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Change in proportion of hatchery-reared, wild ocean- and stream-type chinook in their first and second ocean years in the Strait of Georgia

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Abstract

Otolith microstructure was used to identify hatchery-reared, wild ocean and wild stream-type chinook in their first and second ocean years in the Strait of Georgia. Samples used for the analysis were collected in the early summer, late summer and late fall in 1995, 1996 and 1997. The percentage of wild fish dropped from 71.5% in late summer to 36.8% in the late fall of 1995, and more dramatically from 61.4% in the late summer to 19.2% in the late fall of 1996. The low percentage of wild chinook in 1996/1997 may indicate that wild chinook may be in low abundance in the 1998 and 1999 fisheries. There also was a general decrease in lengths of each rearing type from the 1995/1996 samples to the 1996/1997 samples, suggesting that ocean conditions were possibly less favourable for growth in 1996/1997.

It is difficult to interpret all of the results, as migration behaviour, sample sizes and a general poor understanding of the marine phase of the life history of chinook complicates any interpretation. However, the change in 1996/1997 to a relatively high percentage of hatchery-reared fish is noteworthy. We also suggest that it is time to improve our understanding of the marine stage of the various rearing types that make up the Strait of Georgia chinook fishery.

Résumé

La microstructure otolithique a servi à distinguer le saumon quinnat d'élevage du quinnat sauvage maritime et sauvage de rivières au cours des deux premières années de leur séjour dans le détroit de Georgia. Les échantillons ayant servi aux analyses ont été prélevés au début de l'été, à la fin de l'été et tard à l'automne de 1995, 1996 et 1997. En 1995, le pourcentage de saumons sauvages a diminué considérablement, passant de 71,5% à la fin de l'été à 36,8 % tard en automne. En 1996, cette diminution a été plus spectaculaire encore, la proportion étant passée de 61,4 % à la fin de l'été à 19,2 % tard à l'automne. Le faible pourcentage de quinnat en 1996 - 1997 pourrait annoncer une baisse de l'abondance de ce saumon au cours des saisons de pêche de 1998 et 1999. Une réduction générale de la taille des individus des deux types a été observée entre les échantillons de 1995 - 1996 et ceux de 1996 - 1997, suggérant que les conditions océaniques auraient été moins favorables à la croissance en 1996 -1997.

L'interprétation de tous ces résultats reste difficile parce qu'elle est compliquée par le comportement migratoire, la taille des échantillons et une compréhension inadéquate de la phase marine dans le cycle biologique du quinnat. L'augmentation du pourcentage des sujets d'élevage en 1996 - 1997 a tout de même été remarquable. Aussi, serait-il temps de chercher à mieux comprendre la phase marine des différents types de saumon quinnat qui constituent la pêcherie du détroit de Georgia.

Introduction

Chinook (*Oncorhynchus tshawytscha*) in the Strait of Georgia have two distinct life history types, ocean-type and stream-type. Since the early 1970s, large numbers of hatchery-reared chinook have been released into the Strait to enhance the abundance of chinook population. The number of hatchery releases increased from about 2.5 millions in the mid-1970s to about 41 million in the early 1990s (Beamish et al 1995). Hatchery-reared chinook are virtually all ocean-type, but should be identified separately because of their protected rearing conditions and because they are now a major rearing type of the chinook population in the Strait (Beamish and Zhang 1996). The behaviour and possible interactions among the three rearing (life history) types in their first and second years in the Strait of Georgia has not been studied. In this study, we used otolith microstructure to identify the three rearing types, to identify the seasonal changes in the proportion of the three rearing types in the Strait of Georgia, to assess the differences in length and behaviour between the rearing types, and to determine the times of ocean entry. Our study contrasts the behaviour and composition of rearing types with the latest study when hatchery releases were small (Cross et al. 1991). An important component of this study will be to compare these observations on the early life history with the rearing types caught in the Strait of Georgia fisheries. Of immediate concern is the high percentage of hatchery fish in the 1996-1997 samples, which may indicate poor marine survival or poor production of wild smolts or both.

Materials and Methods

Fish were caught from the Strait of Georgia during six cruises carried out in September 1995, November 1995, April 1996, September 1996, November 1996 and April-May 1997. Chinook samples from the September 1995 cruise were collected by a rope trawl and a beam trawl, while samples from the other five cruises were all collected using a mid-water rope trawl (Beamish and Folkes 1998). The rope trawl was towed at speeds averaging from 4 to 5.2 knots and most fishing occurred at depths ranging from the surface to 45 meters. Samples were collected throughout the Strait (Fig. 1), but the exact sampling program for each survey varied according to specific objectives and time available. The samples collected using the beam trawl and rope trawl differed significantly in size (t test, $p < 0.001$). The fish in the beam trawl were smaller and therefore, have not been included in the analysis.

Otoliths were taken from each fish from the whole sample or a subsample of the catch. Otoliths were later prepared and examined to determine the ocean age in days and the rearing type of each individual. Left otoliths, if possible, were mounted individually anti-sulcus (distal) side up on microscopic slides, using thermosetting plastic resin. Each otolith was then ground on a lapping film of 60 or 30 µm, depending on otolith size, until the primordia were revealed. The resin was then melted on a hot plate and the otolith turned over. The other side of the otolith was ground in a similar manner until the microstructure was clearly visible. The otolith was then polished on a lapping film of 0.3 µm to remove scratches caused by the grinding. If the otolith was damaged or the microstructure was not clearly revealed, the right otolith of the pair was used. Otolith microstructure was examined under a compound light microscope to determine the ocean age and the rearing type of the fish.

In this study we defined an ocean annulus as a transition between increasingly narrow daily growth increments and progressively increasing daily growth increments formed in the ocean. The number of ocean annuli indicated the ocean age of the fish. Stream-type chinook can be readily separated from ocean-type chinook by the appearance of daily increments, a distinct hyaline zone and a larger number of daily increments formed in the fresh water (Beamish and Zhang 1996). Stream-type chinook produce a variable number of 40-100 wide and prominent increments, which are presumably formed during the fast growing season in the fresh-water period. These wide increments are followed by numerous and narrow increments which are difficult to enumerate. A translucent zone formed in most of the stream-type chinook otoliths (86%) and was identified as the fresh-water annulus. Distal from the hyaline zone, increments became wide, regular and prominent. As our samples were collected in the salt water and these wide increments were characteristic of ocean growth, we used the transition from narrow to wide increments to identify when a fish entered salt water. In this study all stream-type chinook were considered to be wild fish, as very few stream-type chinook are reared in hatcheries in Canada. Thus, in this respect, hatchery-reared chinook may be under-estimated, but the underestimation is minimum. Ocean-type chinook otoliths had fewer freshwater increments and did not contain a fresh-water annulus. Daily growth increments from the beginning of these prominent increments to the edge of the otolith were counted to represent days the individual fish spent in the ocean and indicate the ocean entry date. In addition to the fish entering the ocean in late spring and early summer, we observed a large number of wild ocean-type chinook, which entered the Strait of Georgia late, mainly in July. We designated wild ocean-type chinook entering the Strait before July 1 and after June 30 to early and late ocean entry groups respectively,

Hatchery-reared and wild ocean-type chinook exhibit different microstructural patterns in their otoliths in the fresh water period (Zhang and Beamish 1994, Zhang et al. 1995). Daily growth increments formed in the otoliths of hatchery-reared chinook after initiation of feeding appear regular in width and contrast. The regular pattern of daily growth increments usually changes after the fish is released from the hatchery. Increments formed immediately after release usually appear to be relatively irregular and narrow. They are followed by very wide and prominent increments produced in the ocean, presumably after acclimation to the new environment. Increments formed in the otoliths of wild ocean-type chinook after initiation of feeding appear more irregular in width and contrast and their width is, on average, smaller. The narrow and irregular increments are followed by wide and prominent increments produced in the ocean. There is no "transition zone" in between. Presence or absence of this "transition zone" helps greatly in identifying the rearing types.

Test of the otolith method of identifying rearing type showed that this technique correctly identified 89% of coded-wire-tagged (CWT) hatchery-reared fish (Zhang et al.

1995). The error associated with identifying wild ocean-type chinook is unknown. However, the difference in estimating the percentage of wild chinook based on CWT expansion method and the otolith method was about 4% in a previous study (Zhang et al 1995). Thus, this technique appears to be reliable.

Results

September 1995 Sample

In September 1995, 217 chinook were caught in the Strait of Georgia. Otoliths were taken from a sample of 201 chinook and were all used to identify life history of the fish. The sample contained 13 ocean age 1 or older and 188 ocean age 0 chinook. Of the 188 ocean age 0 chinook, 53 (28.5%) were hatchery-reared and 133 (71.5%) were wild and 2 were not identifiable. Of the 133 wild chinook, 53 (40.4%) were stream-type and 80 (59.6%) were ocean-type. The mean lengths of the three groups of fish were significantly different (ANOVA, $p<0.001$). Tukey test (Zar 1984) indicated that on average stream-type chinook were significantly larger than hatchery-reared chinook and hatchery-reared chinook were significantly larger than wild ocean-type chinook (I = 0.001, Table 1).

There were a large number of wild ocean-type chinook, which still contained distinct parr marks. Analysis of daily growth increments indicated that they entered the Strait of Georgia rather late, mainly in July. The ratio of early (before July) and late (July and later) ocean entry group was 9:68 (0.13:1). The mean length of early ocean entry chinook was 143 mm ± 8.7, significantly larger than the mean length, 134 mm ± 12.4, of the late ocean entry chinook (t-test, $p < 0.001$).

November 1995 Sample

In November 1995, 232 chinook were caught in the Strait of Georgia. Otoliths were taken from a sample of 229 fish. The two largest fish were ocean age 1 and the remaining 227 fish were all ocean age 0. Of the 227 ocean age 0 fish, 139 (63.2%) were hatchery-reared and 81 (36.8%) were wild and 7 were not identifiable. Of the 81 wild chinook, 27 (33.3%) were ocean-type and 54 (66.7%) were stream-type. The mean lengths of hatchery-reared, wild ocean-type and stream-type chinook were significantly different (ANOVA, $p < 0.001$). Stream-type chinook were, on average, significantly larger than hatchery-reared chinook and hatchery-reared chinook were significantly larger than wild ocean-type chinook (Tukey test, I = 0.005, Table 1). The ratio of the early and late ocean entry groups was 16:7 (2.3:1). The mean length of early ocean entry chinook was 244 mm ± 33, significantly larger than the mean length, 168 mm ± 23, of the late ocean entry chinook (t-test, $p<0.001$).

April 1996 Sample

In April 1996, 285 chinook were caught and otoliths were taken from all fish. One fish was identified as ocean age 0, 185 as ocean age 1 and 99 as ocean age 2 or older. Of the 185 ocean age 1 chinook, 134 (74.4%) were hatchery-reared, 46 (25.6%) were wild and five could not be determined. Of the 46 wild fish, 39 (84.8%) were ocean-type and 7 (15.2%) were stream-type. There was a significant difference in the mean length between, at least, two groups of fish (ANOVA, p= 0.048). Tukey test identifies no significant difference in mean length between hatchery-reared chinook and wild ocean-type chinook, but the mean length of stream-type chinook was significantly larger than that of hatchery-reared and wild ocean-type chinook (I = 0.05).

Summary of 1995/1996 Analysis

There was a late migration of wild ocean-type smolts into the Strait of Georgia that we detected as a high percentage of wild chinook (71.5%) compared to hatchery-reared fish (28.5%) in September. By November, the percentage of hatchery-reared fish was increasing (63.2%) and in April of the next year the percentage increased to 74.4%. The ratio of wild ocean-type early ocean entry to late ocean entry increased from September to November, indicating that the late ocean entry (July or later) smolts were either leaving the Strait of Georgia, died or both. We could not accurately separate early and late ocean entry fish in April as all daily growth increments can not be counted accurately at this age. Most wild stream-type chinook entered the ocean early (before July) (98% in the September sample and 91.8% in the November sample). The percentage of wild stream-type in the total wild sample varied from 40.4% in September, 66.7% in November to 15.2% in April of the following year.

The lengths of the three rearing types were different in September and November. In April, the few stream-type chinook were still larger than the other two rearing types, but there was no difference in the lengths of the hatchery-reared and wild ocean-type chinook, suggesting that larger hatchery-reared chinook might have left or there was an selective mortality on the smaller wild ocean-type chinook over the winter.

September 1996 Sample

In September 1996, 1303 chinook were caught from the Strait of Georgia. Otoliths were taken from a sample of 664 fish and 401 were randomly selected out of the 664 fish for otolith study. Otolith examination identified 317 fish as being ocean age 0 and 84 as ocean age 1 or older. The sample of 317 ocean age 0 fish contained 122 (38.6%) hatchery-reared, 194 (61.4%) wild chinook and one unidentifiable (Table 1). Of the 194 wild chinook, 117 (61.3%) were ocean-type and 77 (38.7%) were stream-type. The mean length of the three groups of fish was significantly different (ANOVA, $p<0.001$). Tukey test indicated that on average stream-type chinook were significantly larger than hatchery-reared chinook and hatchery-reared chinook were significantly larger than wild ocean-type chinook (I = 0.001, Table 1).

Analysis of daily growth increments revealed that most of these wild ocean-type chinook entered the ocean late with a ratio of early to late ocean entry of 37:79 (0.47:1). The mean length of these early entry chinook was 143 mm ± 23, significantly larger than the mean length (133 mm ± 13) of the late entry fish (t-test, $p < 0.001$).

November 1996 Sample

In November 1996, 272 chinook were caught from the Strait of Georgia. Otoliths were taken from a sample of 235 chinook. Of the 235 fish, 168 were randomly selected for otolith examination, which identified 153 fish of ocean age 0 and 15 fish of ocean age 1 or older. Among the 153 ocean age 0 fish, there were 122 (80.8%) hatchery-reared, 29 (19.2%) wild chinook and two unidentified. One out of the 29 wild chinook was ocean-type of early ocean entry (3.5%) and the other 28 wild fish were stream-type (96.5%). The mean size of the stream-type chinook was significantly larger than those reared in hatcheries (t-test, $p < 0.001$, Table 1).

April-May 1997 Sample

In April-May 1997, 359 chinook were caught from the Strait of Georgia and otoliths were taken from the entire sample. There were 132 fish that were possibly ocean age 1 fish. Otolith examination identified 54 out of the 132 fish (160-500 mm) as being ocean age 2 and the remaining 78 chinook as being ocean age 1. It may be relevant to note that the percentage of ocean age 1 was 21.7% relative to the older fish.

Of the 78 ocean age one chinook, 62 (80.5%) were hatchery-reared, 15 (19.5%) were wild and one was not identifiable. The wild fish contained 3 stream-type and 12 ocean-type. The mean length of hatchery-reared fish was significantly larger than that of wild ocean-type chinook (t-test, $p = 0.04$). Comparisons of length differences between hatchery-reared and stream-type or wild ocean-type and stream-type were not made, because number of the small number (n=3) of stream-type chinook.

Summary of the 1996/1997 Analysis

The late migration of wild ocean-type smolts into the Strait of Georgia that we observed in 1995 occurred again in 1996. The percentage of hatchery-reared chinook in September 1996 was 38.6%, higher than the percentage of 28.5% in September 1995. By November 1996, the percentage of hatchery-reared fish had increased to 80.8%, a larger increment than observed in November 1995. As in 1995, the number of wild ocean-type chinook of late ocean entry were reduced in the November sample, indicating that they had migrated out of the Strait, died or both. In April of 1997, the percentage of hatchery-read fish remained essentially unchanged at 80.5%. Of the few ocean age 1 wild chinook sampled, there was a higher percentage of ocean-type than stream-type, which was similar to the proportion found in April 1996. These observations appear to indicate that wild stream-type chinook leave the Strait during the winter. As in 1995/1996, most wild stream-type chinook entered the ocean early (98.6% in the September sample and 100% in the November sample). The percentage of wild stream-type chinook varied from 38.7% in September, 96.5% in November and 20% in April-May of the following year. The lengths of the rearing types were different in all samples. Unlike the sample in April 1996, the length of ocean age 1 hatchery-reared fish in April-May 1997 were larger than wild ocean-type chinook.

Comparison of Lengths among Years

Wild ocean-type chinook in April 1996 were on average significantly larger than those in April-May 1997 (t-test, $p<0.001$), but average length of wild ocean-type chinook in September 1996 was not significantly different from that in September 1995 (t-test, $p = 0.14$). This indicates that in the fall and/or winter of 1996/1997, factors such as growth, migration, or size selective mortality affected the size composition of wild ocean type chinook relative to 1995/1995. Hatchery-reared chinook in September 1995, November 1995 and April 1996 were on average significantly larger than those in September 1996, November 1996 and April-May 1997 respectively (t-test, $p <0.001$). Stream-type chinook were also on average significantly larger in September and November 1995 than those in September and November 1996 respectively (t-test, $p<0.001$). The average length of stream-type chinook in the April 1996 sample was also larger than that in the April-May 1997 sample, but the sample size was too small to carry out statistical testing.

Discussion

Otolith analyses in this study were used to identify three general types of chinook salmon utilizing the Strait of Georgia. These include hatchery-reared ocean-type chinook, and naturally produced ocean type and stream-type chinook. For the naturally-reared ocean-type chinook, the timing of ocean entry appears to occur throughout the spring and summer. This behaviour may represent different life histories of these fish varying from the coastal fall chinook, which enter the ocean in late spring and early summer, to interior summer chinook which may emigrate during the mid and late summer. The latter is believed to be the summer chinook in the central Fraser River and Thompson River (B. Riddell, pers. comm.).

The size of samples used to estimate hatchery and wild percentages varied from 77 to 316. Based on the binomial distribution, the estimated percentages are correct within ± 10% with 95% confidence level, except for the April-May 1997 sample, which contained only 78 ocean age 1 chinook. Even in that case the estimated percentages are correct within ± 11% with 95% confidence level (Table 1). In general, the sample sizes are big enough to generate reasonable confidence levels.

There was an alarmingly high percentage of hatchery chinook in the Strait of Georgia during the late fall and spring, especially during late 1996/97. Furthermore, in both the 1995 and 1996 samples, the proportion of hatchery fish increased through the fall. Hatchery fish were not found to be moving into the Strait of Georgia in the fall; implying that differential mortality and/or utilization of these waters accounts for this increase.

In both 1995 and 1996, we observed a large number of wild ocean type chinook entering the Strait of Georgia later in the year. These wild juveniles appeared to either leave the Strait of Georgia quickly or die. If they left, the high percentage of hatchery fish may be altered, as wild fish return.

Fish sampled during 1996 were smaller than comparative samples and chinook-types sampled during 1995. The decrease in mean length of juvenile chinook from 1995 to 1996 is consistent with the observations of a decrease in the mean length of coho from 1995 to 1996 (Beamish et al. PSARC S98) and may indicate that ocean conditions were less favourable for growth in 1996/1997. The higher percentage of hatchery chinook and smaller fish size in 1996 suggests that differential mortality may be involved. As wild ocean-type chinook are significantly smaller than hatchery-reared chinook in the Strait of Georgia, they might experience higher mortality rates than hatchery-reared chinook under less favourable ocean growth conditions. Unwin (1997) reported that the fry-to-adult survival rate for the larger hatchery-reared chinook was 4 times higher than the smaller wild fish in the Glenariffe stream, New Zealand. However, increase in percentage of hatchery fish and decrease in fish size observed in our study may have other explanations that relate to differential size-related migration. We will use otolith daily growth increments to study the life history of individual fish to gain a better understanding of the growth, mortality and migration.

The changes in relative abundance of hatchery and wild fish are consistent with changes in chinook spawning escapements during 1996 and 1997. For example, returns of the Harrison River fall chinook (Table 2) indicate strong production from the 1994 brood year but lower production expected from the 1995 brood (the latter is consistent with returns of Harrison stock to the Chilliwack Hatchery during 1996 and 1997). Differential mortality may account for the change in ocean-type fall chinook production. However, wild ocean-type summer and/or spring yearling chinook appeared to survive well, as escapements to populations of these chinook have increased substantially in the Fraser River (Chinook Technical Committee, Pacific Salmon Commission).

The percentage of stream-type chinook among the wild fish increased from September to November, as large numbers of wild ocean-type of late ocean entry chinook, which were present in September, disappeared from our sample by November. By early summer next year, the percentage of stream-type chinook dropped, suggesting a large proportion of them had left the Strait or died.

Our finding on the composition of rearing types contrasts the latest report by Cross et. al. (1991). They reported that there was less than 25% hatchery-reared chinook in the sport fishery in the Strait of Georgia from 1978 and 1989. There are a few differences between their study and ours. The hatchery releases were lower at that period and they estimated the percentage of adult hatchery-reared chinook for sport fishery, while we studied juvenile chinook population. In addition, Georgia Strait ecosystem probably has changed since then. Thus, it is important to re-study the contributions of various rearing types to Strait Georgia fishery and realize the status of wild stocks.

Chinook salmon have a complicated life history, including variation in age at seaward migration, variation in length of freshwater, estuarine, and oceanic residence, variation in ocean distribution, variation in ocean migratory patterns and variation in age and season of spawning migration (Healey 1991). However, knowledge of the life history of the Strait of Georgia chinook is limited. To the best our knowledge, it has been almost 20 years since the last work was carried out and a lot has changed, including the Strait of Georgia ecosystem. It may be timely to revisit some of the early views about the life history types of chinook in relation to the Strait of Georgia fishery. A sound knowledge of life history of chinook in the Strait of Georgia will enable us to interpret the dynamics of wild and hatchery-reared chinook prior to fisheries with greater confidence.

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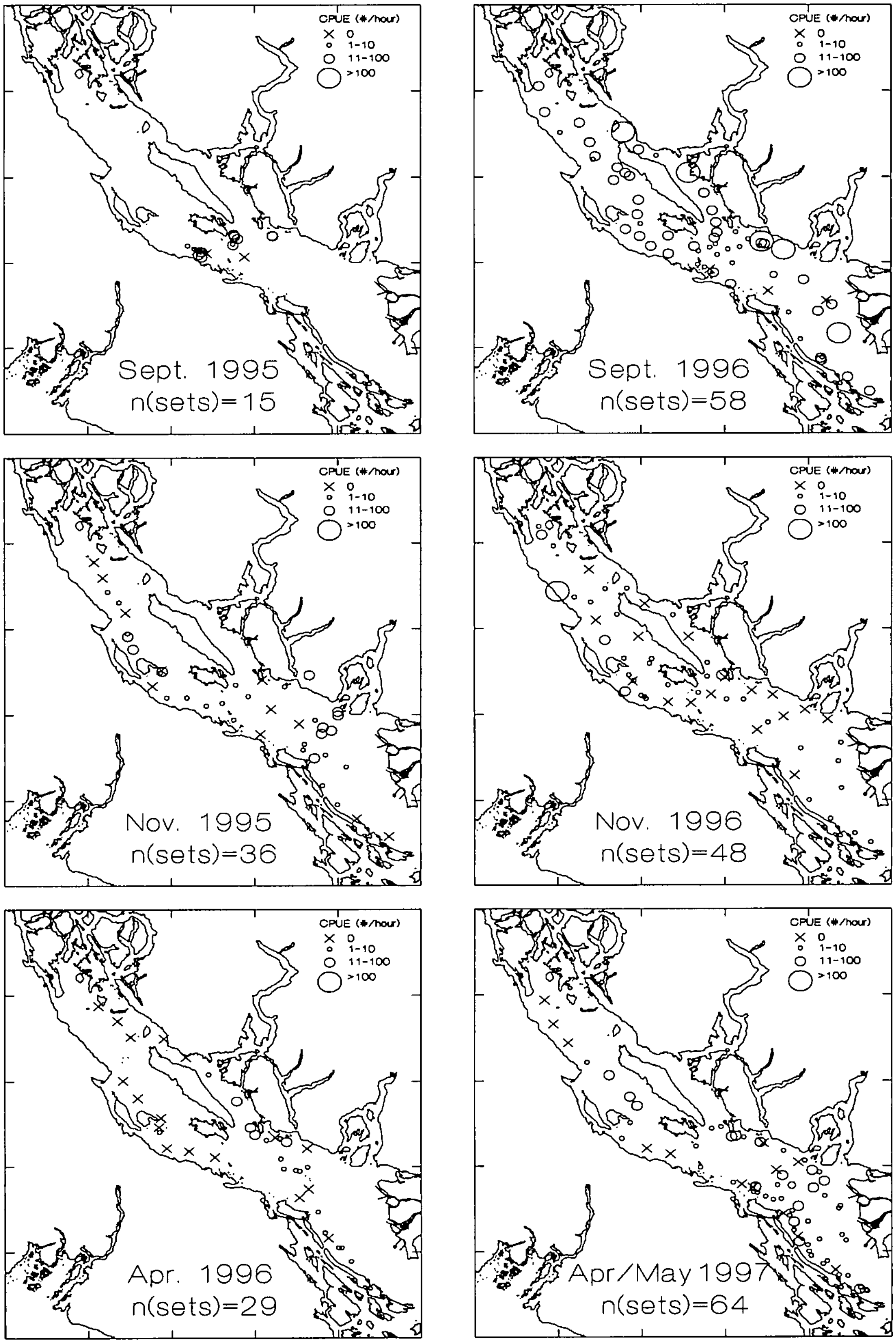

Figure 1. Standardised catch (#/hour) of all ages of chinook salmon, for sets with a headrope depth ≤45m.

Table 1. Percentage of hatchery-reared, wild ocean-type and stream-type chinook.

	Sept. 1995	Nov. 1995	Apr. 1996	Sept. 1996	Nov. 1996	Apr.-May 1997
Total Catch	217	232	285	1303	272	359
Otolith Sample	201	229	285	664	235	359
Sample for Otolith Examination	201	229	285	401	168	359
Ocean-age 0	188	227	-	317	153	-
Ocean-age 1	-	-	185	-	-	78
Hatchery-Reared						
Number	53	139	134	122	122	62
Percentage	28.5%	63.2%	74.4%	38.6%	80.8%	80.5%
95% confidence interval	22.2-35.6%	56.4-69.5%	67.3-80.5%	33.3-44.2%	73.4-86.6%	69.6-88.3%
Mean Length (mm ± sd)	211 ± 38.9	250.4 ± 30.8	334.7 ± 40.2	181 ± 26.5	219.4 ± 24.9	279.7 ± 35.3
_Wild						
Number	133	81	46	194	29	15
Percentage	71.5%	36.8%	25.6%	61.4%	19.2%	19.5%
95% confidence interval	64.4-77.8%	30.5-43.6%	19.5-32.7%	55.8-66.7%	13.4-26.6%	11.7-30.4%
Wild Ocean-type (%)	80 (59.6%)	27 (33.3%)	39 (84.8%)	117 (61.3%)	1 (3.5%)	12 (80.0%
Mean Length (mm ± sd)	134.9 ± 12.3	224.8 ± 45.9	333.2 ± 38.9	136 ± 17.5	193	259.5 ± 40.1
Wild Stream-Type (%)	53 (40.4%)	54 (66.7%)	7 (15.2%)	77 (38.7%)	28 (96.5%)	3 (20.0%)
Mean Length (mm ± sd)	251 ± 16.9	280.5 ± 35.7	372.3 ± 47.2	218 ± 29.7	244.6 ± 14.8	330.3 ± 115.9
unidentifiable	2	7	5	1	2	1

Table 2. Spawning escapements by age for each brood year sampled since the begining of the Harrison River chinook key stream program in 1984.

Brood Year Returns	Age 2	Age 3	Age 4	Age 5	Brood escapement of ages 3 to 5 yr.
1979				7507	
1980			62731	11590	
1981		48792	103228	7204	159224
1982	1806	60075	146556	16795	223426
1983	0	5528	50352	3331	59211
1984	3393	11644	29409	7371	48424
1985	247	2233	19215	3894	25342
1986	143	47365	167042	19731	234138
1987	1056	5151	40711	3300	49162
1988	1257	30171	96329	8144	134644
1989	0	30783	65387	3782	99952
1990	0	45469	90833	7374	143676
1991	0	3730	10996	1137	15863
1992	0	10246	23125	2760	36131
1993	3002	12836	23380		36216
1994	35976	44165			44165
1995	1835				