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Performance and Behavior of Rainbow Trout Reared in Covered Raceways

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Abstract.—Rainbow trout (*Oncorhynchus mykiss*) were reared in outdoor concrete raceways either with or without plywood covers. Growth, feed conversion, and mortality were not significantly different between the two groups after 215 d. Autopsy-based health and condition variables were not significantly different between the two groups. Fin length measurements were also not significantly different, indicating no reduction in fin erosion due to rearing in covered raceways. Fin erosion was worst at the end of the study (mean fin indexes, 1.45 and 1.60), but signs of fin erosion also occurred in the first autopsy sample when the fish were about 10 g each (mean fin indexes, 0.8 and 1.0). In an outdoor observation tank, single fish were observed for 5 min. Preference for the covered end of the tank was evident among fish from both covered and uncovered raceways ($P < 0.001$) and did not differ between treatments. Observations were also made for four-fish groups over a 45-min period either in the presence of a stuffed eagle or without it. During the first 15 min, fish from covered raceways stayed under cover more frequently than fish from uncovered raceways when the eagle was present. No significant differences in cover preference between fish from cover or no-cover treatments were noted during the second and third 15-min periods or when all periods were pooled. There was a tendency for all groups to seek cover less frequently in each successive time period.

Salmonids in nature are known to prefer cover (concealment), the degree of preference depending somewhat upon the species and temperature (Butler and Hawthorne 1968; DeVore and White 1978), size of the cover (Heggenes and Traaen 1988), age of the fish (Kwain and MacCrimmon 1969), and light intensity (McCrimmon and Kwain 1966; Woodhead 1957; Gibson and Keenleyside 1966). Preference by salmonids for low light intensities is often ignored in intensive outdoor fish culture, although some fish culturists do cover portions of raceways.

Research on the effects of cover in aquaculture is limited, but a few results have been reported. Covers on concrete troughs did not affect growth or mortality of coho salmon (*Oncorhynchus kisutch*) alevins, but the combination of cover and substrate resulted in a higher mean weight than achieved by alevins in uncovered troughs with the plastic substrate (Fuss and Johnson 1988). Channel catfish (*Ictalurus punctatus*) cultured in circular tanks with or without covers did not differ in growth, feed conversion, or survival (Allen 1973). Research with lake trout (*Salvelinus namaycush*) reared in covered or uncovered rearing troughs and fed by hand or demand feeders indicated that hand-fed fish in covered raceways were heavier and more active when startled (Roadhouse et al. 1986). Problems with sunburn lesions on Atlantic salmon (*Salmo salar*) were solved when circular pools were covered with saran cloth providing 90% shade (Corson and Brezosky 1961). Hatchery manuals also advise against exposure of eggs and alevins to direct sunlight (Piper et al. 1982; Stickney 1991).

Poor survival of hatchery-reared fish relative to wild fish has been observed (Flick and Webster 1964; Berg and Jørgensen 1991), raising concerns about the effect of hatchery rearing on the behavior of fish (Olla et al. 1992). Some authors attribute the poor survival to an inability to obtain enough food, due possibly to inefficient foraging behavior (Reimers 1963; Ersbak and Haase 1983). Others cite the excessive activity and aggressiveness of hatchery fish, behavior that would lead to greater energy expenditure, less time spent feeding, and greater exposure to predators (Moyle 1969; Symons 1969).

We were interested in determining any possible behavioral differences in cover selection between fish reared in covered or uncovered raceways. This study also compared the performance, health, and condition of fish between fully covered and uncovered raceways.

Methods

Rainbow trout (*Oncorhynchus mykiss*) of the Shepherd of the Hills (Missouri) strain were reared at the Fisheries Experiment Station from eggs supplied by the Egan Hatchery, Bicknell, Utah. On

22 April 1992, equal numbers (4,000) of fish were stocked into each of four outdoor raceways 73 d after hatching. Two raceways were completely covered and two were uncovered except for nylon bird netting (hereafter referred to as uncovered). Covers were constructed of plywood sheets cut to fit within the raceway walls and nailed to wooden supports that crossed the width of the raceway. Holes were cut for demand feeders (Babington Enterprises, Hagerman, Idaho), and a 150-cm section of plastic pipe around the rod insured that all the feed made it from the feeder mouth to the raceway.

Measurements of light intensity at the bottom of covered and uncovered raceways were conducted with an integrating quantum radiometer–photometer (model LI-188B, LI-COR, Inc.) with the probe oriented horizontally. Measurements of direct sunlight were also made.

The initial mean individual weight of fish was 1.46 g. Rations were initially hand-fed; the quantity for each raceway was calculated by the hatchery constant method (Buterbaugh and Willoughby 1967). Care was taken to disburse feed to both covered and uncovered raceways similarly. On 24 June 1992 (day 63), when the fish had reached a mean weight of about 9 g, the fish were switched to demand feeders for the remainder of the study. The demand feeders were continually replenished so fish could feed ad libitum. Flows initially were 291 L/min; they were increased near the end of the study period to 349 L/min and finally to 465 L/min. Flow indices (Piper et al. 1982) during the study ranged from 0.63 to 0.99 and were below the maximum limits for the hatchery. The water temperature was a constant 17°C, and total hardness and total alkalinity were 239 and 222 mg/L, respectively. Dissolved oxygen during the latter period of the study was low at the lower end of the raceways (3.7–5.0 mg/L), prompting removal of a portion of the population from each raceway on day 170 (23.8 kg removed per raceway) and again on day 182 (22.1–28.2 kg removed per raceway).

Autopsy-based health condition profiles (HCP; Goede and Barton 1990) were conducted bimonthly; 10 fish were taken per raceway replicate to give a 20-fish sample for each treatment. On day 190, the HCP sample was also used for measurement (nearest mm) of maximum fin lengths of all fins of all 20 fish. Fin measurements were made parallel to the fin rays. The adipose fin was measured from the anterior junction with the body to the rear of the lobe. The fin index was modified such that it ranged from 0 (fin intact) to 2 (severe fin erosion) instead of from 0 to 3 (Goede and Barton 1990).

Mean weights were determined monthly, based on a mean of three grab samples of 16–110 fish each. Fish for this sample were crowded to the head end of the raceway with a screen and netted from the churning mass. The experiment was terminated on day 216 (24 November 1992).

Observations of behavior.—The influence of cover on behavior was observed in two experiments. In one experiment, we observed the preference of single fish for cover. In the second experiment, we observed groups of four fish. In the first experiment, a single fish was netted from either an uncovered or covered raceway, placed in a bucket of water, carried several meters to a fiberglass observation tank (208 × 55 × 35 cm), and netted into the center of the tank. A plywood board (69 × 55 cm) shaded one end of the tank, providing cover over approximately one-third of the tank area. No water flowed into the tank during the observation period to avoid rheotaxic biases. The cover was alternated between ends of the observation tank to insure that selection was for cover and not tank related. Each fish was given 1 min to acclimate before any observations were recorded. Observations were made from a blind, and the position of the fish was recorded at 15-s intervals for 5 min. Twenty observations were made per fish and six fish per treatment were observed.

In the second experiment, four fish were netted into the tank for each trial. A video camera, which displayed the time of day on the video tape, was used to record the position of each fish relative to cover during 45-min trials. The fish were again allowed 1 min to acclimate before observations began. The position of each fish was observed at 15-s intervals during the first 5 min and at 1-min intervals thereafter for 40 additional minutes. This protocol was followed five times for each treatment, a different group of fish being used each time. An additional four replicates per treatment were conducted to determine if there were any differences in cover selection in the presence of a predator model: a stuffed golden eagle (*Aquila chrysaetos*) with its wings spread, placed at the edge of the cover. In both tests, the observations were conducted only on sunny days between 1000 and 1600 hours.

Statistical analysis.—The SAS computer program (SAS Institute 1988) was used for all statistical analyses, and a significance level of $P < 0.050$ was measured for each test. For analysis of the fin length measurements, each length was scaled to total body length (Kindschi 1987). These relative fin lengths (percentages of body length) were tested for normality (Shapiro–Wilk statistic), and the variables that failed the test were rank-transformed and compared between treatments with the Wilcoxon test. Behavioral data (mean number of times a single fish was under cover) were similarly tested. Normal variables were analyzed with the t-test. Chi-square analysis was used in the behavioral tests to compare expected and observed cover preference. Because the cover occupied one-third of the observation tank area, the fish would be located under cover one-third of the time (40 of 120 possible observations) if the distribution were random.

For analysis of the four-fish groups observed for cover preference, the 45 observations (1-min intervals) for each group were averaged and this mean was used in the nonparametric tests. For further analyses, the 45 observations were divided into three subsets of 0–15, 15–30, and 30–45 min. The Wilcoxon test was used to compare (1) cover preference between fish from covered and uncovered raceways with the eagle present or not (separate tests), (2) cover preference within a treatment (covered or uncovered) between observations with the eagle present or not, and (3) cover preference between the observations with and without the eagle present, observations of fish from covered and uncovered raceways combined.

The categorical data of the HCP (eye, gill, pseudobranch, thymus, liver, kidney, spleen, gut, bile, fin, and opercle) were analyzed with chi-square maximum-likelihood tests (Fienberg 1980). To reduce the number of zero cells in the frequency tables and to make the analysis more meaningful, some categories were combined. The eye and liver categories were reduced to two categories, normal or abnormal. Categories 0 and 1 of bile were combined, as were categories 3 and 4 of mesenteric fat.

Blood variables, length, weight, and condition factor were tested for normality with the Shapiro–Wilk statistic. Plasma protein and condition factor proved to be normally distributed, so these were analyzed with a t-test for each sampling period; the homoscedasticity assumption was tested with the folded form F-statistic. Length, weight, hematocrit, leucocrit, and thymus, fat, bile, and fin index values were rank-transformed prior to analysis of variance within each sampling period.

Results

Light intensity measured on two days was 0.238 and 0.292 μEinsteins (μE) at the bottom in the covered raceway. In an uncovered raceway, the light levels at the bottom were 31.0 and 64.8 μE, or 130 and 222 times as great, respectively, as levels at the bottom of the covered raceway. Light levels at the bottom of the covered raceway averaged 0.0035% of full sunlight compared with 0.61% at the bottom of the uncovered raceway.

There were no significant differences in any of the HCP variables between fish reared in covered and uncovered raceways. After 215 d, there was no significant difference in mean body weight between covered (90.8 g) and uncovered raceways (103.1 g; Figure 1). Feed conversion (weight of feed fed/weight gained by fish) ranged from 1.07 to 1.22 among raceways and did not differ among treatments. Mortality ranged from 3.25 to 4.80% among raceways, and was also not significantly different among treatments.

There were no significant differences in the relative fin length of any fin between fish from covered and uncovered treatments (Table 1). Fin erosion was greatest at the end of the study (mean fin indexes were 1.45 and 1.60 in covered and uncovered raceways, respectively). However, signs of fin erosion also occurred in the first HCP sample, when the fish averaged about 10 g (mean fin indexes, 0.8 and 1.0 in covered and uncovered raceways, respectively).

Fish stocked individually in the observation tank were under the cover during 98 of 120 observation times for each treatment (Table 2). This preference for cover was significant ($P < 0.001$). There were no differences in cover preference between fish from covered and uncovered raceways during the 5-min test period.

Fish stocked into the observation tank in groups of four were also significantly more likely to be under cover (chi-square test, $P < 0.001$). In the presence of the eagle, fish from covered raceways stayed under cover more frequently than fish from uncovered raceways during the first 15 min. In tests without the eagle, there was no difference in cover preference (Table 3). No significant differences in cover preference between treatments (covered versus uncovered raceways) were noted during the second and third 15-min periods or when all periods were pooled. Overall, observa-

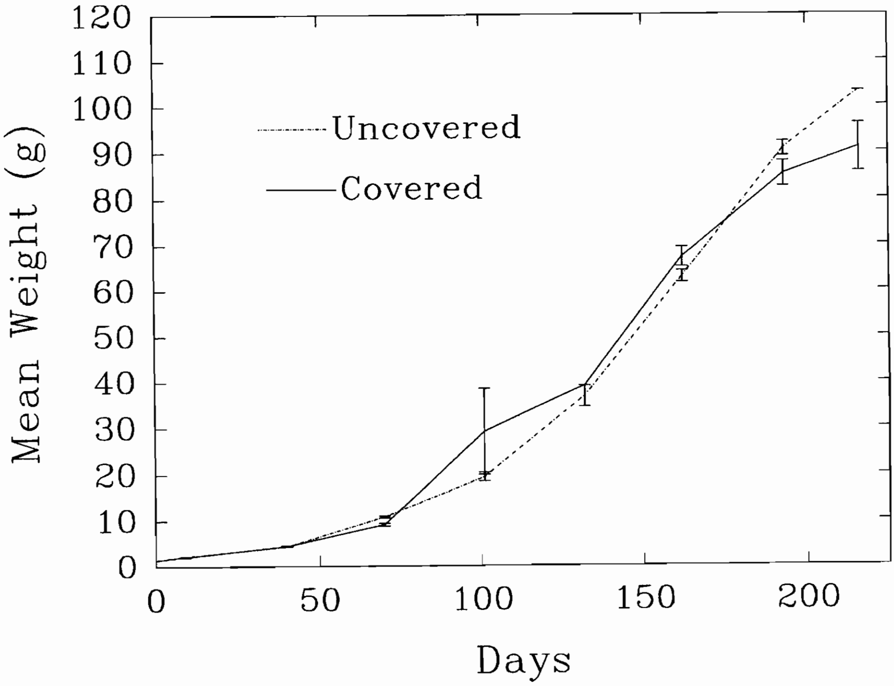

FIGURE 1.—Mean body weights (±SD) of rainbow trout reared in covered or uncovered raceways.

tions with and without the eagle present showed that fish spent less time under cover during each successive time period. There were no significant differences in cover use in the presence of a potential predator when statistical comparisons within a treatment were made for each 15-min segment and the 45-min period overall. When covered and uncovered treatments were combined, there was no significant difference in the cover preference between observations with the eagle present and without.

Discussion

Growth of rainbow trout was not significantly improved with the use of covered raceways. Pickering et al. (1987) also observed no difference in growth of rainbow trout and brown trout (*Salmo trutta*) after 5 months in circular tanks with 67% cover. Total darkness has been found to reduce growth of fish below growth in normal photoperiods (Pyle 1969); conversely, extended hours of light have increased the growth of rainbow trout (Pyle 1969) and Atlantic salmon (Saunders and Harmon 1990; Stefansson et al. 1991). In our study the light levels were low, but diffuse light still entered the upper and lower portions of the raceway.

TABLE 1.—Mean relative fin length (% of total body length ± SD) of rainbow trout reared in covered or uncovered raceways.

Fin	Covered	Uncovered
Dorsal	5.0 ± 2.78	4.9 ± 3.32
Caudal	11.5 ± 0.89	12.0 ± 1.51
Adipose	7.8 ± 0.72	8.3 ± 1.03
Anal	10.3 ± 1.27	10.7 ± 1.02
Right pectoral	10.3 ± 2.16	11.2 ± 2.22
Left pectoral	10.1 ± 2.23	10.1 ± 2.73

TABLE 2.—Frequency of cover selection by individual rainbow trout observed at 15-s intervals over 5 min (20 observations/fish) in a tank covered at one end. Six individuals were randomly selected from covered and uncovered raceways.

	Number of times observed under cover for fish from:	
Fish number	Covered raceways	Uncovered raceways
1	0	20
2	19	20
3	20	1
4	20	17
5	19	20
6	20	20
Mean	16.3	16.3

TABLE 3.—Mean (±SD) number of fish under cover during observations at 1-min intervals for 45 min in the presence of a potential predator or without. Fish from covered and uncovered raceways were observed in a tank covered at one end. The sample size (N) indicates the number of groups (four fish each) observed for each treatment.

	Stuffed eagle present		Stuffed eagle absent	
Minutes	Fish from covered raceways (N = 4)	Fish from uncovered raceways (N = 4)	Fish from covered raceways (N = 5)	Fish from uncovered raceways (N = 5)
0–15	3.8 ± 0.11[a]	2.5 ± 0.21[a]	3.0 ± 1.04	3.3 ± 0.72
15–30	2.6 ± 1.43	2.1 ± 0.11	2.2 ± 1.35	2.8 ± 0.93
30–45	1.7 ± 1.17	1.6 ± 0.40	2.0 ± 1.11	2.6 ± 0.86
0–45	2.7 ± 0.89	2.0 ± 0.11	2.4 ± 1.05	2.9 ± 0.77

[a] Significantly different between fish from covered and uncovered raceways (Wilcoxon test, $P < 0.05$). All other paired comparisons indicated nonsignificant differences ($P > 0.05$).

This presumably gave the fish enough photoperiodic cues to grow normally.

There were no differences in the HCP variables among fish from covered and uncovered raceways. Similarly, there were no differences in feed conversion or mortality among the two groups. This indicated that lower light levels, isolation from view of hatchery personnel, and other factors associated with cover had no effect on normal health and growth. Pickering et al. (1987) observed no differences in mortality or hematology of rainbow or brown trout due to cover. However, Pickering et al. (1987) did note signs of chronic stress and reduced growth among Atlantic salmon without access to cover.

We had anticipated that the lower light in the covered raceways and the use of demand feeders might reduce aggressive behavior. Fin erosion may result from fin nipping (Abbott and Dill 1985); therefore, a reduction in aggressive behavior might lead to healthier fins. Kalleberg (1958) observed that fish did not defend territories at night. Stringer and Hoar (1955) observed that nipping increased with increasing light up to about 26.9 lx, and above this there was a deceleration and a leveling of the number of nips at 43.0 lx (0.40% of full sunlight). No reduction in fin erosion was observed in our study, probably because light levels were well above the sight threshold of rainbow trout (McCrimmon and Kwain 1966).

Kalleberg (1958) and Symons (1968) observed that aggressive behavior was associated with feeding, particularly when food was limiting. Feeding to satiation alleviated the fin erosion problem in some studies (Wolf 1938; Larmoyeux and Piper 1971). Although no controls were used to test the effect of demand feeders per se, the use of demand feeders did not eliminate fin erosion. However, fin erosion was mild until the end of the study, when the fish loading was greatest and oxygen concentrations were low.

There is evidence that rearing environment affects such fish behaviors as the startle reaction to a visual stimulus (Roadhouse et al. 1986) and aggressiveness (Hoelzer 1987; Olla et al. 1992). In this study, there appeared to be only a slight difference in the preference for cover between fish reared in covered and uncovered raceways. The only difference between the two treatments was for the initial 15-min period of the four-fish groups observed in the presence of the stuffed eagle. Fish from covered raceways selected cover more frequently in this case, but the lack of significant differences in the latter periods, or overall, suggests that the fish rapidly habituated to the stuffed eagle. Our findings are congruent with those of Roadhouse et al. (1986), who reported that lake trout reared in covered troughs were significantly more active following a visual startle stimulus (bird silhouette), suggesting a greater responsiveness to potential predators. It was evident in both the single-fish and four-fish studies that fish still sought cover. This innate survival behavior was present in these fish regardless of rearing method and despite several generations of domestication.

In conclusion, completely covered raceways appeared to produce a slight change in behavior, but it is difficult to assess the true effect of this change on survival in the wild. Given the logistical problems with covered raceways (such as cleaning and daily observations of general vigor) and the lack of benefits to growth, food conversion, and general health, we do not recommend covers for the practical rearing of domesticated strains of rainbow trout. However, covers may be useful for other species and for solving particular problems such as preventing sunburn or avian predation.

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