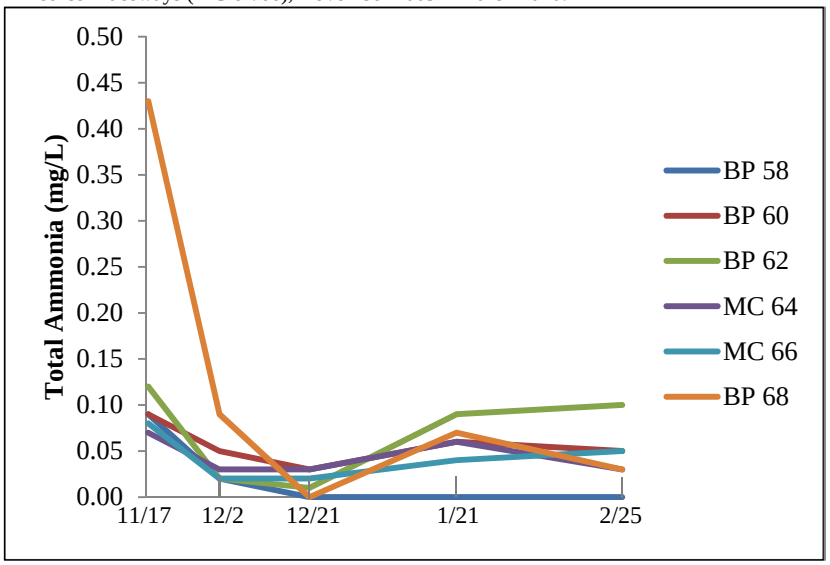


Figure 7. Nitrite concentrations in Burrows ponds (BP 58/68), coated Burrows ponds (BP 60/62), and mixed-cell raceways (MC 64/66), December 2009 – February 2010.

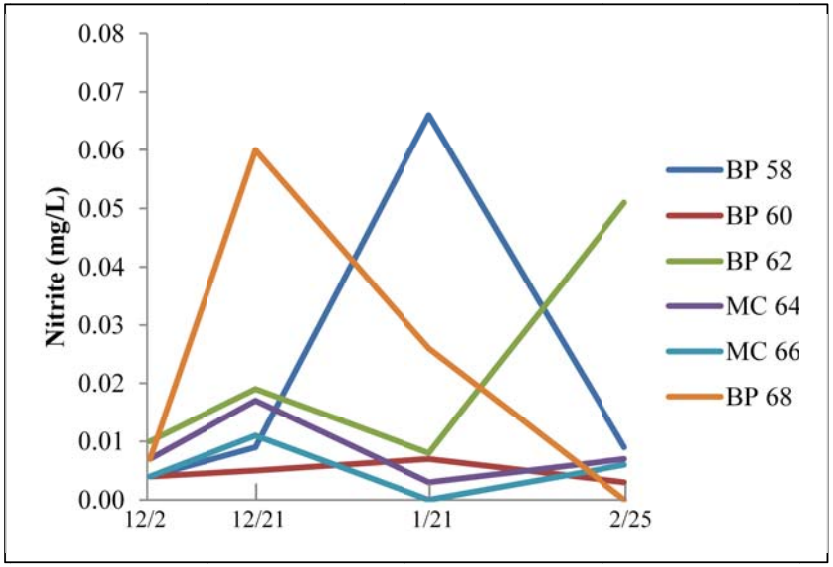


Figure 8. Weight vs. length regressions for steelhead smolts reared in Burrows ponds (m = 0.97), coated Burrows ponds (m = 0.81) and mixed-cell raceways (m = 0.77). Different letters indicate significant differences (ANCOVA, P < 0.001) between the slopes in each treatment group.

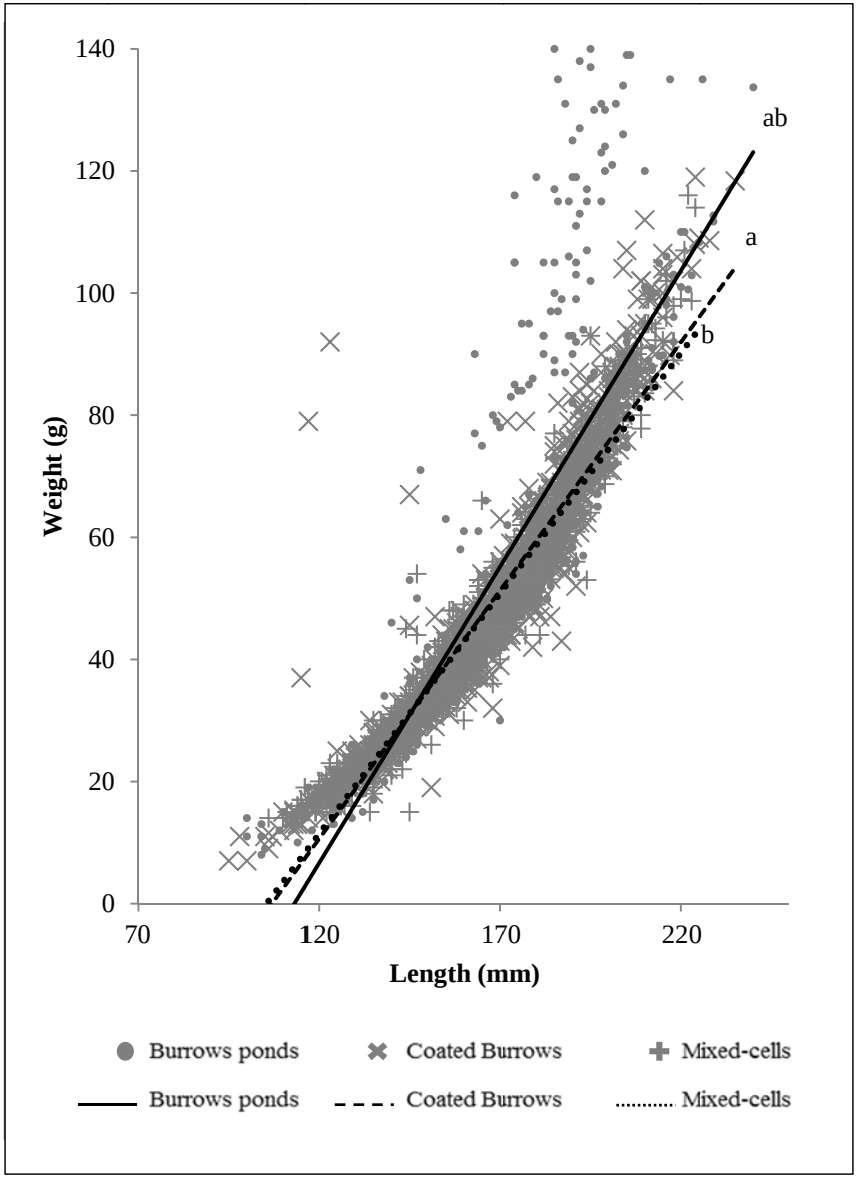


Table 4. Mean specific growth rate of juvenile steelhead.

Pond type	11/24/2009	12/23/2009	1/27/2009	2/22/2009	3/25/2009	4/21/2009	Overall
Burrows	0.59	0.41	0.60	0.26	0.29	0.54	0.45
Burrows coated	0.61	0.87	-0.08	0.76	0.29	0.37	0.45
Mixed-cell	0.57	0.72	0.15	0.31	0.61	0.41	0.45

Table 5. Mean condition (K) of juvenile steelhead.

Pond type	10/27/2009	11/24/2009	12/23/2009	1/27/2010	2/22/2010	3/25/2010	4/21/2010
Burrows	1.0262	1.0565	0.9934	0.9854	0.9738	0.9860	0.9090
Burrows coated	1.0181	0.9746	0.9977	1.0261	0.9905	1.0187	0.9250
Mixed-cells	1.0313	1.0036	1.0005	0.9545	0.9828	0.9871	0.9595

Condition was also compared among rearing treatments by regressing weight against length and comparing the resulting slopes (Figure 8). Weight at length was significantly greater in uncoated Burrows than in both coated Burrows ponds and in mixed-cells.

Mortality

Cumulative mortality was 4.42% in the uncoated Burrows ponds, 5.96% in the coated Burrows ponds, and 4.47% in the mixed cells. Chi squared testing indicates a significant difference between mixed cells and coated Burrows ponds ($Z = 127.93$, $p < 0.001$) and between coated and uncoated Burrows ponds ($Z=134.95$, $p < 0.001$). There was no significant difference between uncoated Burrows ponds and mixed cells ($Z=0.185$, $p > 0.67$).

Proximate Analysis

An initial MANOVA examined tissue composition variables among steelhead smolts samples from each treatment group. After excluding nonsignificant results, follow-up univariate analysis examined variation in Fresh Matter Moisture and Crude Protein percentages. Post-hoc Tukey's HSD tests showed that fresh matter moisture levels in steelhead reared mixed-cells were significantly higher than those found in fish reared in rough Burrows ponds and that crude protein levels were significantly higher in uncoated Burrows ponds than in the other two treatments. Proximate composition is summarized in Table 6.

Table 6. Proximate composition of steelhead reared in Burrows and mixed-cell ponds at Dworshak NFH in 2009-10.

	Dry Matter		Fresh Matter			
Treatment	Crude Fat	Total Ash	Moisture	Crude Fat	Total Ash	Crude Protein
Burrows	21.49	9.10	74.17[a]	5.61	2.33	17.88[bc]
Burrows coated	21.40	9.46	74.74	5.45	2.38	17.44[b]
Mixed-cells	20.27	9.46	75.10[a]	5.12	2.34	17.44[c]

Different superscripts ($p<0.05$) indicate significant differences.

Travel Time

Median travel time (Figure 9) for smolts from coated Burrows ponds was 8.94 days, 13.27 days, and 19.37 days to Lower Granite Dam, Ice Harbor Dam, and Bonneville Dam, respectively. Median travel time for smolts reared in mixed-cells was 9.97 days, 12.39 days, and 19.39 days to Lower Granite Dam, Ice Harbor Dam, and Bonneville Dam, respectively. Smolts reared in mixed-cell raceways arrived at Ice Harbor Dam significantly sooner than those reared in Burrows ponds; travel times to Lower Granite Dam and Bonneville Dam were similar in both treatments. No smolts in uncoated Burrows ponds were PIT tagged, as such, travel times are not available for those fish.

Cumulative travel time curves (Figures 10 – 12) were compared using the Kolmogorov-Smirnov Test. No significant differences were seen in cumulative passage curves.

Smolt survival

Juvenile survival rates of PIT-tagged steelhead (Table 7) were estimated using SURPH 3.5.2 (Lady et al., 2013) developed in the School of Aquatic and Fishery Sciences at the University of Washington. The program uses the Cormack-Jolly-Seber model (Cormack 1964; Jolly 1965; Seber 1965) for single release and multiple recapture events. Juvenile survival in 2010 was similar for both treatment regimens containing PIT tagged smolts – coated Burrows ponds and mixed-cell raceways. No steelhead from uncoated Burrows ponds were PIT tagged, therefore survival of these smolts cannot be estimated.

Table 7. Survival estimates for steelhead smolts (95% confidence intervals) reared in Burrows ponds and mixed-cell raceways. Survival is estimated from release to Lower Granite Dam, Lower Granite Dam to Ice Harbor Dam, and Ice Harbor Dam to Bonneville Dam. Overall survival reflects cumulative survival from release to juvenile detector arrays at Bonneville Dam.

	Lower Granite	Ice Harbor	Bonneville	Overall
Burrows ponds	87.2% (75.2, 103.4)	81.8% (63.4, 105.1)	56.1% (44.0, 71.9)	40.1% (33.9, 48.0)
Mixed-cells	99.3% (83.5, 121.2)	72.0% (54.6, 93.8)	60.0% (46.2, 78.9)	42.9% (35.6, 51.4).

Figure 9. Median travel time for steelhead smolts to Lower Granite (LGR), Ice Harbor (ICH), and Bonneville (BON) dams. Superscript indicates significant difference in travel time (Mann-Whitney U, $p < 0.03$).

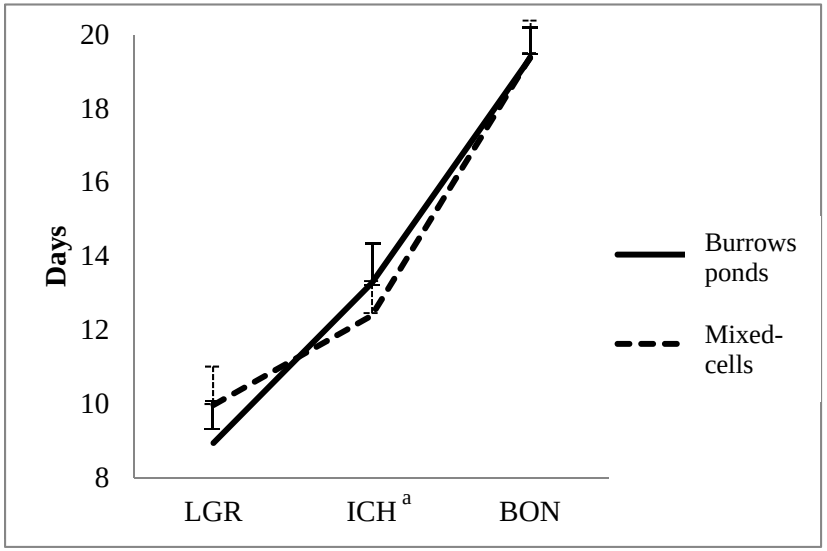


Figure 10. Cumulative proportion of steelhead smolts passing juvenile detector arrays at Lower Granite Dam in 2010.

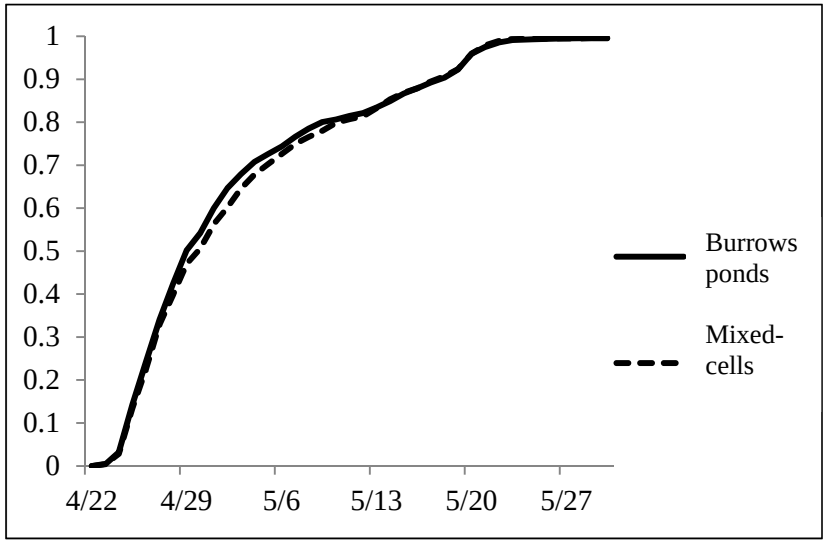


Figure 11. Cumulative proportion of steelhead smolts passing juvenile detector arrays at Ice Harbor Dam in 2010.

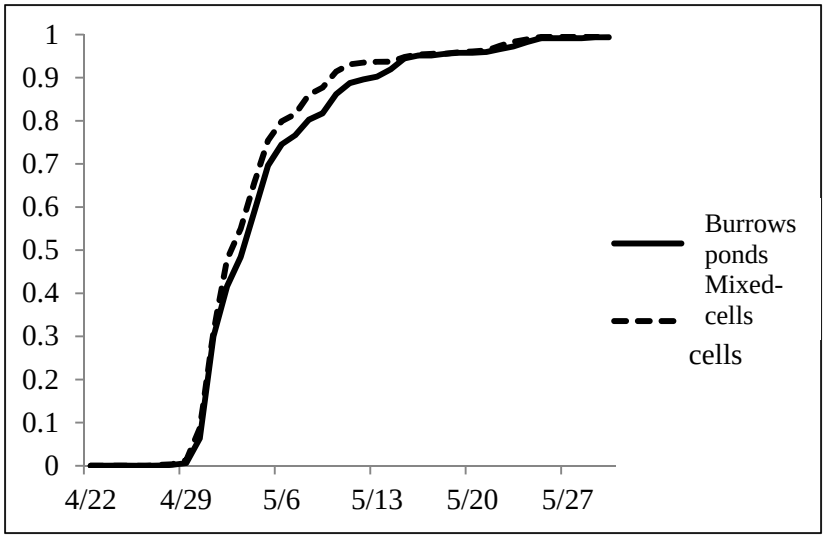
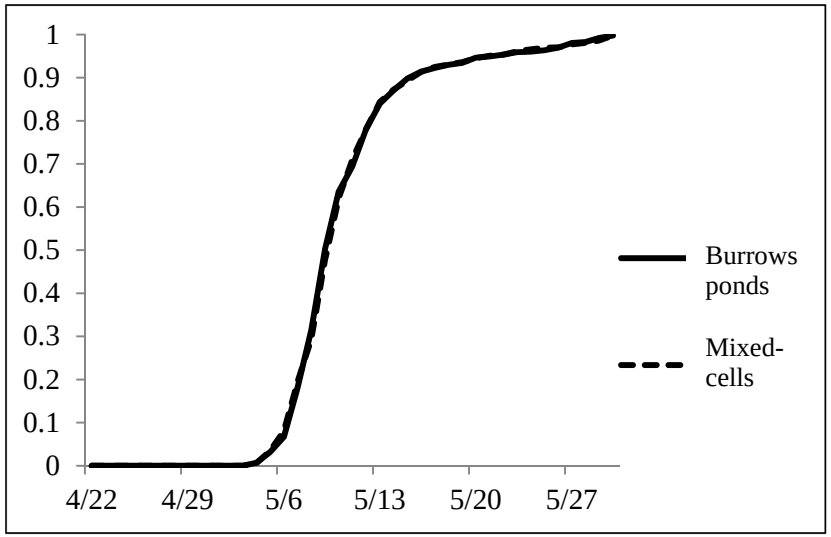


Figure 12. Cumulative proportion of steelhead smolts passing juvenile detector arrays at Bonneville Dam in 2010.



Smolt to Adult Returns

Approximately 30,000 to 60,000 PIT tagged smolts would have been needed to calculate statistically valid smolt-to-adult rates (SARs) for the two rearing groups. Actual tagging rates fell short of this goal at a little under 5,000 PIT tags per pond, and no attempt was made to assess differences in SAR for the two rearing groups. As of Return Year 2013, 62 pit-tagged adults reared in Burrows ponds in this study passed over Lower Granite Dam as adults versus 59 pit tagged adult returns from mixed cells, for SAR rates of 0.62% and 0.60% respectively. Of the fish that have returned, the 1-ocean and 2-ocean components were 13 and 49 for Burrows pond steelhead and 10 and 49 for the mixed-cell steelhead. This age distribution was not significantly different (Chi-square $p > 0.343$). Any 3-ocean aged fish will return during the 2013-14 migration year.

Discussion

While there were small differences in several variables, most important measures of pond performance did not show sizeable differences between treatments. Condition, cumulative mortality, travel times to Lower Granite and Bonneville dams, and survival to Bonneville Dam were similar for fish in all pond types. Steelhead in the mixed-cell ponds had slightly lower lipid content which may have been related to water velocities available in the rotating cells (see below), but the difference was not statistically significant. Steelhead reared in the mixed-cell ponds were smaller, on average, than fish in the Burrows ponds which may have influenced some of the performance measures. But overall, our results indicate limited improvement in the outcome from rearing of steelhead smolts at Dworshak National Fish Hatchery in the mixed-cell ponds.

While condition and weight length regressions were similar for all rearing types, mixed-cells did produce smaller smolts than Burrows ponds. However, this may be less meaningful than it appears. Steelhead at Dworshak NFH are managed for a six fish per pound size at release. This goal is accomplished by withholding feed during late January until early March, the timing calculated at the level of individual ponds. The onset and duration of feed withholding was different for each pond in the study, the intent being to manipulate growth to achieve target weight at release. As such, potential differences in growth across treatments may be masked by differing feeding regimens.

Gains were primarily seen in terms of rearing conditions and flow levels. There was significant water savings with use of the mixed-cell ponds. Typical flow volume for the Burrows ponds range 750 to 800 gallons per minute for a Burrows pond as compared to 500 to 550 gpm used in the mixed cell ponds. Even with the reduce flow, velocities and other water quality measures were comparable between the two pond types. C. Moffitt (University of Idaho; *pers. comm.*) assessed flow velocity at Dworshak NFH in 2009 and found that velocities in mixed-cell raceways averaged 23.38 cm/s with individual point measurements ranging from 12.77 cm/s to a maximum of 36.04 cm/s, and that Burrows ponds had a mean velocity of 16.86 cm/s and ranged from 5.12 cm/s to 30.50 cm/s. Water velocities greater than 15-30 cm/s are considered sufficient to transport solids to the center of a tank or cell (Burrows and Chenoweth, 1970; Mäkinen,

1988); the velocities seen in Dworshak NFH mixed-cell and Burrows ponds in this study fell within that range.

At an individual cell level, Davidson and Summerfelt (2004) reported that a rotational period of 1.3 – 1.7 minutes created optimal conditions for waste removal, as well as fish performance. The design utilized here had a cell circumference of 21.2 m for a rotational period of approximately 1.5 minutes at velocities averaging 23.38 cm/s. Particle removal efficiency was assessed by C. Moffitt (*pers. comm.*) and found to be greater in the mixed-cell raceway, where 98.15% of introduced plastic pellets were cleared from the pond in 10 minutes compared to 3.75% in the Burrows pond. After 50 minutes, 99.80% and 6.10% of pellets were cleared from the mixed-cell and Burrows pond, respectively.

Effective waste removal was also apparent in the water chemistry in the mix-cell raceways, which had minimal levels of ammonia and nitrite in all samples. Water chemistry in the Burrows ponds was not significantly worse, although several isolated spikes in nitrite were noted. Water quality was well within safe levels in all study ponds.

The self-cleaning properties of the mixed-cell raceways were not reflected in shorter cleaning times. Qualitative observations made by Dworshak NFH animal caretakers focused on difficulties of cleaning algae from the tank walls of all ponds. Equivalent cleaning times may reflect a smaller contribution of manually flushing biosolids to total cleaning effort than was assumed. Preliminary studies of mixed-cell raceways at Dworshak NFH indicated lower algae levels in mixed-cells than Burrows ponds, but that effect was not documented in 2009-2010. Equivalent cleaning times across all study ponds indicates that the initial concerns of aquaculture staff regarding potential difficulties in cleaning wider ponds were not manifested.

Losordo and Westers (1994) found that flow velocities in the range of 0.5 – 2.0 times fish body length are ideal for fish health, muscle tone, and respiration. Water velocity profiles in all ponds were in the range considered suitable for optimal smolt performance, and few differences in fish condition were seen between mixed-cell and Burrows ponds in this study. At a mean velocity of 23.38 cm/s in mixed-cell raceways, mean flow ranged from 1.7 body lengths per second in October to 1.3 body lengths per second at release in April. In Burrows ponds, a mean velocity of 16.86 corresponds to 1.2 body lengths per second in October, falling to 0.9 body lengths per second in April. Mixed-cells saw less variation in velocity than Burrows ponds and therefore likely greater volume at optimal flow conditions. However, our results suggest that flow velocities in Burrows ponds at Dworshak NFH create flow conditions sufficient to produce smolts of a similar quality to those reared in mixed-cell raceways but at a higher flow requirement.

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