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Regurgitation Rates of Intragastric Radio Transmitters by Adult Chinook Salmon and Steelhead during Upstream Migration in the Columbia and Snake Rivers

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Abstract.—Regurgitation rates for radio tags gastrically implanted into adult salmon *Oncorhynchus* spp. and steelhead *O. mykiss* are difficult to estimate in the wild because most fish are never recaptured to allow inspection of secondary tags. During 1996–2000, 9,006 Chinook salmon *O. tshawytscha* and steelhead with both radio tags and secondary tags were released near Bonneville Dam on the Columbia River (Washington–Oregon), and 1,764 fish were recaptured in midmigration 460 km upstream on the lower Snake River. Minimum annual regurgitation rates ranged from 0.4% to 10.9% for spring–summer Chinook salmon (pooled rate = 3.0%; n = 838), from 3.5% to 4.3% for steelhead (pooled rate = 4.0%; n = 881), and from 0% to 5.6% for fall Chinook salmon (pooled rate = 2.2%; n = 45). Fish that lost transmitters retained them a median of 7 d (average = 14.1 d) before regurgitation, and a majority of losses occurred in the lower Columbia River. Transmitter retention was improved by placing rubber bands or a ring of surgical tubing around part of each tag.

Radiotelemetry is increasingly used to monitor adult salmonid *Oncorhynchus* spp.migration rates, habitat preferences, behavior at dams, escapement, distribution within a drainage, and survival to spawning areas (Laughton 1991; Schreck et al. 1994; Hockersmith et al. 1995; Stuehrenberg et al. 1995; Pahlke 1997; Bjornn et al. 1998, 2000a, 2000b; Smith et al. 1998; Gowans et al. 1999). Most of the recent telemetry studies of adult salmon and steelhead *O. mykiss* have used intragastric tagging, which does not require surgery and has reduced fish handling and recovery times. A weakness of this method is that some fish regurgitate their transmitters, and regurgitation rates are difficult to measure because the fate of these fish is often unknown or ambiguous (Pahlke and Bernard 1996). Mistaking regurgitated transmitters for deaths or other losses—or vice versa—could bias research results in several ways. For example, a ‘‘stationary’’ transmitter that can be detected but not recovered by researchers could be either a regurgitated transmitter or one still present in the carcass of a fish that died. Similarly, transmitters discarded from fish recaptured in fisheries could, when subsequently found, be misidentified as regurgitated. Either mistake could result in inaccurate survival or escapement estimates or other misinterpretations of data.

The best opportunities for calculating transmitter regurgitation and retention rates are with fish recaptured in cooperative fisheries (Smith et al. 1998), at hatcheries or traps (Bjornn et al. 1998), or from spawning grounds. Secondary tags or markers are required in all cases to allow identification of fish that lose transmitters. Our telemetry study of adult salmonids in the Columbia River basin provided a unique opportunity to evaluate transmitter regurgitation rates. We were able to tag a large number of fish at Bonneville Dam (the first hydroelectric project encountered by adult migrants in the Columbia River) and later recapture and inspect the fish at Lower Granite Dam, 460 km upstream in the Snake River. Our objectives for this paper were to calculate regurgitation rates for adult Chinook salmon *O. tshawytscha* and steelhead, estimate tag retention time for fish that regurgitated transmitters, and evaluate whether tag retention could be increased by adding rubber bands or surgical tubing to transmitters.

Methods

As part of a large-scale study of adult salmon and steelhead migrations in the Columbia River basin (Bjornn et al. 2000a, 2000b), fish were trapped at the adult fish facility adjacent to the Washington-shore fish ladder at Bonneville Dam (river kilometer [rkm] 235 from the Columbia River mouth) as they migrated upstream to natal streams or hatcheries (Figure 1). Over the four

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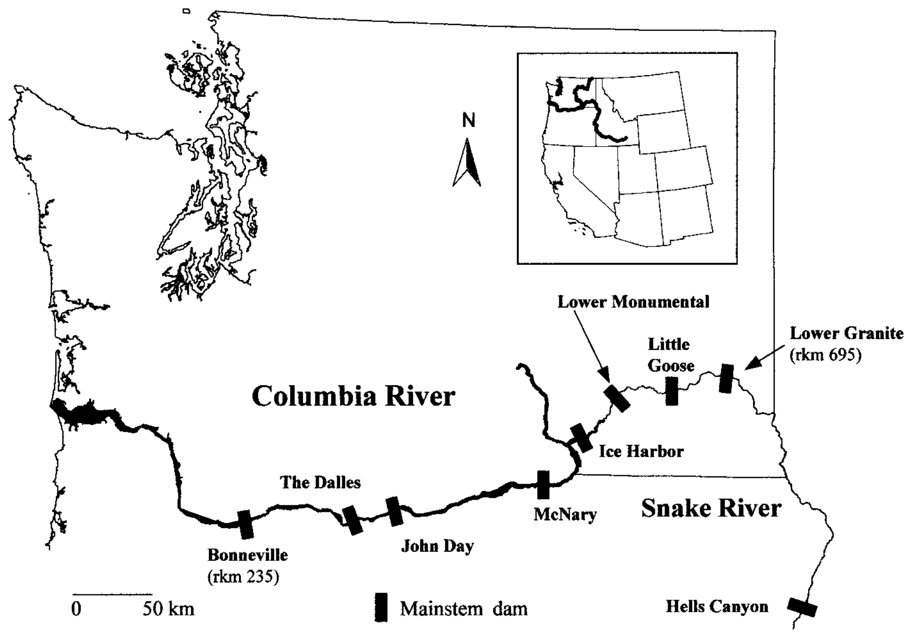

FIGURE 1.—Lower portions of the Columbia and Snake rivers, with locations of main-stem dams. Adult Chinook salmon and steelhead were fitted with radio transmitters at Bonneville Dam and inspected for transmitter retention at Lower Granite Dam.

study years (1996–2000), radio transmitters were gastrically implanted in 3,956 spring–summer Chinook salmon, 2,150 fall Chinook salmon, and 2,900 steelhead (Table 1). Run separation dates for Chinook salmon at Bonneville Dam were 1 June for spring and summer runs and 1 August for summer and fall runs. Nonselective samples were collected approximately in proportion to the size of each run. Samples were nonselective because we tagged fish as they arrived at the trap, but did not randomly sample the overall run: we sampled the fish passing the Washington-shore ladder but not the Oregon-shore ladder, the proportion sampled each day varied, no fish were sampled at night, and we rejected ''jack'' (precocious adult, by size) Chinook salmon and steelhead with fork lengths

TABLE 1.—Number of adult Chinook salmon and steelhead fitted with 3-V, 7-V, and radio–data storage (RDST) transmitters at Bonneville Dam and the number of transmitters with or without the addition of rubber bands or pieces of surgical tubing, 1996–2000.

	Spring–summer Chinook Salmon				Fall Chinook Salmon		Steelhead		
Variable	1996	1997	1998	2000	1998	2000	1996	1997	2000
Number tagged	853	1,014	957	1,132	1,032	1,118	765	975	1,160
3-V transmitters									
No additions							194		
Two rubber bands							197		
Surgical tubing			136	15	76				369
Bands or tubing[a]								427	
7-V transmitters									
No additions	853						184		
Two rubber bands							190		
Surgical tubing			821	904	956	1,038			637
Bands or tubing[a]		1,014						548	
RDST transmitters									
Surgical tubing				213		80			154

[a] Either rubber bands or surgical tubing was added in 1997; the equipment used was not recorded for individual fish.

less than 50 cm to accommodate transmitter size. In 2000, we selected for fish that had received passive integrated transponder (PIT) tags as juveniles. Each PIT tag uniquely identified the bearer, which made the PIT tags suitable as secondary tags. The PIT-tagged fish that we radio-tagged came from throughout the Columbia–Snake river basin and made up only a small proportion of our samples in 2000 (6% of spring–summer Chinook salmon; <1% of steelhead and fall Chinook salmon).

On each day of fish tagging, a weir in the Washington-shore fishway was lowered into place in the morning to divert fish from the main fishway into the adult fish facility via a short section of ladder. Diverted adults entered a collection pool with two weirs at the top of chutes, which led either to a channel back to the main ladder or to an anesthetic tank. Fish selected for tagging were directed to the anesthetic tank by activating hydraulic gates in the chutes. The person selecting fish had about 1 s to identify species and then operate the gates, which aided nonselective sampling.

Fish handling and radio tag insertion methods were the same during all years. We did not handle any fish until they were anesthetized, thereby minimizing fish stress. Anesthetics were either a 100-mg/L solution of tricaine methanesulfonate (MS-222) or a 25-mg/L solution of clove oil. Once a fish was anesthetized, we recorded its length and estimated sex. We then inserted a radio transmitter coated with glycerin through the mouth and into the stomach (Mellas and Haynes 1985). The transmitter antenna was bent at the corner of the mouth and allowed to trail alongside the fish. We used 3-V, 7-V, and radio–data storage (RDST) transmitters supplied by Lotek Engineering (Newmarket, Ontario). All tags transmitted digitally coded signals every 5 s that included the unique frequency and code of the transmitter. The 3-V tags were typically used in smaller fish, especially early-run steelhead. All transmitters were cylindrical, with 43–47-cm antennas. The 3-V transmitters weighed 11 g in air and measured 4.3 × 1.4 cm. The 7-V transmitters weighed 29 g and measured 8.3 × 1.6 cm. The RDSTs weighed 34 g and measured 9.0 × 2.0 cm. Lithium batteries powered the transmitters, and most batteries had rated operating lives of 270 d or more.

In 1996, we experimentally attached two rubber bands to odd-numbered 3-V and 7-V transmitters used in steelhead, whereas even-numbered transmitters had no rubber bands (Table 1). We expected the rubber bands to increase roughness of transmitters and therefore decrease the likelihood that transmitters would slide past the esophageal sphincter muscles and be regurgitated. Spring–summer Chinook salmon tags in 1996 had no rubber bands. In 1997, all transmitters were ringed with either rubber bands or a ~5-mm-wide piece of latex surgical tubing (3 mm thick; 12-mm inside diameter). Surgical tubing was easier to use than rubber bands, and was attached to all transmitters in 1998 and 2000. Because fish were anesthetized and rubber bands/tubing were glycerin-coated, the modifications did not impede tag insertion.

All radio-tagged fish received a coded-wire tag (CWT) that could be detected magnetically by sensors upstream at Lower Granite Dam. In 1996, 1997, and 1998, this 1-mm-long piece of magnetic wire was inserted into the muscle near the dorsal fin of each fish. In 2000, the CWT was delivered either dorsally or as part of a PIT tag. In all years, each radio-tagged fish also received a unique visible implant (VI) tag, which was inserted into the clear tissue posterior to one eye. The VI tags allowed us to later identify fish that had regurgitated their transmitters; PIT tags served the same purpose in 2000.

After they were tagged, fish were moved to a 2,275-L, oxygenated transport tank, where they were held until release (usually within 3 h). All fish radio-tagged from 1996 to 1998 were released about 9.5 km downstream from Bonneville Dam at Dodson, Oregon, or Skamania, Washington, landings. In 2000, 91% of radio-tagged spring Chinook salmon, 74% of summer Chinook salmon, 67% of fall Chinook salmon, and 73% of steelhead were released at the downstream sites, and the remainder were released in the forebay of Bonneville Dam. Fish released downstream had to re-ascend Bonneville Dam, and therefore had slightly longer migration distances to Lower Granite Dam and an additional dam passage compared to fish released in the Bonneville forebay.

A combination of fixed-receiver sites and mobile tracking allowed us to locate, but not recover, most regurgitated transmitters. We estimated the date of tag loss from the last telemetry record at a fixed receiver that clearly indicated fish movement at a dam or tributary. Estimates of tag retention time were therefore minimums, but should have been similar to actual retention times because most fish were actively migrating upstream and because we used many fixed monitoring sites. We used aerial Yagi antennas to monitor dam tailrace areas and tributary mouths, and underwater antennas made of coaxial cable to monitor fine-scale

TABLE 2.—Transmitter regurgitation rates of Snake River Chinook salmon and steelhead tagged at Bonneville Dam and examined at Lower Granite Dam, based on transmitter type and the presence or absence of rubber bands (RB) or pieces of surgical tubing (ST), 1996–2000. Regurgitation rates in parentheses are for each species in each year, for all transmitter types combined; RDST = radio–data storage transmitter.

Year	Tag type	Tag additions	Number inspected	Number without transmitter	Regurgitation rate
Spring–summer Chinook salmon					
1996	7 V	None	110	12	10.9 (10.9)
1997	7 V	RB or ST	265	1	0.4 (0.4)
1998	3 V	ST	15		0.0 (2.9)
	7 V	ST	226	7	3.1 (2.9)
2000	7 V	ST	148	4	2.7 (2.3)
	RDST	ST	74	1	1.4 (2.3)
All years			838	25	3.0
Fall Chinook salmon					
1998	3 V	ST	5		0.0 (5.6)
	7 V	ST	13	1	7.7 (5.6)
2000	7 V	ST	13		0.0 (0.0)
	RDST	ST	14		0.0 (0.0)
All years			45	1	2.2
Steelhead					
1996	3 V	None	43	2	4.7 (4.1)
	3 V	RB	57		0.0 (4.1)
	7 V	None	55	7	12.7 (4.1)
	7 V	RB	67		0.0 (4.1)
1997	3 V	RB or ST	122	8	6.6 (3.5)
	7 V	RB or ST	166	2	1.2 (3.5)
2000	3 V	ST	105	7	6.7 (4.3)
	7 V	ST	216	6	2.8 (4.3)
	RDST	ST	50	3	6.0 (4.3)
All years			881	35	4.0

movements in fishways and at dam ladder exits (see Bjornn et al. [2000b] for a complete description of antenna arrays). Areas not covered by fixed receivers (reservoirs, tributaries) were monitored occasionally with mobile units; mobile tracking data were used only to locate transmitters, not to calculate tag retention time.

Transmitter retention was evaluated only for Chinook salmon and steelhead that reached Lower Granite Dam on their way to upriver spawning areas or hatcheries. A detection system near the top of the Lower Granite fish ladder automatically diverts about 90% of fish with CWTs to an adult collection facility (Durkin et al. 1969; Harmon et al. 1994). More than 91% of the radio-tagged fish that passed Lower Granite Dam in the 4 years of this study were first diverted into the collection facility. Only fish that were checked for transmitters in the collection facility were used to calculate regurgitation rates; we excluded radio-tagged fish that passed the dam but were not diverted. Fish that regurgitated tags in the holding tank immediately after tagging at Bonneville Dam (<0.3% in each year, usually when antenna wires snagged on the tank or tank door) were also excluded. We used *Z*-tests or median tests to evaluate whether transmitter size, sex, release location, fork length, or the addition of rubber bands/surgical tubing affected regurgitation rates.

Results

Over the four study years, 1,764 adult Chinook salmon and steelhead radio-tagged at Bonneville Dam were recaptured at the Lower Granite Dam collection facility and inspected for transmitter retention (Table 2). Annual regurgitation rates for 838 spring–summer Chinook salmon ranged from 0.4% to 10.9%, with an overall rate of 3.0%. Annual rates were from 0.0% to 5.6% for 45 fall Chinook salmon (overall rate = 2.2%) and from 3.5% to 4.3% for 881 steelhead (overall rate = 4.0%). The highest regurgitation rates were for steelhead in 1996 (12.7%) and spring–summer Chinook salmon in 1996 (10.9%) that had 7-V transmitters with no roughness elements (rubber bands or surgical tubing) added to tag exteriors.

In the experimental test, regurgitation rates were significantly higher for steelhead released in 1996 with no rubber bands on their 7-V transmitters (7/55, 12.7%) than for steelhead whose 7-V trans-

TABLE 3.—Spatial distributions of radio tag regurgitation by Chinook salmon and steelhead migrating to Lower Granite Dam, as estimated from the last fixed-receiver telemetry record for each fish, all years (1996–2000) combined.

River reach (dam to dam)	Spring–summer Chinook salmon		Steelhead	
	Number	Percent ($N = 25$)	Number	Percent ($N = 35$)
Near release site	4	16	7	20
Bonneville to The Dalles	6	24	11	31
The Dalles to John Day	4	16	11	31
John Day to McNary			1	3
McNary to Ice Harbor[a]	4	16	3	9
Ice Harbor to Lower Monumental	1	4	2	6
Lower Monumental to Little Goose	1	4		
Little Goose to Lower Granite	5	20		

[a] Includes 16 km of the Snake River below Ice Harbor Dam.

mitters had two rubber bands (0/67, 0.0%) ($Z = 3.01$; $P = 0.003$) (Table 2). The difference was less significant for steelhead with 3-V tags: 2 of 43 fish (4.7%) with no rubber bands regurgitated the transmitters, versus 0 of 57 fish (0.0%) with two rubber bands ($Z = 1.64$, $P = 0.100$). When 3-V and 7-V transmitters were combined, regurgitation rates were significantly higher for steelhead without rubber bands on tags (9/98, 9.2%) than for those with rubber bands (0/124, 0.0%) ($Z = 3.45$; $P = 0.0006$).

In nonexperimental comparisons of transmitter type, steelhead were more likely to regurgitate 3-V (6.6%) than 7-V (1.2%) transmitters in 1997 ($Z = 2.45$, $P = 0.014$) and 2000 (3-V = 6.7%, 7-V = 2.8%) ($Z = 1.66$, $P = 0.097$) (Table 2). In 1996, rates were not significantly different ($P > 0.15$) for steelhead with 3-V versus 7-V transmitters for pairs with or without rubber bands. Regurgitation rates for fall Chinook salmon with 3-V and 7-V tags were not different in 1998 ($P = 0.52$). Fish from all three runs in 2000 did not regurgitate RDSTs at significantly different rates than either 3-V or 7-V transmitters ($P > 0.25$).

Regurgitation rates did not differ significantly ($P > 0.10$) for fish released at different locations at Bonneville Dam in 2000: 6.6% of forebay-released steelhead regurgitated transmitters compared to 3.0% of steelhead released downstream, and rates were 0.0% for forebay-released and 2.3% for downstream-released spring–summer Chinook salmon. Sample sizes for fall Chinook salmon in 2000 were too small for meaningful comparison.

We estimated when and where radio-tagged fish regurgitated transmitters primarily from the last telemetry record of fish at fixed-receiver sites. Repeated mobile tracking at suspected loss sites and occasional tag recovery further verified the location for some tags. Regurgitation occurred throughout the migration, but among fish that lost transmitters en route to Lower Granite Dam, 56% of spring–summer Chinook salmon, 85% of steelhead, and the single fall Chinook salmon lost their transmitters by the time they reached the migration midpoint at McNary Dam (rkm 470) (Table 3).

Distributions of minimum estimated times that fish retained transmitters before regurgitating them were skewed to the right, and therefore we emphasize median data over means. Over the study period, median retention times were 11 d for spring–summer Chinook salmon and 6 d for steelhead; the single fall Chinook salmon kept its transmitter for 4 d (Table 4). Most fish that regurgitated their transmitters at or near the release site did so within 1 d after release. Forty-two percent of steelhead and 56% of spring–summer Chinook salmon retained tags for more than 10 d, and about 25% of both species retained them for more than 20 d before telemetry records indicated regurgitation. Fish release date did not appear to be related to tag retention time for any species.

We found no significant differences ($P > 0.25$, Z-tests) in regurgitation rate between male and female fish for either spring–summer Chinook salmon or steelhead, although sex differentiation can be difficult at the onset of upstream migration, and we were not fully confident in gender identifications. Regurgitation was not consistently related to fish size for the seven groups with four or more fish recaptured without a transmitter (Table 2). In 1996, 1998, and 2000, median lengths were not significantly different between spring–summer Chinook salmon that regurgitated their 7-V transmitters and those that did not ($P > 0.10$, median tests). Steelhead that regurgitated 7-V transmitters were nonsignificantly shorter than their counterparts in 1996 (10.5 cm, $P = 0.14$) and 2000 (6.7

TABLE 4.—Minimum estimated radio-tag retention times before regurgitation for Chinook salmon and steelhead that regurgitated their transmitters en route to Lower Granite Dam.

Species	Year	*N*	Minimum retention time (d) Range	Median	Mean
Spring–summer Chinook salmon	1996	12	3–54	17.5	20.8
	1997	1	15		
	1998	7	<1–17	6.0	7.0
	2000	5	0–41	3.0	11.0
	All years	25		11.0	14.5
Fall Chinook salmon	1998	1	4		
Steelhead	1996	9	<1–14	2.0	3.6
	1997	10	<1–57	14.5	18.4
	2000	16	1–70	9.0	17.1
	All years	35		6.0	14.0
All species	All years	61	<1–70	7.0	14.1

cm, $P = 0.13$); steelhead that regurgitated 3-V transmitters were longer than those that did not regurgitate in 1997 (11.8 cm, $P = 0.06$) and 2000 (3.0 cm, $P = 0.33$). Small samples for all species and years limited statistical power, and years could not be pooled due to differences in stock composition (e.g., different between-year proportions of larger summer-run Chinook salmon or late-migrating *B*-group steelhead).

Discussion

In this study, 883 spring–summer and fall Chinook salmon recaptured and inspected in mid-migration showed a minimum pooled radio tag regurgitation rate of 2.9%. The pooled rate for the species is 1.8% if we exclude 1996 spring–summer Chinook salmon, whose transmitters lacked roughening features. Bjornn et al. (1998), in a similar study, released radio-tagged adult spring–summer Chinook salmon near Ice Harbor Dam in 1991 and 1992 and at John Day Dam in 1993; the fish were recaptured and inspected at the Lower Granite Dam adult facility. Regurgitation rates were 3.8% (14/370) in 1991, 4.3% (16/376) in 1992, and 7.8% (22/282) in 1993. Given that these fish migrated substantially shorter distances to Lower Granite Dam than the fish in our study, their regurgitation rates were relatively high. The 1991–1993 transmitters did not have rubber bands or surgical tubing to aid retention.

Similar research with steelhead in the early 1990s (Bjornn et al., unpublished data) showed much higher regurgitation rates than we found (minimum 4.0%, pooled) for this species. Steelhead released at Ice Harbor Dam and recaptured at Lower Granite Dam had regurgitation rates of 24.4% (96/393) in 1991, 19.6% (72/368) in 1992, and 26.0% (84/323) in 1994; the rate was 18.0% (59/328) for fish released at John Day Dam in 1993. No additions were made to transmitters to aid retention. High rates were attributed in part to very active fisheries in the Columbia and Snake rivers, and the associated angling or handling stress for steelhead hooked but not captured, or captured and released.

Reported regurgitation rates in other adult salmon and steelhead telemetry studies range from about 6% to 17%. The Washington Department of Fish and Wildlife (WDFW) calculated a rate of 6.9% (5/72) for radio-tagged adult fall Chinook salmon released at Ice Harbor Dam in 1995 and recaptured at the Lower Granite Dam adult trap, and found a rate of 10.4% (14/135) for fish recaptured at the trap, at hatcheries, and in fisheries (WDFW, unpublished data). Blankenship and Mendel (1994) calculated a rate of 6.2% (3/48) for radio-tagged fall Chinook salmon released at Ice Harbor Dam and recaptured in hatcheries, in traps, and on spawning grounds. The rate for adult steelhead in the Yakima River was 13.9% (27/194) (Hockersmith et al. 1995). Smith et al. (1998) reported 12.5–16.7% regurgitation rates for small numbers of adult Atlantic salmon *Salmo salar* recaptured in fisheries on the River Tweed, Scotland. From the published reports, it is not clear whether modifications were made to transmitters in any of these studies to aid retention.

Our experiment with steelhead transmitters in 1996 indicated that the addition of rubber bands to radio tags reduced regurgitation rates for fish with 3-V or 7-V transmitters. When fish from all species and years were combined, regurgitation rates were 10.1% (21/208) for fish with unmodified transmitters and 2.6% (40/1,556) for fish with modified transmitters. Although this difference was not experimentally derived, we believe it strongly supports the results from the 1996 steelhead experiment. Adding rubber bands or surgical tubing increased transmitter roughness and diameter, which may have made expulsion through the esophagus more difficult; we found no published literature on this subject, and more research is needed to confirm that additions to transmitters can aid retention.

Comparisons of regurgitation rates among transmitter types and fish size in this study were not based on experiments and should be interpreted with more caution. For example, higher proportions of steelhead regurgitated 3-V than 7-V tags, but the smaller 3-V tags were used in smaller fish. We did not have adequate sample sizes for a post hoc evaluation of interactions between fish size and transmitter type.

Among the fish that regurgitated radio transmitters in our study, a majority (including a strong majority of steelhead) did so in the lower Columbia River. Regurgitation might be at least partly a function of overall migration time, such that faster-migrating fish are less likely than slower migrants to drop transmitters before they reach Lower Granite Dam. Our data suggest that steelhead migrate more slowly through the lower river than Chinook salmon, in part because many steelhead stray temporarily into tributaries when main-stem water temperatures are high. Stress-induced regurgitation may also be higher in the lower river, where adult salmonids are exposed to greater gill-net and recreational fisheries, and fallback over Columbia River dam spillways occurs at higher rates than at Snake River dams (Dauble and Mueller 2000; Boggs et al., in press). Resolution of these and other possibilities awaits further research.

Only fish migrating up the Snake River were inspected in this study, but the regurgitation rates we calculated are consistent with anecdotal information from elsewhere in the Columbia–Snake river basin. We examined recapture records for our radio-tagged fish from several hatcheries on basin tributaries—Carson Hatchery (Wind River), Little White Salmon Hatchery (Little White Salmon River), Warm Springs Hatchery (Deschutes River), Ringold Hatchery (Hanford Reach of the Columbia River), Dworshak Hatchery (Clearwater River), Leavenworth Hatchery (Icicle River), and Wells Hatchery (Wells Dam)—and estimated overall regurgitation rates of 0.0–7.8%. As with fish inspected at Lower Granite Dam, regurgitation rates for spring–summer Chinook salmon recaptured at hatcheries were higher in 1996 (when no roughening agents were applied to transmitters) than subsequent years. Regurgitation rates were also higher for 1996 steelhead whose transmitters had no rubber bands than for those with two rubber bands. Sample sizes at hatcheries were typically small (especially for steelhead), collection and inspection for tag retention efforts varied among sites, and some regurgitation occurred either in hatchery holding ponds or in staging areas immediately downstream, so the regurgitation values from hatcheries were not individually definitive.

Almost all fish inspected at hatcheries upstream of Lower Granite Dam still had transmitters if they had retained them at the Lower Granite trap, but we cannot say that transmitter regurgitation had ended by the time fish reached the dam. Because fish regurgitated throughout the migration to Lower Granite Dam, we suspect some fish likely did so upstream from the dam as well, and full-migration regurgitation rates were likely higher than those reported here. Rates would also increase if a disproportionate number of fish that passed Lower Granite Dam without being diverted to the trap had lost transmitters, or if both visual implant (VI) and radio tags were lost during migration. We were more likely to underestimate regurgitation rates for steelhead than for Chinook salmon, because far more steelhead were diverted into the Lower Granite trap each year—allowing less time for inspection—and because steelhead were more likely than Chinook salmon to lose VI tags due to their protracted migration times (e.g., Mourning et al. 1994). We could not evaluate transmitter retention for the several thousand fish tagged at Bonneville Dam that did not return to Lower Granite Dam or to hatcheries; these fish returned to spawning tributaries, were recaptured in fisheries, or died during migration.

Our study indicates that transmitter regurgitation rates for adult salmonids migrating upstream within the Columbia–Snake hydrosystem can be less than 5% when steps are taken to inhibit tag loss. We recommend the addition of a ring of surgical tubing or rubber bands to transmitters to aid transmitter retention. To ensure accurate evaluation of regurgitation rates, secure and unique secondary tags should be used whenever fish are likely to be recaptured or inspected during their migration. Survival and escapement estimates should be adjusted upward when sufficient information on regurgitation rates is available.

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