Estimating the Abundance and Distribution of Locally Hatchery-Produced Chinook Salmon Throughout a Large River System Using Thermal Mass-Marking of Otoliths

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The role of hatchery production in the management of Pacific salmon (*Oncorhynchus spp.*) has undergone extensive review and scrutiny in recent years (for example, Schramm and Piper 1995). Among the potential hazards to natural production caused by the presence of hatchery fish are deterioration of wild stock gene pools due to incorporation of genes from hatchery strays into wild populations (Campton 1995), overharvest of wild fish by fisheries harvesting at the higher rates appropriate to the hatchery fish mixed with them (Lichatowich and MacIntyre 1987), and masking of the true abundance status of natural populations due to the misidentification of hatchery strays on natural spawning grounds as natural production.

To assess the risks posed by these hazards to naturally produced fish in a large river basin, we thermally mass-marked chinook salmon (*O. tshawytscha*) released at the two hatcheries in the area, and sampled returning adults in a local terminal fishery and comprehensively throughout the natural spawning grounds and hatchery return facilities. The study area is the Snohomish basin (4,800 km^2), which produces a significant fraction of the naturally spawning Pacific salmon returning to Puget Sound in northwest Washington State, USA. Chinook salmon in the basin are managed for natural spawning objectives, but approximately one-half the return to the river each year is production from the Wallace River hatchery, located approximately 60 km upstream of the Snohomish River mouth. In addition, significant numbers of chinook salmon produced at the Bernie Kai-Kai Gobin Hatchery return to Tulalip Bay, located in the Snohomish River estuary.

From brood year 1993 through 1997 all chinook salmon produced at the Wallace and Gobin hatcheries were thermally mass-marked, and can be identified to brood year and hatchery of origin by microscopic examination of otoliths. Otolith marking followed the method described by Volk et al. (1990). Water chillers lowered incubation water 3–5°C below ambient temperature on prescribed schedules to induce unique otolith banding patterns on all fish in a production group. Each combination of hatchery and brood year received a unique banding pattern. Two broodstocks are used as sources of eggs: an early returning group ("summer") originally derived from fish within the Snohomish system and a late returning group ("fall") originally derived from outside the system. Beginning with the 1994 brood year, the summer and fall fish at Wallace hatchery received distinguishable marks. Releases of thermally marked chinook salmon from the two facilities are summarized in Table 1.

Table 1. Numbers of thermally marked chinook salmon released at the Gobin and Wallace River hatcheries, brood years 1993–1997. Each combination of hatchery, brood year, and stock (summer or fall) received distinguishable marks. Yearling and fingerling release stages are distinguishable from scale patterns.

	Hatchery, stock, and release stage				
	Gobin	Wallace			
	Fall	Summer		Fall	
Brood Yr.	Fingerling	Yearling	Fingerling	Yearling	Fingerling
1993	1,280,000	281,000	642,700	268,000	519,200
1994	1,265,000	278,000	0	280,000	1,200,000
1995	1,860,000	270,000	918,000	265,000	975,000
1996	1,900,000	530,000	1,120,000	0	1,110,000
1997	1,700,000	394,000	920,000	0	0

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Sampling of the terminal marine fishery in and near Tulalip Bay, adjacent to the Gobin Hatchery return facility, commenced in 1997. Otoliths were extracted from 100 chinook salmon per week and preserved in 95% ethanol for later examination for mark presence. Details of weekly catch and sampling for 1998 are shown in Table 2. The estimates of the contribution rate of Gobin hatchery chinook salmon to the Tulalip Bay fishery over the three years ranged from 92.5% (1998) to 98.0% (1999) (Table 3).

Sampling of hatchery rack returns began at Gobin Hatchery in 1998 and at Wallace Hatchery in 1997. At Gobin Hatchery, 100% of fall chinook salmon sampled at the hatchery rack were of local origin (Table 4). At Wallace Hatchery the local contribution to hatchery escapement ranged from 73% to 96% (Table 4).

Sampling of the natural escapement involved extraction of otoliths from spawned-out carcasses throughout all areas in the Snohomish system where chinook salmon spawn. Over the three years, otoliths were extracted from 9% of the total estimated naturally spawning population. An example of the detailed distribution of otolith marks by stratum for 1999 is shown in Table 5. Clearly, the stratification is necessary, since the estimated contribution rate of marked hatchery fish to the natural spawning populations ranged from 6% to 94% among the six strata over the three years (Table 6).

There is a large variance in marked fish contribution rate among both years and strata, and the pattern of variation appears to be consistent, indicating that year and stratum factors could be estimated separately (Fig. 1). It would also be possible to determine if factors that vary annually, such as streamflow, are related to the stray rates of hatchery fish. We have not yet completed the necessary statistical analysis to estimate these factors.

Table 2. Tulalip Bay terminal fishery weekly catch, otolith samples, and number of Gobin Hatchery (GH) marks in the sample, 1998.

Stat. Week	Catch	Samp.	GH Marks	95% c.i.[a] lower	95% c.i.[a] upper
32	1446	100	83	75%	89%
33	1904	100	93	87%	97%
34	1286	100	96	91%	98%
35	1102	100	96	91%	98%
36	522	100	94	88%	97%
37	672	100	93	87%	97%
≥38	169	0			
Total	7101	600	555	89%	94%

[a]Confidence intervals for proportions computed using the method described by Fleiss (1981), eqns. 1.26 and 1.27.

Table 3. Annual estimates of the contribution of Gobin hatchery (GH) chinook salmon to the Tulalip Bay fishery, 1997–1999.

Year	Catch	Samp.	GH Contrib.	95% c. i. Lower	95% c. i. upper
1997	8,295	514	95.3%[a]	93%	97%
1998	7,101	600	92.5%	89%	94%
1999	15,076	507	98.0%	97%	99%

[a]This estimate is for age 3 and 4 fish only since the 1993 brood year was the first year marked.

Table 4. Annual estimates of the fraction of the hatchery return that was from local hatchery production for the Gobin and Wallace hatcheries.

Hatchery	Year	Total Sample	Otolith Mark[a] UNM	GH	WRH	UNR	Fraction Local[b]
Gobin	1998	50	0	50	0	0	100%
Gobin	1999	28	0	28	0	0	100%
Wallace	1997	195	48	4	142	1	73%
Wallace	1998	250	27	2	217	4	88%
Wallace	1999	200	7	0	191	2	96%

[a]UNM: unmarked, GH: Gobin hatchery mark, WRH: Wallace hatchery mark, UNR: otolith mark unreadable.
[b]Number of otoliths with local hatchery mark divided by the number of readable samples (Total sample – UNR).

Table 5. Example of results of stratified sampling of natural escapement, 1999.

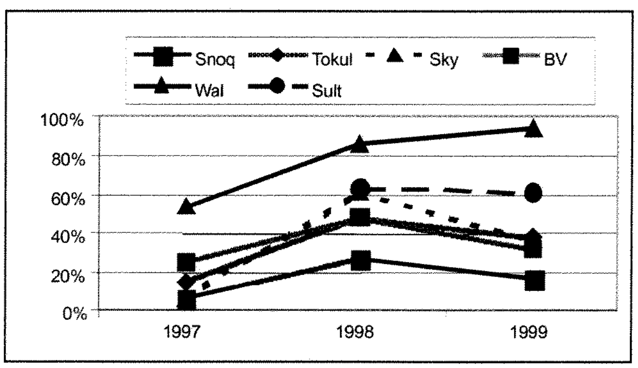
	Total	Otolith Mark					Proportion
Stratum	Sample	UNM	GH	WH	UNR	CWT[a]	marked[b]
Snoqualmie	119	96	17	2	3	1	17%
Tokul Creek	98	57	26	9	6	0	38%
Skykomish	92	58	1	33	0	0	37%
Bridal Veil	41	28	0	13	0	0	32%
Wallace	119	7	0	104	8	0	94%
Sultan	64	25	0	39	0	0	61%
Total	533	271	44	200	17	1	

[a]CWT: otolith was not marked, but the fish contained a coded-wire tag indicating a stray from outside the system.
[b]Number of marked otoliths divided by number of readable samples (Total sample – UNR).

Table 6. Summary of estimated marked fish contribution rates by stratum and year, 1997–1999.

	Year					
	1997		1998		1999	
Stratum	Sample	% marked	Sample	% marked	Sample	% marked
Snoqualmie	70	6%	116	27%	119	17%
Tokul	41	15%	39	48%	98	38%
Skykomish	33	6%	99	61%	92	37%
Bridal Veil	67	25%	75	48%	41	32%
Wallace	110	54%	105	86%	119	94%
Sultan	0		93	63%	64	61%
Total	321		527		533	

Fig. 1. Contribution rates of marked hatchery fish to natural escapement by stratum and year, 1997–1999.



To estimate the contribution of hatchery fish to the overall natural spawning escapement, we multiplied the stratum-specific contribution rates reported above by the estimated number of natural spawners, as determined from a combination of aerial and foot surveys using standard expansion methods employed by the Washington Department of Fish and Wildlife (Smith and Castle 1994). Summing these stratum-specific estimates for each year allows us to report escapement to the river in four categories according to both the origin (natural or hatchery production) and destination (natural or hatchery escapement areas) of the fish (Table 7). Over the three years the system-wide contribution rate of hatchery fish to natural spawning escapement ranged from 19% to 55%, and the bias in the estimate of natural escapement ranged from –2% to 95%.

Our results show that by marking all hatchery production in the area and sampling the fishery, hatchery escapement, and natural escapement with appropriate stratification we can develop the information necessary to improve management of the chinook salmon resource. Because this species is now listed under the US Endangered Species Act, we are required to maintain harvest rates on wild stocks below strict guidelines and to make necessary adjustments to hatchery programs to minimize the impacts of this production on wild populations. The precise estimates of hatchery contribution to the fishery and escapement from our study is the first step implementing these management mandates. The high variability in hatchery contribution to natural escapement among years and among strata shows that hatchery straying is a complex problem. The regular pattern of variation observed gives us optimism that we may be able to discover relationships with independent variables that allow us to predict and ultimately to adjust our programs to minimize stray rates.

Table 7. Summary of stratified estimates of the escapement of natural and hatchery origin fish to natural and hatchery escapement areas. A small number of non-local hatchery fish (fish from outside the Snohomish system, identified from coded-wire tags) are included with the hatchery fish in this table.

	Escapement areas and origin					
	Natural areas		Hatchery facility		Overall	Bias in
Year	Natural	Hatchery	Natural	Hatchery	HCR[a]	NEE[b]
1997	3,525	770	868	2,639	0.18	-2.2%
1998	2,856	3,450	375	4,377	0.55	95.1%
1999	2,436	2,354	240	6,089	0.49	78.9%

[a]Overall hatchery contribution rate (HCR) is hatchery origin fish escaping to natural areas divided by total escapement to natural areas.
[b]Bias in natural escapement estimate (NEE) is (total escapement to natural areas less total natural origin escapement to natural and hatchery areas) divided by total natural origin escapement to natural and hatchery areas.

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