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Fisheries Research 46 (2000) 239–250

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# Use of otolith microstructure to study life history of juvenile chinook salmon in the Strait of Georgia in 1995 and 1996

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## Abstract

The pattern of otolith daily increments was used to identify hatchery-reared, wild ocean-type and wild stream-type chinook and study their life history in the Strait of Georgia. In 1995 and 1996, almost all of hatchery-reared and wild stream-type chinook entered the Strait of Georgia in May and June, while wild ocean-type chinook entered from April to August. Upon ocean entry stream-type fish were the largest and wild ocean-type the smallest. Hatchery-reared and wild ocean-type chinook leaving fresh water later in the year were larger than those leaving earlier. The mean length of wild stream-type chinook was not related to the time of ocean entry. All the life history types maintained their size differences throughout the summer and fall despite some differences in rates of size increase. Hatchery-reared and wild stream-type chinook grew faster in 1995 than in 1996. Wild ocean-type grew at about the same rate. During early summer, the percentage of wild ocean-type chinook was low in contrast to the percentage of hatchery-reared and wild stream-type chinook in 1995 and 1996, respectively. In September of both years, the percentage of wild ocean-type chinook increased and the percentage of hatchery-reared and wild stream-type chinook dropped. By November in both years, the percentage of hatchery-reared chinook increased, especially in 1996 when the percentage exceeded 80%. After the first ocean winter, the percentage of hatchery-reared fish remained high. © 2000 Elsevier Science B.V. All rights reserved.

*Keywords:* Chinook; Otolith; Growth; Life history type

## 1. Introduction

The Strait of Georgia is located between Vancouver Island and mainland British Columbia, Canada (Fig. 1). Chinook salmon (*Oncorhynchus tshawytscha*) in the Strait of Georgia have three distinct life history types, hatchery-reared, wild ocean-type and wild stream-type. The stream-type chinook

usually spend just over one year in the fresh water as fry and the ocean-type chinook remain in fresh water within a few months after onset of feeding before migrating to the ocean (Healey, 1991). Ocean-type chinook enter the ocean after spending one part of the year in the fresh water. Consequently, stream-type chinook are larger than ocean-type chinook upon ocean entry. Within the Strait of Georgia, studies in late 1970s and early 1980s (Healey 1980, 1991) showed that the stream-type entered salt water first and dispersed seaward as the wild ocean-type were moving into the nearshore areas. In the open

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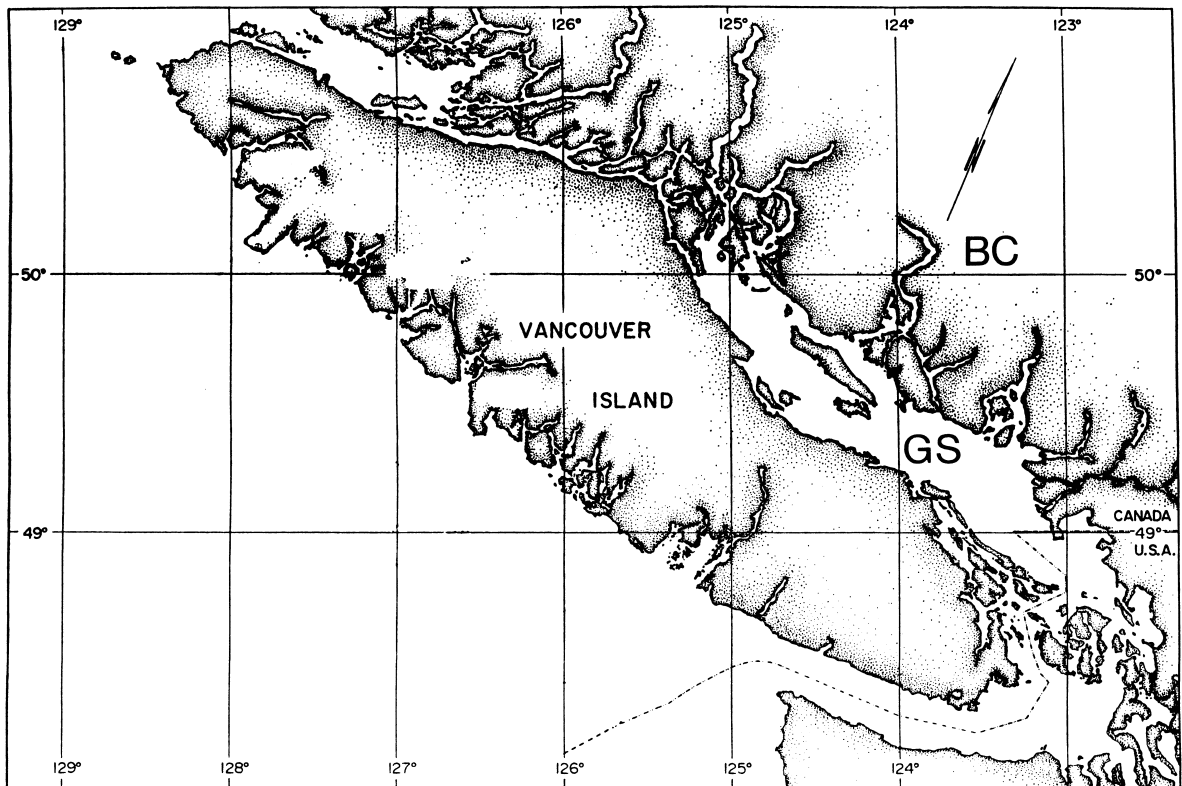


Fig. 1. Location of the Strait of Georgia (GS) between Vancouver Island and mainland British Columbia (BC).

waters of the Strait of Georgia, Healey reported that there was a gradual change in the composition of the catches of juveniles as the stream-type became less abundant in the fall.

Since the beginning of the 1970s hatchery-reared chinook have been added to the Strait of Georgia to enhance the abundance of chinook population and improve recreational catch. Virtually all of the hatchery smolts from Canadian hatcheries are of the ocean-type. The number of hatchery releases increased from about 2.5 million in the mid-1970s to about 41 million in early 1990s (Beamish et al., 1995). Beamish et al. (1995) estimated that the number of hatchery smolts released in the early 1990s was equivalent to the number of wild smolts and the total of approximately 82 million was between 2–3 times the number of wild chinook smolts that entered the Strait at the time of Healey's studies in the 1970s. Thus, a substantial number of this life history type have been added to the populations of wild ocean-type and stream-type.

We used otolith microstructure to identify hatchery-reared, wild ocean-type and stream-type chinook to evaluate the changes in the interactions among these life history types in the Strait of Georgia as a consequence of the addition of hatchery chinook.

## 2. Materials and methods

Fish were caught throughout the Strait of Georgia from 10 cruises which were carried out in May, June, July, September and November 1995, and April, June, September and November 1996 and April–May 1997. Large surface nets and beam trawls were used in the surveys of May 1995, June 1995, and June 1996, while rope trawls (Beamish and Folkes, 1998) were used in the surveys of November 1995, April 1996, September 1996, November 1996 and April–May 1997 (Table 1). The beam trawls were fished continuously at the surface at a speed of 3 kn. A rope trawl was initially

Table 1  
Catches of chinook in the Strait of Georgia and otolith sampling in 1995, 1996 and 1997

Sampling date	Fishing gear	Ocean age	Total catch	Otoliths sampled	Otoliths analysed		
					Total	Ocean age 0	Ocean age 1
23–30 May 1995	Beam trawl (1) <sup>a</sup>	0	513	513	513	513	
19–26 June 1995	Beam trawl (1) <sup>a</sup>	0	361	361	361	361	
6–21 July 1995	Beam and rope trawl	0	841	841	271	271	
	Beam trawl (2)	0	621	621	200	200	
	Rope trawl (1) <sup>b</sup>	0	71	71	71	71	
11–22 September 1995	Beam and rope trawl	0 and older	378	378	349	336	
	Beam trawl (1,2)	0	148	148	148		
	Rope trawl (2)	0 and older	217	201	201		
7 November–17 April 1995	Rope trawl (2)	0 and older	232	229	229	227	
10–25 April 1996	Rope trawl (2)	1 and older	285	285	285		185
17–27 June 1996	Beam trawl (2)	0	580	579	200	200	
9–20 September 1996	Rope trawl (2)	0 and older	1303	664	404	320	
4–15 November 1996	Rope trawl (2)	0 and older	272	235	168	153	
7 April–2 May 1997	Rope trawl (2)	1 and older	359	359	359		78

<sup>a</sup> Beam trawl (1) is smaller than beam trawl (2) and was fished from a smaller vessel than beam trawl (2).

<sup>b</sup> Rope trawl (1) was slightly larger than the rope trawl (2).

used in July 1995 and a modification of this net was used in later surveys. The rope trawl was towed at speeds averaging from 4 to 5.2 kn. Most (81%) fishing occurred at depths ranging from the surface to 45 m and the rest (19%) occurred deeper than 45 m.

Otoliths (sagittal otoliths) were taken from each fish in the total sample or a subsample of the total catch. Left otoliths were processed for sagittal sections as described in Zhang et al. (1995). The right otolith was used, if the left one was either missing or a vateritic otolith. Otolith microstructure was examined under a compound light microscope to determine the ocean age in days if the individual was caught before the first winter in the ocean or in years if it spent, at least, one winter in the ocean. Ocean age in days was determined by counting all daily growth increments produced in the ocean. In this study we defined an ocean annulus as a transition between systematically narrowing daily growth increments and progressively increasing daily growth increments formed in the ocean (Fig. 2). Ocean annual age corresponds to the number of winters the fish spent in the ocean.

Life history types of ocean age 0 chinook from the surveys of 1995, and June, September and November 1996 and ocean age 1 chinook from April 1996 and April–May 1997 were determined. Each individual

was first identified as a stream-type or an ocean-type. The ocean-type chinook was then identified as a hatchery-reared or wild. Wild ocean-type fish entering the ocean before July and after June were referred to as early entry and late entry, respectively.

Stream-type chinook can be readily separated from ocean-type chinook by the appearance of daily growth increments, a distinct freshwater annulus and a larger number of daily increments formed in the fresh water (Fig. 2, Beamish and Zhang, 1996). Stream-type chinook produce a variable number of 40–100 wide and prominent increments, which are presumably formed during the summer in the fresh water. These wide increments are followed by numerous, narrow and obscure increments which are difficult to enumerate. A distinct translucent zone, when viewed under the transmitted light, is formed in most of the stream-type chinook otoliths (86%) following these narrow increments. Distal from this translucent zone, increments become wide, regular and prominent and they are presumably produced in salt water. The freshwater annulus appeared as the translucent zone or the transition between narrow and obscure increments and wide and prominent increments formed in the ocean. Ocean-type chinook otoliths have fewer freshwater increments and do not contain a fresh water annulus

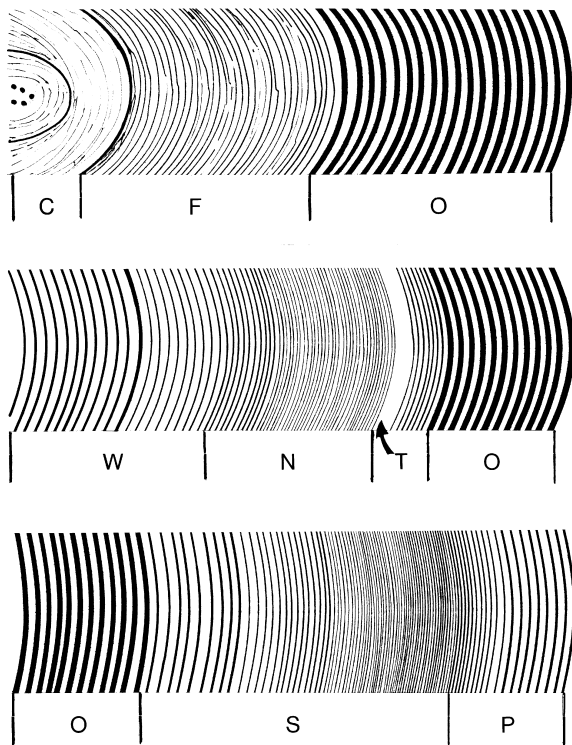


Fig. 2. Representation of otolith microstructure of chinook salmon. Top: Ocean-type chinook. The centre of the otolith (C) is formed before feeding and relatively narrow increments (F) are formed in the fresh water period. Wide and prominent increments (O) are formed in the ocean. Middle: Stream-type chinook. The wide increments (W) are formed in the fast growing season. Following the wide increments are narrow increments (N) and a translucent zone (T) foamed in the slow growing season in the freshwater. Very wide and prominent increments at the margin are formed after ocean entry (O). Bottom: An ocean annulus. The wide increments (O) are formed in the fast growing season in the ocean, followed by systematically narrowing increments (N). After these narrow increments are progressively increasing increments (P).

(Fig. 2). In this study all stream-type chinook were considered to be wild fish, as very few stream-type chinook are reared in hatcheries in British Columbia, Canada. Among the smolts released by the hatcheries around the Strait of Georgia in 1995 and 1996, only 2.6 and 3% were of the stream-type, respectively (Canadian Fisheries and Oceans Database, Kuhn, 1988). Daily growth increments formed in the otoliths of hatchery-reared chinook after initiation of feeding appear regular in width and contrast. Increments formed in the same region in the wild fish otoliths are often narrower and appear more irregular in width

and contrast than the otoliths from hatchery fish (Zhang and Beamish, 1994; Zhang et al., 1995).

Otolith size was measured under the light microscope using a micrometer for ocean age 0 fish only. Salmon otoliths contain multiple primordia, which generally form an elongated ellipse in the otolith centre. Measurement was taken in the ventral side of the otolith along a line perpendicular to the imaginary longitudinal axis of this ellipse. The distance from the otolith centre to the edge of the otolith represented the otolith size when the fish was caught. The distance from the otolith centre to the first wide increment formed in the ocean was considered to be the otolith size at ocean entry. Measurement in this orientation is more consistent than measurement towards the posterior end. The increments are wider and clearer in the ventral section than in the dorsal section, making it easier to enumerate daily growth increments.

The back-calculation method introduced by Monastyrsky (Chugunova, 1963; Francis, 1990) was used to estimate fish length and growth. A regression of  $\log(\text{fish length})$  on  $\log(\text{otolith size})$  was developed for ocean age 0 hatchery-reared, wild ocean-type of early and late entry, and stream-type. A *t*-test was used to determine the similarity of slopes and intercepts of the regressions for the same life history types between 1995 and 1996. A common slope was used if there was no significant difference in the slopes, and both the common slope and intercept were used if there was no significant difference in slopes and intercepts (Table 2). A high coefficient of determination ( $\geq 85$ ) indicates that there is a good correlation between otolith size and fish length for hatchery-reared, wild ocean-type of early entry and stream-type. The relatively low coefficient of determination for wild ocean-type of late entry chinook suggests that there is more variation in otolith sizes in regard to fish length.

The ocean entry date of each individual was estimated by subtracting the ocean age in days from the sampling date. To examine the relationship between fish length at ocean entry and time of ocean entry, back-calculated lengths at ocean entry were regressed on ocean entry date for each life history type. Fish growth was determined to be the difference between fish length upon being caught and upon ocean entry. The average growth rate for each life history type was

Table 2  
 Linear regressions of log(fish length) on log(otolith size) for back-calculation<sup>a</sup>

	1995				1996				<i>p</i> -value	Common slope	<i>p</i> -value	Common intercept
	Slope	Intercept	<i>n</i>	<i>R</i> <sup>2</sup> <sup>b</sup>	Slope	Intercept	<i>n</i>	<i>R</i> <sup>2</sup> <sup>b</sup>				
Hatchery	1.1938	−3.3693	1004	0.95	1.1247	−2.9073	282	0.94	<0.001	–		
Wild ocean-type of early entry	1.2376	−3.864	168	0.93	1.1831	−3.3372	44	0.85	0.53	1.2329	0.1	−3.6594
Wild ocean-type of late entry	0.9097	−1.4591	121	0.56	0.9964	−2.0693	80	0.62	0.48	0.9378	0.69	−1.658
Wild stream-type	1.2738	−3.9963	259	0.92	1.1168	−2.8826	227	0.88	<0.001	–		

<sup>a</sup> Common slope was expressed if there was no significant difference ( $p>0.05$ ) in slopes. Common slope and intercept were expressed, if there was no significant difference in slopes and in intercepts.

<sup>b</sup> Coefficient of determination.

Table 3

Summary of ocean entry date, mean length at ocean entry, average daily growth rate in the ocean and percentage of life history types

	Main ocean entry date	Mean length (mm) at ocean entry	Daily rate of growth (mm per day)	Percentage in the sample					
				May	June	July	September	November	April of next year
1995									
Hatchery-reared	May–June	82.9	1.1	83.6	60.7	73.2	40.2	63.2	74.4
Wild				16.4	39.3	26.8	59.8	36.8	25.6
Wild ocean-type	April–July	63.4	1.1	36.6	62.6	25.7	71.7	33.3	84.8
Wild stream-type	May–June	110.2	1.2	63.4	37.4	74.3	28.3	66.7	15.2
1996									
Hatchery-reared	May–June	83.9	0.9		35		38.6	80.8	80.5
Wild					65		61.4	19.2	19.5
Wild ocean-type	April–August	74.1	1.1		4.6		60.3	3.4	80
Wild stream-type	May–June	116.4	0.9		95.4		39.7	96.6	20

the slope of the linear regression of fish growth on ocean age in days.

### 3. Results

Most chinook salmon entered the Strait of Georgia from May to July (Tables 3 and 4). Virtually all hatchery fish ( $\geq 98\%$ ) entered in these two months, which corresponded closely to the time of hatchery release (mainly in May and June). Most of the wild ocean-type chinook entered in two distinct periods; from April to June and from July to August (Table 4). The percentage of wild ocean-type chinook entered after June was 42% in 1995 and 64.2% in 1996.

Stream-type fish were the largest, wild ocean-type fish were the smallest and hatchery-reared fish were intermediate in size at ocean entry (Tables 3 and 5). There were two distinct size groups of wild ocean-type chinook. The early entry fish (before July) were much smaller than the late entry fish (after June). The latter were similar in size to hatchery-reared fish at ocean entry (Tables 3 and 5), but they entered the ocean approximately 2–3 months later. The mean size at ocean entry of stream-type was smaller in 1995 sample than in 1996 sample. At ocean entry, the mean lengths of hatchery-reared, wild ocean-type of early entry and late entry were similar in 1995 and in 1996 (Table 5). There was no relationship between the length of stream-type fish leaving fresh water and the time they entered the ocean (Table 6). Hatchery-

Table 4

Month of ocean entry for hatchery-reared, wild ocean-type and stream-type chinook

Ocean entry month	1995						1996					
	Hatchery-reared		Wild ocean-type		Wild stream-type		Hatchery-reared		Wild ocean-type		Wild stream-type	
	<i>n</i>	(%)	<i>n</i>	(%)	<i>n</i>	(%)	<i>n</i>	(%)	<i>n</i>	(%)	<i>n</i>	(%)
April	1	0.1	38	13.2	3	1.2	0	0.0	5	4.1	1	0.4
May	533	54.7	107	37.2	198	77.0	97	34.4	28	22.8	138	60.3
June	422	43.3	22	7.6	49	19.1	181	64.2	11	8.9	88	38.4
July	18	1.8	113	39.2	4	1.6	3	1.1	61	49.6	2	0.9
August	0	0.0	8	2.8	2	0.8	1	0.4	18	14.6	0	0.0
September or later	0	0.0	0	0.0	1	0.4	0	0.0	0	0.0	0	0.0
Total number	974		288		257		282		123		229	

Table 5

Back-calculated mean length of hatchery-reared, wild ocean-type, and stream-type chinook upon ocean entry and comparison of the mean lengths between the same rearing types in 1995 and 1996

	1995		1996		<i>t</i> -test <i>p</i> -value
	<i>n</i>	Mean length (mm)±S.D.	<i>n</i>	Mean length (mm)±S.D.	
Hatchery	974	82.9±10.7	282	83.9±13.0	0.163
Wild ocean-type	287	63.4±27.1	123	74.1±29.4	<0.001
Wild ocean-type of early entry	166	42.4±11.8	44	38.9±13.4	0.125
Wild ocean-type of late entry	121	92.1±10.9	79	93.7±12.8	0.335
Wild stream-type	254	110.2±21.0	225	116.4±16.1	<0.001

reared fish that entered later in the year were larger in both of the years than those that entered earlier (Table 6).

In 1995, the average daily growth rates were 1.10, 1.09 and 1.16 mm for hatchery-reared, wild ocean-type and stream-type chinook, respectively (Table 3, Fig. 3). In 1996, the average daily rates were 0.89, 1.05 and 0.93 mm for hatchery-reared, wild ocean-type and stream-type chinook, respectively. Although the growth rates among the three life history types were not all equal (ANCOVA,  $p < 0.001$ ), there was no evidence of a convergence in lengths later in the year, indicating that the sizes of life history types remained distinct (Table 7).

The length difference among hatchery-reared, wild ocean-type and stream-type persisted throughout the summer and fall in both 1995 and 1996 (Table 7). However, after the winter in both years, there was no significant difference in mean lengths between hatchery-reared and wild ocean-type chinook (*t*-test,  $p = 0.89$  for ocean entry in 1995,  $p = 0.08$  for ocean entry in 1996). The few stream-type chinook sampled were still larger than hatchery-reared and wild ocean-type chinook (Table 7).

The percentage of hatchery-reared fish exceeded wild fish except in September 1995 and 1996 and June 1996 (Table 3, Figs. 4 and 5). The low percentage in September 1995 and 1996 reflected the large number of wild ocean-type chinook that entered late in the year. Among the wild ocean-type chinook, the percentage of late entry fish fell from 85.1% in September to 30.4% in November 1995. There were very few wild ocean-type chinook present in November 1996, while the percentage of late entry fish was 68.1% in September 1996. The percentage of stream-type fish among the wild chinook declined by September of both years (Table 3, Figs. 6 and 7). By November of 1995 and 1996, the percentage of stream-type chinook increased as most of the wild ocean-type chinook disappeared. Over the winter, the percentage of stream-type chinook fell from 67% in November 1995 to 15% in April 1996 and from 97% in November 1996 to 20% in April 1997. Wild ocean-type chinook of early and late entry could not be identified in April, as daily growth increments formed in the winter could not be accurately identified. The percentage of hatchery-reared chinook at the end of the year was 63.2% in November 1995 and 80.8% in Novem-

Table 6

Analysis of variance on the slopes of regressions of fish length at ocean entry on ocean entry date

	1995			1996		
	Coefficient	<i>n</i>	<i>p</i> -value	Coefficient	<i>n</i>	<i>p</i> -value
Hatchery	0.1251	974	<0.001	0.1409	282	0.017
Wild ocean-type	0.7052	288	<0.001	0.8158	123	<0.001
Wild stream-type	-0.0011	254	0.951	-0.0943	227	0.266

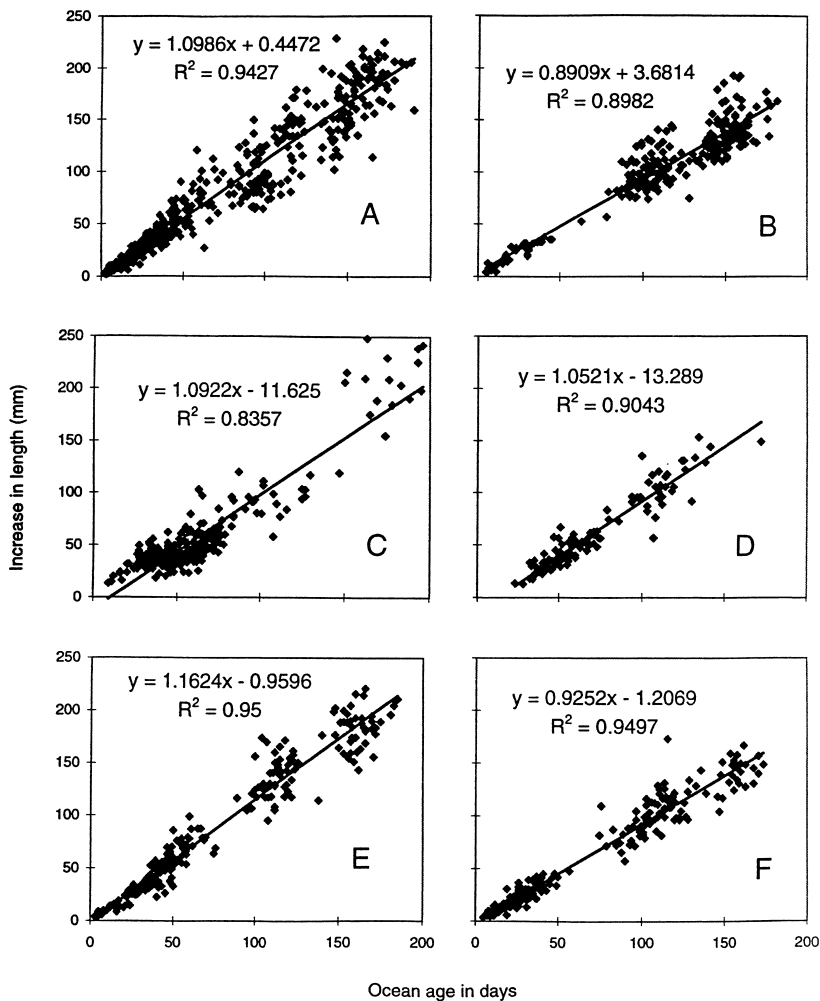


Fig. 3. Relationship between increase in fish length in the ocean and the ocean age in days. The increase is the difference between fish length at the sampling date and back-calculated length at the ocean entry: (A) Hatchery-reared fish in 1995; (B) Hatchery-reared fish in 1996; (C) Wild ocean-type fish in 1995; (D) Wild ocean-type fish in 1996; (E) Wild stream-type fish in 1995; (F) Wild stream-type fish in 1996.

ber 1996. Over the winter, the percentage of hatchery-reared chinook remained high at 74% in April 1996 and 80% in 1997.

#### 4. Discussion

Previous studies used the pattern of scale growth to separate wild ocean-type from stream-type chinook (Healey, 1983). The otolith microstructure was found to be an effective way of identifying these two life history types as well as separating hatchery-reared fish

(Zhang et al., 1995; Beamish and Zhang, 1996). We note that our back-calculated estimates of the ocean entry dates of hatchery fish correspond closely with the known release dates, confirming that the estimated ocean entry dates are probably reliable. In 1995 and 1996, most hatchery-reared and stream-type fish caught in the summer and fall entered the Strait of Georgia about the same time in May and June. Wild ocean-type entered over a longer period and had two distinct entry times, in April–June and July–August. Thus, the release of hatchery smolts is matched more closely with the natural migration of stream-type



Table 7  
Mean fish length (mm) at the sampling date

Sampling date	Ocean age	<i>n</i>	Hatchery length+S.D.	<i>n</i>	Wild ocean-type length+S.D.	<i>n</i>	Wild stream-type length+S.D.
23–30 May 1995	0	419	82.8±6.3	30	77±8.8	52	104±18.5
19–25 June 1995	0	215	94±15.1	87	79±10.8	52	160±16.5
6–19 July 1995	0	191	132±25.3	18	124±26.8	52	174±25.3
11–22 September 1995	0	133	186±39.5	142	137.7±16.3	56	248.8±33.2
6–18 November 1995	0	139	250.4±30.8	27	224.8±45.9	54	280.5±35.7
10–25 April 1996	1	134	334.7±40.2	39	333.2±38.9	7	372.3±47.2
17–27 June 1996	0	70	104±13.3	6	84.2±9.9	124	140.8±18.3
9–20 September 1996	0	122	181.3±26.5	117	136.1±17.5	77	218.4±29.7
4–15 November 1996	0	122	219.4±24.9	1	193	28	244.6±14.8
7 April–2 May 1997	1	62	279.7±35.3	12	259.5±40.1	3	330.3±115.9

chinook and not the wild ocean-type smolts. In both years, the stream-type smolts were the largest juveniles to enter salt water. The hatchery fish were intermediate in mean size and the wild ocean-type smolts were the smallest at ocean entry.

The estimated growth pattern is consistent with the pattern reported by Neilson et al. (1985), using otolith microstructure. Our estimates of growth are also similar to the results of Fisher and Pearcy (1995), who estimated that the average growth rate of tagged

yearling (stream-type) chinook was 1.05 mm per day off the Oregon and Washington coast. Our estimates are almost double those determined by Kjelson et al. (1981), Levy and Northcote (1981) and Levings et al. (1986). It is surprising that wild ocean-type chinook of early entry grew as fast as hatchery-reared chinook, although they were about half the size of hatchery-reared chinook upon ocean entry.

While the three life history types may grow not at the same rates, the size differences persist, indicating

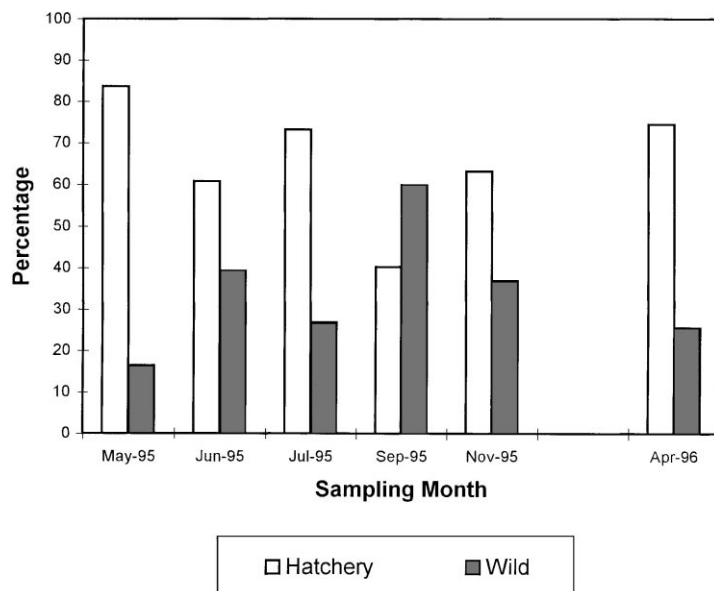


Fig. 4. Percentage of hatchery-reared and all wild chinook at different sampling months in 1995 (ocean age 0) and April 1996 (ocean age 1).

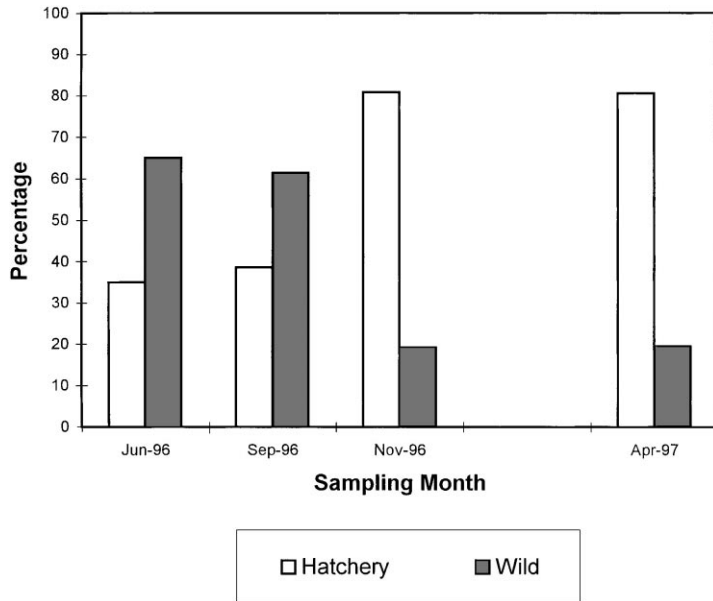


Fig. 5. Percentage of hatchery-reared and all wild chinook at different sampling months in 1996 (ocean age 0) and April 1997 (ocean age 1).

that there was no obvious growth compensation in the first ocean year. After the first marine winter, the mean lengths of hatchery-reared and wild ocean-type chinook were similar. There were few stream-type chinook still present after the winter and they were still

larger than hatchery-reared and wild ocean-type chinook. The change in the trends in growth and size over the winter could result from growth, mortality or migration. At this time we cannot identify the principal cause. If predation-based mortality is size related,

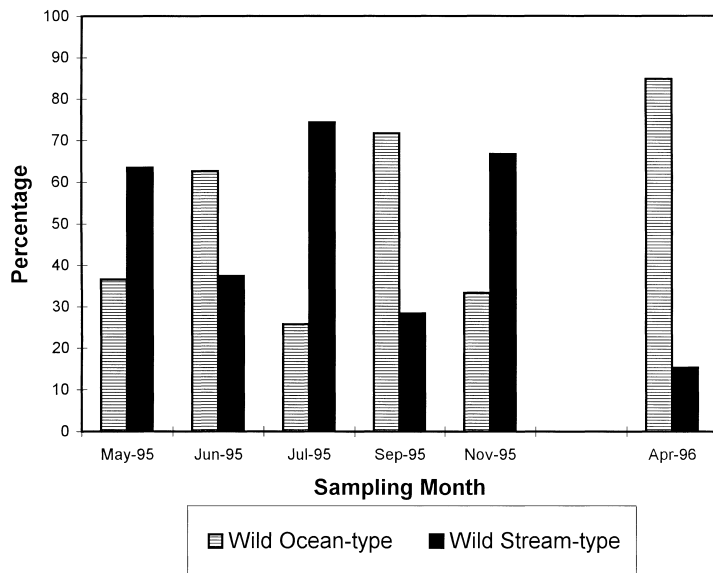


Fig. 6. Percentage of wild ocean-type and wild stream-type chinook at different sampling months in 1995 (ocean age 0) and April 1996 (ocean age 1).

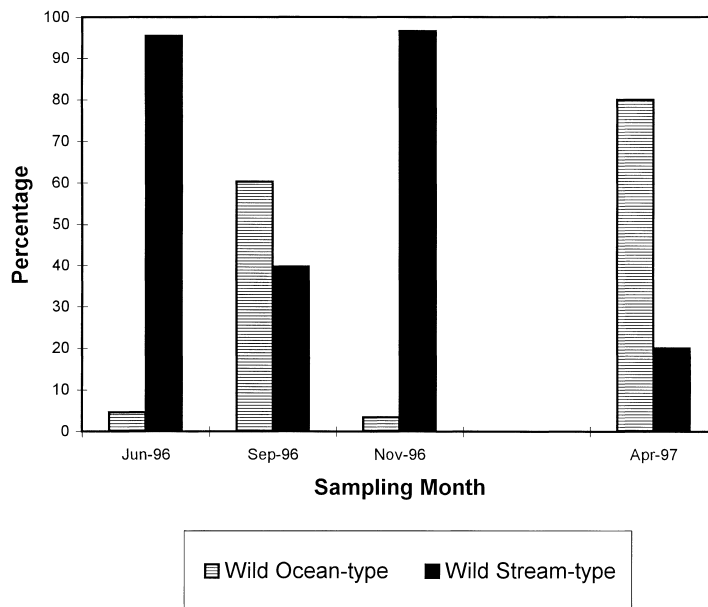


Fig. 7. Percentage of wild ocean-type and wild stream-type chinook at different sampling months in 1996 (ocean age 0) and April 1997 (ocean age 1).

as often proposed (Ellis and Gibson, 1995; Gleason and Bengston, 1996), it is apparent that the impact would be greater on some life history types than on others.

The percentages of hatchery-reared, wild ocean-type and stream-type fish changed throughout the year, but by fall the percentages of hatchery fish were high (63% in 1995 and 81% in 1996). There was an increase in the percentage of wild fish in September, consistent with ocean entry of a large number of wild ocean-type chinook in July and August, but these fish disappeared quickly as the November samples were mostly hatchery fish. Over the winter the percentages of hatchery fish increased in 1995/1996 and remained essentially unchanged in 1996/1997 from these late fall estimates.

Fish generally grew faster in 1995 than in 1996, suggesting that ocean conditions might be more favourable in 1995 than in 1996. Stream-type chinook were significantly smaller upon ocean entry in 1995 than in 1996, however the reasons for the size differences could not be determined. The mean length of hatchery-reared, wild ocean-type chinook of early entry and late entry at ocean entry in 1995 were not significantly different from that of the same type in 1996. This indicates that growth conditions for these

types of fish were probably similar in the hatchery and in the fresh water between the two years.

In general, we observed that large numbers of wild chinook smolts enter the Strait throughout the summer, but by late fall, only a small percentage of the juveniles were wild. Even in September, there were a high percentage of wild ocean-type juveniles in our samples. However, within 4–6 weeks, most wild fish disappear from our samples and presumably have either died or left the Strait. It is clear that it is not only the first few weeks of marine life that affect the total marine survival of chinook. It is also clear that the wild chinook population dynamics are different now than in 1970s (Healey 1980, 1983) and it is important to understand why. The high percentage of hatchery fish in the fall and after the first ocean winter should be considered to be alarming. The intent of the hatchery programs was to rebuild the declining wild stocks (Beamish et al., 1995), and not to replace wild fish (Perry, 1995). The addition of the hatchery fish to the Strait of Georgia has clearly changed the composition of life history types.

Ultimately, it is desirable to interpret our observations in relation to marine survivals and returns to a fishery and to spawning streams and hatcheries. Hope-

fully these studies will be carried out and hopefully it will be recognised that monitoring the percentages of hatchery and wild chinook is an important part of management.

## References

- Beamish, R.J., Folkes, M., 1998. Recent changes in the marine distribution of juvenile chum salmon off Canada. *N. Pac. Anadr. Fish Comm. Bull.* 1, 443–453.
- Beamish, R.J., Riddell, B.E., Neville, C.M., Thompson, B.L., Zhang, Z., 1995. Declines in chinook salmon catches in the Strait of Georgia in relation to shifts in the marine environment. *Fish. Oceanogr.* 4, 243–256.
- Beamish, R.J., Zhang, Z., 1996. Biology of ocean Age 0 hatchery, wild ocean, and wild stream type chinook in the Strait of Georgia. *N. Pac. Anadr. Fish Comm. Doc.* 202, 25.
- Chugunova, N.I., 1963. Age and Growth Studies in Fish. Israel Program for Scientific Translations, Jerusalem, Israel, 133 pp.
- Ellis, T., Gibson, R.N., 1995. Size-selective predation of 0-group flatfishes in a Scottish coastal nursery ground. *Mar. Ecol. Prog. Ser.* 127, 27–37.
- Fisher, J.P., Pearcy, W.G., 1995. Distribution, migration, and growth of juvenile chinook salmon, *Oncorhynchus tshawytscha*, off Oregon and Washington. *Fish. Bull.* 93, 274–289.
- Francis, R.I.C.C., 1990. Back-calculation of fish length: a critical review. *J. Fish Biol.* 36, 883–902.
- Gleason, T.R., Bengtson, D.A., 1996. Growth, survival and size-selective predation mortality of larval and juvenile inland silversides, *Menidia beryllina* (Pisces; Atherinidae). *J. Exp. Mar. Biol. Ecol.* 199, 165–177.
- Healey, M.C., 1980. The ecology of juvenile salmon in Georgia Strait, British Columbia. In: McNeil, W.J., Himsworth, D.C. (Eds.), *Salmonid Ecosystems of the North Pacific*. Oregon State University Press, Corvallis, Oregon, pp. 203–229.
- Healey, M.C., 1983. Coastwide distribution and ocean migration patterns of stream- and ocean-type chinook salmon, (*Oncorhynchus tshawytscha*). *Can. Field-Nat.* 97, 427–433.
- Healey, M.C., 1991. Life history of chinook salmon (*Oncorhynchus tshawytscha*). In: Groot, C., Margolis, L. (Eds.), *Pacific Salmon Life Histories*. UBC Press, Vancouver, pp. 311–393.
- Kjelson, M.A., Raquel, P.F., Fisher, F.W., 1981. Influences of freshwater inflow on chinook salmon (*Oncorhynchus tshawytscha*) in the Sacramento-San Joaquin estuary. In: Cross, R.D., Williams, E.L. (Eds.), *Proceedings of the National Symposium on Fresh Water Inflow to Estuaries*. US Fish Wildl. Serv. Biol. Serv. Prog. FWS/OBS-81/04 (2).
- Kuhn, B.R., 1988. The MRP-reporter program: a data extraction and reporting tool for the mark recovery program database. *Can. Tech. Rep. Fish. Aquat. Sci.* 1649, 145.
- Levings, C.D., McAllister, C.D., Chang, B.D., 1986. Differential use of the Campbell river estuary, British Columbia, by wild and hatchery-reared juvenile chinook salmon (*Oncorhynchus tshawytscha*). *Can. J. Fish. Aquat. Sci.* 43, 1386–1397.
- Levy, D.A., Northcote, T.G., 1981. The distribution and abundance of juvenile salmon in marsh habitats of the Fraser river estuary. *Westwater Res. Cent. Univ. Br. Col. Tech. Rep.* 25, 117.
- Neilson, J.D., Geen, G.H., Bottom, D., 1985. Estuarine growth of juvenile chinook salmon (*Oncorhynchus tshawytscha*) as inferred from otolith microstructure. *Can. J. Fish. Aquat. Sci.* 42, 899–908.
- Perry, E.A., 1995. Salmon stock restoration and enhancement: strategies and experiences in British Columbia. In: Harold, L.S. Jr., Robert, G.P. (Eds.), *Uses and Effects of Cultured Fishes in Aquatic Ecosystems*, Vol. 15. American Fisheries Society, Bethesda, MD, USA, pp. 152–160.
- Zhang, Z., Beamish, R., 1994. Use of otolith microstructure to identify hatchery-reared and wild pacific salmon. *N. Pac. Anadr. Fish Comm. Doc.* 90, 26.
- Zhang, Z., Beamish, R.J., Riddell, B.E., 1995. Differences in otolith microstructure between hatchery-reared and wild chinook salmon (*Oncorhynchus tshawytscha*). *Can. J. Fish. Aquat. Sci.* 52, 344–352.