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An abrupt increase in the abundance of Juvenile salmon in the Strait of Georgia

by

R.J. Beamish, K.L. Poier, R.M. Sweeting and C. M. Neville
Fisheries and Oceans
Pacific Biological Station
Science Branch
Nanaimo, B.C.
Canada V9R 5K6

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Abstract

The abundance of ocean age 0 coho, chinook, and chum salmon estimated from surveys conducted in the Strait of Georgia in June and July indicated a substantial increase in 2000 compared to the previous three years. Pink salmon catch per unit effort increased from 1998 to 2000, however sockeye catch per unit effort was the lowest in 2000 among the four years. The increases in coho abundance occurred despite a slight reduction in hatchery releases. An increase in wild coho abundance in 2000 may be related to a reduction in fishing mortality in 1998 or an improved freshwater survival or both. The synchrony of increased abundances among species, except sockeye, indicates that a common factor is involved. These increases were also associated with good growth relative to previous years. This indicates that the productivity of the marine habitat may have increased in 2000. Because of the improvement of the early marine survival it is tempting to suggest that marine survival increased, but this will not be known until 2001 for pink and coho salmon and later for chinook, chum and sockeye. This common factor may be related to a change in climate, which could be indicative of a regime shift.

Introduction

In 1997 we started a study of the relationship between climate and ocean conditions and juvenile salmon survival and behaviour in the Strait of Georgia. The Strait of Georgia (Figure 1) is an excellent study site because it is an enclosed marine system that is a rearing area for large numbers of juvenile salmon. Wild or naturally spawning juvenile salmon enter the Strait from the Fraser River which is the major Pacific salmon producing system on Canada's West Coast. There are also a number of smaller salmon producing rivers and streams that flow into the Strait. In addition to the naturally produced Pacific salmon, approximately 50 hatcheries produce a variety of salmon species that enter the Strait of Georgia. In 2000, approximately 59.2 million juvenile salmon of all species were released from these hatcheries. This enhanced production was reduced from the numbers of salmon produced in previous years with approximately 93.2 million, 143.4 million and 144.1 million released in 1997, 1998, and 1999 respectively. A third source of juvenile salmon is from hatchery and wild salmon produced in and around Puget Sound in the United States. Our recovery of tagged salmon indicates that about 11% of the ocean age 0 coho salmon in the Strait of Georgia were from the United States and about 70% of these are from hatcheries (Beamish et al. 1998a).

In this report we summarise our catches of juvenile salmon in June and July surveys from 1997 to 2000. The exact dates of the surveys have not been constant because of scheduling constraints, but adequate ship time has been available to provide estimates of abundances of the various species in their first marine year.

Methods

The survey design (Figure 2) and the method of using the swept volume to estimate abundance is described in Beamish et al. (2000). The opening of the net is 14m deep x 30m wide and it is fished at 5 knots (Beamish and Folkes 1998). The survey tract lines are fixed and the depths fished are randomised with the greatest effort in the surface 15m.

An important assumption in the abundance estimate is that we use a catchability of 1, which implies that all juvenile salmon in front of the net opening are caught. In Russian studies (Shuntov et al. 1993) the catchability of a similar, but much larger net, is less than 0.5. We also note that the trawl is fished astern of the vessel. Therefore, we fish in the wake of the vessel and there is a possibility that the juvenile salmon may avoid this area. The meshes in the front of the net are approximately 3.8m square, thus it is the "herding" effect of the gear that catches the juveniles. All of these considerations indicate that our abundance estimates should be considered low. Since the trawl cannot be opened or closed when it is set, there is a possibility that the catches below the surface 15m may have captured fish at shallower depths. Crew familiar with the gear believe that the gear probably does not "fish" either on the way down or way up, but this view cannot be confirmed. Tows were ½ hour and fishing occurred from 6 AM to 6 PM. Abundance estimates were made for coho, chum, and chinook. A comparison of pink and sockeye estimates among years was not made because these species tend to be highly migratory with residence times considerably shorter than the other species (Healey 1980). Also, pink salmon are virtually all from the Fraser River where spawning occurs almost exclusively in years ending in odd numbers with juveniles entering the Strait in years that end in even numbers.

The percentage and abundance of hatchery and wild coho are estimated using the analysis reported in Beamish et al. (1998a). In the analysis, we assume that the percentage of wild and hatchery coho from the United States (Puget Sound) was similar to the percentage from Canadian sources. Length and condition frequencies are reported for all species and are not separated by depth strata.

Results

The catches and catch per unit effort (CPUE) in June and July for the past four years indicate that for all species, the largest catches were in the surface 15m (Table 1). The exception was for chinook in 1999 when the CPUE in 0-15m was about half of the CPUE in 16-30m. Even though the largest catches usually occurred in the surface 15m, the percentage of the total CPUE for all depths varied among species for the individual depth strata (Table 1). Although the preferred depths were characteristic of species the preferences differed slightly in some years. The depth preferences, as indicated by catches, identified pink, chum and probably sockeye near the surface, coho in the top 45 meters and chinook in the top 60 meters. In 2000, CPUE of coho in the surface 15m was approximately 8 times larger than in 1997, 2.9 times larger than in 1998, and 3.5 times larger than in 1999. Chum CPUE in the surface 15m was 12 times, 1.5 times and 3.4 times larger than in 1997, 1998, and 1999 respectively. Chinook CPUE also was the largest in 2000, when compared for the combined catches from 0-30m. CPUE in 2000 was 93.2 compared to 63.5, 57.2 and 51.0 in 1997, 1998, and 1999 respectively. Pink salmon CPUE increased from 1998 to 2000, however, sockeye CPUE was the lowest in 2000 among the four years.

The abundance estimates (Table 2) indicate that there was a large increase in abundance in 2000 for coho, chinook, and chum salmon. Abundance of coho salmon in 2000 was 11.2 million ($\pm$ 4.6 million) and exceeded the combined abundances of the previous three years. Chum salmon abundance of 27 million ($\pm$19.7 million) was 3.7 times larger than the previous year. Chinook salmon abundance in 2000 (7.9 million $\pm$4.8 million) was not quite double the 1999 estimate. The total abundance estimate in 2000 of 26.15 million coho, chinook, and chum, was a substantial increase from the 1997, 1998 and 1999 estimates of 8.4 million, 15.8 million, and 15.1 million respectively.

Coho caught in 2000 were the largest of the four years and had the largest condition factor (F-test, $p<0.05$, Table 3, Figure 3A). Chinook in 2000 were similar in length to chinook in 1997 (F-test, $p>0.05$) but were larger than in 1998 and shorter than in 1999 (F-test, $p<0.05$, Table 2, Figure 3B). The condition factors were similar among years with the exception of a lower condition in 1998 compared to 2000 (F-test, $p < 0.05$). There was a significant difference in length between chum in all years (F-test, $p<0.05$) with length in 2000 being larger than in 1998 and 1999 (Table 3, Figure 3C). The condition factor of chum was similar in 1998, 1999 and 2000 but lower in 1997 (F-test, $p<0.05$). The length and condition factors of pink salmon in 2000 were significantly larger than

1998 (F-test, $p<0.05$, Table 3). The length and condition factors of sockeye were variable throughout the four years (Table 3).

The length frequency for coho had normal shaped distribution in all years (Figure 3A). Chinook, however, had distributions that were not normal (Figure 3B). It is known that hatchery-reared chinook tend to be larger than wild ocean type chinook smolts and that wild ocean type chinook are smaller than wild stream type chinook. These length frequency distributions are believed to represent different combinations of these life history types. The length frequency of chum salmon also were not normal (Figure 3C) in all years except possibly 2000.

Using the estimated percentage of coho from Canadian hatcheries (Table 4) and our abundance estimates (Table 2) we estimated that the number of naturally spawned or "wild" coho in the 2000 survey was or 4.5 million. This was larger than in any of the three previous years. Similarly, the number of hatchery fish was also larger than in any of the previous three years.

Discussion

There were large increases in the CPUE and abundance of ocean age 0 coho, chinook, and chum in the 2000 survey compared to the three previous years. In addition to an increase in abundance, the length and condition factor was larger for coho salmon compared to the previous 3 years. The large increase in abundance and corresponding increase in size and condition indicates that food availability for coho was greater in 2000 than in 1997, 1998 or 1999.

Releases of coho from Canadian hatcheries in 2000 were 11.8 million compared to 11.7, 12.1 and 14.0 million in 1997, 1998 and 1999 respectively. The lower release in 2000 compared to 1999 and 1998 indicates that the increase in abundance was not the result of an increase in hatchery production. There was a reduction in the percentage of hatchery coho in the catch in 2000. The increase in the percentage of wild coho in 2000 may be related to increased escapement in 1998 but also could be related to the reduced hatchery releases. We note that in 1997, the hatchery releases were similar to 2000, but the percentage of hatchery coho was 80.1% compared to 60% in 2000 (Table 4). Therefore, the reduced percentage of hatchery coho in 2000 probably reflects an improved escapement in 1998 or improved freshwater survival in 1999 or both.

The increased abundance for chum salmon in 2000 was associated with larger fish and good condition when compared to previous surveys. This indicates that feeding conditions for juvenile chum in 2000 were very good. Chinook lengths were slightly shorter in 2000 than in 1999 but either similar or larger than the mean length in 1997 or 1998. However, the condition factor in 1999 was unchanged or higher than in previous years indicating that the larger abundances in 2000 were associated with similar or improved food availability.

In general, the very large increases in abundance were associated with good growth relative to previous years. This indicates that available food may have also increased, suggesting that the productivity of the marine habitat increased in 2000.

Estimates of the abundance were not made for sockeye or pink. For sockeye, the Adams River traditionally has been the dominant run in the Fraser River. The 1998 cycle would contribute to the ocean age 0 catches in 2000. However, in recent years the Adams stock has declined in abundance and the Quesnel stock has increased. The 1997 brood year was the strong cycle for Quesnel, which would contribute to our catches in 1999. A confounding issue is that the Chilko stock has apparently changed its cyclic dominance to a more uniform four- year return. Thus, it might be expected that juvenile sockeye catches in 2000 and 1999 would be larger than in 1998 and 1997. Our catch per unit effort for sockeye do not correspond to these expected smolt abundances. This may be explained by the timing of our surveys, which occurred when many sockeye smolts have been reported to have left the Strait of Georgia (Healey and Groot, 1987).

Virtually all the pink salmon that enter the Strait of Georgia came from the Fraser River in years ending in even numbers. Thus we caught pink in 1998 and 2000 but in 1997 and 1999 there were very few ocean age 0 pink salmon in the Strait of Georgia. The pink caught in 2000 were in good condition compared to 1998. The CPUE for pink in 2000 was larger than in 1998 and it will be interesting to compare their survival with 1998 when they return in 2001.

Increases in abundance of coho, chinook, chum, and possibly pink may be due to improved marine survival. We note that marine survival is measured using the estimated numbers of fish that return and are captured in fisheries. It appears from this study that early marine survival is higher and the larger size of individuals may indicate that total marine survival may be higher. An improved total marine survival can be confirmed when this brood year returns as adults in 2001 for coho and pink and in subsequent years for chinook and chum. There are other possible explanations for the increases in abundance including changes in distribution or catchability of the year. However, the large and synchronous increase in the abundances is evidence that there is a common explanation for the increase. This may be consistent with the previous report (Beamish et al. 1998b) that a new regime may have occurred in 1997/1998. The new regime may be characterised by an increase in the productivity of the rearing area for juvenile salmon in the Strait of Georgia.

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Table 1. Catches and catch per unit effort (CPUE) by species for June/ July from 1997 to 2000. Depths are shown in meters.

	Depth	1997 CPUE	1997 Catch (N)	1997 % of CPUE	1998 CPUE	1998 Catch (N)	1998 % of CPUE	1999 CPUE	1999 Catch (N)	1999 % of CPUE	2000 CPUE	2000 Catch (N)	2000 % of CPUE
COHO													
	0-15	29.8	473	81.4	79.1	837	84.8	66.6	1366	72.9	230.8	4269	85.2
	16-30	5.0	35	13.6	10.4	100	11.2	19.5	234	21.3	29.1	276	10.7
	31-45	0.7	3	1.8	1.6	11	1.7	1.5	9	1.6	6.6	56	2.4
	46+	1.2	13	3.2	2.2	33	2.3	3.8	40	4.2	4.5	27	1.7
CHINOOK													
	0-15	81.7	1297	63.3	88.6	938	69.8	39.5	809	27.6	127.6	2360	72.1
	16-30	28.9	204	22.4	22.4	215	17.6	70.6	847	49.4	26.3	250	14.9
	31-45	16.2	73	12.5	9.5	66	7.5	28.8	173	20.0	13.8	117	7.8
	46+	2.4	26	1.8	6.5	97	5.1	4.5	47	3.0	9.3	56	5.2
CHUM													
	0-15	55.3	879	92.7	425.5	4503	97.0	193.5	3967	93.7	655.8	12132	97.9
	16-30	2.3	16	3.8	7.1	68	1.6	8.3	100	4.0	12.5	119	1.9
	31-45	0.9	4	1.5	0.9	6	0.2	2.3	14	1.1	0.6	5	0.1
	46+	1.2	13	2.0	5.3	79	1.2	2.4	25	1.2	12	7	0.1
PINK													
	0-15	1.3	20	100.0	142	1503	92.8	0.4	8	100.0	185.6	3433	97.2
	16-30	0	0	0	7.9	76	5.2	0	0	0	4.9	47	2.6
	31-45	0	0	0	1.3	9	0.9	0	0	0	0.1	1	0.1
	46+	0	0	0	1.7	26	1.1	0	0	0	0.2	1	0.1
SOCKEYE													
	0-15	132.8	2109	68.1	31.4	332	97.6	34.0	696	90.5	16.7	309	88.1
	16-30	47.9	338	24.6	0.5	5	1.6	2.3	28	6.2	1.9	18	10.0
	31-45	14	63	7.1	0.1	1	0.4	0	0	0	0.4	3	1.9
	46+	0.4	4	0.2	0.1	2	0.4	1.2	13	3.3	0	0	0

Table 2. Abundance of ocean age 0 coho, chinook and chum salmon in the Strait of Georgia in June/ July from 1997 to 2000. Depth strata used in the abundance estimate are shown in parentheses.

	Abundance	Lower Interval – Upper Interval
COHO (0-45 meters)		
1997	1,660,000	350,000 – 2,970,000
1998	2,430,000	1,510,000 – 3,350,000
1999	3,400,000	2,220,000 – 4,570,000
2000	11,220,000	6,600,000 – 15,840,000
CHINOOK (0-60 meters)		
1997	4,740,000	1,810,000 – 7,660,000
1998	2,420,000	1,200,000 – 3,650,000
1999	4,410,000	3,050,000 – 5,760,000
2000	7,940,000	3,160,000 – 12,710,000
CHUM (0-30 meters)		
1997	1,980,000	800,000 – 3,150,000
1998	11,000,000	3,530,000 – 18,470,000
1999	7,280,000	130,000 – 1,440,000
2000	27,000,000	7,330,000 – 46,660,000

Table 3. Average length and condition factor of ocean age 0 coho, chinook, chum, pink, and sockeye during June/July from 1997 to 2000.

	Length			Condition Factor		
	Average (mm)	Std Dev	Catch (N)	Average	Std Dev	Catch (N)
COHO						
1997	172	23.6	126	1.15	0.15	126
1998	177	23.4	825	1.19	0.11	825
1999	172	20.2	1332	1.15	0.10	1332
2000	200	23.5	2961	1.23	16.41	2176
CHINOOK						
1997	141	40.7	680	1.19	0.19	680
1998	133	35.0	694	1.17	0.16	695
1999	146	28.3	890	1.19	0.43	890
2000	143	37.2	1780	1.19	0.15	722
CHUM						
1997	134	26.6	290	0.94	0.11	290
1998	124	15.3	418	1.00	0.10	418
1999	116	20.2	309	0.98	0.12	309
2000	128	18.5	2159	1.00	0.09	314
PINK						
1997	106	20.5	20	0.76	0.08	9
1998	118	16.0	1188	0.96	0.11	339
1999	106	8.8	5			0
2000	119	13.0	1621	0.92	0.08	213
SOCKEYE						
1997	115	10.7	1580	0.96	0.15	128
1998	91	19.3	229	1.02	0.11	113
1999	120	17.5	640	0.95	0.15	175
2000	116	17.1	244	0.95	0.09	112

Table 4. The abundance of coho of each rearing type in the Strait of Georgia, calculated using Canadian hatchery percentage estimates reported in Beamish et al. (1998a) and updated for 1999 and 2000.

	Hatchery %	Abundance		
		Hatchery	Wild	Total
1997	80.1	1,330,000	330,000	1,660,000
1998	67.8	1,650,000	780,000	2,430,000
1999	72	2,450,000	950,000	3,400,000
2000	60	6,730,000	4,490,000	11,220,000

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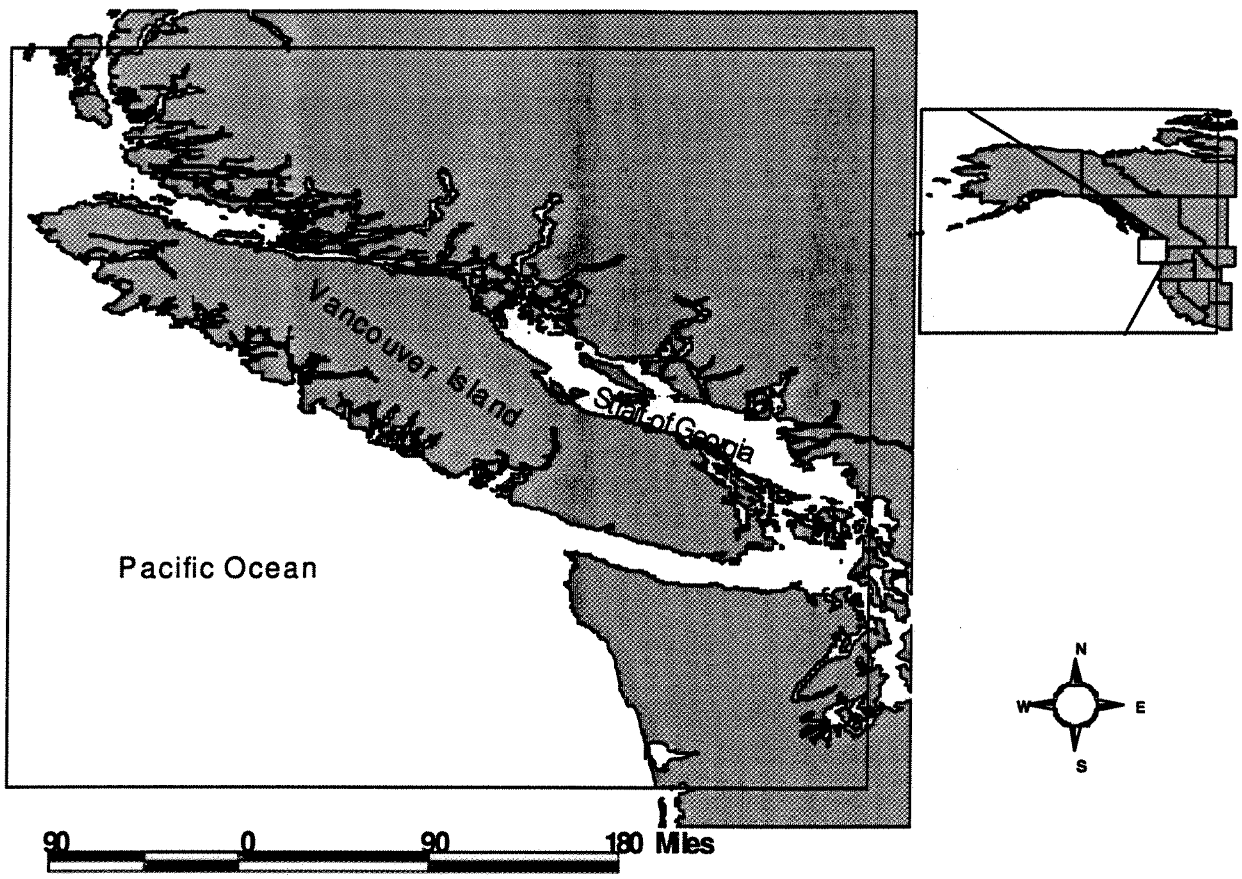
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Figure 1.

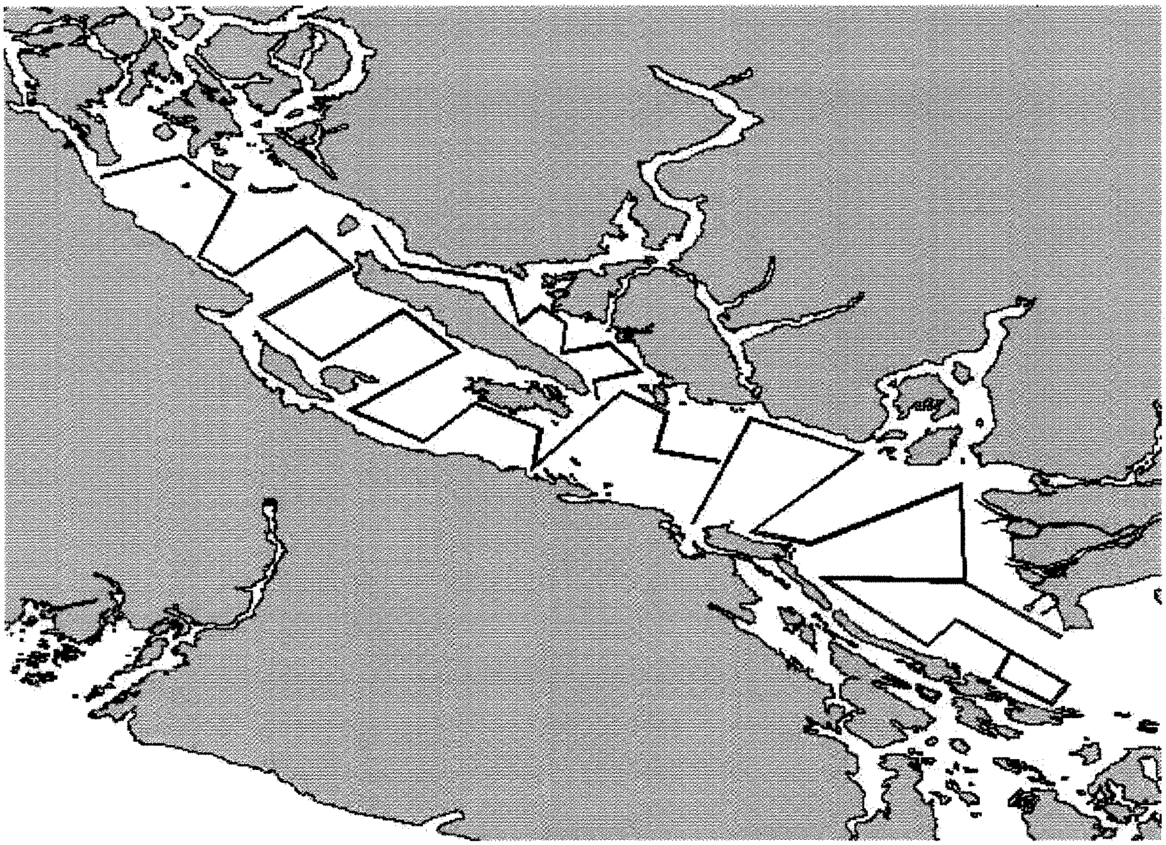

Figure 2.

A. COHO

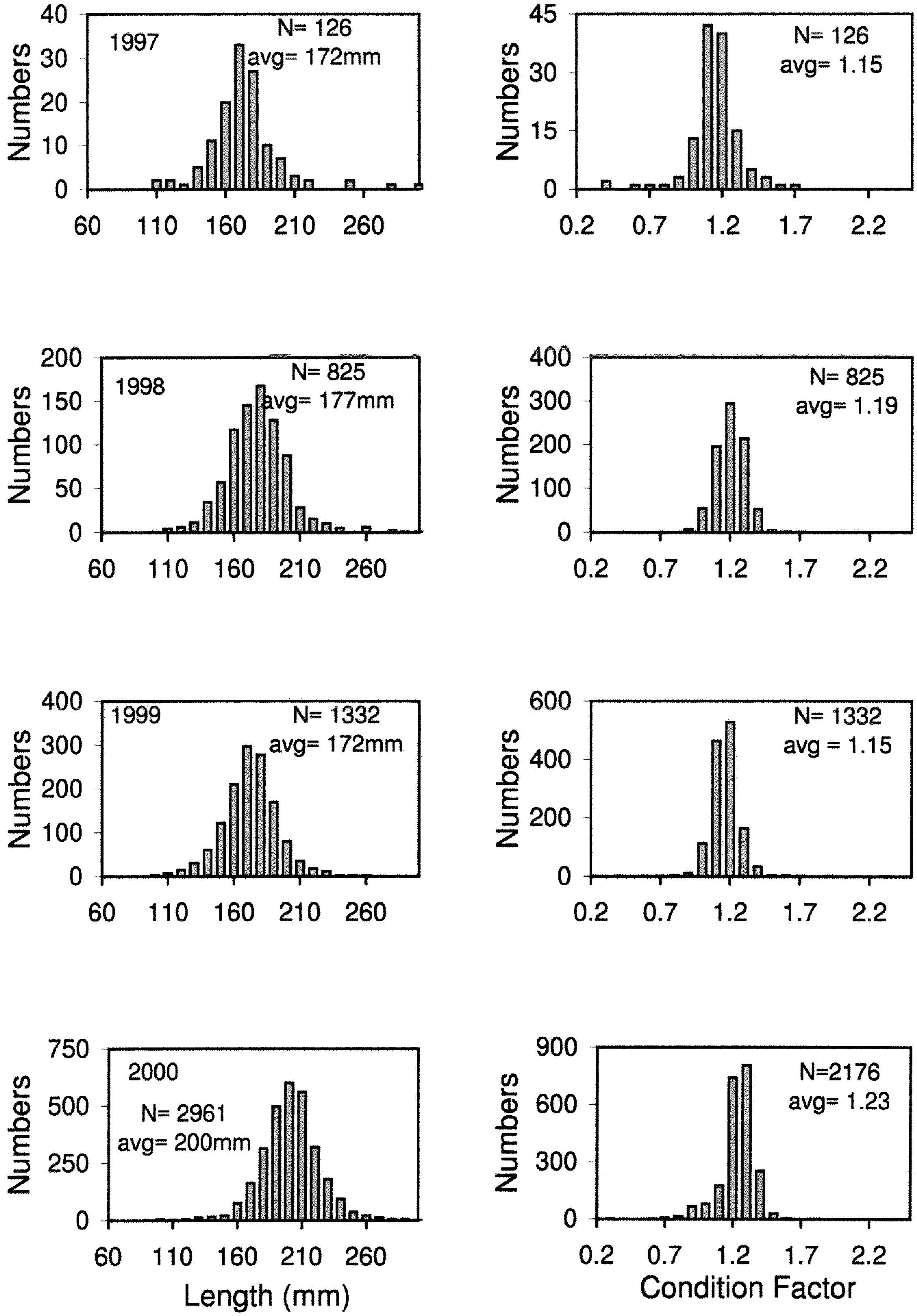

Figure 3.

B. Chinook

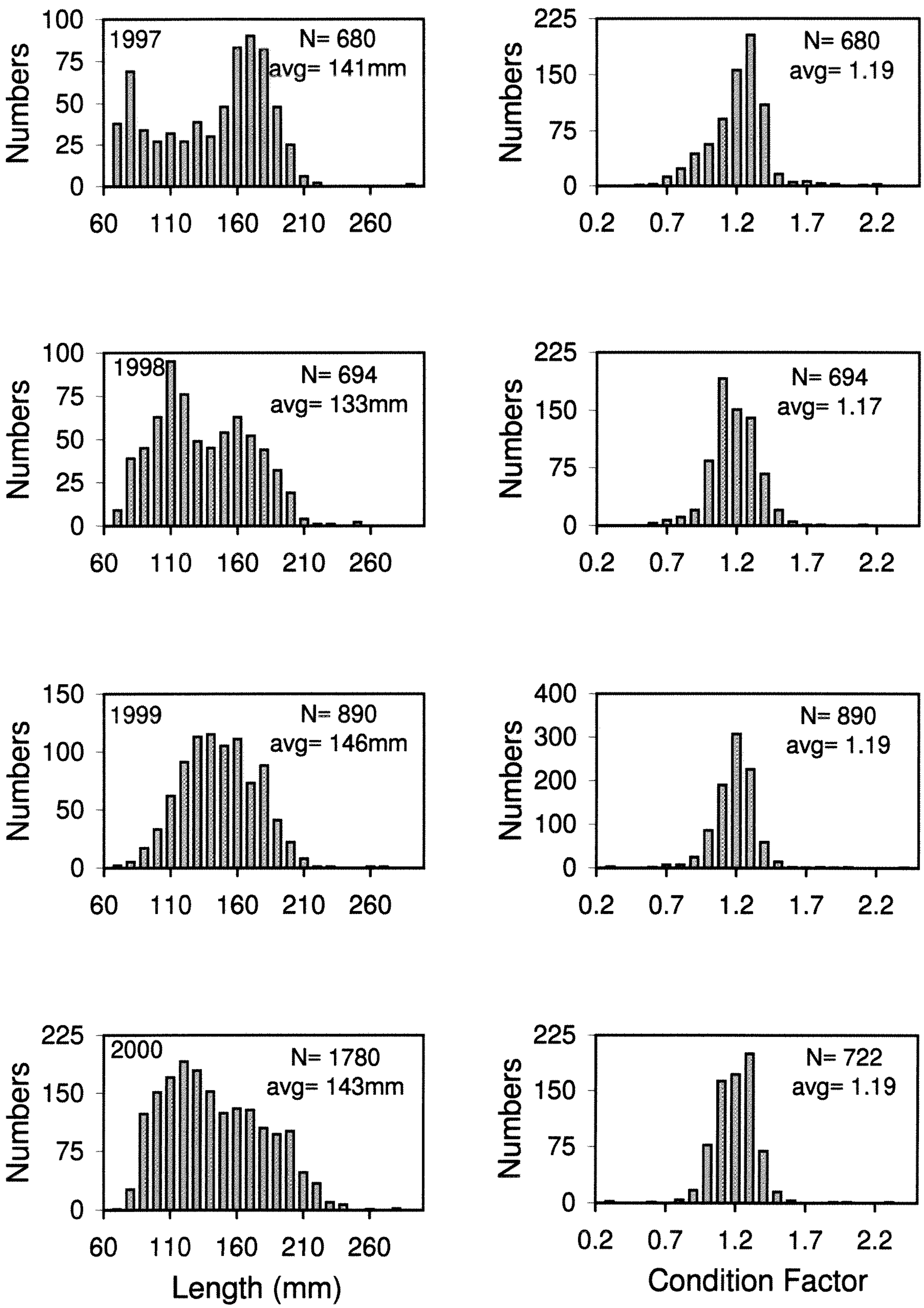

Figure 3. Continued

C. Chum

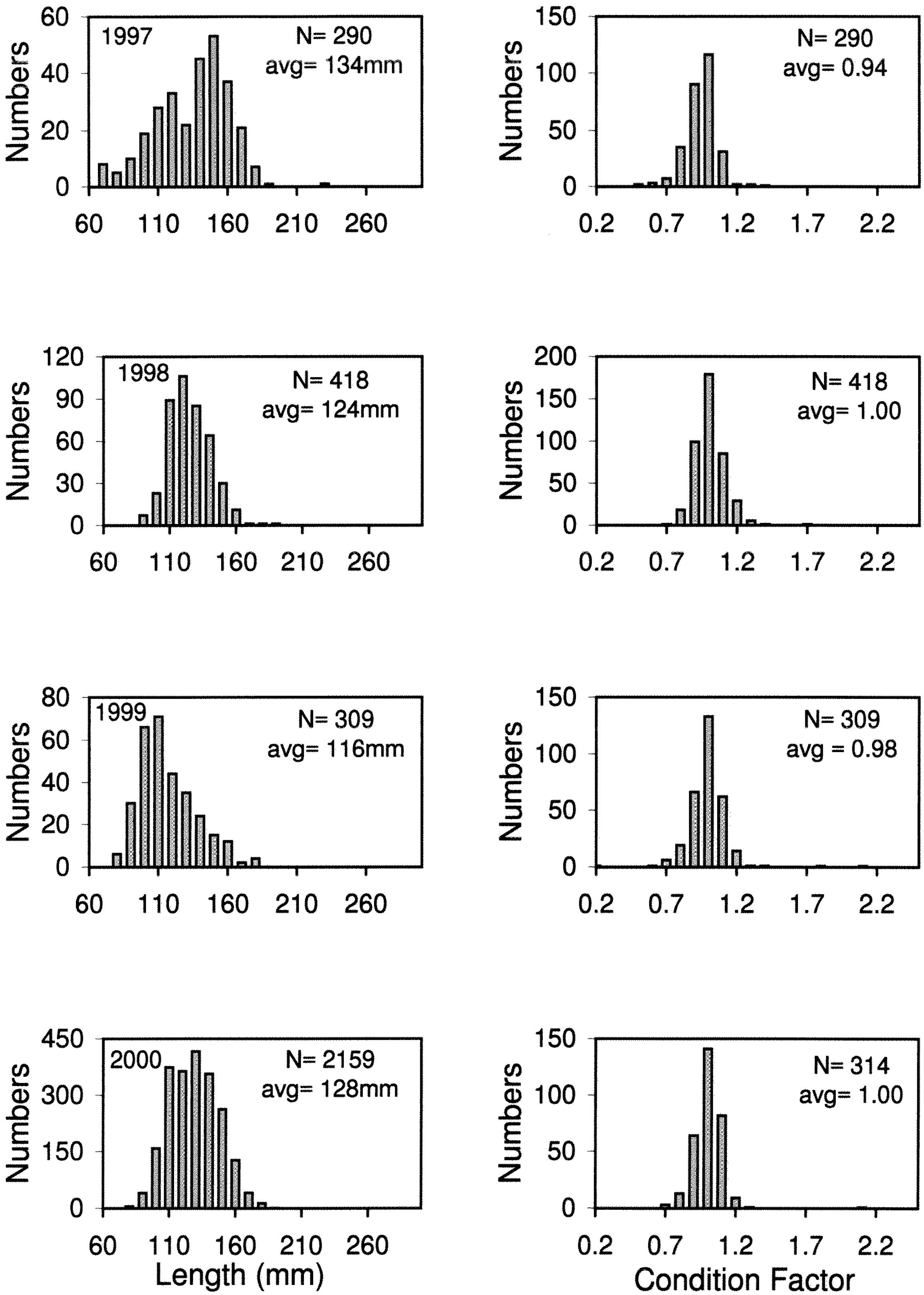

Figure 3. Continued