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COMMUNICATIONS

Length and Condition Factor of Migrating and Nonmigrating Hatchery-Reared Winter Steelhead Smolts

JACK M. TIPPING, RANDY V. COOPER, JAMES B. BYRNE, AND THOM H. JOHNSON

Washington Department of Fish and Wildlife
600 Capitol Way North, Olympia, Washington 98501-1091, USA

Abstract.—Effects of length and condition factor on emigration rates of hatchery-reared smolts of winter steelhead (*Oncorhynchus mykiss*) stocked 4.7 km upstream of a permanent fish trap were examined. For three releases, an average of 19.8% of fish did not emigrate past the trap. Fish with fork lengths of 190 mm or more and condition factors ($K = 10^5$ [weight, g]/[length, mm]^3) of 0.90–0.99 generally migrated at higher rates than other fish.

The influence of smolt length on adult survival of hatchery steelhead (*Oncorhynchus mykiss*) has been previously investigated (Larson and Ward 1955; Wagner et al. 1963; Wagner 1967, 1968; Royal 1972). Hatcheries in Washington State generally target smolts for release at lengths that correspond with weights of 60–114 g. Dawley et al. (1985) sampled steelhead smolts in the lower Columbia River that had been released upriver and found that the mean length of recovered fish was frequently greater than the mean length at release, indicating that successful migration was influenced by length or that growth occurred en route.

However, little research has been done on the influence of condition factor ($K = 10^5$ [weight, g]/[length, mm]^3) on postrelease smolt emigration. Ewing et al. (1984) examined hatchery smolts allowed to migrate volitionally from hatchery raceways and found that nonmigrant fish had higher K-values than migrants. Fessler and Wagner (1969) reported that lipid levels and condition factors of hatchery steelhead decreased during spring migration and increased thereafter among fish retained in a hatchery. Tipping and Blankenship (1993) found no effect of condition factor on adult returns from actively migrating smolts of sea-run cutthroat trout (*O. clarki*).

The Pacific coast-wide hatchery steelhead program is large; 24.6 million winter and summer steelhead smolts were released annually from 1978 to 1987 (Light 1989). In an attempt to improve returns, we examined the effects of length and condition factor on the emigration rates of hatchery winter steelhead smolts.

Methods

Winter steelhead juveniles at the South Tacoma Hatchery (a Puget Sound, Washington, stock) whose adipose fins had been excised were tagged in late April of three years: 951 fish in 1991, 1,271 in 1992, and 1,270 in 1993. Fish were anesthetized in a solution of MS-222 (tricaine), weighed (g) on a Ohaus C300-M electronic scale, and measured for fork length (mm). Each smolt was then tagged with a syringe-loaded, 2.5-mm × 0.9-mm, three-digit, alphanumeric visible implant (VI) tag in the left postocular eyelid tissue by a procedure similar to that of Blankenship and Tipping (1993). Precocious (sexually mature) males, identified by darkened skin color and presence of sperm, were excluded from this experiment.

After they were tagged, the fish were held for about 24 h without food. Then they were transported for about 1.5 h in an oxygenated 1,500-L tank and released in Snow Creek about 4.7 km upstream of a permanent fish trap. Snow Creek is a small stream flowing directly into saltwater via Discovery Bay and the Strait of Juan de Fuca; the 100% efficient trap was just above tidewater (Loch et al. 1988). From 1978 through 1993, wild steelhead production from Snow Creek averaged 1,381 smolts (Johnson and Cooper 1993); from 1978 to 1992, their mean length was 165 mm and their mean K-value was 0.91 (Johnson and Cooper 1992). Snow Creek is closed to fishing all year.

In Washington, hatchery steelhead smolts are typically released between April 15 and May 15; release dates in this study were April 26, 1991, April 30, 1992, and April 29, 1993. Smolts were captured at the trap and anesthetized, and their tag numbers were identified. The trap was operated through June.

Hatchery fish without a VI tag were differentiated from wild fish by their larger size, eroded

TABLE 1.—Emigration rates by fork length for hatchery steelhead smolts released in Snow Creek, Washington.

Smolt length (mm)	Percent emigration (number tagged)			
	1991	1992	1993	Mean
146–169	56.0 (109)	68.8 (32)	62.5 (16)	62.4
170–179	62.8 (102)	79.8 (109)	70.8 (48)	71.1
180–189	71.6 (148)	85.7 (244)	75.7 (169)	77.7
190–199	81.0 (189)	86.1 (381)	84.5 (310)	83.9
200–209	79.2 (183)	85.7 (280)	78.8 (359)	81.2
210–219	80.0 (115)	90.2 (102)	82.4 (245)	84.2
≥220	78.1 (105)	95.1 (123)	82.9 (123)	85.4
Overall	73.9 (951)	86.2 (1,271)	80.4 (1,270)	80.2

fins, and excised adipose fin. Hatchery smolts captured that did not have VI tags were measured, and these lengths were used in determining emigration rates. However, weights for these fish were not recorded, resulting in fewer recoveries for condition factors than for length evaluations.

The Kolmogorov–Smirnov two-sample test (Statgraphics version 2.1) was used to determine if the distributions of fish length or K-factor differed between released fish and migrants. The hypothesis of equal cumulative distributions was rejected at $\alpha = 0.05$.

Results

For 1991, 1992, and 1993, 73.9%, 86.2%, and 80.4% of released steelhead smolts successfully migrated to the trap (Table 1). Over the three years, 44.5–54.7% of recaptured fish were caught within 3 d and 73.1–82.6% were captured within 7 d after release.

In each of the three years, the cumulative length distributions of fish at release and at capture differed significantly ($P < 0.004$); larger fish made up a greater proportion of the migrant population. However, the length advantage was not as pronounced among larger smolts; 190–199-mm smolts averaged 83.9% emigration and still larger fish averaged 83.6% (Table 1).

The cumulative condition factor distributions of fish at release and at capture were not significantly different in any year. However, emigration rates tended to decrease as K increased; fish with K-values of 0.90–0.94 had 81.8% emigration, whereas those with K-values of 1.15 or greater had only 66.6% emigration (Table 2). An average 81.7% of fish with K-values of 0.90–0.99 emigrated compared with 70.3% of fish with K-values above 1.0. In general, larger migrant and nonmigrant fish had lower K-values (Table 3).

In July 1991, Snow Creek was electrofished with

TABLE 2.—Emigration rates by condition factor (K)[a] for hatchery steelhead smolts released in Snow Creek, Washington.

K	Percent emigration (number tagged)			
	1991	1992	1993	Mean
≤0.89	70.6 (34)	81.3 (48)	82.7 (404)	78.2
0.90–0.94	80.4 (92)	89.1 (192)	75.9 (394)	81.8
0.95–0.99	76.1 (230)	90.4 (417)	78.1 (311)	81.5
1.00–1.04	71.8 (262)	80.2 (373)	77.3 (119)	76.4
1.05–1.09	68.8 (205)	76.1 (163)	66.7 (30)	70.5
1.10–1.14	68.1 (91)	72.9 (48)	62.5 (8)	67.8
≥1.15	64.9 (37)	60.0 (30)	75.0 (4)	66.6
Overall	72.3 (951)	83.6 (1,271)	78.4 (1,270)	78.1

[a] $K = 10^5$(weight, g)/(length, mm)^3.

two Smith-Root type VII backpack shockers from the release site downstream to the trap in an attempt to locate VI-tagged fish. Only one fish was found; its length had increased from 203 mm at release to 218 mm at capture, and its K-value had decreased from 1.12 to 1.06.

One fish from the 1991 release was recovered at the trap in spring 1992. The fish had grown from 178 mm at release to 228 mm, and its K-value had declined from 1.08 to 0.89. No other fish were captured at the trap a year after release.

In 1991, about 95% of emigrants had migrated by May 19. Smolts emigrating after May 19 in 1992 (2.1% of smolts) and 1993 (1.6%) were measured and weighed to monitor changes in length and condition. In 1992, mean length increased from 193 mm at release to 200 mm at recovery ($N = 23$) while mean K decreased from 1.06 to 0.95. In 1993, mean length increased from 194 mm at release to 212 mm at capture ($N = 16$) while mean K decreased from 0.98 to 0.92 ($N = 7$).

From time of tagging until recapture at the trap,

TABLE 3.—Mean condition factors (K)[a] by fork length for hatchery steelhead migrants and nonmigrants released in Snow Creek, Washington.

Smolt length (mm)	1991		1992		1993	
	Migrants	Nonmigrants	Migrants	Nonmigrants	Migrants	Nonmigrants
146–159	1.05	1.09	1.02	1.01		1.01
160–169	1.04	1.03	1.02	1.05	0.94	0.93
170–179	1.05	1.04	1.01	1.02	0.94	0.95
180–189	1.01	1.03	1.01	1.02	0.92	0.95
190–199	1.02	1.01	0.99	1.00	0.93	0.95
200–209	1.01	1.03	0.98	1.04	0.91	0.92
210–219	1.00	1.00	0.98	1.02	0.91	0.92
≥220	1.01	1.01	0.98	1.00	0.92	0.91
Mean	1.02	1.03	0.99	1.02	0.92	0.93

[a] $K = 10^5$(weight, g)/(length, mm)^3.

VI tag loss was 1.6% in 1991, 2.6% in 1992, and 2.0% in 1993.

Discussion

For optimum emigration rates, our results suggest that steelhead smolt lengths should be at least 190 mm and that K-values should be in the range 0.90–0.99. However, to account for a normal length distribution in a population, mean length at release should exceed 190 mm. Longer steelhead smolts also appear to have higher survival rates in salt water (Ward and Slaney 1988; Ward et al. 1989).

Conversely, excessively large smolts are costly to produce and may not provide commensurate returns. Although adult survival data were not gathered, our study indicated that once the 190-mm threshold was attained, greater size conferred no clear emigration advantage. Tipping (1986) found that hatchery sea-run cutthroat survival was not enhanced for smolts longer than 220 mm.

The lower rate of migration by shorter fish and by those with high K-values probably indicated that these fish were not physiologically ready to migrate, as reported by Fessler and Wagner (1969) and Folmar and Dickoff (1981). Hatchery smolts emigrating in Snow Creek after May 19 had delayed their departures until their lengths had increased and their K-values had decreased. Delays in emigration may lead to increases in mortality, and if fish do not migrate in the year they are planted, few survive to the following year; Ward and Slaney (1990) also noted this outcome for hatchery steelhead in the Keogh River, British Columbia.

Losses of hatchery steelhead smolts prior to ocean entry appear to be substantial and may be common. Our smolt losses averaged 19.8% over 4.7 km of stream. Ward and Slaney (1990) reported 42.0–42.7% losses of smolts over 10 km of a small river, and McMichael et al. (1992) estimated a 36% loss over 11 km and a 98% loss over 241 km of a large river. Although the source of smolt mortality in Snow Creek was uncertain, it likely occurred by the end of June.

Additional work is needed to determine if targeting certain K-values will increase survival of hatchery steelhead smolts. In the interim, a target K range of 0.90–0.99 may maintain or increase overall emigration rates and may reduce feed costs.

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References

Blankenship, H. L., and J. M. Tipping. 1993. Evaluation of visible implant and sequentially coded wire tags in sea-run cutthroat trout. North American Journal of Fisheries Management 13:391–394.

Dawley, E. M., and eight coauthors. 1985. Migrational characteristics, biological observations, and relative survival of juvenile salmonids entering the Columbia River estuary, 1966–1983. Bonneville Power Administration, Portland, Oregon.

Ewing, R. D., M. D. Evenson, E. K. Birks, and A. R. Hemmingsen. 1984. Indices of parr–smolt transformation in juvenile steelhead trout undergoing volitional release at Cole Rivers Hatchery, Oregon. Aquaculture 40:209–221.

Fessler, J. L., and H. H. Wagner. 1969. Some morphological and biochemical changes in steelhead trout during the parr–smolt transformation. Journal Fisheries Research Board Canada 26:2823–2841.

Folmar, L. C., and W. W. Dickoff. 1981. Evaluation of some physiological parameters as predictive indices of smoltification. Aquaculture 23:309–324.

Johnson, T. H., and R. Cooper. 1992. Snow Creek anadromous fish research annual performance report for project AFS 124-5, July 1, 1990–June 30, 1991. Washington Department of Wildlife, Report 92-5, Olympia.

Johnson, T. H., and R. Cooper. 1993. Anadromous fish research annual performance report for project F-109-R, July 1, 1992–June 30, 1993. Washington Department of Wildlife, Report 93-23, Olympia.

Larson, R. W., and J. H. Ward. 1955. Management of steelhead trout in the State of Washington. Transactions of the American Fisheries Society 84:261–274.

Light, J. T. 1989. The magnitude of artificial production of steelhead trout along the Pacific Coast of North America. Fisheries Research Institute, FRI-UW-8913, University of Washington, Seattle.

Loch, J. J., S. A. Leider, M. W. Chilcote, R. Cooper, and T. H. Johnson. 1988. Differences in yield, emigration timing, size and age structure of juvenile steelhead from two small western Washington streams. California Fish and Game 74:106–118.

McMichael, G. A., J. P. Olson, E. L. Bartrand, M. Fischer, J. N. Hindman, and S. A. Leider. 1992. Yakima River species interactions studies, annual report for 1991. Bonneville Power Administration, Portland, Oregon.

Royal, L. A. 1972. An examination of the anadromous trout program of the Washington State Game Department. Washington Department of Game, Olympia.

Tipping, J. 1986. Effect of release size on return rates of hatchery sea-run cutthroat trout. Progressive Fish-Culturist 48:195–197.

Tipping, J. M., and H. L. Blankenship. 1993. Effect of condition factor at release on smolt-to-adult survival of hatchery sea-run cutthroat trout. Progressive Fish-Culturist 55:184–186.

Wagner, H. H. 1967. A summary of investigations of the use of hatchery-reared steelhead in the management of a sport fishery. Oregon State Game Commission, Research Division, Fishery Report 5, Portland.

Wagner, H. H. 1968. Effect of stocking time on survival of steelhead trout in Oregon. Transactions of the American Fisheries Society 97:374–379.

Wagner, H. H., R. L. Wallace, and H. J. Campbell. 1963. The seaward migration and return of hatchery-reared steelhead trout in the Alsea River, Oregon. Transactions of the American Fisheries Society 92: 202–210.

Ward, B. R., and P. A. Slaney. 1988. Life history and smolt-to-adult survival of Keogh River steelhead trout and the relationship to smolt size. Canadian Journal Fisheries and Aquatic Sciences 45:1110–1122.

Ward, B. R., and P. A. Slaney. 1990. Returns of pen-reared steelhead from riverine, estuarine, and marine releases. Transactions of the American Fisheries Society 119:492–499.

Ward, B. R., P. A. Slaney, A. R. Facchin, and R. W. Land. 1989. Size-biased survival in steelhead trout: back-calculated lengths from adults' scales compared to migrating smolts at the Keogh River, British Columbia. Canadian Journal Fisheries and Aquatic Sciences 46:1853–1858.