JOURNAL OF THE
WORLD AQUACULTURE SOCIETY

Vol. 25, No. 2
June, 1994

A Survey of Trout Fin Erosion, Water Quality, and Rearing Conditions at State Fish Hatcheries in Utah

THOMAS BOSAKOWSKI AND ERIC J. WAGNER[1]

Utah Division of Wildlife Resources, Fisheries Experiment Station, 1465 W 200 N, Logan, Utah 84321 USA

Abstract

A total of 600 hatchery trout were examined for signs of fin erosion including rainbow trout *Oncorhynchus mykiss*, cutthroat trout *O. clarki*, brook trout *Salvelinus fontinalis* and brown trout *Salmo trutta*. A scoring system was used to evaluate erosion on all fins from 20 fish samples. Water quality and hatchery rearing variables were also determined for corresponding raceways or ponds. For rainbow trout groups (N = 24), stepwise multiple linear regression was used to interpret the relationship between fin erosion and the other variables. These fish groups averaged between 92 and 243 mm in total length and no significant correlation was observed between length and a fin erosion index (r = 0.045). The best-fit regression model (adjusted R^2 = 0.689) suggested that fin erosion was correlated with lower alkalinities, unnatural bottom substrates (concrete or steel), higher unionized ammonia levels, and higher fish densities. Despite significant variation between hatcheries, fin condition was significantly better in rainbow trout than in cutthroat trout in three of four hatcheries containing both species and the same substrate. Fin erosion in rainbow trout occurred primarily on dorsal fins, followed in order of decreasing severity, by pectoral, caudal, anal, and ventral fins.

Fin erosion is a common malady of hatchery-raised salmonids and is often used in the field as an indicator of hatchery origin (Sternberg 1988). While some studies on fin clipping have reported detrimental effects of fin loss on survival (Saunders and Allen 1967; Weber and Wahle 1969; Nicola and Cordone 1973; Mears and Hatch 1976), others have reported no significant differences from unclipped fish (Heimer et al. 1985; Gjerde and Refstie 1988). However, while the effect of partial fin loss may be minimal, active fin erosion of hatchery fish is often accompanied by microbial infection and hemorrhage (Schneider and Nicholson 1980; Goede and Barton 1990) which could compromise survivability when fish are released into the wild. Furthermore, hatchery-raised trout with complete, uninfected fins represent quality production, which is more aesthetically pleasing to the angler or consumer.

Despite numerous references to fin erosion in the literature, there are few definitive studies on the subject. Previous investigators have blamed the problem on a wide variety of factors, including: fin nipping (Abbott and Dill 1985), dietary differences (Lemm et al. 1988; Kindschi et al. 1991), undersatiation (Wolf 1938; Larmoyeux and Piper 1971), and bacterial infection (Post 1987).

In this study, the authors examined fins from trout raised at all ten Utah state hatcheries and investigated possible causal relationships with concurrent water quality and hatchery rearing variables.

Materials and Methods

The study was conducted from 17 March 1992 to 1 May 1992 at all 10 state hatcheries in Utah. This time period represented the time when fish loading rates (weight of fish/unit of flow) were near maximum for catchable size trout, just prior to spring stocking. At each of the 10 hatcheries, 2–4 samples of 20 fish each were dip-netted from raceways (or seined from ponds) containing different species, strains, lots, or bottom sub-

[1] Corresponding author.

strates. A total of 600 hatchery trout (100–300 mm) were examined from 30 different groups. These included 22 groups of rainbow trout *Oncorhynchus mykiss,* 4 groups of cutthroat trout *O. clarki,* 2 groups of albino rainbow trout, and one group each of brook trout *Salvelinus fontinalis* and brown trout *Salmo trutta.*

Fish were temporarily immobilized with tricaine methane sulfonate (MS-222), weighed to the nearest 0.1 g on a digital electronic scale, and measured for total length to the nearest mm. Each fin was scored using a modification of Goede's (1991) HCP fin index, in that fins were considered eroded regardless of the presence of active infection and hemorrhaging, and each fin received a separate score instead of a single value for the fish. Thus, a perfect fin received a '0' score, 1 = slight erosion, and 2 = severe erosion. All fins were scored by the same observer (TB) throughout the entire survey to avoid observer bias.

The sum of scores for all fins were totaled for each fish (representing individual fin scores) and then the sum of scores for each group of 20 fish was tabulated. This quantity, called hereafter 'fin index sum', could yield a maximum range of 0–320, with zero representing perfect fins for all twenty fish and 320 representing severe erosion of all fins for all 20 fish.

Fin index scores for each fin were also summarized by totaling the number of individuals with fin erosion for each fin and converting it to a percent. For example, if 5 of the 20 individuals sampled had a fin erosion score of 1 or 2 for the dorsal fin, then the "percent fin erosion" for that fin was 25%.

A total of 14 water quality and hatchery rearing variables were determined for raceways or ponds containing the sample groups (Table 1). All readings or samples were taken at the tail end of raceways except for gas saturation which was taken at the head. Dissolved oxygen was measured with YSI oxygen meters (Yellow Springs Instruments Co., Yellow Springs, Ohio), calibrated daily with Winkler azide-modification titrations (APHA et al. 1989). The pH was measured with a digital pH Meter (Model SA 720, Orion Research Incorporated, Cambridge, Massachusetts) calibrated daily with factory-prepared pH standard buffer solutions. Total gas saturation (total gas pressure minus barometric pressure) was determined directly with a Weiss saturometer (Model ES-2, ECO Enterprises Incorporated, Seattle, Washington). Water temperature was taken with a digital temperature probe (Model TM99A, Reotemp Instrument Corporation, San Diego, California). Total alkalinity and total hardness were determined with Hach Kit drop count titrations (Hach Co., Loveland, Colorado). Ammonia-nitrogen was determined colorimetrically with a Hach Color Comparator and ammonia color disc, 20 min after addition of Nessler's reagent. Values for ammonia-nitrogen were converted to unionized ammonia (NH_3) by using Table B-1 in Piper et al. (1989) and the concurrent values obtained for pH and temperature. Carbon dioxide concentrations were calculated based on alkalinity and pH (APHA et al. 1989). Pond volume, water flow, fish density, density index, flow index, and feed conversion were obtained from hatchery records.

Statistical Analysis

Multiple regression analysis was performed on personal computers with NCSS software (version 5.03, Number Cruncher Statistical System, Kaysville, Utah). Other statistical analyses were performed with SAS software (version 6.03, SAS Institute, Inc., Cary, North Carolina). Significance was determined at $P \leq 0.05$ in all cases. Multiple linear regression (ordinary least squares) was used to identify hatchery rearing variables that were correlated with the fin indices of rainbow trout. The variables initially considered for the regression model and any normality transformations are listed in Table 1.

Collinearity of the predictor variables was determined by first using a simple correla-

TABLE 1. *Variables, units, mean, range, and normality transformations required for water quality and rearing variables for 24 groups of rainbow trout.*

Variable	Mean	Range	Transformation[a]
Group fin index sum	44	7–155	Sqrt(Ln(*x*))
Mean total length (mm)	192.8	92.2–243.2	arcsin(*x*•*x*/1,000)
Feed conversion	1.23	0.8–2.1	none
Pond volume (L)	255,589	10,507–4,394,620	Ln(Ln(*x*))
Flow (L/s)	74.3	9–446	Sqrt(Ln(*x*))
Flow index	0.78	0.16–2.12	none
Density (kg/L)	0.033	0.0025–0.08	none
Density index	0.281	0.0175–0.58	none
Temperature (C)	13.4	8.4–17.2	arcsine(*x*•*x*/1,000)
Dissolved oxygen (mg/L)	6.7	4.3–10.9	none
pH	7.7	7.3–8.1	none
Total hardness (mg/L)	301	86–684	Ln(*x*)
Total alkalinity (mg/L)	210	103–342	Ln(*x*)
Unionized ammonia (mg/L)	0.0061	0.001–0.0192	Ln(*x*)
Carbon dioxide (mg/L)	13.3	2.1–41.2	none
Gas saturation (mm-Hg)	6.8	−12.0–52.0	none
Substrate[b]	0.75	0–1	none

[a] Ln = natural log, Sqrt = square root.

[b] Dichotomous variable – assigned values are: 0 = gravel/dirt, 1 = cement or steel.

tion matrix of the response and predictor variables to identify highly correlated predictor variables. Variables with Pearson correlation coefficients greater than 0.85 were considered collinear. Hardness and alkalinity were collinear, and hardness was dropped from the model because of a lower simple correlation. Secondly, the variance inflation factor (VIF) for pH and carbon dioxide were above the general cutoff of 10 (Belsley et al. 1980). These were also highly correlated with alkalinity and were subsequently dropped from the model. Total length, food conversion, flow index, and density index were poorly correlated ($r < 0.10$) with the fin index and were also dropped from consideration in model building.

Final variable selection for the model was performed using the automatic stepwise multiple regression analysis in the NCSS program. After the analysis was performed, not all the selected predictor variables had significant slopes, so a robust regression analysis (Montgomery and Peck 1992) was used with these variables to correct for heteroscedasticity by dampening the effect of outlier variables. This study used Andrew's sine function with a constant of 2.1 as suggested in the NCSS program. Results of the robust regression analysis showed that all but one variable (dissolved oxygen) had significant slopes, so this variable was rejected. The four remaining variables represented the final model and these data were then entered into an unweighted full-model multiple regression analysis to obtain real betaweights and an adjusted R-squared value for the equation.

The fin index sums for rainbow trout were compared among hatcheries using one-way ANOVA of rank-transformed data. Lack of a significant difference among hatcheries permitted pooling data from all the hatcheries for a comparison of the fin index sum between cutthroat and rainbow trout, and between substrate types, using the Wilcoxon test. Brook and brown trout were not tested because only data for one group of each was collected.

Individual fin index scores were analyzed by the general linear model approach to analysis of variance (ANOVA), using rank transformed data. Two-way ANOVA in-

TABLE 2. *Results of a stepwise multiple regression analysis of rainbow trout group fin index sums (N = 24) versus water quality and rearing variables.*

Variables	Equation β-estimate	Standardized β-estimate	R^2-added	Unweighted[a] P	Robust P
Intercept	3.404	0	—	0.0000	0.0000
In> Alkalinity	−0.241	−0.453	0.168	0.0023	0.0037
In> Substrate	0.201	0.429	0.147	0.0038	0.0001
In> Ammonia	0.095	0.303	0.090	0.0186	0.0041
In> Density	2.377	0.225	0.048	0.0762	0.0145
Out< Gas saturation			0.018	0.2633	
Out< Dissolved oxygen			0.009	0.4287	
Out< Temperature			0.007	0.4811	
Out< Volume			0.003	0.6684	
Out< Flow			0.002	0.7136	

Equation statistics
F-ratio = 13.73
$P = 0.000$
$R^2 = 0.743$
Adjusted $R^2 = 0.689$

[a] Unweighted and robust (weighted regression) P levels refer to the significance level of the t-statistic testing for $\beta = 0$ (no slope) where β = beta coefficient.

dicated highly significant differences among species and hatcheries, so one-way ANOVA was performed separately for each hatchery to evaluate species differences. Using the Wilcoxon test, differences in individual fin index scores among strains of rainbow trout were tested separately at seven hatcheries, controlling for substrate. Differences in substrate among rainbow trout of the same strain were similarly tested in two hatcheries. The percent fin erosion was arcsine and rank-transformed and compared among species for each fin using ANOVA.

Results

Multiple Regression Analysis

In order to eliminate any variation due to species differences, the regression analysis was conducted only with rainbow trout groups ($N = 24$) which represented 80% of the fish sampled. The response variable chosen was the fin index sum which was not affected by total length ($r = 0.045$), at least within the size range of fish examined (92–243 mm). The rainbow trout data set included two groups of albino strain, since these were not significantly different in fin erosion from normally pigmented rainbow trout when tested within hatcheries (see next section).

Table 2 presents the regression model which best explained the data, that is, had the highest correlation (adjusted $R^2 = 0.689$) and fewest number of independent variables. The selected predictor variables, in order of importance, were: alkalinity, substrate, ammonia, and density. The importance of each value was determined by the standardized beta coefficients. These results are interpreted to suggest that fin erosion was correlated with lower alkalinities, unnatural bottom substrates (concrete or steel), higher unionized ammonia levels, and higher fish densities.

Fin Index Scores

Overall, the fin index sums averaged 22 ± 5.7 (SD) for albino rainbow trout, 46 ± 37.2 for rainbow trout, 55 for brown trout, 57 for brook trout, and 80.5 ± 29.8 for cutthroat trout. Rainbow and cutthroat trout fin index sums were not significantly different ($P = 0.095$). There were no significant differences among hatcheries in the fin in-

TABLE 3. *Species differences in individual fin index scores of various trout species analyzed within hatcheries and only in concrete raceways (i.e., controlling for hatchery and substrate).*

Hatchery	Species RT	CT	AB	BN	BK
Egan	5.10[a]	6.05[a]	—	2.75[b]	2.85[b]
	±2.594	±2.837		±1.410	±1.927
Ft. Green	1.15[a]	2.55[b]	—	—	—
	±1.040	±1.146	—	—	—
Kamas	0.50[a]	4.10[b]	1.30[a]	—	—
	±0.607	±2.63	±1.949	—	—
Mantua	1.95[a]	4.20[b]	—	—	—
	±1.276	±1.963	—	—	—
Midway	0.88[a]	—	1.00[a]	—	—
	±1.043	—	±2.026	—	—

[a] Values represent means (±SD) within a hatchery. Those sharing a common superscripted letter within hatcheries are not significantly different ($P > 0.050$). RT = rainbow trout, CT = cutthroat trout, AB = albino rainbow trout, BN = brown trout, BK = brook trout.

dex sums of rainbow trout. Other species comparisons were not possible due to the lack of replicate groups within a hatchery.

Considering the type of bottom substrate, rainbow trout raised in steel raceways ($N =$ 2 groups) had a mean fin index sum of 69.5, rainbow trout in concrete raceways ($N = 23$) averaged 54.7, and the average was 18.2 for rainbow trout in gravel or dirt substrates ($N = 5$). Fish from concrete or steel raceways had significantly higher fin index sums than fish in gravel/dirt rearing units ($P < 0.001$).

The study next examined differences among hatcheries within each species (data not shown). No difference in individual fin index scores was found between albinos at two hatcheries. For rainbow trout, significant variation in individual fin index scores occurred among the 10 hatcheries ($P <$ 0.0001), with mean fin scores for hatcheries ranging from 0.72 to 5.10. For cutthroat trout, significant variation in fin index scores also occurred among four hatcheries ($P <$ 0.0001) with mean individual fin index scores for hatcheries ranging from 2.55 to 6.05.

Since species differences for individual fin index scores were affected by hatchery, the authors examined species differences within hatcheries to determine the validity of overall means for species. In this analysis, five hatcheries containing two to four species were selected. Results indicated that fin index scores for cutthroat trout were significantly higher than rainbow trout in three of four hatcheries (Table 3). Individual fin index scores from normally pigmented rainbow trout were not significantly different from albino rainbow trout in two hatcheries. Both brook and brown trout were significantly lower than rainbow trout in one hatchery.

The data were also analyzed to compare the percent of fin erosion among species for each fin. Overall, there were few species differences in the pattern of afflicted fins (Table 4). The only significant difference among species was for the left ventral fin. Brook trout had the highest and brown trout had the lowest percentage of erosion for this fin. Pairwise comparisons between groups was not possible because of the small number of groups per species, except for rainbow and cutthroat trout. In a pairwise comparison, cutthroat trout had a greater percentage of fish with fin erosion of both pectoral ($P < 0.045$) and left ventral fins ($P < 0.020$) than rainbow trout. The right ventral fin of cutthroat trout was also more frequently eroded than in rainbow trout ($P < 0.056$).

The study also examined the individual fin index sums for each fin of rainbow trout

TABLE 4. *Summary of the percentage of fish with fin erosion (fin score of 1 or 2) for each fin by species.*

Trout species	Number of groups	Fins							
		AD[a]	AN	CD	DR	LP	RP	LV	RV
Brook	1	0	0	35.0	40.0	25.0	10.0	45.0	35.0
Brown	1	0	0	30.0	65.0	55.0	40.0	5.0	0
Cutthroat	4	—[b]	13.8	30.0	51.2	57.5	56.2	22.5	16.2
Rainbow	22	1.1	2.3	3.3	74.1	28.9	30.6	11.0	12.1
Albino rainbow	2	0	12.5	15.0	35.0	15.0	12.5	7.5	7.5
P-value[c]		0.020	0.998	0.896	0.182	0.164	0.254	0.019	0.134

[a] AD = adipose, AN = anal, CD = caudal, DR = dorsal, LP = left pectoral, RP = right pectoral, LV = left ventral, RV = right ventral.

[b] Adipose fin-clipped, comparison not valid.

[c] *P*-value refers to the results of ANOVA.

from eight hatcheries where two or more groups were sampled. This analysis demonstrated that there was substantial variation in fin erosion among hatcheries within a single species (Fig. 1). Clearly, the dorsal fin of rainbow trout was most affected, followed by pectoral fins.

Discussion

Fin Index Regression with Water Quality and Hatchery Variables

The best-fit multiple regression model for the fin index included four predictor variables for the equation (alkalinity, substrate, ammonia, and density) which resulted in an R^2 value of 0.689 ($r = 0.830$). This correlation coefficient was substantially higher than the largest simple correlation ($r = -0.678$) between alkalinity and the fin index sum. Thus, it is likely that a combination of several variables had an effect on fin erosion rather than a single variable.

Bullock (1968) suggested that "fin rot" is the result of opportunistic bacteria that invade after some predisposing factor such as poor nutrition or injury. This injury may result from abrasion. The regression model showed that rainbow trout had better fin condition (lower fin index scores) in natural bottom substrates (gravel/dirt ponds) compared to concrete or steel raceways, which suggests that abrasion from concrete/steel walls may cause and/or worsen fin erosion. The abrasion may breach the fish's first line of defense, permitting invasion by opportunistic bacteria and fungi that continue to erode the fin. This hypothesis is supported by Mahoney et al. (1973) who failed to induce fin necrosis in mummichogs *Fundulus heteroclitus* by adding *Vibrio* bacteria to the tank water. However, when Mahoney et al. (1973) abraded the caudal fin and rubbed on bacteria, there was necrosis.

Fish density was another important variable selected in the regression model suggesting that crowding does have a detrimental effect on fin health. Crowding could induce behavioral changes such as fin nipping (Abbott and Dill 1985) or lead to water quality and disease problems (Piper et al. 1989). However, studies on salmonids that examined the effect of density on fin condition have reported mixed findings. Soderberg and Meade (1987) and Moring (1982) found no difference in fin condition of Atlantic salmon *Salmo salar* and chinook salmon *O. tshawytscha,* respectively, reared at different densities. Similar results were found for lake trout *Salvelinus namaycush* (Soderberg and Krise 1987). On the contrary, Westers and Copeland (1973) and Maheshkumar (1985) found an increase in fin erosion as densities of Atlantic salmon were increased. Results from this survey suggest the need for controlled studies of the relationship between rainbow trout rearing-density and fin condition.

Ammonia was another important variable selected in the regression model which was positively correlated with fin erosion. Although a mechanism for direct toxicity of ammonia on fins has not been established, the build-up of ammonia is usually associated with the accumulation of metabolic wastes, microbes, and suspended solids in overcrowded raceways (Piper et al. 1989; Brannon 1991). Such a decline in environmental quality would likely worsen the condition of fins which are already infected. Although the specific toxic action of ammonia on fish is unknown, higher levels can decrease the ability of hemoglobin to bind oxygen (Wedemeyer et al. 1976). Chronic exposure to ammonia can also cause a reduction in growth rate, proliferation of gill lamellae, reduced stamina, reduction in lymphoid tissue in the spleen, reduction in hematopoietic tissue in the kidney, lesions in blood vessels, and abundant mucus secretion (Hillaby and Randall 1979).

Alkalinity was also selected in the regression model as an important predictor variable. The reason for a relationship between fin health and higher alkalinity is not clear, but waters with higher alkalinities have a better buffering capacity against pH shifts, certain water pollutants, and acid mine drainage (Reid and Wood 1976). Alkalinity was also strongly correlated with water hardness ($r = 0.952$), but only one of these variables could be used in the model to avoid collinearity problems. Wedemeyer et al. (1976) stated that harder water is more beneficial to fish health because of the reduced osmotic work to replace blood electrolytes.

Fin Index Scores: Comparison of Species and Fins

Analysis of species differences, both within hatcheries and across all hatcheries, indicated that fin condition of rainbow trout was significantly better than that of cutthroat trout. This result is not entirely unexpected since the rainbow trout in the Utah hatchery system have been domesticated for several generations whereas the cutthroat trout are taken as eggs from wild populations in Utah.

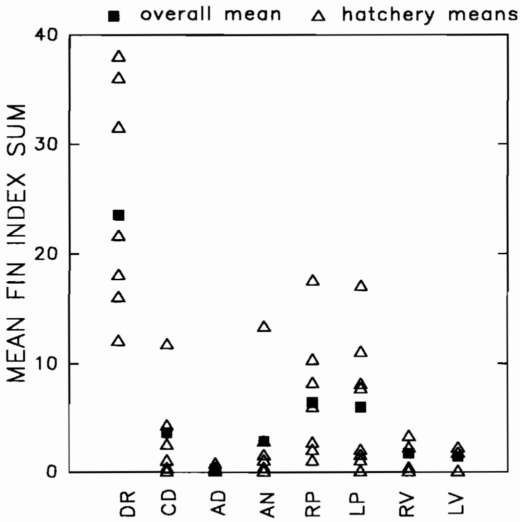

FIGURE 1. *Hatchery means (triangles) for rainbow trout fin index sums (N = 20 scores/group) for individual fins. DR = dorsal, CD = caudal, AD = adipose, AN = anal, RP = right pectoral, LP = left pectoral, RV = right ventral, LV = left ventral. Overall mean represented by black square.*

Overall, the results showed erosion of all rayed fins in the hatchery populations, but not of the adipose fin. In rainbow trout, fin erosion was worst for dorsal fins, followed by pectoral fins, caudal fins, anal fins, and ventral fins. In juvenile steelhead trout, fin nipping was directed mainly at the dorsal fin (Abbott and Dill 1985), which is consistent with the present results for the fin with the greatest damage. Abbott and Dill (1985) also observed attacks on other fins and areas of the body, with reciprocal bouts directed at anterior portions of the body. Non-reciprocal bouts were directed at the dorsal fin, central body section, and caudal fin. Wolf (1938) and Larmoyeux and Piper (1971) both observed reduced fin erosion when fish were fed to satiation. A satiated fish would presumably be less aggressive. The effect of ration on aggressive behavior has been demonstrated by Olla et al. (1992) who observed that chum salmon *Oncorhynchus keta* reared for 8 wk on a low ration (3% of body weight per day) were more aggressive than those fed a high ration (11%).

Nutritional factors may also contribute to the degree of fin erosion. For example, Kindschi et al. (1991) found a significant difference in dorsal fin measurements of steelhead trout fed different diets (shorter fins were found on fish fed meal supplemented with herring oil rather than menhaden oil). In this study, no nutritional analyses were performed since all the feed in the state hatchery system were either trout or salmon feed supplied by one manufacturer (Nelson and Sons, Murray, Utah).

From these overall results, a generalized management strategy to produce trout with better fin quality would include: keeping lower fish densities, using gravel or dirt bottom ponds if available, maintaining lower ammonia levels by reducing fish density or increasing water flow, and utilizing water sources with higher alkalinities (or liming ponds with low flow). Higher ration levels to reduce fin-nipping and experimentation with the nutritional value of other feeds may also be helpful.

Acknowledgments

We thank all of the Utah fish hatchery staff for their cooperation and enthusiasm in assisting with the field work. Dr. Jerry L. Hintze provided technical advice on our multiple regression model selection and application of his NCSS software. We also thank Bruce Schmidt, Joe Valentine, Ron Goede, Russ Lee, and Christopher Wilson for their review of the manuscript. Research was supported by the Federal Aid in Sport Fish Restoration program, project number F-35-R, and the Utah Division of Wildlife Resources.

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.

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.

Belsley, D. A., E. Kuh and R. E. Welsch. 1980. Regression diagnostics: identifying influential data and sources of collinearity. Wiley and Sons, New York, New York, USA.

Brannon, E. L. 1991. Rainbow trout culture. Pages 21–55 *in* R. R. Stickney, editor. Culture of salmonid fishes. CRC Press, Boca Raton, Florida, USA.

Bullock, G. L. 1968. The bacteriology of brook trout with tail rot. Progressive Fish-Culturist 30:19–22.

Gjerde, B. and T. Refstie. 1988. The effect of fin-clipping on growth rate, survival and sexual maturity of rainbow trout. Aquaculture 73:383–389.

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.

Heimer, J. T., W. M. Frazier and J. S. Griffith. 1985. Post-stocking performance of catchable-size hatchery rainbow trout with and without pectoral fins. North American Journal of Fisheries Management 5:21–25.

Hillaby, B. A. and D. J. Randall. 1979. Acute ammonia toxicity and ammonia excretion in rainbow trout (*Salmo gairdneri*). Journal of the Fisheries Research Board of Canada 36:621–629.

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

Larmoyeux, J. D. and R. G. Piper. 1971. Reducing eroded fin condition in hatchery trout. U.S. Trout News 1971:8–9.

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.

Maheshkumar, S. 1985. The epizootiology of finrot in hatchery-reared Atlantic salmon (*Salmo salar*). Master's thesis. University of Maine, Orono, Maine, USA.

Mahoney, J. B., F. H. Midlege and D. G. Deuel. 1973. A fin rot disease of marine and euryhaline fishes in the New York Bight. Transactions of the American Fisheries Society 102:596–605.

Mears, H. C. and R. W. Hatch. 1976. Overwinter survival of fingerling brook trout with single and multiple fin clips. Transactions of the American Fisheries Society 6:669–674.

Montgomery D. C. and E. A. Peck. 1992. Introduction to linear regression analysis, 2nd edition. Wiley and Sons, New York, New York, USA.

Moring, J. R. 1982. Fin erosion and culture-related injuries of chinook salmon raised in floating net pens. Progressive Fish-Culturist 44:189-191.

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.

Olla, B. L., M. W. Davis and C. H. Ryer. 1992. Foraging and predator avoidance in hatchery-reared Pacific salmon: achievement of behavioral potential. Pages 5–12 *in* J. E. Thorpe and F. A. Huntingford, editors. The importance of feeding behavior for the efficient culture of salmonid fishes. World Aquaculture Society Workshop 2, Baton Rouge, Louisiana, USA.

Piper, R. G., I. B. McElwain, L. E. Orme, J. P. McCraren, L. J. Fowler and J. R. Leonard. 1989. Fish hatchery management, 4th edition. U.S. Fish and Wildlife Service, Washington, D.C., USA.

Post, G. 1987. Textbook of fish health. T.F.H. Publications, Neptune, New Jersey, USA.

Reid, G. K. and R. D. Wood. 1976. Ecology of inland waters and estuaries. D. Van Nostrand and Company, New York, New York, 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.

Soderberg, R. W. and W. F. Krise. 1987. Fin condition of lake trout *Salvelinus namaycush* Walbaum, reared at different densities. Journal of Fish Diseases 10:233-235.

Soderberg, R. W. and J. W. Meade. 1987. Effects of rearing density on growth, survival, and fin condition of Atlantic Salmon. Progressive Fish-Culturist 49:280–283.

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

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.

Wedemeyer, G. A., F. P. Meyer and L. Smith. 1976. Chemical factors in fish diseases. Pages 89–149 *in* S. S. Snieszko and H. R. Axelrod, editors. Diseases of fishes, book 5: Environmental stress and fish diseases. T.F.H. Publications, Inc., Neptune, New Jersey, USA.

Westers, H. and H. Copeland. 1973. Atlantic salmon rearing in Michigan. Fisheries Division Technical Report 73-27. Michigan Department of Natural Resources, Lansing, Michigan, USA.

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