

The Effects of Adipose Fin Clipping and Coded Wire Tagging on the Survival and Growth of Spring Chinook Salmon

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Abstract.—Each year, millions of Pacific salmon are identified by the insertion of a coded wire tag and removal of the adipose fin. To evaluate the effects of adipose fin clipping and coded wire tagging on the survival, growth, and straying of spring Chinook salmon *Oncorhynchus tshawytscha*, we coded-wire-tagged juveniles over a 3-year period and excised their adipose fins at three hatcheries on the Columbia River. In addition, the study fish and control fish were marked with otolith marks so that returning adults without tags and the untagged controls could be distinguished from untagged strays. We collected otoliths, tags, and length data from adults returning to the three hatcheries. Because the proportions of fish with coded wire tags returning to the hatchery were similar to those released and there was no discernable pattern of increase or decrease, we concluded that coded wire tags and adipose fin marks did not affect juvenile-to-adult survival. Although there was an indication that coded-wire-tagged fish were more likely to be smaller when they returned than fish without coded wire tags, the size discrepancy was less than one standard deviation of the natural biological variation in size. Tagged juveniles released at the rearing site did not tend to stray when they returned as adults. Based on these results, we concluded that coded wire tagging is a useful method for gathering information with minimal bias on the fates of groups of fish.

One of the most important tools in fisheries management and research is the ability to mark and tag fish for recognition at recapture (Hilborn et al. 1990). Many different tags and marks are available, each having advantages and disadvantages. The coded wire tag (CWT) offers an essentially unlimited number of codes, provides very high tag retention, and can be applied to very small animals (Thrower and Smoker 1984; Blankenship 1990; Kaill et al. 1990). However, tag recovery usually involves killing the animal, and tag decoding is relatively expensive compared with other tagging methods (Hammer and Blankenship 2001).

Since its introduction in the mid-1960s, the CWT identification system (Jefferts et al. 1963) has been a critical tool for studying and managing Pacific salmon on the West Coast of North America. Since the mid-1980s, over 50 organizations have released more than 40 million tagged salmon annually (Johnson 1990), which is, to our knowledge, the largest tagging program in zoological history. The importance of the CWT is recognized

in the Pacific Salmon Treaty between the United States and Canada, which requires that the two countries maintain a viable CWT program for stock assessments and fishery evaluations. Coded wire tags are also used for managing and studying many other species around the world.

A basic assumption in most identification systems is that marked or tagged individuals are representative of their unmarked or untagged counterparts with respect to growth, behavior, and survival. Despite the widespread use of CWTs in salmonids, research on the effects of fish handling, anesthesia, adipose fin removal, and tagging is scant. Previous attempts to measure the effects of coded wire tagging on fish survival were limited by a lack of benign methods for marking control groups. The development of thermal otolith marking technology (Brothers 1985; Volk et al. 1987; Volk et al. 1990) made such evaluation feasible by allowing nonintrusive marking of control groups. Some previous research has indicated that fish are not effected by the tagging process (Thrower and Smoker 1984; Elrod and Schneider 1986; Zajac et al. 1988; Barnes 1994), whereas other studies suggest that survival could be impaired. Blankenship and Hanratty (1990) showed that trapping, handling, and coded wire tagging of migrating coho salmon *Oncorhynchus kisutch* smolts reduced survival by 16%, and Crozier and Kennedy (2002)

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found that similar procedures may have reduced the survival of Atlantic salmon *Salmo salar* smolts by 66%. Morrison et al. (1990) reported olfactory nerve damage or misplacement of half-length CWTs into the frontal brain lobe in 18–37% of tagged chum salmon *O. keta* and coho salmon fry. Elliott and Pascho (2001) showed that coded-wire-tagging procedures could transmit bacterial kidney disease (which is caused by *Renibacterium salmoninarum*) in Chinook salmon *O. tshawytscha* via contaminated tagging needles.

Our study followed spring Chinook salmon from tagging as juveniles to their return as adults and evaluated the cumulative effects of handling, anesthesia, adipose fin removal, and coded wire tagging on survival, growth, and straying. Our hypothesis was that the ratio of tagged to untagged juveniles released would not be significantly different than the ratio of tagged to untagged adults returning. Consistently unequal ratios (i.e., ratios consistently favoring untagged adults) would indicate that survival was impaired for the tagged group or that the tagged group was more likely to stray. Alternatively, similar ratios with inconsistent patterns would indicate that there was no directed survival impact. We also hypothesized that there would be no significant difference in the size of tagged and untagged adults, indicating no effect of coded wire tagging on growth. We evaluated straying to see whether there were increased rates that might suggest that the presence of a coded wire tag affects the navigational ability of the returning adults.

Methods

Spring Chinook salmon were coded-wire-tagged at three facilities in the Columbia River Basin. The first, Carson National Fish Hatchery (U.S. Fish and Wildlife Service), is on the Wind River, which enters the Columbia River above Bonneville Dam, the first of a series of hydroelectric facilities on the main stem of the Columbia River. The hatchery is 275 river kilometers (rkm) from the mouth of the Columbia River. The second, South Santiam Hatchery (Oregon Department of Fish and Wildlife), is on the North Fork Santiam River, a tributary of the Willamette River, which enters the Columbia River below Bonneville Dam. The hatchery is 389 rkm from the mouth of the Columbia River. The third, Cowlitz Salmon Hatchery (Washington Department of Fish and Wildlife), is on the Cowlitz River, which enters the Columbia River below Bonneville Dam, 188 rkm from the mouth of the Columbia River.

For each brood year from 1989 through 1991, all juvenile spring Chinook salmon at each hatchery were otolith marked; one-third were also tagged with standard length (1.1-mm-long) CWTs, and their adipose fins were excised. Each year, unique thermal marks were induced on the otoliths so that untagged returning adults could be identified as native to the hatchery and sorted by brood year. The marks were induced using methods similar to Volk et al. (1990). Marks were induced by exposing the embryos to cold water for 4–12 h to produce an obvious optically dense band in the otoliths. Shifts between the relatively warmer rearing water and the colder water for marking occurred quickly by simply turning one water source off and the other on. Cold water exposures continued throughout embryonic development on a predetermined schedule until several days before hatching, producing a regularly repeating band pattern on the otolith. After hatching, marking episodes of 24 h duration resumed on alevins at Carson National Fish Hatchery and South Santiam Hatchery, and of 12 h duration at Cowlitz Salmon Hatchery until the fish were large enough to be placed in rearing ponds. When the fish were placed into the raceways at each facility, samples of each group were collected for future analysis of otolith patterns. Otoliths from all samples were dissected, mounted, and prepared as described by Volk et al. (1990).

Evaluating the effect of tagging procedures required a comparison of the ratio of untagged to tagged juveniles with the ratio of untagged to tagged adults. We therefore had to count each group of juveniles at each hatchery. Before coded wire tagging and enumeration at each hatchery, fish were crowded in a raceway, netted, and placed into buckets. Each bucket carried a standardized amount of water and fish by volume so that each bucket contained approximately the same number of fish. Because the desired tagged to untagged ratio was 1:2, every third bucket went to the tagging trailer and the other two were emptied into a trough and enumerated without anesthesia by hand-counting for the 1989 brood or, thereafter, with an electronic counter (Bioscanner Counting Tub, Reykjavik, Iceland).

Fish placed in the tagging trailer were anesthetized with tricaine methanesulfonate (MS-222) and the adipose fin was excised. The fish were then tagged and counted with tagging machines (Northwest Marine Technology Inc., Shaw Island, Washington) before being returned to the appropriate rearing vessel, as detailed by Schurman and

Thompson (1990). In each year, tagging began when fish averaged 65 mm fork length (between April and June). Fish that were too small for tagging (<55 mm fork length), deformed, or injured were sorted and eliminated from both the tagging trailer and counting trough. Fish destined for South Santiam Hatchery were tagged at Willamette Hatchery then transported to South Santiam Hatchery.

Mortality of fish with and without CWTs was monitored daily after tagging until release at the Cowlitz Salmon Hatchery. The total monthly percent mortality was calculated and the arcsine-transformed values were compared between groups via a paired *t*-test ($\alpha = 0.05$; null hypothesis was that differences = 0 within each year). Mortality was not recorded at the other hatcheries, so we assumed that equal proportions of tagged and untagged fish died or were removed by predators before release, such that tagged: untagged fish at release remained 1:2. Tag retention for each group was estimated by holding 2,000 fish in net pens for several weeks, then checking the number of fish with tags. The numbers of tagged fish released were reduced accordingly.

Adults began returning to the hatcheries in 1990. The fork length (cm) of each adult returning to each hatchery was measured, and scales were collected to age untagged fish and assign them to the correct brood year. The snouts of adults missing their adipose fins were removed for CWT recovery. Otoliths were collected from all returning adults to distinguish hatchery from wild or stray fish.

To adjust for inaccuracies, blind samples of known marked and unmarked otoliths from returning adults were sent to the laboratory to estimate error rates in otolith mark-scoring. The numbers of returning adults with and without otolith marks were corrected for both errors using the following equations:

$$U_t = \frac{M_o p_m - U_o(1 - p_m)}{p_u p_m - (1 - p_u)(1 - p_m)} \quad \text{and} \quad (1)$$

$$M_t = \frac{M_o - U_t p_u}{1 - p_m}, \quad (2)$$

where U_t = the true number of unmarked fish returning, M_t = the true number of marked fish returning, U_o = the observed number of unmarked fish, M_o = the observed number of marked fish, p_m = the proportion of marked fish incorrectly identified as being unmarked, and p_u = the pro-

portion of unmarked fish incorrectly identified as being marked.

Using the adjusted data, we calculated the proportion of fish recovered with CWTs. Then we calculated the ratio of the proportion of adults returning with CWTs to the proportion released with CWTs. If CWTs had no effect on postrelease survival, this ratio would be 1.0. We used an analysis of variance (ANOVA) to determine whether there was a significant difference in the ratios between hatcheries and if not, we combined the data for a one-sample *t*-test with a hypothesized mean of 1.

To evaluate whether the returning adults that we tagged strayed from their streams of origin, we queried the Pacific States Marine Fisheries Commission CWT database, where all the CWT releases and recoveries from Alaska, British Columbia, Washington, Oregon, Idaho, and California are compiled. We defined a fish as having strayed if it was recovered outside of the Columbia River tributary where the release hatchery was located. We used tags recovered at hatcheries, fish screens, fish traps, and on spawning grounds, but did not include tag recoveries from nonterminal areas (e.g., preterminal fisheries) because those fish had not completed their migration. We defined the percent of the returning adults that were strays as the number of observed tags recovered outside the tributary of origin divided by the total number of tags recovered.

We also tested length at return for differences between fish with and without CWTs. Although there are many analysis techniques we might have used, we chose to treat each hatchery, age, and sex combination as a replicate test of a length effect and then to consider the proportion of all tests where the length of tagged fish was significantly smaller. This meta-analysis approach circumvented the need for assumptions such as the homogeneity of variance with regression. Each test was considered an independent Bernoulli trial, either resulting in a significant decrease or not. Selecting a size decrease that could have a detrimental effect is difficult. The most obvious long-term effect of smaller body size would be a decrease in fecundity, but there is no exact relationship between body size and fecundity in Chinook salmon (Healy and Heard 1983). We therefore determined a significant decrease to be at least one standard deviation of the natural variability in observed lengths, say L . The probability of a test resulting in significance was a measure of the power of that particular test. If the power among tests were the same, then the number of significant tests would follow a bino-

TABLE 1.—Annual releases of coded-wire-tagged (with adipose clips) and untagged juvenile spring Chinook salmon at Carson National Fish Hatchery, Cowlitz Salmon Hatchery, and South Santiam Hatchery, all on tributaries of the Columbia River of Washington and Oregon.

Hatchery	Brood year	Number of tagged fish	Number of untagged fish	Percent tagged after tag loss adjustment
Carson	1989	620,798	1,860,814	24.9
	1990	745,274	1,490,805	32.7
	1991	773,277	1,546,554	33.1
Cowlitz	1989	649,308	1,296,838	32.3
	1990	713,383	1,425,468	32.4
	1991	669,094	1,338,187	33.1
South Santiam	1989	404,092	806,231	32.3
	1990	415,687	838,051	33.2
	1991	447,121	894,241	32.9
Total		5,438,034	11,497,189	

mial distribution. Because power is a function of sample size, effect size, and significance level and because for each test, the sample size was fixed and we set the effect size, we were therefore left with normalizing the power among tests by adjusting the significance level. By setting power at level P , we would expect at least $P\%$ of the tests to result in significance if the effect of CWTs on length was at least L .

For each group (a combination of hatchery, brood year, sex, age at return) we used a two-sample t -test. To conduct each test, we first calculated the appropriate level of α so that the power would be P . That is, each t -test had a $P\%$ proba-

bility of detecting a difference of at least L centimeters, and we recorded the results in a matrix.

Results

A total of 5,438,034 spring Chinook salmon were adipose-clipped and coded-wire-tagged at the three hatcheries over three brood years (Table 1). Tag loss rates were low, generally less than 2%. Each year, the mortality of tagged juvenile spring Chinook salmon during the 11 months in captivity after tagging at the Cowlitz Salmon Hatchery was significantly higher than for untagged fish (Figure 1; in 1989 $t = 2.63$, in 1990 $t = 6.09$, in 1991 $t = 2.34$; $N = 11$ for each year; $P < 0.05$). Tagging

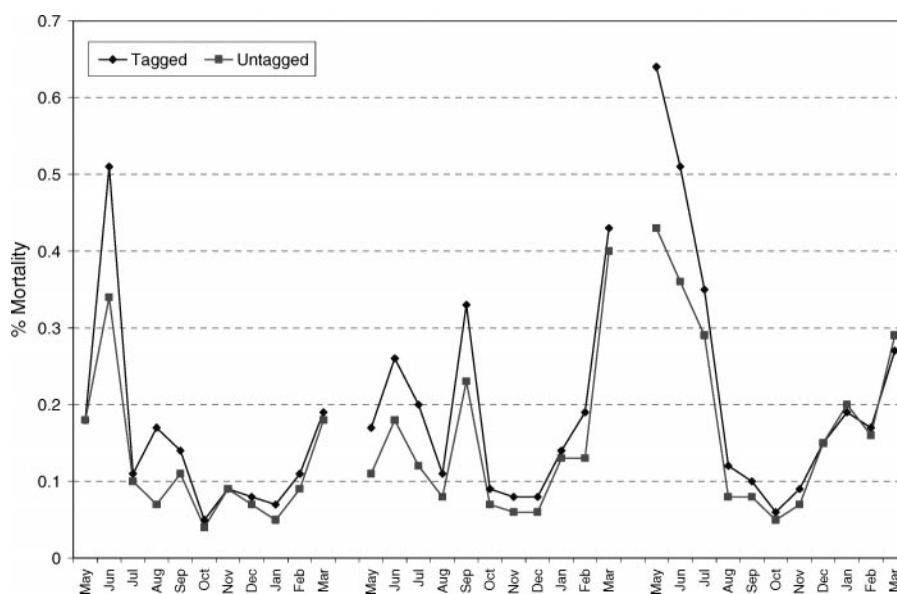


FIGURE 1.—Monthly percent mortality of coded-wire-tagged and adipose fin clipped juvenile Chinook salmon compared with untagged, nonclipped juveniles in 1989 (first series), 1990 (second series) and in 1991 (third series) at the Cowlitz Salmon Hatchery on the Cowlitz River, Washington.

TABLE 2.—Errors (%) in reading otolith marks among spring Chinook salmon released each year at three Columbia River hatcheries (Washington and Oregon). Errors were estimated by using blind samples; p_u is the proportion of unmarked fish that were incorrectly identified as marked, and p_m is the proportion of marked fish incorrectly identified as unmarked; NA = not available.

Error category	Return year				
	1992	1993	1994	1995	1996
Carson National Fish Hatchery					
p_m	NA	0.0	7.6	0.0	0.0
p_u	NA	1.7	15.0	0.0	0.1
Cowlitz Salmon Hatchery					
p_m	1.2	4.6	4.0	0.0	0.8
p_u	16.2	10.4	10.0	0.0	1.6
South Santiam Hatchery					
p_m	NA	0.0	11.5	0.0	3.3
p_u	NA	59.3	14.0	1.4	11.6

mortality appears to be additive to other sources of mortality because the patterns of mortality in tagged and untagged fish are very similar, but the magnitude differs. The average annual mortality ranged from 1.7% to 2.7% for tagged fish and from 1.3% to 2.2% for untagged fish.

From 1991 through 1996, we recovered over 18,000 untagged adults and nearly 8,400 adults tagged with CWTs at the three hatcheries. Our blind samples showed that otolith reading errors occurred in many of the return years (Table 2) and that accuracy improved over the course of the study. After adjusting for otolith error rates (Table 3), the proportion of returning Chinook salmon adults with CWTs ranged from 22.7% to 35.0% (Table 4). Ratios of tagged adults returning to

tagged juveniles released ranged from 0.87:1–1.06:1. Differences in the CWT ratios between hatcheries were not significant (ANOVA: $F = 1.92$, $P = 0.23$), and we therefore pooled the data across brood years and hatcheries to test whether the ratios were significantly different from 1:1. We found no significant difference between the proportion released with tags and the proportion returning with tags ($t = 1.03$, $P = 0.17$). The power of the test indicated that we had an 80% probability of detecting a 10% difference in proportions.

Very few fish released from Cowlitz Salmon Hatchery or South Santiam Hatchery were recovered as strays (Table 5). However, up to 38% of the fish released from Carson National Fish Hatchery were recovered as strays, mainly at Little White Salmon National Fish Hatchery, which is located on the Little White Salmon River about 0.5 mi from its confluence with the Columbia River. The Little White Salmon River is the next major tributary up the Columbia River from the White River. Several groups of the tagged fish that were reared at Carson National Fish Hatchery were released in the Little White Salmon and Umatilla rivers, a practice that is well known to increase straying. The majority of the strays we detected were from those groups, and if they were removed from the analysis, the numbers of strays recovered were reduced to less than 4% of all recoveries.

The natural variability in length was estimated by the data with the largest sample size and resulted in one standard deviation of $L = 1.9$ cm. Of the 46 individual t -tests comparing the length at return of tagged and untagged fish, 21 tests indicated that untagged fish returned significantly

TABLE 3.—Number of untagged Chinook salmon returning with or without otolith marks to Carson National Fish Hatchery, Cowlitz Salmon Hatchery, and South Santiam Hatchery. The observed numbers of marked fish (M_o) were adjusted based on the error rates in reading otolith marks (Table 2) to give the true number of marked fish returning (M_t). The reading errors for the 1989 brood of fish returning to Cowlitz Salmon Hatchery in 1991 were not estimated, so this data was corrected using the rates for 1992.

Return year	Brood year	Carson			Cowlitz			South Santiam		
		1989	1990	1991	1989	1990	1991	1989	1990	1991
1991	M_o				2,835					
	M_t				2,876					
1992	M_o				711	3,061				
	M_t				721	3,090				
1993	M_o	1,459			2,564	38	182	1,131	42	
	M_t	1,453			2,680	39	192	861	39	
1994	M_o	230	333		409	476	66	438	668	3
	M_t	249	361		424	496	67	496	764	3
1995	M_o		62	234	21	376	548	2	571	687
	M_t		62	234	21	376	548	2	571	687
1996	M_o			46		11	222		5	550
	M_t			46		11	222		5	566

TABLE 4.—Summary of coded-wire-tagged and untagged adult Chinook salmon returning to Carson National Fish Hatchery, Cowlitz Salmon Hatchery, and South Santiam Hatchery. The number of untagged adults was adjusted for otolith scoring errors as shown in Table 2.

Brood year	Number of adults		Returns with tags (%)	Releases with tags (%)	Tagged returns: tagged releases ^a
	Untagged	Tagged			
Carson National Fish Hatchery					
1989	1,701	499	22.7	24.9	0.91:1
1990	423	206	32.8	32.7	1.00:1
1991	280	151	35.0	33.1	1.06:1
Cowlitz Salmon Hatchery					
1989	6,721	3,204	32.3	32.3	1.00:1
1990	4,012	1,950	32.7	32.4	1.01:1
1991	1,029	541	34.5	33.1	1.04:1
South Santiam Hatchery					
1989	1,359	627	31.6	32.3	0.98:1
1990	1,547	631	31.4	33.2	0.87:1
1991	1,256	565	31.0	32.9	0.94:1

^a The ratio of the percentage of adult fish returning with a tag to the percentage of tagged juvenile fish released.

larger than tagged fish. However, out of 46 tests we would have expected 41 significant tests if the difference had been at least 1.9 cm (Table 6); that is, the total number of significant tests would have followed a binomial distribution given an $N = 46$ and a $P = 0.9$. With 21 significant tests, the probability that the difference was 1.9 cm is less than 0.0001. Therefore, we concluded that the impact of coded wire tagging on fish is less than 1 SD of the natural variability in length.

Discussion

When using marked or tagged animals to represent the behavior of their unmarked counterparts, it is critical to understand the effect that

the mark or tag may have on the animal in order to avoid bias and misinterpretation of the tag or mark recovery information. Our results indicate that the CWT with an adipose clip had no biologically significant detrimental effects on the growth or survival of spring Chinook salmon from smolt through adult stages. We therefore conclude that spring Chinook salmon tagged with CWTs can reasonably represent the untagged portion of their population. This is an important finding given the vast number of animals tagged with CWTs and the reliance of fish managers on the tag recovery data. Although CWTs have some disadvantages, compared with other marks and tags, few other tags or marks can claim to have

TABLE 5.—Observed coded wire tag recoveries of spring Chinook salmon released from Carson National Fish Hatchery, Cowlitz Salmon Hatchery, and South Santiam Hatchery reported to the Pacific States Marine Fisheries Commission. Only terminal recoveries at hatcheries, fish screens, fish traps, wild broodstock collection sites, and natural spawning grounds were included. Strays were defined as tags recovered outside the Columbia River tributary of origin.

Brood year	Total reported	Strays (%)	Recovery sites of strays
Carson National Fish Hatchery			
1989	454	9.7	Umatilla River; Little White Salmon NFH
1990	177	11.9	Little White Salmon NFH; White Salmon River
1991	151	38.4	White Salmon River; Little White Salmon NFH
Cowlitz Salmon Hatchery			
1989	3,256	<0.1	Kalama Falls Hatchery
1990	2,110	<0.1	Kalama Falls Hatchery; Kalama River
1991	564	0.4	Lewis River Hatchery; Kalama Falls Hatchery
South Santiam Hatchery			
1989	728	0.1	Lyons Ferry Hatchery
1990	642	0	
1991	657	0	

TABLE 6.—Individual *t*-test results with 90% power of detecting an absolute difference in fork length (FL) of 1.9 cm between tagged and untagged Chinook salmon adults. Abbreviations are as follows: F = female, M = male, NS = not significant, *U* = untagged, and *T* = tagged.

Brood year	Sex	Recovery age (years)	Mean FL, tagged fish ^a	Difference in FL (untagged – tagged fish) ^b	Test result
Carson National Fish Hatchery					
1989	F	4	75.8 (226)	0.34 (935)	NS
	M	4	79.2 (106)	0.38 (456)	NS
	F	5	87.9 (47)	0.23 (165)	NS
	M	5	92.0 (27)	3.11 (120)	<i>U</i> > <i>T</i>
1990	F	4	75.8 (90)	–0.45 (271)	NS
	M	4	77.1 (70)	1.47 (199)	<i>U</i> > <i>T</i>
	F	5	88.9 (18)	1.56 (50)	<i>U</i> > <i>T</i>
	M	5	95.6 (15)	0.21 (41)	NS
1991	F	4	77.9 (54)	–0.44 (149)	NS
	M	4	81.9 (47)	–0.65 (146)	NS
	F	5	88.0 (9)	2.68 (31)	<i>U</i> > <i>T</i>
	M	5	95.7 (14)	1.71 (33)	<i>U</i> > <i>T</i>
Cowlitz Salmon Hatchery					
1989	M	2	27.7 (1,459)	0.79 (2,155)	NS
	M	3	50.7 (295)	–0.90 (1,132)	NS
	F	4	71.0 (478)	0.92 (937)	NS
	M	4	68.7 (668)	2.14 (1,248)	<i>U</i> > <i>T</i>
	F	5	78.5 (142)	2.78 (369)	<i>U</i> > <i>T</i>
	M	5	83.0 (95)	2.24 (221)	<i>U</i> > <i>T</i>
	F	6	84.8 (18)	–2.09 (31)	<i>T</i> > <i>U</i>
	M	6	84.3 (7)	2.57 (14)	<i>U</i> > <i>T</i>
1990	M	2	29.0 (919)	–0.13 (1,529)	NS
	M	3	51.4 (50)	–1.71 (77)	<i>T</i> > <i>U</i>
	F	4	71.7 (100)	0.86 (288)	NS
	M	4	70.9 (105)	1.89 (327)	<i>U</i> > <i>T</i>
	F	5	80.2 (151)	1.69 (364)	<i>U</i> > <i>T</i>
	M	5	83.7 (77)	1.43 (210)	NS
	F	6	84.2 (6)	–3.28 (15)	<i>T</i> > <i>U</i>
	M	6	84.3 (7)	2.57 (14)	<i>U</i> > <i>T</i>
1991	M	2	28.9 (102)	1.40 (138)	<i>U</i> > <i>T</i>
	M	3	51.8 (25)	0.52 (82)	<i>U</i> > <i>T</i>
	F	4	73.3 (156)	0.44 (393)	NS
	M	4	73.9 (140)	1.03 (409)	NS
	F	5	82.0 (71)	0.12 (211)	NS
	M	5	85.8 (36)	1.21 (95)	<i>U</i> > <i>T</i>
	M	5	85.8 (36)	1.21 (95)	<i>U</i> > <i>T</i>
	M	5	85.8 (36)	1.21 (95)	<i>U</i> > <i>T</i>
South Santiam Hatchery					
1989	F	4	76.3 (183)	0.98 (611)	NS
	M	4	76.5 (209)	2.15 (725)	<i>U</i> > <i>T</i>
	F	5	84.5 (124)	0.52 (303)	NS
	M	5	87.4 (102)	2.68 (296)	<i>U</i> > <i>T</i>
1990	M	3	61.7 (22)	0.86 (57)	<i>U</i> > <i>T</i>
	F	4	77.2 (138)	1.45 (390)	<i>U</i> > <i>T</i>
	M	4	78.7 (155)	1.54 (600)	NS
	F	5	87.0 (153)	0.77 (440)	NS
1991	M	5	89.7 (150)	2.10 (357)	<i>U</i> > <i>T</i>
	F	4	75.7 (114)	1.39 (384)	NS
	M	4	75.6 (126)	4.39 (461)	<i>U</i> > <i>T</i>
	F	5	84.3 (187)	1.36 (455)	<i>U</i> > <i>T</i>
	M	5	87.4 (130)	1.50 (341)	NS

^a The numbers in parentheses are the numbers of fish tagged with coded wire tags.

^b The numbers in parentheses are the total numbers of tagged and untagged fish.

as little effect on the host animal. When properly used, otolith marks, elastomer tags, PIT tags, and genetic markers, are examples of comparably benign identifiers. However, external tags and removal of useable fins have generally been shown

to reduce survival (Bergstedt 1985) and, thus, bias data.

In their recent study of wild Atlantic salmon smolts migrating from the River Bush in Ireland, Crozier and Kennedy (2002) conclude that the pro-

cess of trapping, anesthetizing, handling, and coded wire tagging reduced fish survival by about 66% compared with unhandled and untagged fish. In many ways, our handling and tagging procedures were similar, but Crozier and Kennedy (2002) were handling and tagging out-migrating wild smolts, which are generally known to be sensitive to handling and, therefore, prone to reduced survival (Lister et al. 1981; Blankenship and Hanratty 1990). Because the smolts were being released back into the river, the fish had little time to recover from the effects of the anesthetic, possibly making them more susceptible to predation than our fish that were returned to the hatchery ponds after tagging. We expect different results in our studies because we were measuring a different suite of variables.

When we began this study, we believed that thermal otolith marks produced as described by Volk et al. (1987) and Volk et al. (1990) would be unambiguous and would reliably identify our control fish. Indeed, in most cases, the errors were small, so the otolith mark was an accurate method of sorting control and stray fish. However, in one instance, 60% of unmarked samples in a blind test were scored as marked. This suggests that the marking pattern applied in that instance was poor or similar to the natural banding pattern on the unmarked sample. Although this reading error was alarming and undesirable, we believe our correction factors were appropriate and that, overall, the thermal otolith mark sufficiently identified the control fish.

Because injection of CWTs requires piercing the skin, it provides a potential portal for bacterial infection. It is well known that coded wire tagging should be avoided during disease outbreaks. Zajac et al. (1988) found that coded wire tagging did not enhance transmission of bacterial gill disease in healthy coho salmon, but Elliott and Pascho (2001) demonstrated that coded wire tagging of spring Chinook salmon progeny from parents with high infection levels of *Renibacterium salmoninarum* can enhance transmission of this bacterium. The long-term survival effects are unclear; the spring Chinook salmon we tagged at Cowlitz Salmon Hatchery and Carson National Fish Hatchery were from populations that were frequently infected with and treated for bacterial kidney disease (BKD), yet coded wire tagging did not impair survival. Although further studies might evaluate how tagging and disease are related to the long-term survival of the tagged animals, we believe it is preferable to implement tagging or other handling

procedures during times when the fish are healthy and when the environmental conditions are favorable. We did observe higher mortality of tagged fish than untagged fish during rearing at Cowlitz Salmon Hatchery. The average mortality during the 11 months in the hatchery environment after tagging was 0.5% higher than the untagged controls. The mortality patterns in 1989 and 1991 reflect what we would predict would happen after tagging: a short-term increase in mortality, as a response to additional handling, then a stabilization to control levels. In 1990 the increase persisted throughout the rearing period, and during that year, there had been an outbreak of BKD. Perhaps, as Elliott and Pascho (2001) describe, those fish were more susceptible to infection. Unfortunately, we did not collect information to verify that idea.

The numbers of strays recovered that were from Cowlitz Salmon Hatchery were consistent with a previous evaluation of homing in spring Chinook salmon on the Cowlitz River (Quinn and Fresh 1984). Both studies recovered stray fish from similar locations. Morrison et al. (1990) and Morrison and Zajac (1987) observed damage to the mainstem olfactory nerves in some coded-wire-tagged chum salmon and coho salmon fry tagged at a very small size (0.3 g). Such damage is of particular concern because of the well documented role that olfaction plays in salmonid migration and because of the poor regenerative capacity of nerve tissue. The expected detrimental effect of this damage would be an increase in straying. We observed no such effect in our study that could be attributed to olfactory damage, as evidenced by the low numbers of CWTs recovered in other locations and the equal survival rates of tagged and untagged fish. However, our study fish were considerably larger at the time of tagging than 0.3 g, and achieving good tag placement in such small fish would logically be more difficult. The long-term effects of coded-wire-tagging very small fish in the snout should be further evaluated.

In this study, we isolated the effects of anesthetization and the application of a coded wire tag and adipose fin clip from the other handling procedures associated with a tagging operation. When applied using normal tagging procedures at hatcheries, fish managers and researchers should expect that CWTs will have little detrimental impact on the populations they tag. The effects of CWTs and the related handling activities under different tagging situations, such as tagging wild fish or tagging

very small fish, may differ and should be further investigated.

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