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Assessment of Demand Feeder Spacing on Hatchery Performance, Fin Condition, and Size Variation of Rainbow Trout *Oncorhynchus mykiss*

ERIC J. WAGNER,[1] M. DOUGLAS ROUTLEDGE AND STEVEN S. INTELMANN

Fisheries Experiment Station, Utah Division of Wildlife Resources, 1465 West 200 North, Logan, Utah 84321 USA

Abstract.—Fingerling rainbow trout, *Oncorhynchus mykiss,* were fed for 133 d by one of three feeding methods: one demand feeder per 5.5 m of raceway, 2 demand feeders per 5.5 m of raceway, and hand-fed controls. Mean weight, total length, mortality, and feed conversion were not influenced by the method of feeding. Size variation did not differ among treatment groups, as assessed by comparing the coefficient of variation of total length. Necropsy-based health and condition profiles were conducted three times during the rearing period, and results indicated that fish were generally normal and healthy in all treatments. Several parameters differed significantly over time, but no trends were observed except for the fin index and hematocrit. Over time, hematocrit decreased from 48.6 to 45.0%, and the fin index increased from 0.80 to 1.57. Fin index values did not differ among the feeding methods. Fin condition assessed by measuring relative fin length was better in the single feeder treatment than controls for caudal and ventral fins in the last sample. However, since fish from the two-feeder treatment did not differ from controls, demand feeding per se did not improve fin condition relative to fish that were fed by hand, four to six times per day. The lack of significant improvements in growth or health with the addition of another demand feeder indicated that using more than one feeder per 5.5 m of raceway length is unnecessary for culture of juvenile rainbow trout.

Hatchery fish are often characterized by poor fin condition that can be aesthetically unpleasing to anglers (Sternberg 1988). Poor fin condition may also impact survival after stocking (Saunders and Allen 1967; Weber and Wahle 1969; Nicola and Cordone 1973). Despite numerous studies, fin erosion is still a widespread problem in many hatcheries (Bosakowski and Wagner 1994).

The causes of fin erosion have been attributed to several sources, including bacterial infection (Schneider and Nicholson 1980) and nutrition (Lemm et al. 1988; Kindschi et al. 1991a). Abbott and Dill (1985) noted that fin nipping in juvenile steelhead trout *Oncorhynchus mykiss* directed at dorsal and pectoral fins may be responsible for fin erosion. This hypothesis was supported by Kindschi et al. (1991b) who noted that steelhead trout held in isolation had perfect fins. Aggressive behavior may be affected by competition for food (Newman 1956; Symons 1968). Wolf (1938) and Larmoyeux and Piper (1971) have noted reduced fin erosion when fish were fed to satiation.

Based upon these previous investigations, this study tested the hypothesis that demand-fed fish have reduced fin erosion relative to hand-fed controls. Demand feeders have become increasingly popular in aquaculture (Schweinforth et al. 1984). Several benefits have been noted for demand-fed fish. These include reduced feed costs, improved feed conversion ratios, reduced swings in dissolved oxygen and ammonia, and improved dress-out weights (Boydstun and Patterson 1982; Tipping et al. 1986). In a study with rainbow trout *Oncorhynchus mykiss,* Landless (1976) noted that a single fish would often trigger the feeding rod of the demand feeder, and that territorial and hierarchical behaviors were present. Brännäs and Alanärä (1993) also noted similar hierarchies in tests with Arctic char *Salvelinus alpinus.* Although Landless (1976) did not observe any fish that were deprived of food in groups of up to 20 fish, it is conceivable that on a production scale territoriality may play a more significant role.

[1] Corresponding author.

Hence, the number of demand feeders available per unit length of raceway may be a factor in providing all fish an opportunity to feed.

Methods

The experiment was started on 15 June 1994, using Fish Lake-DeSmet strain rainbow trout reared at the Fisheries Experiment Station, Logan, Utah, USA, from eggs received from the Egan Hatchery, Bicknell, Utah, USA. Prior to starting the experiment, fry were initially reared in fiberglass troughs and transferred to outdoor raceways on 16 May 1994. Upon initiating the experiment, there were 3,980 fish (mean weight, 3.66 g) in each of six outdoor concrete raceways (11 m × 1.22 m × 0.57 m water depth). The fish in two raceways were hand fed (controls), those in two other raceways had a single demand feeder per 5.5 m of raceway, and two others had a pair of demand feeders per 5.5 m of raceway. The hand fed groups were fed ad libitum, initially feeding them six times a day, five days per week. On day 57, the feeding frequency was reduced to four times per day. The demand feeders (Babington Enterprises Inc., Hagerman, Idaho, USA) were continually replenished to insure that fish could feed to satiation. The fish were fed a commercial trout pellet (about 40% protein, 10% fat; Silvercup) and reared for 133 d. The hand fed fish were fed at 4.05% of body weight initially, increasing to 4.5% on day 19, and decreasing to 4.08 to 3.74% on day 47 for the remainder of the experiment. Density indices (Piper et al. 1986) ranged from 0.17 (8.64 kg/m^3) to 0.45 (44.22 kg/m^3) during the study. Densities were maintained by adjusting crowding screens which divided the 11-m long raceway in half. Mortality, feed conversion values, and mean weight were derived from hatchery records. For each raceway, mean weight was determined monthly from three to five dip-net samples taken from the mass of fish crowded to the head end of the raceway.

Water quality of the incoming water was: temperature, 17.3 C; total hardness, 222 mg/L; total alkalinity, 222 mg/L; total gas saturation, 105–107%. At the tail end of the raceways near the end of the study (day 128), un-ionized ammonia-nitrogen did not exceed 0.0067 mg/L, pH was 7.3–7.4, dissolved oxygen was 3.7 mg/L, and CO_2 was 18–26 mg/L. Alkalinity and hardness were measured with a commercial kit, and ammonia was measured by the Nesslerization method (APHA et al. 1989). Dissolved oxygen was determined by a polarographic probe calibrated with replicate Winkler titrations (APHA et al. 1989), and pH was determined with a digital meter calibrated the day of the determinations. Carbon dioxide was determined by calculation (APHA et al. 1989). Water flows were initially 166 L/min, and increased to 295 L/min for the last 8 wk of the study.

Necropsies were conducted on 20 fish per treatment (10 per raceway) on day 77, 107, and 131, using the Health/Condition Profile system (HCP; Goede 1991; Goede and Barton 1990). For each of these samples, fish were crowded to the head end of the raceway and dip-netted into 100 mg/L of MS-222 (tricaine methane sulfonate). To prevent observer bias, the identity of the treatments was not revealed to the observer until all necropsies were completed. Also, the same person conducted each of the HCP observations. The HCP fin index was modified slightly; instead of ranging from 0 to 3 and scoring being related to the degree of hemorrhaging, the fins were scored based on fin length: 0 = perfect fin, 1 = slight erosion, and 2 = severe erosion.

In addition to the HCP fin index, the same 20 fish per treatment were used to measure maximum fin lengths of all fins except the adipose. The fin lengths were converted to a percent of total length (relative fin length = fin length/body length · 100; Kindschi 1987). Fin lengths were measured on an additional sample (30 June 1994) that was not necropsied since the fish were too small. Variation in fish length among treatments were compared by measuring total length of

TABLE 1. *Mean weight, total length (N = 20), feed conversion (weight of feed fed/weight gain of fish), and mortality of rainbow trout after feeding for 133 d by hand, with one demand feeder, or with two demand feeders.*

Parameter	Hand fed	Demand fed (1)	Demand fed (2)
Feed conversion	1.24	1.28	1.31
Mortality (%)	2.20	1.95	2.10
Weight (g)	53.22	51.60	57.85
Total length (mm)	169.35	152.05	170.02

44 to 67 fish per raceway and analyzing the coefficient of variation.

Each of the parameters was tested for normality using the Wilk-Shapiro statistic or the Lilliefors test (SPSS 1993). Normally distributed parameters (plasma protein, condition factor, caudal fin length) were tested by a factorial ANOVA model that included date, treatment, replicate raceway, and all possible interaction terms. Non-normal data were transformed for analysis; some parameters were normalized by a square root transformation (dorsal and ventral fin lengths), but most could not be normalized and were rank transformed. Significant interactions with date occurred for several parameters (condition factor, plasma protein, leucocrit, bile index, and caudal fin length), and were therefore analyzed separately for each date in a two-way ANOVA model. Categorical data were analyzed by maximum likelihood chi-square analysis (SAS Institute 1989).

Size variation was compared using the coefficient of variation of total length, testing for differences among the three treatments with the Kruskal-Wallis test. Feed conversion, mortality, mean total length, and mean weight at the end of the study were analyzed in a one-way ANOVA comparing feeding methods. A significance level of 0.05 was used for each test.

Results

There were no significant differences in mean weight, total body length, feed conversion, or mortality after 133 d among fish demand fed or hand fed (Table 1). The coefficient of variation of total length ranged from 9.7 to 13.2, and did not differ among feeding methods. This indicated that size did not vary significantly.

Relative fin length differences among fish from the three treatments were significant for the anal ($P = 0.013$), caudal ($P = 0.013$), dorsal ($P < 0.001$), and ventral ($P = 0.044$) fins (Fig. 1). Fish from the single feeder treatment had longer dorsal fins than fish from the double demand feeder treatment in the first two samples, but did not differ from hand fed controls. The difference was not sustained throughout the rearing period. Relative anal fin length differed only in the second sampling period in which fish from raceways with two feeders had longer fins than controls or raceways with a single feeder. Likewise, caudal and ventral fins were significantly different in only the last sample, with fin length in the single feeder treatment being longer than in the controls. The HCP fin index did not differ significantly among treatments, but did differ among dates, increasing over time. Date effects were also noted for each of the relative fin length measurements.

Most of the HCP parameters did not differ among treatments and were indicative of normal, healthy fish. Leucocrit, plasma protein, and hematocrit varied over time, but hematocrit was the only parameter to follow any trend, decreasing from 48.6 to 45.0% over time (Table 2). Leucocrit and plasma protein concentrations were greatest in the second sample (day 107). Hematocrit values did not significantly differ among treatments. However, leucocrit in the first sample (day 77) was significantly greater in fish from the two-feeder treatment than from the single-feeder treatment, but did not differ from controls (Table 2).

Bile index and condition factor values were significantly different among dates, with the bile index being highest in the final sample (2.02) and condition factor highest in the second sample (1.24). Differences in bile index among treatments within a sam-

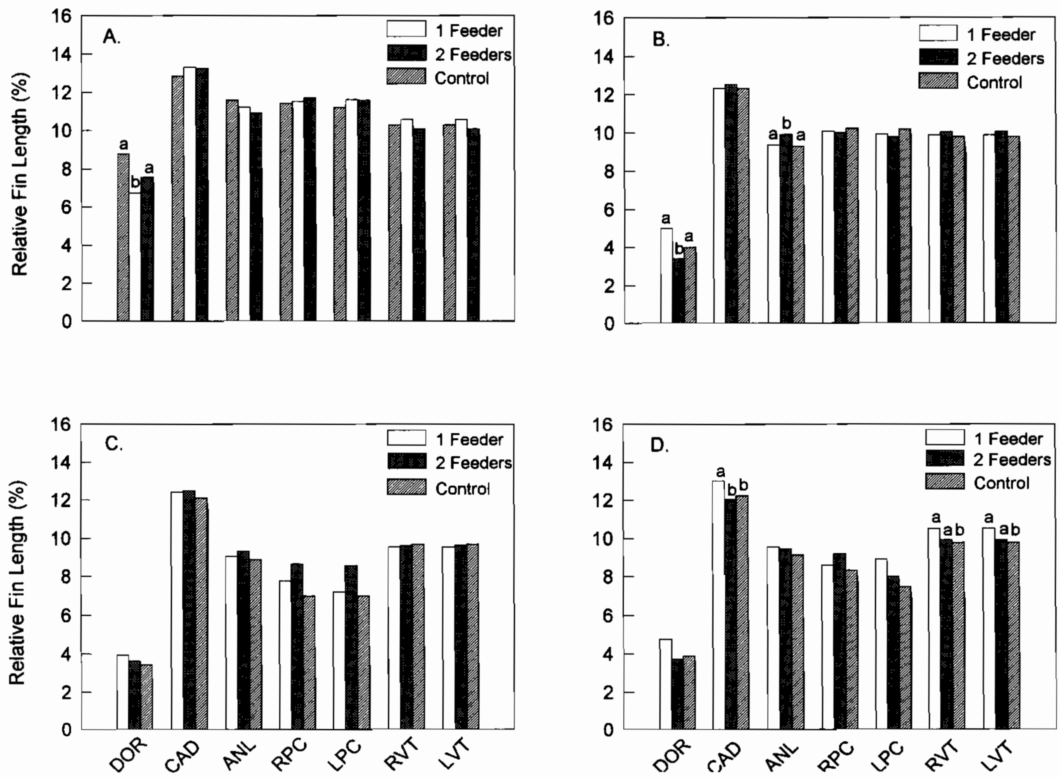

FIGURE 1. *Relative fin length (fin length × 100/total length) of rainbow trout in 5.5 m long raceways that were hand fed (control) or demand fed with two or one self-feeders. Fins from 20 fish per treatment were measured on four occasions: 30 June (A), 31 August (B), 30 September (C), and 24 October 1994 (D). Abbreviations for the fins are as follows: DOR = dorsal, CAD = caudal, ANL = anal, RPC = right pectoral, LPC = left pectoral, RVT = right ventral, and LVT = left ventral. Means for each fin that are significantly different (P ≤ 0.05) among the feeding methods have different subscript letters above the bar. If no letters are shown there were no significant differences among treatment means.*

pling period occurred only during the first sample in which fish from the single-feeder treatment had significantly higher index values than the control or double-feeder treatments ($P = 0.004$; Table 3). Condition factor differed among treatments only in the first sample, in which fish from the single-feeder treatment had significantly lower condition values than either controls or fish from the double-feeder treatment (Table 3). There were no significant differences in mesenteric fat content or thymus indices due to feeding method (Table 3).

Fin condition, as measured by visual assessment, did not differ among fish on the three feeding methods. Relative fin length measurements did indicate that fish fed by using a single feeder had better caudal and ventral fin condition than controls. However, the dorsal and pectoral fins which are the principal fins attacked during aggressive bouts (Abbott and Dill 1985), had progressively worse fin erosion over the course of the experiment and were not improved by the use of demand feeders. In an experiment with cutthroat trout, Wagner et al. (1995) also noted no improvement in fin condition with the use of demand feeders. Kindschi (1984) measured dorsal fin erosion in steelhead and did not observe any differences related to demand feeding. However, in a 1982 survey of demand feeder users, G. E. Kuhn (U.S. Fish and Wildlife Service, unpublished data) noted that some respon-

TABLE 2. *Mean hematocrit (Hct), leucocrit (Lct), and plasma protein concentrations for rainbow trout collected on three dates and fed with one demand feeder (1 DF), two demand feeders (2 DF), or by hand (control). Means (N = 20) of a parameter within an experiment day that are significantly different (P ≤ 0.05) have different subscript letters. If no subscript letters are shown there were no significant differences among treatment means.*

Experiment day Treatment	Hct (%)	Lct (%)	Plasma protein (g/dL)
77			
1 DF	49.00	0.00_a	4.48_b
2 DF	49.15	0.32_b	4.71_{ab}
Control	47.55	0.30_{ab}	5.05_a
107			
1 DF	48.60	0.41	4.53_b
2 DF	47.75	0.71	5.53_a
Control	47.45	0.86	5.58_a
131			
1 DF	44.35	0.30	4.04
2 DF	43.95	0.29	4.20
Control	46.75	0.52	4.10

TABLE 3. *Mean thymus, fat, bile, fin, and condition factor indices from rainbow trout collected on three dates and fed with one demand feeder (1 DF), two demand feeders (2 DF), or by hand (control). Means (N = 20) of a parameter within an experiment day that are significantly different (P ≤ 0.05) have different subscript letters. If no subscript letters are shown there were no significant differences among treatment means.*

Experiment day Treatment	Thymus	Fat	Bile	Fin	Condition factor[a]
77					
1 DF	0.35	3.15	0.70_y	0.70	1.12_y
2 DF	0.60	3.10	0.20_z	0.85	1.19_z
Control	0.70	3.00	0.20_z	0.85	1.17_z
107					
1 DF	0.10	3.30	0.35	1.65	1.21
2 DF	0.20	3.20	0.10	1.45	1.24
Control	0.60	3.50	0.40	1.65	1.26
131					
1 DF	0.35	3.60	2.10	1.45	1.12
2 DF	0.25	3.70	2.10	1.60	1.18
Control	0.25	3.70	1.85	1.65	1.12

[a] Weight/(length)^3 × 10^5.

dents observed better pectoral and dorsal fin condition in demand fed fish. Many of the survey respondents noted better feed conversion factors, reduced labor, and increased growth of fish with the use of demand feeders. In this study, survival and growth of rainbow trout or variation in size were unaffected by use or spacing of demand feeders.

Increased growth has been reported for demand-fed fish (Boydstun and Patterson 1982; Statler 1982; Alanärä 1992), although Kindschi (1984) did not note any increase in growth when demand feeders were used with steelhead *O. mykiss*. Similarly, Aloisi (1994) did not observe any significant increase in mean weight, total length, or condition factor of demand-fed lake trout *Salvelinus namaycush*.

However, Aloisi (1994) reported that size variation was greater in demand-fed fish, with the distribution of total length being skewed slightly to the left at the end of the study. Kindschi (1984) also noted a slightly greater variation in total length for demand-fed fish. This was likely due to the formation of social hierarchies and territorial behavior that limits the ability of some fish to feed (Landless 1976; Brännäs and Alanärä 1993). In this study, the lack of significant size variation of fish between demand feeding and hand feeding indicated that all fish had a similar opportunity to feed. Landless (1976) observed that although only one member of a group of twenty fish would trigger the demand feeder rod, all fish would feed and were in good condition. The difference between this study and the others cited may be related to the spacing of demand feeders. With less space between feeders, there is greater opportunity for all fish to find feed.

What is the optimum feeder spacing? In this study, use of more than one feeder per 5.5 m of raceway length did not result in significant improvements in growth, fin condition, and health; nor was size variation reduced relative to controls or a single feeder. These results indicate that the optimum feeder density for culture of domesticated rainbow trout (8–16 cm) lies somewhere at or above 1 feeder per 5.5 m of raceway length (width 1.22 m). Comparison with other studies is difficult since feeder spacing was not reported.

Feed conversions have been improved in fish fed by demand feeders in several studies (Statler 1982; Kindschi 1984; Alanärä 1992; Aloisi 1994), but not in this study. The discrepancy may be related to feeding frequency which was not reported in several of the above studies. Feeding frequency generally correlates positively with feed conversion (Sedgwick 1979; Piper et al. 1986; Bocek et al. 1992). Feeding by hand at frequencies of four to six times per day in this study was enough to match the fish growth observed in demand fed raceways.

Health and condition parameters (Goede and Barton 1990) generally did not differ among feeding methods, indicating that demand feeding had no adverse effect on fish health. Similar results were found with cutthroat trout (Wagner et al. 1995). Increased waste accumulation was noted in the demand fed raceways, especially after heavy winds. This did not affect fish mortality or health, but increased the time required to clean the raceways and probably affected feed conversion. Adjusting and moving the demand feeders to crowd fish for samples also required time that was not necessary in the hand fed groups.

Overall, rainbow trout on demand feeders performed as well as hand-fed fish, but did not show any improvement in fin condition. Although initially more labor intensive, the demand feeders did reduce the time required to feed the fish.

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Literature Cited

Abbott, J. C. and L. M. Dill. 1985. Patterns of aggressive attack in juvenile steelhead trout (*Salmo gairdneri*). Canadian Journal of Fisheries and Aquatic Sciences 42:1702–1706.

Alanärä, A. 1992. Demand-feeding as a self-regulating feeding system for rainbow trout in net-pens. Aquaculture 100:167–174.

Aloisi, D. B. 1994. Growth of hatchery-reared lake trout fed by demand feeders. Progressive Fish-Culturist 56:40–43.

APHA (American Public Health Association), American Water Works Association, and Water Pollution Control Federation. 1989. Standard methods for the examination of water and wastewater, 17th edition. APHA, Washington, D.C., USA.

Bocek, A., R. P. Phelps and T. J. Popma. 1992. Effect of feeding frequency on sex-reversal and on growth of Nile tilapia, *Oreochromis niloticus*. Journal of Applied Aquaculture 1:97–103.

Bosakowski, T. and E. J. Wagner. 1994. Assessment of fin erosion by comparison of relative fin length in hatchery and wild trout in Utah. Canadian Journal of Fisheries and Aquatic Sciences 51:636–641.

Boydstun, H. and T. Patterson. 1982. The pros and cons on the use of self-feeders. Salmonid Jan/Feb.: 14–16.

Brännäs, E. and A. Alanärä. 1993. Monitoring the feeding activity of individual fish with a demand feeding system. Journal of Fish Biology 42:209–215.

Goede, R. W. 1991. Fish health/condition assessment procedures. Utah Division of Wildlife Resources, Fisheries Experiment Station, Logan, Utah, USA.

Goede, R. W. and B. A. Barton. 1990. Organismic indices and an autopsy-based assessment as indicators of health and condition of fish. Pages 93–108 *in* S. M. Adams, editor. Biological indicators of stress in fish. American Fisheries Society Symposium 8.

Kindschi, G. A. 1984. Notes on two feed types and methods for steelhead trout production. Progressive Fish-Culturist 46:44–47.

Kindschi, G. A. 1987. Method for quantifying degree of fin erosion. Progressive Fish-Culturist 49:314–315.

Kindschi, G. A., H. T. Shaw and D. S. Bruhn. 1991a. Effect of diet on the performance, fin quality, and dorsal skin lesions in steelhead. Journal of Applied Aquaculture 1:113–120.

Kindschi, G. A., H. T. Shaw and D. S. Bruhn. 1991b. Effects of baffles and isolation on dorsal fin erosion in steelhead trout (*Oncorhynchus mykiss*). Aquaculture and Fisheries Management 22:343–350.

Landless, P. J. 1976. Demand-feeding behaviour of rainbow trout. Aquaculture 7:11–25.

Larmoyeux, J. D. and R. B. Piper. 1971. Reducing eroded fin condition in hatchery trout. American Fishes and U.S. Trout News 16(3):8–9.

Lemm, C. A., D. V. Rottiers, D. S. Dropkin and B. A. Dennison. 1988. Growth, composition, and fin quality of Atlantic salmon fed different diets at seasonal temperatures in a laboratory and hatchery. U.S. Fish and Wildlife Service Biological Report 88:1–12.

Newman, M. A. 1956. Social behavior and interspecific competition in two trout species. Physiological Zoology 29:64–81.

Nicola, S. J. and A. J. Cordone. 1973. Effects of fin removal on survival and growth of rainbow trout (*Salmo gairdneri*) in a natural environment. Transactions of the American Fisheries Society 102:753–758.

Piper, R. G., I. B. McElwain, L. E. Orme, J. P. McCraren, L. G. Fowler and J. R. Leonard. 1986. Fish hatchery management. U.S. Fish and Wildlife Service, Washington, D.C., USA.

SAS Institute. 1989. SAS/STAT® user's guide, version 6, 4th edition. SAS Institute Inc., Cary, North Carolina, USA.

Saunders, R. L. and K. R. Allen. 1967. Effects of tagging and fin-clipping on the survival and growth of Atlantic salmon between smolt and adult stages. Journal of the Fisheries Research Board of Canada 24:2595–2611.

Schneider, R. and B. L. Nicholson. 1980. Bacteria associated with fin rot disease in hatchery-reared Atlantic salmon (*Salmo salar*). Canadian Journal of Fisheries and Aquatic Sciences 37:1505–1513.

Schweinforth, R. L., G. L. Burton and C. M. Collins. 1984. Modifying demand feeders for use with floating food in raceways. Progressive Fish-Culturist 46:211–212.

Sedgwick, R. W. 1979. Effect of ration size and feeding frequency on the growth and food conversion of juvenile *Penaeus merguiensis* de Man. Aquaculture 16:279–298.

SPSS. 1993. SPSS® base system syntax reference guide, release 6.0. SPSS Inc., Chicago, Illinois, USA.

Statler, D. P. 1982. Use of self-feeders for rearing steelhead trout at Dworshak National Fish Hatchery. Progressive Fish Culturist 44:195.

Sternberg, D. 1988. Trout. The Hunting and Fishing Library, Cy DeCosse Inc., Minnetonka, Minnesota, USA.

Symons, P. E. K. 1968. Increase in aggression and in strength of the social hierarchy among juvenile Atlantic salmon deprived of food. Journal of the Fisheries Research Board of Canada 25:2387–2401.

Tipping, J. M., R. L. Rathvon and S. T. Moore. 1986. Use of demand feeders on large steelhead rearing ponds. Progressive Fish-Culturist 48:303–304.

Wagner, E. J., D. A. Ross, D. Routledge, B. Scheer and T. Bosakowski. 1995. Performance and behavior of cutthroat trout reared in covered raceways or demand fed. Aquaculture 136:131–140.

Weber, D. and R. J. Wahle. 1969. Effect of fin clipping on survival of sockeye salmon (*Oncorhynchus nerka*). Journal of the Fisheries Research Board of Canada 26:1263–1271.

Wolf, L. E. 1938. Effect of amount of food on fin condition of fingerling trout. Progressive Fish-Culturist 39:16–18.