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Estimating the percentage of hatchery-reared juvenile coho salmon in the Strait of Georgia in 1997

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Abstract

The marking of a large number of hatchery coho in 1997 by removal of the left pelvic fin provided an opportunity to estimate the percentage of hatchery and wild coho in the Strait of Georgia. The survey of juvenile coho abundance and distribution in the Strait of Georgia and Puget Sound in 1997 provided samples that enabled estimates of hatchery and wild coho to be determined prior to any fishery. These marked coho and catches from surveys in June/July and in September indicated the proportion of juvenile hatchery coho within the Strait of Georgia ranged from 76-79%. If estimates of smolts from enhanced adults (i.e., hatchery fish spawning in the wild) were included as hatchery releases, estimates of hatchery percentages in the catch could be as high as 87%. Both hatchery and wild juvenile coho remained within the Strait of Georgia until after September, several months after coho left Puget Sound. There was no difference in the length of coho with or without the left pelvic fin.

Résumé

En 1997, le marquage d'un grand nombre de saumons coho, par ablation de la nageoire pelvienne, a permis d'estimer la proportion des sujets sauvages et des sujets d'élevage dans le détroit de Georgia. Les échantillons prélevés au cours d'un relevé effectué en 1997, pour étudier l'abondance et la répartition des juvéniles dans le détroit de Georgia et la baie Puget, ont permis de prédire les proportions des saumons coho sauvages et d'élevage avant le début de la saison de la pêche. Selon les résultats du marquage ainsi que ceux des relevés de juin - juillet et de septembre, la proportion des juvéniles d'élevage dans le détroit de Georgia aurait été de 76 à 79 %. Si, de surcroît, on comptait comme juvéniles d'élevage les saumoneaux de frayères naturelles issus de parents d'élevage, la proportion estimée des prises de coho d'élevage pourrait s'élever à 87 %. Les juvéniles des deux groupes, sauvage et d'élevage, sont demeurés dans le détroit de Georgia après septembre, soit plusieurs mois après le départ du coho de la baie Puget. Aucune différence de taille n'a été observée entre les sujets ayant subi l'ablation de la nageoire pelvienne et les autres.

INTRODUCTION

In 1997, both Canada and the United States started releasing a relatively large number of hatchery-reared coho marked by removal of the left pelvic fin or the adipose fin. The use of a large rope trawl in a study of the abundance and distribution of coho in the Strait of Georgia and in Puget Sound provided relatively large samples of these marked juvenile coho. In this report, we use these catches to estimate the percentages of hatchery and wild coho in the Strait of Georgia in the summer of 1997. There are some uncertainties relating to marking/tagging mortalities and the recognition of marks that require additional study, however, the release of a large number of marked fish in Canada and the United States and the new methods to collect juvenile coho during the early marine phase offered an opportunity to provide information on wild coho abundance prior to any fishery. This study also provided a method of checking our earlier estimates of the percentage of hatchery fish using the otolith microstructure (Zhang and Beamish, 1994).

METHODS

In June/July (June 17 to July 12) and in September (08 to 27) of 1997, juvenile coho salmon were collected in the Strait of Georgia as part of a study on climate/ocean environment effects on the carrying capacity for coho and chinook salmon within the Strait. The research vessel W.E. Ricker was used to fish a mid-water rope trawl (Model 250/550/14) that had an average opening of 13 m (height) by 25 m (width). The net was towed at an average speed of 5.0 Kt (2.6m/sec) and most fishing occurred at depths ranging from the surface to 45 m. The track lines followed a modified rectangular pattern (Figure 1) that provided more effort closer to shore than in the central areas of the Strait. Fishing times ranged from 6:00 AM to 6:00 PM. Unfortunately, the W.E. Ricker developed steering problems mid-way through the September cruise and after a delay of 4 days, the cruise was completed using the commercial vessel Frosti (Beamish et al., 1998), equipped with the net from the W.E. Ricker. In a separate publication we report the catch results and use the catches to estimate total abundance (Beamish et al. 1998). In this report, we combine all catches to estimate the percentages of hatchery-reared coho salmon. Catches, standardized to number per hour (CPUE), are shown in Figure 1.

Ventral Clip (LVC) program

In 1997, approximately 60% of the coho salmon smolts released into the Strait of Georgia from British Columbia hatcheries had the left pelvic fin removed (LVC). A small percentage of these fish also had the adipose fin removed and a coded-wire tag (CWT) inserted. Additionally, other hatcheries continued the standard practice of removing only the adipose fin and inserting a CWT in a small percentage (2-10%) of fish prior to release.

At the present time, the marking and release estimates have not been completely organized into the mark-recovery program (MRP) database. With the assistance of Sue Lehmann and Ron Kadowaki, we have summarized the various releases from hatcheries into the Strait of Georgia in 1997. The primary data were obtained by searching the MRP database (Kuhn, 1988) for all 95 brood year (BY) coho released by all hatcheries which enter the Strait of Georgia. Thus, all hatcheries (including Public Involvement Programs and Community Development Projects) for Georgia Strait Vancouver Island (GSVI), Johnstone Strait (JNST), Mainland North and South (GSMN and GSMS) and Lower Fraser River (LWFR), as well as those on Thompson Mainstem (TOMM), Thompson Forks (TOMF), and Upper Fraser River (UPFR) regions are included. Those hatcheries participating in the LVC program were identified as a sub-group (Table 1). We checked the accuracy of our estimates by contacting each of the participating hatcheries and confirming that the numbers recorded within the database matched their records.

Otolith Study

For this study, one hundred random pairs of otoliths from Ocean Age 0 coho caught in our September survey were prepared and examined for rearing type according to the procedures in Zhang and Beamish (1994). Whenever possible, the left otolith was used in the determination. If the left otolith was crystalline (Zhang and Beamish, 1994), or if it was not taken in the survey, then the right otolith was used. If both otoliths were crystalline, then the origin could not be determined. In this situation, rearing types were assigned using the proportions observed in those fish with a single crystalline otolith (crystalline otoliths rarely found in wild fish - Zhang, pers. comm.)

RESULTS

The total number of smolts released from British Columbia hatcheries into the Strait of Georgia in 1997 was approx. 9.6 million (Sue Lehmann, pers. comm.). In addition, these hatcheries released some 4.6 million fry in 1996 from the 1995 brood year (BY) (Sue Lehmann, pers. comm.). The contribution of these fry releases to the number of smolts entering the Strait in 1997 is dependent on the fry to smolt survival (Table 2). Using a conservative survival rate of 10%, we estimate these fish would contribute a further 460,000 fish to the 1997 hatchery smolt production, increasing it to 10.06 million smolts (Table 2). The 4,988,292 LVC fish (from Table 1) thus composed 49.6% of the total number of British Columbia hatchery smolts entering the Strait of Georgia in 1997. Doubling the fry survival rate to 20% would increase the total number of smolts entering the strait to 10.52 million, with the LVC coho then comprising 47.4% of that total (Table 2).

The September survey captured a total of 2,402 ocean age 0 coho, of which 723 had a LVC (Table 3). There was no significant difference ($P > .05$) in fork length between the unmarked and LVC fish (243.37 ± 24.27 mm *vs.* 243.33 ± 19.80 mm, respectively) ($\bar{x} \pm SD$). The expansion of the LVC coho captured in the survey (Table 3) included estimates of tagging mortality and an estimate of tagged fish not recognized (i.e., awareness). While ventral fin clipping mortality can range from 6-25% (PSC 1995, 1997), we have no measures of the mortality for the 1997 program and used conservative error estimates of 7% for mortality and 7% for awareness.

We estimated the number of United States (US) hatchery fish using information from our earlier Puget Sound surveys (Beamish et al. 1998). In our sets in Puget Sound in June/July, 1696 coho were caught, of which 280 (17%) had adipose clips Only 50, or 17.8%, of these adipose clipped fish also had a CWT. In the Strait of Georgia we considered all adipose clipped fish without a CWT to be US fish and added to this number all fish with a CWT from a US hatchery to obtain an initial American contribution. We also assumed that 70% of the coho in Puget Sound were hatchery reared (Bill Tweit, WDFW, pers. comm.) and, therefore, 70% of the estimated coho from Puget Sound in our catches in the Strait of Georgia would be from US hatcheries. Thus, the 40 US coho caught in our September survey (Table 3) expanded to 177 US hatchery-reared coho (including a 7% awareness factor). Based on these assumptions, the total hatchery contribution (Canadian and US) to our September catch was 1840 coho, representing 76.6% of the total catch and, therefore, of the total coho smolt population within the Strait of Georgia in September of 1997.

The remaining 24.4% of the coho population in the September survey that were not estimated to have been reared in hatcheries are a mixture of offspring from both wild spawners and hatchery-reared fish which spawned in the wild. The escapement database enumerates all fish spawning in a river regardless of origin and, as a result, both wild fish and hatchery-reared fish spawning in the river are included. However, in some areas returning hatchery spawners may contribute substantially to the total escapement (e.g., Big Qualicum, Chilliwack, and Quinsam). For example, at the Quinsam hatchery in 1990 there was a total estimated escapement of 25,000 fish to the river, of which the hatchery took 8400 spawners. Based on CWT returns, it was estimated that there were 16,926 hatchery coho that returned to the river and hatchery combined, leaving 8563 (33.6%) wild spawners. Similarly, at the Big Qualicum hatchery it was estimated that wild escapements to the river in 1990, 1991 and 1992 were 13.0, 13.0 and 26.7% respectively. These number indicate that nearly 80% of the spawning occurring in these river systems may be by fish released as hatchery-reared coho. For the purposes of this paper, we define wild coho as the offspring of parents that reared in the wild, and enhanced coho as the offspring of parents which were hatchery reared but which spawned in the wild. All coho spawning in the wild, regardless of parental origin, are considered to be natural spawners.

Based on releases (and sex ratios) of adult coho back into the rivers to spawn naturally, it is estimated that 19,600 females spawned naturally in 1995 (Sue Lehman, pers. comm.). Using an average fecundity of 2699 eggs per female (Sandercock, 1991) and an egg-to-smolt survival of 2% (Sandercock, 1991), the number of enhanced F_1 coho smolts would be approximately 1.06 million. In a sense, the enhanced smolts derived from this calculation are "theoretical hatchery" smolts as it was assumed that hatchery fish paired with hatchery fish. This is also a minimal estimate, as there is no accurate estimate of the total number of spawning fish in all these river systems (i.e., including fish that did not return to the hatchery). Our point is that a large percentage of escapements are either releases from hatcheries or hatchery fish that did not return to the hatchery at all. The importance relates to obtaining a true estimate of wild spawners, assuming that there can be agreements on the definition of a wild coho. If we include these potential 1,058,000 enhanced smolts into our calculations, the total number of non-wild coho smolts entering the Strait of Georgia in 1997 rises to approximately 11.12 million, and the percentage of LVC coho adjusts to 44.9% (4988292/11,118,000). The number of coho smolts in the survey increases to 1837 (825 caught/44.9%) + 177 (US contribution) which means a total of 2014 fish or 83.8%, an increase of approximately 7% from the 76.6% estimate based only on hatchery releases.

In the June/July survey (data not shown), 523 ocean age 0 coho were captured and 162 of these had a LVC. The mean fork length of these two groups was not significantly different (160.30 $\pm$ 27.05 mm vs. 158.25 $\pm$ 15.02 mm)($P > 0.05$, $\bar{x} \pm$ SD). We adjusted the LVC captures by adding 7% for both mortality and awareness (as in Table 3), which produced an adjusted estimate of 184 LVC coho. As the LVC fish comprise 49.6% of the total hatchery smolts released into the Strait of Georgia, this adjusted catch can be regarded as representing 371 (184/49.6%) hatchery coho. In addition, there were 4 US tags caught and a further 6 fish with adipose clips but no CWT's. These 10 fish are adjusted (as in Table 3) to represent 44 US hatchery fish, and the total hatchery contribution in the June/July survey is estimated (as in Table 3) as 415/523 or 79.3% which is similar to the 76.6% estimated in the September survey.

Otolith Results

Of the 100 pairs of otoliths examined from the September survey, 21 pairs were found to be both crystalline (Table 4) and thus hatchery or wild origin could not be determined directly. A further 17 pairs were found to have one crystalline otolith. Of the 62 pairs of non-crystalline otoliths, 39 were determined to be hatchery in origin and 23 to be from naturally spawned fish. Of the 17 pairs with a single crystalline otolith, 15 (or 88%) were determined to be of hatchery origin and 2 (12%) to be natural. Using the same proportions for the 21 double crystalline otoliths, 88% or 18.53 fish were assigned as hatchery in origin and 2.47 or 12% as non-hatchery or wild (Table 4). Thus, 72.5% of the 100 pairs of otoliths sampled were determined to be from fish of hatchery origin and 27.5% to be from fish derived from natural spawners.

Movement of Puget Sound Coho into the Strait of Georgia

The relatively large numbers of adipose clipped coho released into Puget Sound with and without a CWT provided an opportunity to study the movement of US coho into the Strait of Georgia. In the June/July survey, we estimated 10 of the 523 coho which were captured had a US mark and, in September, 40 of the 2402 captured coho had a US mark. The percentage in both cases is virtually identical (1.9% vs. 1.7%, respectively).

DISCUSSION

The survey of coho abundance in the Strait of Georgia and in Puget Sound using a large rope trawl produced samples of coho from most areas throughout their distribution. The analysis of the samples indicated that hatchery fish in the Strait of Georgia in June/July and in September comprised approximately 76-79% of the population. We believe this estimate to be conservative because the combined clipping mortality and missed recognition (awareness) may exceed 14%. While mortalities due to adipose clip of juvenile coho have routinely been estimated as 2.4% (PSC 1997), the limited number of studies examining post-clip mortality of ventral fins ranges from 6-25%, with values as high as 50% (PSC, 1995, 1997). Values ranging from 0-90% have also been reported (PSMFC 1992). We arbitrarily chose 7% post-clip mortality rates in our calculations as it was close to the minimal estimate reported and was also a conservative value. In addition to the mortality estimates, remaining portions of the pelvic fins have a large regenerative capacity, unlike adipose fin clips. Coombs et al. (1990) found 50% of left/right pelvic fins clipped from Atlantic salmon smolts had regenerated almost completely within 3 months, a similar time frame to fish caught in the September survey. The proper identification of fish with regenerated fin clips in our survey would be extremely difficult, and our awareness factor, and thus catches, of LVC fish may be underestimated. We again chose a conservative 7% value for this potential error. If the true error percentages combine to approach 25% rather than the 14% used in this analysis, the estimated hatchery percentage would be approximately 83%. Regardless, the percentage of hatchery fish within the Strait of Georgia population appears to be considerably higher than previous reports (e.g., Cross et al. 1991).

The possible inclusion of enhanced fish may appear to be an incorrect inclusion of wild fish in the hatchery fish category. However, it is important to recognize that a large number of hatchery fish do spawn naturally, instead of being spawned artificially in hatcheries. If the offspring are a direct result of two hatchery parents, in theory they are still hatchery fish. While these fish subsequently do undergo natural selection pressures, it is only when these enhanced progeny return and spawn naturally would we consider the subsequent F_2 offspring to be wild. The recognition of these enhanced fish spawning naturally is a critical consideration in any wild coho management policy. We believe it is important to recognize that some of the larger escapements have high percentages of spawning coho that were released from hatcheries in the previous year. It appears that the situation is repeated each year. Our assumption of including the offspring of naturally spawning enhanced fish with hatchery-reared fish allowed us to estimate the total number of "hatchery fish" produced and would be a maximum estimate. This assumption highly oversimplifies the problem of separating offspring of hatchery and naturally spawning coho. The appropriate issue really is to be able to identify and protect the truly wild coho. We suggest that the hatchery coho percentage of 75-80% is sufficiently high to indicate that there is some urgency in addressing the need to develop a wild coho management policy.

Fish growth did not appear to be adversely affected by the removal of the left pelvic fin, as indicated by the absence of any size differences between LVC and non-clipped coho in either the June/July or the September survey. The apparent absence of an impact on feeding and/or growth, at least during the early marine phase, is in agreement with previous reports (Coombs et al., 1990). The question of clipping mortality, growth and survival effects was addressed at several of the hatcheries involved in the LVC program (e.g., Big Qualicum and Inch Creek) by special marking studies (Sue Lehmann, pers comm.). Catch and escapement data in 1998 will provide new information on these questions.

The otolith method provided an estimate of 72.5% hatchery fish in the Strait of Georgia in 1997, a value similar to but slightly lower than the estimates determined from the LVC program. While Zhang et al. (1995) observed that the accuracy of determinations for coded-wire tagged (CWT) hatchery coho was approximately 91%, a pitfall with the otolith method of identifying coho rearing type is that it is difficult to validate the method for wild coho. The LVC program provided an opportunity to independently assess the accuracy of the conclusions based on otoliths. Large numbers of double crystalline otoliths complicate the proper identification of origin using the microstructure method. We assign the rearing type of coho with two crystalline otoliths in proportion to the hatchery-wild percentages we observe for coho with only one crystalline otolith. We know from our unpublished studies that crystalline otoliths are relatively common in coho reared in hatcheries and relatively rare in wild coho, thus we think that our approach is valid. Furthermore, the proportion of crystalline otoliths in enhanced coho has yet to be examined. The sample sizes used the otolith microstructure method are also smaller, which may introduce further variability. Regardless, the estimate of 72.5% hatchery fish was very similar to the 76.6% estimate obtained via the LVC method. If large numbers of coho are marked in the future, it may not be appropriate to continue to use otolith based estimates even though they can provide a direct method of measuring rearing types. The difference in the development of otolith microstructure between hatchery and wild coho is important and the causes and consequences of crystalline otolith development in hatchery-reared coho should be ascertained.

The June/July survey, similar to September, provided a minimal estimate of 79% for hatchery reared fish in the ocean age 0 coho population within the Strait of Georgia. The similarity of these percentages over these 3-4 months indicated that there was no selective migration of marked fish out of the strait during this period. Furthermore, the catches of coho in the Strait of Juan de Fuca and off the west coast in the summer, fall and winter indicated that LVC coho were not detected until October (Appendix 1), indicating that relatively large numbers of both hatchery and naturally spawning coho remain in the Strait of Georgia until at least the end of September.

Lastly, the relatively large numbers of coho with adipose clips in Puget Sound provided an opportunity to study the movement of coho from Puget Sound into the Strait of Georgia. In another report (Beamish et al. 1998), we show that almost all the coho left Puget Sound between July and September (1997). Despite this movement out of the sound, there was no increase in percentages of US coho caught within the Strait of Georgia in the September survey, suggesting that most of the coho migrating from Puget Sound proceed to either Juan de Fuca or further out to the west coast.

In summary, in summer and early fall of 1997 we took advantage of a new marking program instituted by DFO to estimate the proportion of hatchery and wild coho within the Strait of Georgia. The high percentage of hatchery fish, and the possibility that these percentages may be as high as 75%, indicate that wild coho may be in low abundance. If total abundance of hatchery and wild fish is also low, then the actual numbers of wild coho may be very low relative to the abundance's in the 1960s and 1970s.

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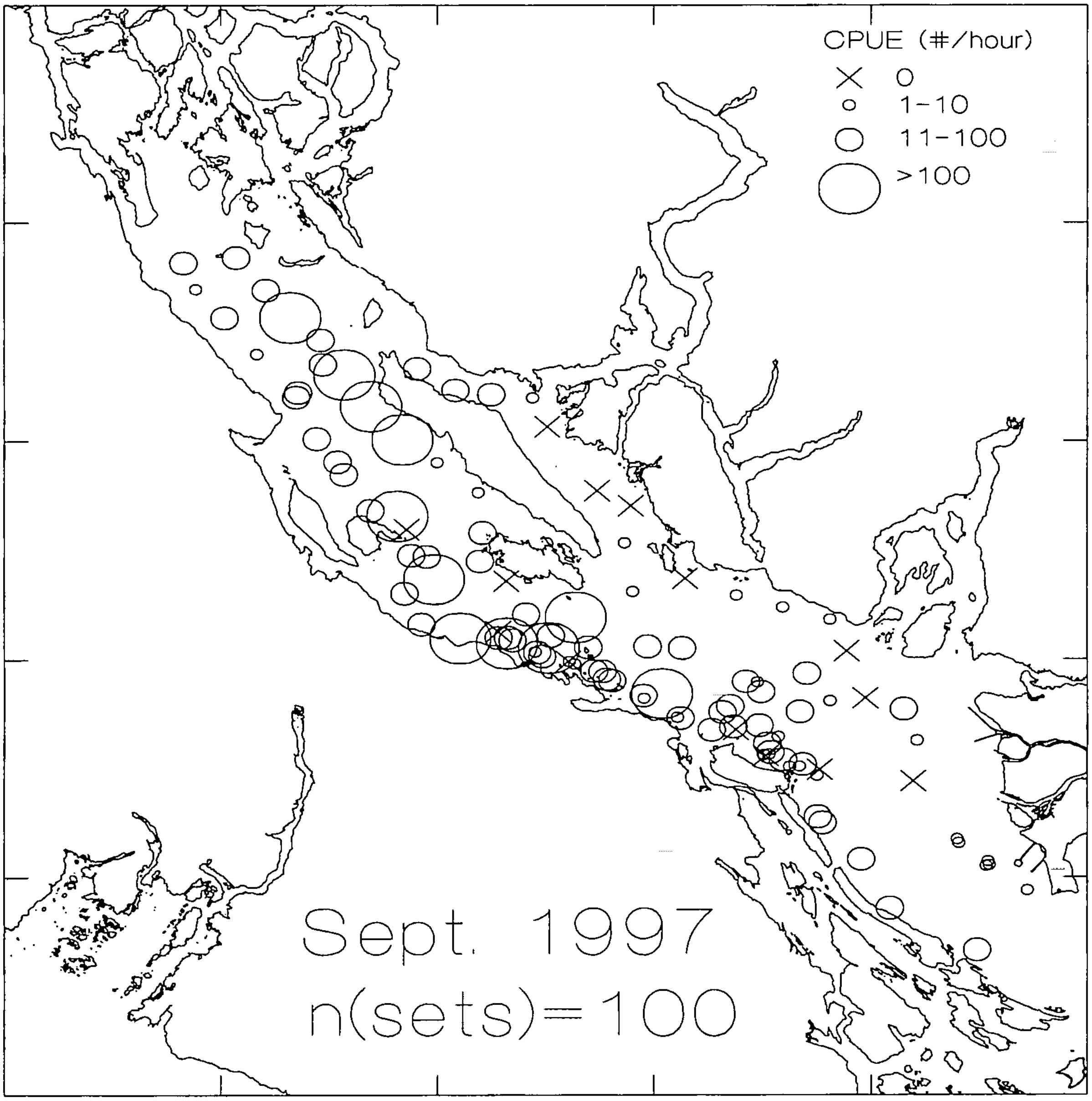

Figure 1. Standardized catch (number caught/hour) of ocean age 0 coho salmon for September 1997 survey.

Table 1. Left Ventral Clipped coho released from British Columbia hatcheries into the Strait of Georgia in 1997.

Hatchery	*Number Released*	*Number with LVC* *	*Percent Marked*
Big Qualicum	964532	964478**	99.99
Capilano	463342	432891	93.43
Chehalis	837455	834990	99.71
Chilliwack	1673623	1671430	99.87
Inch Creek	436669	434296	99.46
Puntledge	650886	650307	99.91
TOTALS:	5026507	4988292^	99.24

* *Includes fish with coded wire tags (ie., Left Ventral and Adipose fins removed).*

** *Includes 18984 partial clips from Big Qualicum.*

^ *Excludes 30143 fish from Capilano which were unclipped and 7972 AD only (no CWT) fish*

Table 2. Estimates of the contribution of fed fry (released in 1996) to the overall smolt population entering the Strait of Georgia in 1997.

Fry to Smolt Survival Rate	*Contribution to 1997 smolts*	*Total number of smolts*	*Percent LVC*
10%	460,000	~10,060,000	49.6
20%	920,000	~10,520,000	47.4

***Note**: Based on fry releases of 4.6 Million in 1996 and releases of 9.6 Million smolts in 1997.*

Table 3. Estimates of percentage of ocean age 0 hatchery coho in the Strait of Georgia for September 1997.

A. Total number of Age 0 coho caught	2402
Total number of LVC fish in above	723
+ Correction for clipping mortality (7%)	51
+ Correction for awareness of mark (7%)	51
Corrected Total for Survey	825
B. Percentage of BC hatchery smolts with LVC marks (Table 1)	49.6
Estimated total BC hatchery fish in survey (825 fish/49.5 %)	1663
C. Number of Adipose clips in survey with either no CWT or US tag (assume all US)	40
Expanded US hatchery component	
40 fish/17% clip rate = 235 fish	
235 fish x 70% hatchery	165
Plus 7% error rate	12
Estimated US hatchery coho in survey	177
Number of hatchery fish in catch	1840
Percentage of hatchery fish in catch	76.6

Table 4. The number and proportions of wild and hatchery coho determined from otolith microstructure analysis. Fish with both otoliths in the crystalline form cannot be determined and are therefore assigned an origin, based on proportions observed in fish with single crystalline otolith.

Otolith type	Hatchery Origin	Wild Origin	Unknown
Both normal	39	23	-
One crystalline	15	2	-
Both crystalline			21
*Assigned origin**	*18.53*	*2.47*	-
TOTAL	72.53	27.47	-
Percentage	72.53	27.47	-

* Fish with double crystalline otoliths assigned origins based on proportion of those with single crystalline otolith. Note that the crystalline otoliths are commonly found in wild fish.

Appendix 1. Breakdown of coho catches in 1997 and 1998 by survey and by region. The catch for each region is further broken down into proportions of coho with left ventral fin clips (LVC), those with adipose clips (AD clip) and those coho with an AD clip and with an implanted CWT (included in AD total).

1. June 17 to July 10

Catch Area	No. Coho Caught	Percentage with LVC	Percentage with AD clip	Percentage with CWT
Strait of Georgia	523	31.0	8.0	8.0
Juan de Fuca	226	0.0	27.9	9.7
Puget Sound	1696	0.0	16.5	4.3
West Coast	81	0.0	25.9	25.9

2. September 08-27

Catch Area	No. Coho Caught	Percentage with LVC	Percentage with AD clip	Percentage with CWT
Strait of Georgia	2402	30.1	2.6	2.3
Juan de Fuca	-	-	-	-
Puget Sound	69	1.4	14.5	5.8
West Coast	-	-	-	-

3. October 17-30

Catch Area	No. Coho Caught	Percentage with LVC	Percentage with AD clip	Percentage with CWT
Strait of Georgia	625	26.6	5.6	4.8
Juan de Fuca	-	-	-	-
Puget Sound	-	-	-	-
West Coast	685	2.2	11.1	3.6

4. February 10-23, March 04-07

Catch Area	No. Coho Caught	Percentage with LVC	Percentage with AD clip	Percentage with CWT
Strait of Georgia	1	-	-	-
Juan de Fuca	478	6.1	9.0	4.2
Puget Sound	-	-	-	-
West Coast	960	6.5	12.3	3.9