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The Effects of Fry Rearing Density on Hatchery Performance, Fin Condition, and Agonistic Behavior of Rainbow Trout *Oncorhynchus mykiss* Fry

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Abstract

Rainbow trout *Oncorhynchus mykiss* fry were reared at four densities ranging from 10,800 to 43,926 fish/m^3 (9.91 to 37.60 kg/m^3) during an initial feeding period of 35 d. Each of the four initial density treatments were then split into high (3,780 fish/m^3) and low (1,890 fish/m^3) density groups and reared in outdoor raceways for an additional 74 d. A necropsy-based general health and condition assessment indicated that hematocrit, plasma protein, and the thymus index were significantly elevated in the outdoor high density group. Changes in these variables were unrelated to the initial rearing density, except for plasma protein which decreased as the initial density increased at low densities. Other necropsy variables indicated normal, healthy fish. Agonistic behavior was assessed at 4, 9 and 13 wk of age by observing the number of aggressive chases in paired and group (five fish) trials. The number of chases generally increased with age, although the difference between 9 and 13 wk was variable. Feeding did not elicit more chases in this study except for 9-wk-old fry. Initial rearing density did not have any impact on the number of chases at 4 or 13 wk, but at 9 wk the number of chases increased with initial density for the group tests. Relative fin length measurements of all fins except the adipose indicated no combination of initial density and outdoor density was superior to another for reducing fin erosion. This study indicated that rainbow trout fry may be reared at initial densities approaching 44,000 fish/m^3 (Piper density index of 1.1) without negatively affecting growth and fin condition or inducing higher levels of agonistic behavior later on.

To attain high post-stocking survival and return to the creel, the stocking of high quality fish must be as important an objective as maintaining quality habitat. One aspect of fish quality is fin condition. Eroded fins may be accompanied by microbial infection or hemorrhage (Schneider and Nicholson 1980; Goede and Barton 1990), resulting in partial fin loss (Kindschi et al. 1991). Fin erosion can potentially affect swimming ability and survival in the wild (Saunders and Allen 1967; Nicola and Cordone 1973).

Fin erosion is common in hatcheries where high densities of fish are reared (Kindschi et al. 1991; Bosakowski and Wagner 1994a). Bullock and Snieszko (1981) correlated fin erosion with density; however, Soderberg and Meade (1987) found that fin erosion in Atlantic salmon *Salmo salar* could not be attributed to rearing density alone.

Rearing densities can affect the agonistic behavior of juvenile fish (Keenleyside and Yamamoto 1962; Fenderson and Carpenter 1971). For example, Todd (1968) found that the degree of aggression for juvenile yellow bullhead *Ictalurus natalis* was inversely correlated with density. Fin nipping is an aggressive behavior of many salmonids and may be a major cause of fin erosion (Abbott and Dill 1985). Modification of aggressive behavior by manipulating environmental variables may reduce fin erosion and improve the survival and aesthetic quality of cultured fish.

The hypothesis tested by this study was that early rearing density of fry influences aggressive behavior later in life. This in-

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vestigation evaluated the effect of four fry rearing densities upon fin erosion, hatchery performance, aggressive behavior, and general health of juvenile rainbow trout *Oncorhynchus mykiss.*

Materials and Methods

Rainbow trout (Sand Creek strain) were reared at the Fisheries Experiment Station in Logan, Utah, USA, from eggs supplied by the Egan Hatchery. On 11 November 1994, fry were placed into eight fiberglass troughs (2.12 × 0.33 × 0.127 m, rearing space dimensions) at four densities: 10,799, 21,940, 33,060, and 43,926 fish/m^3 (Piper (1972) density indices of 0.27, 0.55, 0.82, and 1.10, respectively). Densities at the end of the indoor rearing period expressed as weight per unit volume were 9.91, 20.86, 30.18, and 37.60 kg/m^3. Water flow to each trough was 38 L/min. After 35 d (16 December 1994), the fry had reached average mean weights of 0.86–0.95 g and were transferred from the hatchery troughs to outdoor raceways where each of the treatments were then split into a high and low target density of 3,780 (0.50 density index) and 1,890 fish/m^3 (0.25 density index). This resulted in eight treatments, hereafter referred to by the initial density index-outdoor density combination: 0.27low, 0.27high, 0.55low, 0.55high, 0.82low, 0.82high, 1.10low, and 1.10high. The eight treatments were randomly assigned to sixteen outdoor raceways (7.62 × 0.91 × 0.38 m). In order to maintain target densities, crowding screens were adjusted monthly to accommodate projected growth rates. At the end of the study, maximum densities were 15.48 kg/m^3 among low density raceways and 31.60 kg/m^3 among high density raceways.

Fish were hand fed a commercial diet (Silvercup trout) ten times daily from week 1 to week 3; eight times daily during week 4, decreasing to six times daily by week 10; and four times daily until week sixteen when the experiment was concluded. The ration varied from 4.5% of body weight at the beginning of the experiment to 4.0% at the end. Water quality values in the outdoor raceways at the end of the study were as follows: water flow rate, 37.9 L/min; temperature, 17.2 C; total alkalinity, 171–222 mg/L; incoming pH, 7.5–7.6.

Necropsies were conducted on 28 February 95 using 20 fish per treatment, following the Health/Condition Profile (HCP) system (Goede and Barton 1990). A random sample of fish was dipnetted by a person not conducting the HCP. In this fashion the HCPs were not biased by the observer having prior knowledge of the treatment. Fish were euthanized with 100 ppm of MS-222 (tricaine methane sulfonate) and all fish were examined by one person. A sample of ten fish was taken from each raceway, except in three treatments in which one of the replicate raceways was dropped from the study due to excessive predation by a mink. In these treatments (0.27low, 0.27high, 0.55high), 20 fish were taken from the single replicate left in the treatment. Similarly, samples for the 13-wk behavior test were taken from the remaining replicate of these treatments. This action was justified by the lack of significant replicate (raceway) effects (*t*-tests), indicating that raceway effects were not impacting the number of chases or HCP variables. The HCP fin index was modified in that fins were considered to be eroded with or without active infection and hemorrhaging. Thus, a perfect fin received a '0' score, 1 = slight erosion, and 2 = severe erosion. In addition to the HCP fin observations, maximum fin lengths were also measured to the nearest mm on 15 December 1994 and 28 February 1995, and "relative" fin lengths were calculated (fin length/total length × 100, Kindschi 1987).

Feed conversion ratios (weight of food fed/weight gain), mean weight, and mortality data were derived from hatchery records. Mean weight was determined monthly from three random grab samples taken from fish crowded to the head of the trough or raceway.

Behavior Tests

Fish behavior was recorded during week 4, 9, and 13 of the experiment. The behavior trials were conducted in six rectangular (620 × 325 × 415 mm) aquaria, each with three covered sides and a transparent glass front. Temperature of the aquaria fluctuated haphazardly due to air temperature during the trials within a range of 13–17.2 C, but the variation was distributed across all treatments. Behavior was monitored and recorded by video observation (Panasonic Palmcorder PV-10 with aid of a wide angle lens, and JVC GR-SZ7U Super VHS camcorder). Paired trials consisted of two fish of similar size from each treatment, and group trials used five fish from each treatment. Experimental protocols were otherwise the same for both the paired and group trials.

Fish were netted randomly from each treatment and were transferred into one of six aquaria placed side by side. Fish in each aquarium could not see fish in another. Fry were allowed to acclimate to the aquaria for a period of 2 h. The tanks were aerated, but water was not exchanged during the acclimation and observation process. Preliminary observations revealed that 2 h of acclimation were sufficient for the fish to settle down and begin interacting normally. Longer acclimation periods (e.g., 24 h) resulted in dominance being established with little interaction to observe. Immediately following the 2-h acclimation, behavior was videotaped for a total of 60 min. Thirty minutes after the onset of video recording, a small ration of food pellets (approximately 2–3% of the combined body weight of the pair/group) was introduced to the aquarium to test if agonistic behavior differed when food was present. The stocking times were staggered so that two trials could be videotaped while the next four trials could be simultaneously acclimated. Six replicates were conducted for each combination of treatment, group size (pairs or groups), and age, resulting in 240 h of observation. Fish were not returned to their respective rearing units after testing. Total body weight and total length were recorded for each fish to test the effect of size on agonisfic behavior.

The number of aggressive chases were recorded for two 30-min periods, one prior to feeding, and the other immediately after the food was introduced. Video tapes were reviewed, freezing frames if necessary to document a chase. An aggressive chase is defined here as a short-lived (1–2 sec), rapid, aggressive charge toward another individual (Keenleyside and Yamamoto 1962), eventually culminating in one fish fleeing. Dominance was concluded to be established if: 1) a fish successfully defended a particular area of the tank; 2) a fish continually chased others out of its territory; and 3) an individual retained its territory throughout the 60-min trial. Nips were not recorded due to the small size of the fry and the inability to accurately verify the behavior.

Statistical Analysis

Analyses were performed with either SPSS for the personal computer (SPSS Inc., Chicago, Illinois, USA) or a mainframe version of SAS (SAS Institute Inc., Cary, North Carolina, USA). A probability level of 0.05 was used for each test. Normality was tested for each variable using the Lilliefors test. If a natural log or arc-sine transformation did not normalize the distribution, the data were rank transformed for further analysis. The number of paired chases at week 4 were rank transformed for two-way ANOVA, testing for differences among the four initial density treatments. Paired chases at age 9 and 13 wk were also rank transformed and analyzed by a four-way full factorial model that included initial density, time relative to feeding, age, and outdoor density (low/high). Significant interactions prompted a separate three-way full factorial analysis for each age. Comparison of group behavior data was similar, except that the 4-wk data were normally distributed and there were no significant interactions in the four-way ANOVA of the rank-transformed 9 and 13-wk data.

Analysis of the influence of size difference on the number of chases in paired trials and the establishment of dominance were conducted with the maximum likelihood chi-square test and ordinary least squares regression. Relative fin lengths were normally distributed for all fins except the caudal. The relative fin lengths were analyzed separately for each sampling date. For the first sample, a full factorial two-way ANOVA model including initial density and replicate (raceway) was used. For the second sample, the outdoor density was included as an additional factor in a general linear model (the SAS GLM procedure) approach that used contrasts to properly compare the treatment effects, adjusting for the missing replicates. This GLM model was also used to analyze necropsy variables (length, plasma protein, hematocrit, leucocrit, fat index, fin index, and thymus index). The indices, hematocrit, and leucocrit were rank transformed prior to analysis. Condition factor was normalized with a log transformation. Loglinear analysis was used to analyze categorical variables of the HCP. If significant, categorical data were further tested by maximum likelihood tests of partial tables.

Results

Feed conversions did not differ significantly among initial density treatments. Percent mortality in the outdoor raceways was significantly greater in the lower densities than in the higher density treatments (Table 1). This difference was largely attributable to the mink predation upon fish in those particular raceways, although treatment effects cannot be ruled out. Final mean weights ranged from 10.7 to 13.0 g and differed among the eight initial-outdoor density treatments (Fig. 1). However, no pattern in mean weight was apparent relative to initial or outdoor density. Mean weight was greatest in the 0.55high and lowest in the 1.10high density treatments.

TABLE 1. *Final mean feed conversion and percent mortality for rainbow trout after rearing at four density indices (Piper 1972) for 35 d and at high and low outdoor densities for an additional 74 d. Means with a common letter are not significantly different.*

Initial density index	Feed conversion[1] (feed fed/weight gain)	Mortality[2] (%)
0.27	0.79	13.68a
0.55	0.82	5.25ab
0.82	0.84	4.50b
1.10	0.84	4.80b

[1] Total degrees of freedom = 12, F-value for density effect = 1.569.

[2] Total degrees of freedom = 12, F-value for density effect = 8.562.

Relative dorsal fin length was significantly greater at the 0.27 rearing density than at the higher rearing densities in the first sample (day 34), but was significantly lower in the second sample (Table 2). Relative pectoral fin length in the first sample differed between left and right; only the left pectoral had shorter fins at the higher densities. In the second sample (day 109), the right pectoral fin was significantly shorter in the 0.55high treatment. Relative caudal fin length in the first sample was significantly lower at the highest rearing density (1.10) than in the other three treatments, but there was no difference related to initial rearing in the second sample. This pattern was similar for the ventral fins as well. In general, relative fin length differences were variable over time and density, with no one density resulting in better general fin condition than another.

Necropsy data indicated that the fish were generally healthy with no differences among density treatments. A few of the variables differed among treatments, but raceway effects were not significant. Plasma protein, hematocrit, and the thymus index were significantly higher in fish reared at high outdoor densities than low ($P < 0.001$) when pooled across replicates (raceways) and initial density treatments. At low outdoor densities, plasma protein decreased as the initial density increased

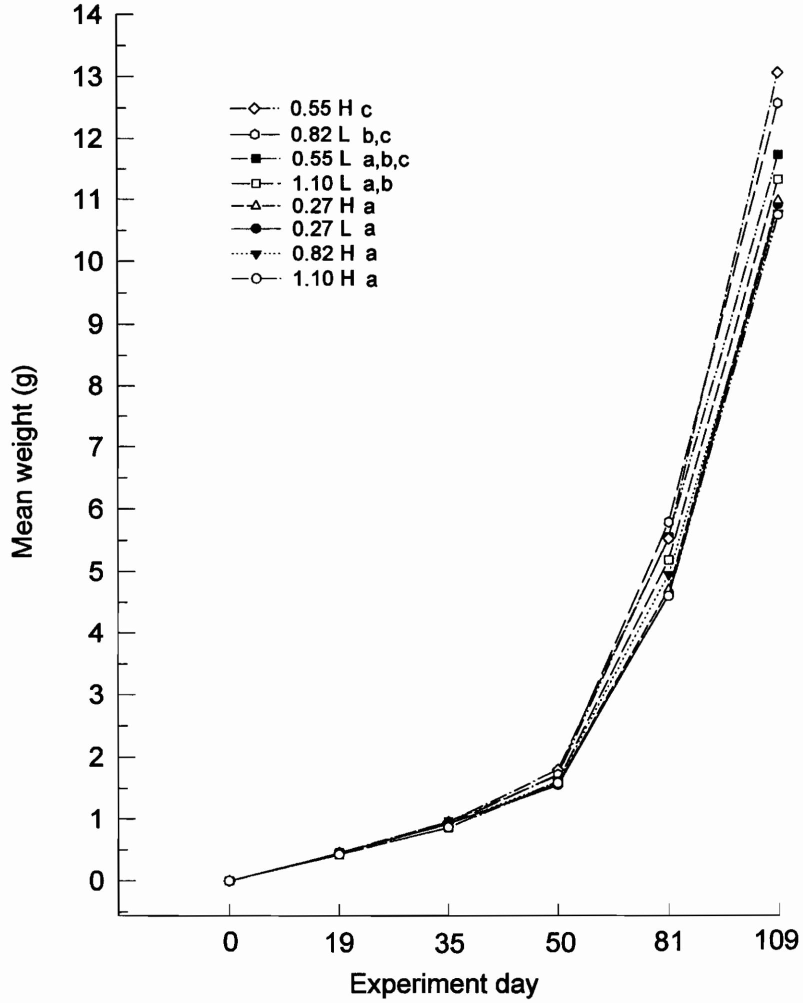

FIGURE 1. *Mean weight of eight groups of rainbow trout initially reared for 35 d at four different densities and subsequently split into high (H) and low (L) densities for 74 d. The numbers in the legend are initial density indices. A common lowercase letter indicates no significant difference among the density treatment means.*

(Table 3). At high outdoor densities, there were no significant differences in plasma protein related to initial density. Hematocrit, leucocrit, and the thymus index did not follow any trend related to initial density, whether reared at high or low outdoor densities (Table 3). Condition factor was significantly higher in fish reared at the low outdoor density than the high density, but did not follow any pattern regarding initial density.

Behavior Tests

At week 4, 9, and 13, the number of chases in the paired fish trials did not differ among the four initial densities (Tables 4, 5). Post-feed chases in paired trials were significantly higher than pre-feed chases at 9 wk ($P = 0.001$), but not at 4 or 13 wk (Fig. 2). At 9 and 13 wk, the number of chases in the paired trials were also unaffected by the outdoor density.

For group trials, the number of chases at

TABLE 2. *Relative fin lengths (mean ± standard deviation) of rainbow trout held at four densities for 35 d and transferred to low or high densities in outdoor raceways. A common letter among means for each fin or no letter indicates no significant difference.*

Age-Outdoor density	Initial density index			
Fin	0.27	0.55	0.82	1.10
Day 34—indoors				
Dorsal	11.1 ± 0.96a	10.2 ± 0.81b	9.6 ± 1.22bc	9.4 ± 1.28c
Caudal	14.7 ± 1.01a	14.5 ± 0.79a	14.5 ± 0.84a	13.8 ± 0.68b
Anal	13.0 ± 1.39a	11.6 ± 0.97b	12.7 ± 1.47a	12.3 ± 1.62ab
Left ventral	10.5 ± 0.91a	10.4 ± 0.80a	9.7 ± 1.04b	9.2 ± 0.96b
Right ventral	10.5 ± 0.91a	10.4 ± 0.80a	9.7 ± 1.04b	9.2 ± 0.96b
Left pectoral	10.8 ± 0.84a	10.7 ± 1.02a	10.0 ± 1.35b	10.3 ± 0.81ab
Right pectoral	10.8 ± 1.06	10.6 ± 0.57	10.2 ± 1.16	10.4 ± 0.93
Day 109—low density				
Dorsal	5.8 ± 1.72a	6.0 ± 1.89a	6.9 ± 1.19b	7.1 ± 1.01b
Caudal	13.9 ± 0.92	13.5 ± 0.76	14.0 ± 1.13	13.9 ± 0.79
Anal	11.3 ± 1.20a	10.5 ± 0.70b	10.4 ± 1.16b	10.7 ± 0.76b
Left ventral	10.6 ± 0.83	10.9 ± 0.55	10.7 ± 0.51	11.0 ± 0.53
Right ventral	10.6 ± 0.83	10.9 ± 0.55	10.7 ± 0.51	11.0 ± 0.53
Left pectoral	12.4 ± 1.11	12.2 ± 0.84	12.0 ± 1.10	12.0 ± 0.74
Right pectoral	12.3 ± 0.54	12.2 ± 0.71	12.3 ± 0.99	12.3 ± 0.79
Day 109—high density				
Dorsal	4.3 ± 1.32a	5.5 ± 1.07b	5.2 ± 1.64b	5.3 ± 1.06b
Caudal	13.3 ± 0.84	13.7 ± 0.96	13.3 ± 0.71	13.6 ± 0.93
Anal	10.5 ± 1.00a	10.6 ± 1.08a	10.7 ± 0.67a	11.1 ± 0.86b
Left ventral	10.7 ± 0.66	10.7 ± 0.59	10.5 ± 0.58	10.9 ± 0.77
Right ventral	10.7 ± 0.66	10.7 ± 0.59	10.5 ± 0.58	10.9 ± 0.77
Left pectoral	11.3 ± 0.97	11.0 ± 0.76	11.3 ± 0.77	11.5 ± 0.95
Right pectoral	11.5 ± 1.18a	10.9 ± 0.96b	11.3 ± 0.77a	11.5 ± 1.01a

TABLE 3. *Health and condition profile data from 109-d-old rainbow trout held in raceways at high or low densities after initial rearing for 35 d at four densities. A common letter indicates no significant difference among the initial density treatment means (N = 20) within an outdoor density treatment. Abbreviations: K_{TL} = condition factor (weight in g/length^3 × 10^5). Hct = hematocrit, and Lct = leucocrit.*

Outdoor density Initial density index	K_{TL}	Fat index	Fin index	Thymus index	Plasma protein	Hct (%)	Lct (%)
Low							
0.27	1.12a	2.9a	0.9a	0.5a	3.87a	48.0a	0.18a
0.55	1.18b	3.0a	0.9a	0.5a	3.53ab	47.3a	0.25b
0.82	1.16ab	3.0a	0.8a	0.6b	3.25b	45.8a	0.45c
1.10	1.19b	3.0a	0.9a	0.5a	3.10b	46.9a	0.05abc
High							
0.27	1.15ab	3.0a	1.0a	0.4ab	4.08a	50.3a	0.10a
0.55	1.12a	3.0a	1.0a	1.1a	4.08a	50.0b	0.10b
0.82	1.16b	2.9a	1.0a	1.1ab	3.98a	47.2a	0.28a
1.10	1.17b	3.0a	1.0a	0.8b	3.98a	48.8ab	0.20a

TABLE 4. *Mean ± SE and median number of pre-feed and post-feed chases (paired and group trials) for the four different initial densities for 4-wk-old rainbow trout.*

	Pre-feed		Post-feed	
Density	Mean	Median	Mean	Median
Paired				
0.27	4.5 ± 2.9	0.0	9.7 ± 4.6	6.5
0.55	9.7 ± 8.5	0.0	10.8 ± 6.4	3.0
0.82	2.7 ± 2.5	0.0	12.7 ± 5.5	11.5
1.10	19.5 ± 9.9	14.5	7.5 ± 4.8	0.5
Five fish group				
0.27	33.5 ± 6.4	31.5	52.5 ± 12.7	51.5
0.55	40.7 ± 14.3	37.5	59.7 ± 15.3	48.5
0.82	45.3 ± 7.2	47.0	82.2 ± 16.4	84.5
1.10	66.3 ± 2.8	68.5	65.8 ± 7.3	61.0

4 wk did not differ among the initial density treatments or before or after feeding (Table 4). When 9- and 13-wk data (Table 5) were analyzed together in a four-way ANOVA model, the number of chases were unaffected by time relative to feeding and outdoor density. However, initial density and age were significantly different ($P = 0.037$ and 0.001, respectively), with a higher number of chases at 9 wk (median, 57) than 13 wk (median, 36). A subsequent one-way ANOVA for each age indicated that the number of chases in groups of five fish increased significantly with initial rearing density at 9 wk ($P = 0.025$), but not at 13 wk. Age effects were significant when tested separately for pre-feed and post-feed data, pooling across replicates and densities. Median chase number values were greater at 9 wk (5) and 13 wk (6) than at 4 wk (0) prior to feeding. After feeding, median values were greater at 9 wk (16) than at 13 wk (6), and both were significantly greater than the median value at 4 wk (2.5).

TABLE 5. *Median number of chases observed for 30-min periods prior to and immediately after feeding among either pairs or five-fish groups of 9- and 13-wk-old rainbow trout fry initially reared for 35 d at four densities and transferred to low (1,890 fish/m³) or high (3,780 fish/m³) densities in outdoor raceways.*

	Age (wk)							
	9				13			
Outdoor density	Low		High		Low		High	
Time relative to feeding	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Group size Initial density index								
Pairs								
0.27	3.5	17.5	0.0	22.0	12.0	13.0	0.5	7.0
0.55	9.5	18.5	7.5	6.0	12.5	11.0	5.0	4.0
0.82	2.0	1.5	9.0	33.5	9.5	10.0	12.0	5.0
1.10	2.0	12.0	5.0	16.5	8.5	1.5	5.5	0.5
Five-fish groups								
0.27	23.0	27.5	34.5	53.5	43.5	26.5	37.5	34.0
0.55	58.5	81.5	60.0	63.0	62.5	59.0	33.5	13.5
0.82	74.0	51.0	60.5	87.0	40.0	31.0	23.0	57.5
1.10	83.0	60.0	45.5	84.0	30.5	37.5	53.0	43.0

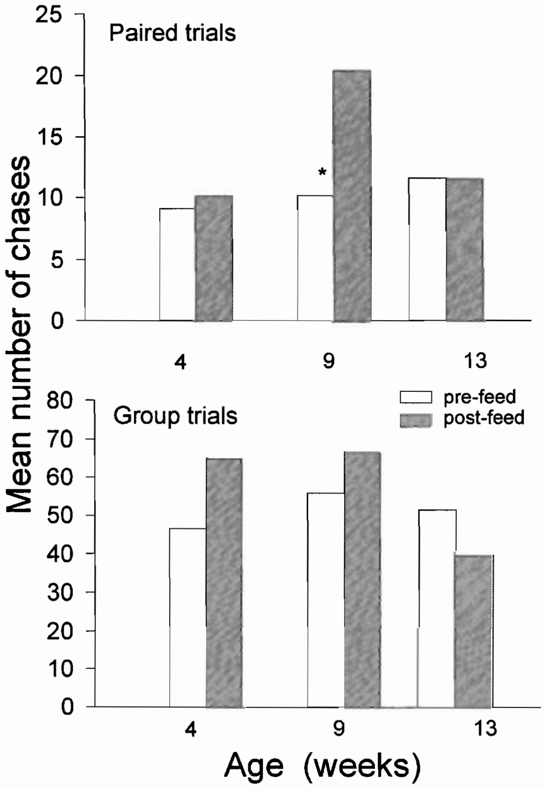

FIGURE 2. *Comparison of the mean number of chases for a 30-min period before and after feeding for rainbow trout of three different ages in paired and group trials. A significant difference between feeding periods is indicated by an asterisk (*).*

At 4 wk, there were 13 of the 48 replicates in which there were no aggressive chases during the hour of observation. To test a possible relation between chases and size differences between the two fish, the replicates were classified into one of four categories based on weight difference (<0.200 or >0.200 g) and the presence or absence of chases. No significant differences were observed when all the data at 4 wk were pooled. The establishment of dominance by the time the fish were observed was similarly tested. Chi-square analysis of pooled data (week 4) indicated that the lack of chases was unrelated to the presence or absence of dominance.

At 9 wk, correlations between the number of chases in paired trials and the difference in weight (r^2 = 0.057) or length (r^2 = 0.041) were not significant. For both 9- and 13-wk data, plots of the difference in weight or length between pairs and dominance were insignificant, similar to the wk-4 data, and not influenced by initial density.

Discussion

Impacts of environmental conditions during the fry stage upon behavior are only beginning to be understood. These conditions may mold later behavior, a phenomenon well documented in birds and mammals (Alcock 1975). For example, adult mice reared in groups during youth fought more readily than animals isolated at 20 d of age. Later tests showed that most of the effect was produced in a 10-d period just after weaning, and that similar experience as adults produced little or no effect (Scott 1962). Similarly, fox terriers reared in isolation during a critical period would not initiate conflicts (Scott 1962).

The identification of critical learning periods or of the effects of early experience upon fish behavior has only begun. Olla et al. (1992) observed that aggressive behavior of chum salmon fry (*Oncorhynchus keta*) was greater for fish fed a lower ration. Higher population densities increased aggressiveness of gopher rockfish *Sebastes carnatus,* an effect that was not reversible (Hoelzer 1987).

In this study, the effect of early rearing density on aggressive behavior was not apparent. The behavioral observations and fin erosion data both indicated that early rearing densities in the ranges tested did not impact later aggressive interactions. Outdoor rearing densities from 1,890 to 3,780 fish/m^3 had no impact on the number of chases observed for either pairs or groups. Some authors have noted that agonistic behavior was more prevalent at higher densities (Kalleberg 1958; Keenleyside and Yamamoto 1962; Cole and Noakes 1980). It should be noted that these studies had more fish in a tank, and hence had more aggressive interactions, similar to the increase in chases observed for the five-fish groups relative to pairs in this study. Fenderson and Carpenter (1971) scaled nipping to a rate (nips per fish per h) and still observed density effects; however, these effects were related to the density condition at the time of the test and were not related to the prior rearing density of the fish as in this study.

Decreases in aggressive behavior at higher densities have been noted by Fernö and Holm (1986) for Atlantic salmon in aquaria at densities ranging from 0.6 to 4.39 fish/L. Kalleberg (1958) noted that Atlantic salmon parr were "slower in exhibiting aggressiveness the longer they had previously been exposed to the influence of over-crowding."

The number of chases generally increased with age, although the difference between 9 and 13 wk was variable. Cole and Noakes (1980) noted a gradual increase in aggressive behavior in rainbow trout from the time 50% of the alevins were free swimming to 30 d afterward. Feeding did not elicit more chases in this study except for 9-wk-old fry. Newman (1956) observed that feeding stimulated additional aggressive behavior in both rainbow and brook trout *Salvelinus fontinalis.* Similar observations have been reported for Atlantic salmon (Keenleyside and Yamamoto 1962), chum salmon (Davis and Olla 1987), and brown trout *Salmo trutta* (Jenkins 1969). This study differed from Newman (1956) in that no 15-min waiting period after feeding was incorporated into the study design, and fish actively feeding would have been less likely to be actively engaged in agonistic behavior. Keenleyside and Yamamoto (1962) starved fry for 24 h prior to observations, whereas in this study fry were taken from troughs where fish were still actively being fed. This discrepancy indicates that hunger plays an important role in aggressive behavior as Davis and Olla (1987) and Symons (1968) have noted.

The impact of density upon growth has been studied in fish, with mixed results. While some studies have shown growth rates to be highest at low densities (Refstie and Kittelsen 1976; Backiel and LeCren 1978; Trzebiatowski et al. 1981), others (Wallace et al. 1988; Fernö and Holm 1986; Brown et al. 1992) came to the conclusion that growth rates were greatest at high densities. Each species may have an optimal rearing density for growth. For example, Brown (1946a, 1946b) observed less than optimal growth rates in brown trout at low densities as well as high densities, presumably due to the formation of social hierarchies and intraspecific competition respectively. In this study, differences in growth did not follow any pattern related to density. The short duration of the experiment may have been a factor, and differences may be more pronounced over time. For example, Refstie and Kittelsen (1976) noted that there were no significant differences in mean weight for Atlantic salmon fry after the initial feeding period of 42 d, but did observe large differences related to density after 205 d of additional rearing. However, Refstie (1977) noted differences in growth of rainbow trout at the end of the initial 42-d rearing period, but at densities that ranged lower than in this study. This study indicated that rainbow trout fry may be reared at densities approaching 44,000 fish/m^3 without negatively affecting growth or producing excessive aggressive behavior. Higher densities during later rearing did have impacts upon condition factor which was lower in the high outdoor density treatments.

The impact of density upon general health was limited. Fin erosion was variable, with dorsal and pectoral fin percentages in all treatments being generally lower than wild fish (Bosakowski and Wagner 1994b). Density effects were limited primarily to slight hematological changes. Plasma protein and hematocrit were higher in fish reared at high outdoor densities, but were unaffected by initial rearing density. Both variables were within normal ranges (Snieszko 1961; Barnhart 1969). Further study is needed to determine the components of total plasma protein which are altered by density.

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