Recent Changes in the Marine Distribution of Juvenile Chum Salmon off Canada

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In 1995, abundance surveys for juvenile Pacific salmon were carried out in the Strait of Georgia using either rope trawls or beam trawls. All five species of salmon were captured and in this paper we report the preliminary results of the distribution and abundance of chum salmon. Chum were not caught in the earliest survey and were not abundant in the samples until late May. Once chum were abundant in the catches, they were distributed throughout the Strait, including the Gulf Islands area. By mid-November, chum were still abundant and had a mean size of 22 cm and ranged from 16-28 cm. A swept volume estimate of abundance indicated there could be approximately 1.3 million juveniles at this time. Depending on the amount of marine mortality that had occurred by November, the juveniles that remained in this relatively small marine ecosystem could contribute significantly to the future catch and escapement. It appears that the occurrence of such large numbers of juveniles in the Strait of Georgia, so late in the year, is a recent phenomena that may be related to natural changes in the Strait of Georgia ecosystem that, in turn, are linked to large scale climate-ocean events in the North Pacific.

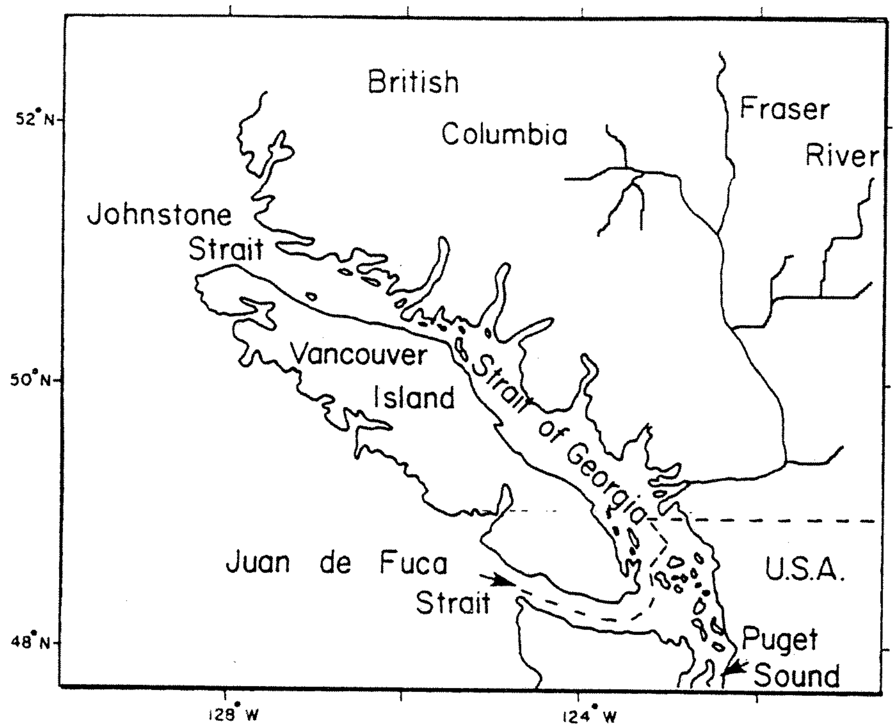
INTRODUCTION

The Strait of Georgia (Fig. 1) is a small marine ecosystem located between Vancouver Island and the mainland British Columbia, Canada. It is the most important juvenile rearing salmon area on Canada's west coast and possibly one of the most important salmon rearing areas in the North Pacific. Historically, Fraser River salmon stocks accounted for 35-40% of the total Canadian catch of Pacific salmon. Thus, large numbers of pink, chum, sockeye, coho, and chinook salmon enter the Strait early in the year from the Fraser River. In addition to the wild stocks from the Fraser River and other smaller rivers that flow into the Strait, large numbers of hatchery-reared salmon are presently released into the Strait. In general, more than one half of Canada's one half billion artificially enhanced Pacific salmon are released into the Strait of Georgia (Dept. of Fisheries and Oceans 1996). These releases are mostly chinook and coho from Canadian hatcheries, but hatchery released salmon from United States hatcheries in Puget Sound, and a few wild salmon also feed for varying lengths of time in the Strait of Georgia. Beamish et al. (1995A,B) and Beamish (1996) showed that the number of hatchery-reared chinook and coho either are equal to or exceed the number of wild juveniles from Canadian rivers and that the combined number represents a substantial increase in total smolt abundance compared to earlier years when there was mostly wild production.

Throughout the range in the distribution of chum salmon, there is a general tendency for the average time of ocean entry to be later with increasing latitude (Godin 1982), with the latest migrants entering salt water by the end of June (Salo 1991). In British Columbia, chum salmon commonly migrate into salt water from February to May. Migration from the shoreline and shallow nearshore areas occurs for most North Pacific stocks after a few weeks and is believed to be related to food abundance (Whitmus 1985, Bax 1983). Movement into the deeper waters in the Strait of Georgia was reported by Healey (1980) to occur in June at an average size of 80-100 mm. Movement out of the Strait of Georgia occurred in July, with movements possibly related to foraging success (Healey 1980).

We show that relatively large numbers of chum salmon are presently remaining in the Strait of Georgia until late in the year and that this behaviour is different than observed during the studies of Healey and others in the 1960s and 1970s. The reasons for the change in behaviour are unknown, but may be associated with a change in the Strait of Georgia

Fig. 1 Study area showing the Strait of Georgia, Puget Sound and the Fraser River.



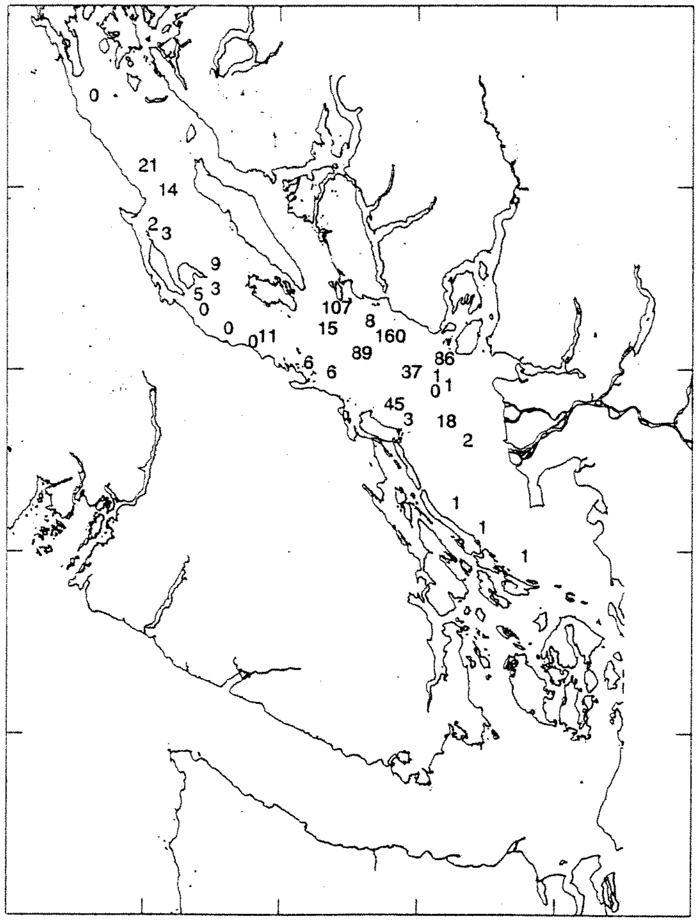
ecosystem that was associated with basin wide changes in climate in the North Pacific. Our study is continuing and the results reported here should be considered as preliminary observations of work in progress.

METHODS

Surveys of juvenile salmon abundance were made in the Strait of Georgia, throughout 1995. Initially, samples were collected with a beam trawl, but the catches reported here were made with a rope trawl that was fished at different depths and towed at speeds averaging from 4 to 5.2 knots. When fishing to design specifications the rope trawl will fish 21.3 m deep and 63.5 m wide. The first 54.3 m of the net, or the front end, consists of large rope meshes that can range from a minimum of less than 2 m in width to over 3.8 m. The intermediate portion has meshes ranging from 1.6 m to 20 cm. The cod end has 10 cm meshes with a 1 cm liner in the last 7.6 m of the net. The net is held open with USA Jet Doors Model P that can be hooked up to fish at the surface or any depth. The specified bridle length is 61 m, but we used 30.5 m to fish the net at the surface. This shorter bridle length reduced the opening of the net to approximately 14 m deep by 28 m wide, but the size and shape of the opening varied according to tides and sea conditions. When the doors were at the surface, the head rope was between the surface and 3.5 m. A Simrad TS3300 net sounder was attached near the head rope and provided a continuous image of the net opening, large schools of fish that were entering the net, and a continuous indication of head rope depth. The survey design represented a series of sets along track lines that were distributed within the Strait of Georgia (Fig. 2) so that juvenile salmon were collected from areas of known abundance, as well as sampling in the centre and both sides of the Strait. All rope trawls were made during daylight hours because the large net could readily be fished at all depths. The amount of daily effort was limited to 12 hours because of controls on the hours that the crew could work.

The abundance was estimated using the average area of the mouth of the net as determined from a net sounder attached to the head rope. The distance fished was the distance traveled during the set which was usually 1 hour. The efficiency of the net was assumed to be between 1 and 0.5 (i.e., the net caught everything in its path or 50% of the fish in its path). The habitat depth was determined from preliminary surveys in which 90-95% of chum caught were in the top 30 m. The habitat area was considered to be the surface area of the Strait of Georgia minus the island areas. The abundance, therefore, was the total catch at depths from the surface to 30 m x Strait of Georgia volume to 30 m / swept volume of the trawl net. One method of estimating the accuracy of the swept volume estimates of chum salmon was to compare

Fig. 2 Catches of ocean age 0 chum salmon in the Strait of Georgia, in November 1995. The tows were approximately one hour, and the catches indicated have been standardized to one hour. Standardized catches are identified for all fishing depths.



swept volume abundance estimates of coho in November 1995 with the total abundance of coho as determined from sport and commercial catches and from estimates of escapements. The abundances for coho for past years was known and if the swept volume estimates of coho from the November 1995 sample were consistent with the known abundance it would indicate that the estimate of chum abundance probably was a reasonable approximation of the true abundance.

We compared our catches of chum salmon with catches of chum salmon from other, earlier studies of juvenile chum salmon in the Strait of Georgia. We were able to identify 79 separate cruises or distinct sampling efforts from 1965 to the present. In addition to 20 surveys in our study, there were 59 other studies. However, 11 occurred from September 1st to December 31st and were directed at salmon life history, movement, and diet. Those past collections were typically summarized in federal technical and data reports available at the Pacific Biological Station library. The samples from other surveys were collected using a variety of gear including small mesh purse seines, surface trawls, and two boat trawls. We standardized catches by comparing the ratio of chum catches to the combined chinook and coho catches. This was necessary because the various studies used different sampling gear. We used this method of comparing abundances because our surveys showed that coho and chinook also remained in the Strait of Georgia later until late in the year. We believe this method of comparing chum abundances is conservative because the abundance of coho and chinook juveniles actually increased in the 1990s compared to the 1970s as mentioned earlier, and this would bias the abundance estimate in favour of a lower estimate of chum abundance.

The Strait of Georgia (Fig. 1) has a water surface area of 6320 km^2 and an average depth of 155 m. The flushing time of the basin ranges from 50-75 days in the summer to 100-200 days in the winter (Thomson 1994). The flushing time and the circulation in and out of the Strait is related primarily to the flows of the Fraser River drainage, which accounts for approximately 80% of the land runoff area. The circulation is the typical estuarine circulation which brings in offshore bottom water to compensate for the movement of surface low salinity water that moves out of the Strait through Johnstone Strait as a result of the discharge from the Fraser River (Thomson 1981). The estuarine circulation is also the major supplier of nitrates to the Strait, accounting for approximately 5 times the amount contributed by other sources (Yin et al. 1995).

RESULTS

The comparison of survey catches in the present study with earlier studies, indicates that there has been an increase in chum abundance (Fig. 3). The abundance of chum salmon in the Strait of Georgia after September 1 is about 4 times higher in the 1990s than in the past. We have five observations in the 1990s and there is considerable variation. The lowest catch ratio, or the lowest abundance of chum, in the 1990s was in 1993, a year in which large numbers of coho did not move offshore (Fig. 4). There is less variation in the catch ratio in the early 1970s, with 6 of the 7 surveys finding relatively small abundances of chum relative to the combined abundance of chinook and coho. There has been an increase in hatchery produced chum salmon in the 1980s and 1990s (Fig. 5), however, hatcheries were also producing relatively large numbers of chum at the time of the surveys in the 1970s.

In 1995, there were 6 cruises, (Table 1). In April, no chum were caught. The first and largest catches were in late May when chum had an average length of 8 cm. By mid-November, chum had an average length of 22 cm. In 1995, the estimated abundance of chum using a net efficiency of 100% in September was 1,797,000 and 1,314,000 in

The estimated abundance of coho salmon in November 1995, using a net efficiency of 100% was 563,000 (Table 2). This compares to an average commercial and sport catch in the Strait of Georgia in the 1990s (1990-1994) of approximately 650,000 (Fig. 6). A difficulty with this calibration is the tendency for coho to move out of the Strait in the 1990s (Fig. 4) The estimates in Fig. 6 are for commercial and sport catches, while our estimates are for juveniles before they enter the fishery and before all the coho moved offshore. In 1994, the catches of coho in the Strait of Georgia were 352,000 and 74% of the Strait of Georgia coho were offshore for a total catch of 1.35 million. Assuming escapements were approximately 25% of the total (75% harvest rate), the total catch and escapement was 1.8 million fish. In November, 1995 the estimate of 563,000 coho represents about one third of the total catch and escapement in 1994.

The estimate of 1,314,000 ocean age 0 chum in

Fig. 3 **Comparison of chum catches in this study with catches from other, earlier studies. The catch ratio is the ratio of the catch of chum divided by the combined catch of coho and chinook. Each value represents the average catch ratio from one study.**

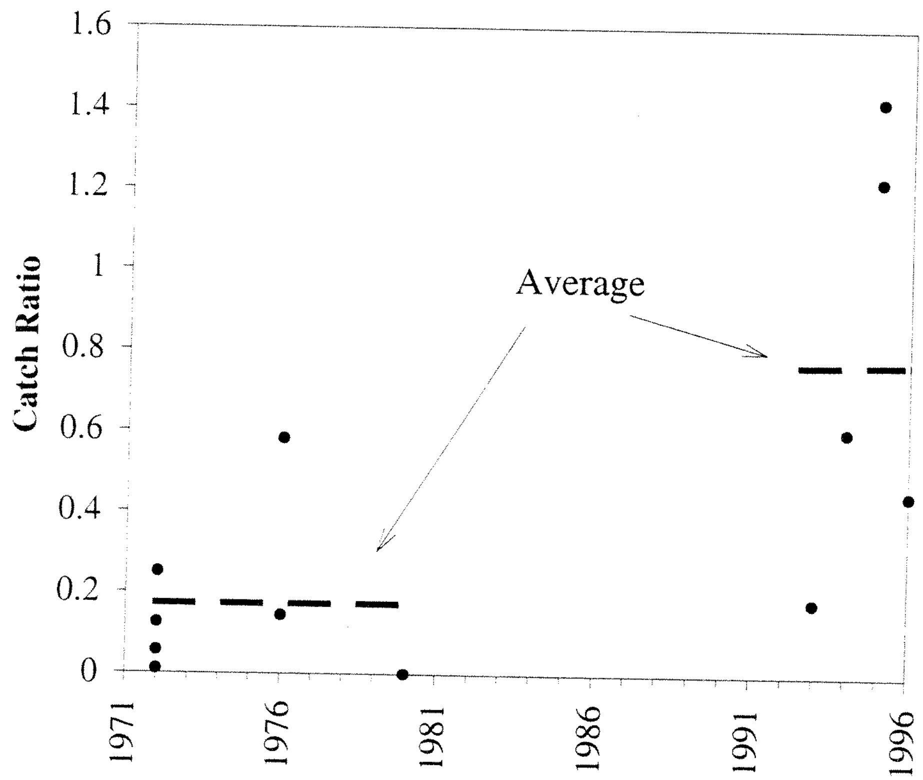


Fig. 4 The percentage of coho that were caught in offshore fisheries showing that in recent years more coho move out of the Strait of Georgia. Data labels indicate catch year which is one year later than the year coho enter the ocean (x axis). The 1997 catch is an estimate based on catches as of July 30, 1997.

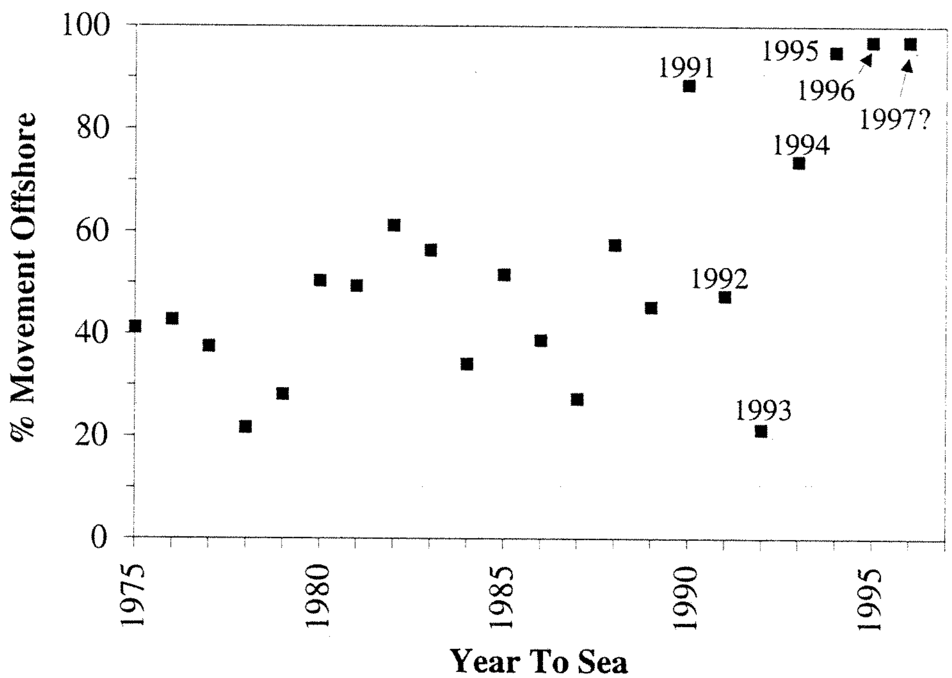


Fig. 5 Numbers of chum salmon reared in hatcheries and released into the Strait of Georgia or in Puget Sound.

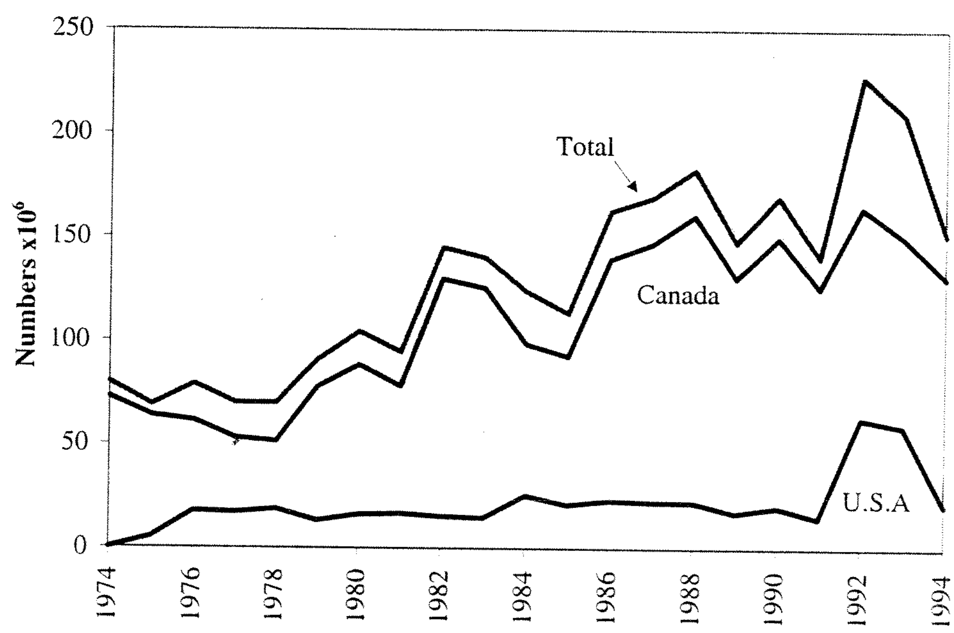


Table 1. Catches of Chum salmon from the cruises in the Strait of Georgia in 1995.

Date	Number of Sets	Gear	Catch	Average Length (cm)
April 21-27	33	Rope Trawl	0	
May 23-30	120	Beam Trawl	10,177	8
June 19-26	109	Beam Trawl	4,987	10
July 6-21	44	Beam Trawl	1,799	10
Sept. 11-24	138	Beam Trawl/ Rope Trawl	577	16
Nov.6-18	40	Rope Trawl	657	22

Table 2. Swept volume abundance estimates, using a 100% net efficiency and 50% net efficiency. The habitat depth was 30m. The estimates of coho abundance are included.

	Species	N	Estimated abundance using a Net Efficiency of: 100	50%
September 11-24, 1995	Chum	145	1,797,000	3,594,000
November 7-17, 1995	Chum	657	1,314,000	2,628,000
November 7-17, 1995	Coho	305	563,000	1,126,000

Fig. 6 Commercial & sport catch of coho salmon in the Strait of Georgia.

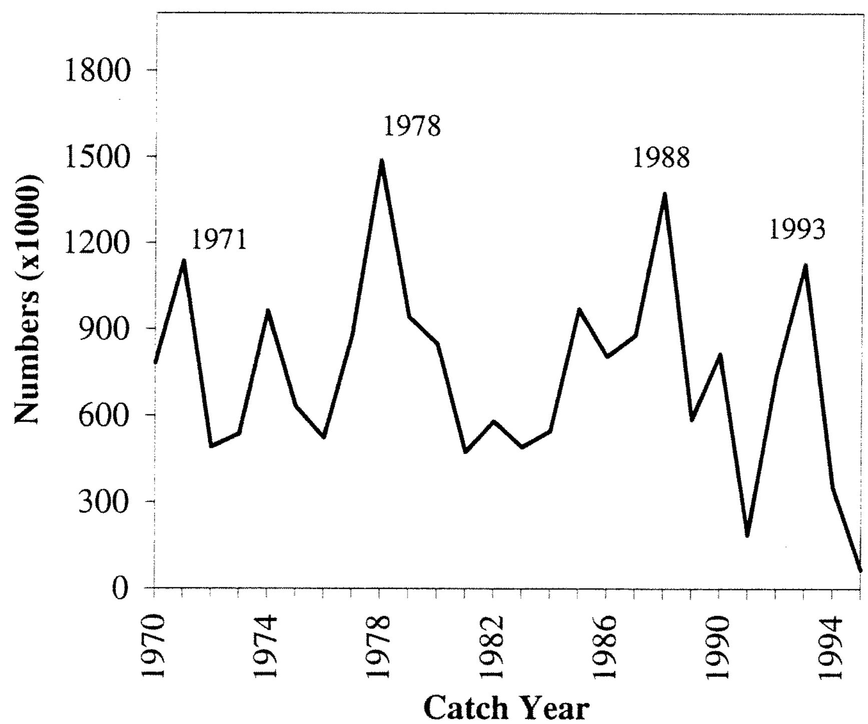
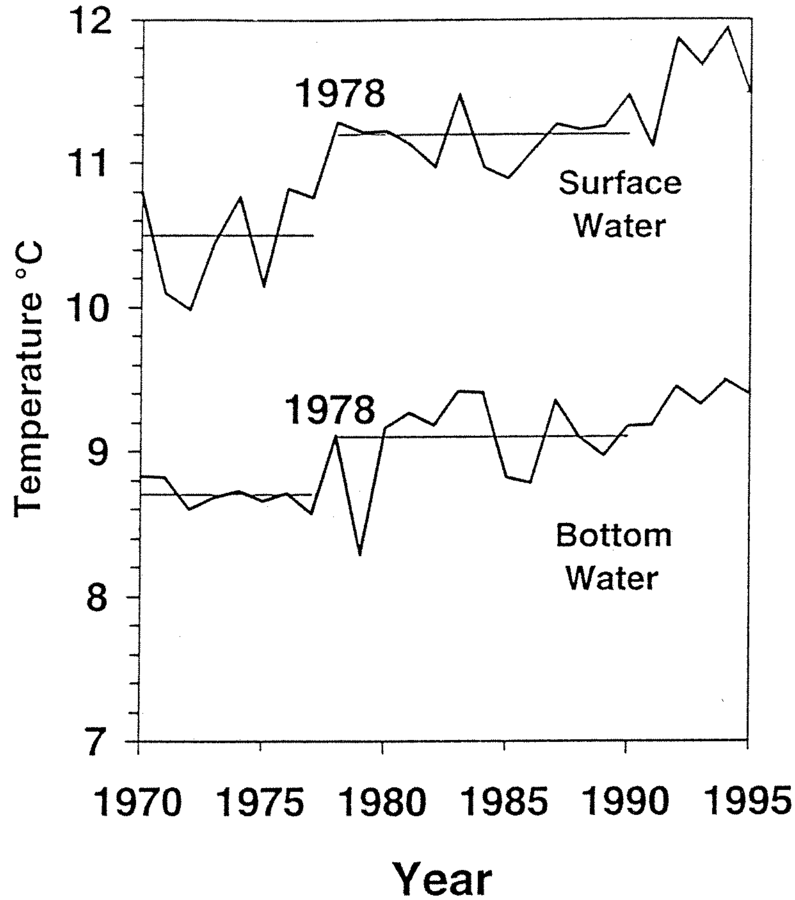


Fig. 7 Strait of Georgia temperatures, sampled at the Nanoose site. The Strait lines are the average temperatures from 1970 to 1977 and 1978 to 1990. After 1990 it appears that warming is still occurring.



November 1995 was converted to catch using an average harvest rate of 35% and assuming that the November 1995 abundance is what remained after 95% of the total 98% expected marine mortality had occurred. The resulting calculated future catch of 184,000 (Table 3) compares to average catches of 465,000 in the Strait from 1992-1995 (Table 4) or 2,384,000 for the entire southern catch, including catches outside of the Strait. If the catch in the Strait of Georgia in 1995 of 66,000 fish or 610,000 for all southern stocks, is an indication of continued low catches, then the potential catch from the ocean age 0 chum in the Strait of Georgia in November 1995 could represent 3 times the total catch within the Strait and approximately 1/3 of the total southern catch if the total returns (catch and escapement) from these fish are similar to the 1995 total returns.

The importance of the Strait of Georgia as a juvenile salmon rearing area is illustrated by the mid-September 1996 survey catches (Table 5). All five species of Pacific salmon were present in the catches including pink, chum, and sockeye. Using a net efficiency of 100%, abundance per km^2 of surface area was 793 for sockeye, 499 for chum, 334 for chinook, and 265 for pink, and 192 for coho.

Beginning in the late 1970s, the temperatures in the Strait of Georgia increased (Fig. 7) as a result of the Pacific basin wide changes that occurred with the 1976-1977 regime shift (Beamish et al. 1995A). In the 1990s, it appears that there may be a continued trend of increasing temperatures (Fig. 7), although there has been cooling in 1995. Associated with the warmer water, there has been a decline in the Fraser River flows that also started with the 1976-1977 regime shift (Fig. 8). Since the late 1980s, there has been earlier spring freshets as indicated by the larger April flows (Fig. 9). These earlier flows indicate an earlier melting of the snow pack, which would occur if the air temperatures were warmer. There was a change in the intensity of the Aleutian Low (Fig. 10) beginning in the late 1980s which would result in less intense winter winds as well as a change in the dominant direction of the winter winds. We included the 1997 winter anomaly to show the extreme change from 1996. The less intense low, means that high pressures were more common.

Table 3. The November 1995 abundance estimates of juvenile chum salmon, and the estimated catch when adults return.

	Net Efficiency	Net Efficiency
	100%	50%
November Abundance	1,314,000	2,628,000
Estimated adult catch from the juveniles in the Strait of Georgia in 1995[1]	184,000	368,000

[1] The estimated future catch was made by assuming that 95% marine mortality had occurred before the November survey and the total marine mortality would be 98%. The harvest rate of the remaining chum was assumed to be 35%.

Table 4. Catches of chum salmon in the Strait of Georgia and southern British Columbia and the estimated total adult returns (catch plus escapement).

	Southern British Columbia	Strait of Georgia
1995 chum catch	610,000	66,000
1995 total chum returns assuming 35% harvest rate.	1,743,000	189,000
1992-1995 average chum catch	2,384,000	465,000
1992-1995 average chum returns assuming 35% harvest rate	6,811,000	1,329,000

Table 5. Catches of ocean age 0 Pacific salmon from 62 sets in the Strait of Georgia September 9-20, 1996. The abundance estimate was made assuming a net efficiency of 100% and a habitat depth of 30m.

Species	Catch	Total Abundance Estimate	Numbers per km^2
Chum	2,121	2,496,000	499
Pink	1,125	1,324,000	265
Coho	814	958,000	192
Sockeye	3,370	3,965,000	793
Chinook	1,824	2,146,000	334

Fig. 8 The trend in the annual Fraser River total from the discharge. Since 1976, there has been a decreasing trend.

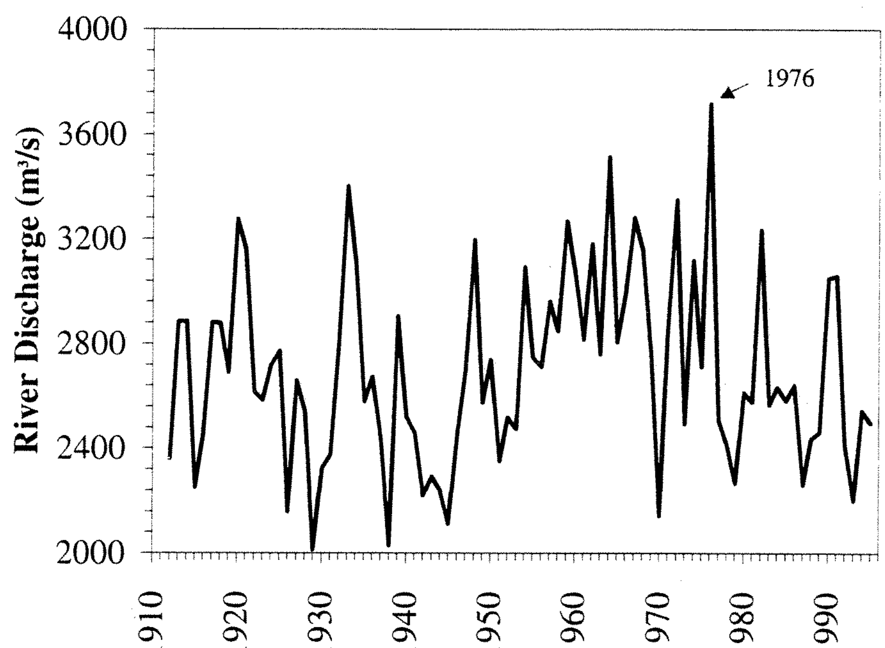


Fig. 9 **The daily discharge in April (m^3/sec). Beginning in the late 1980s, the flows in April increased. The individual graphs show the daily values for the entire month.**

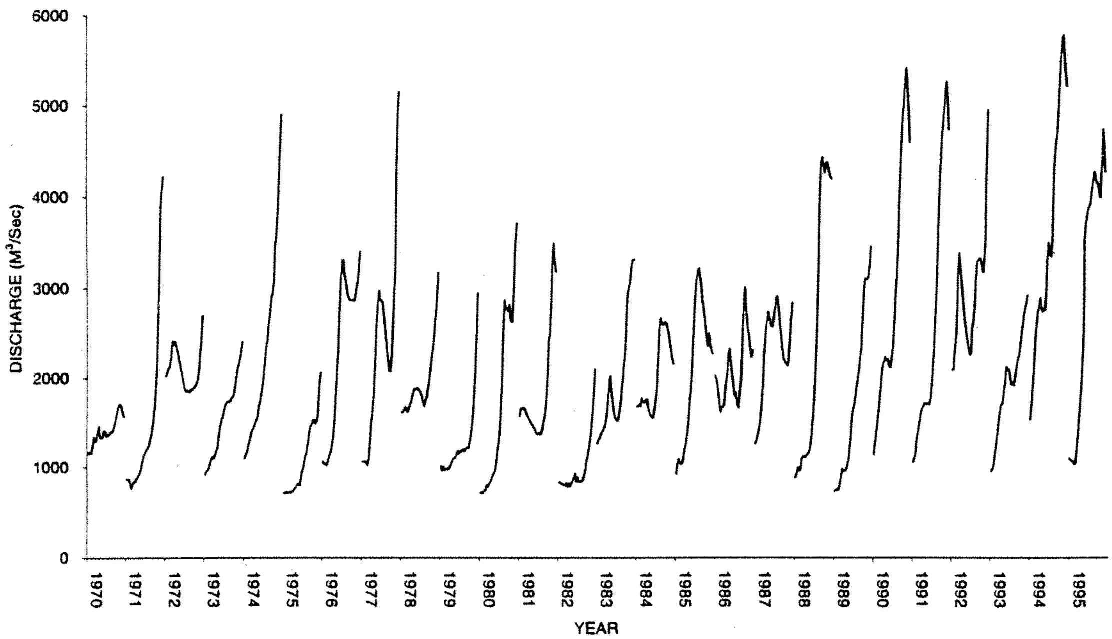
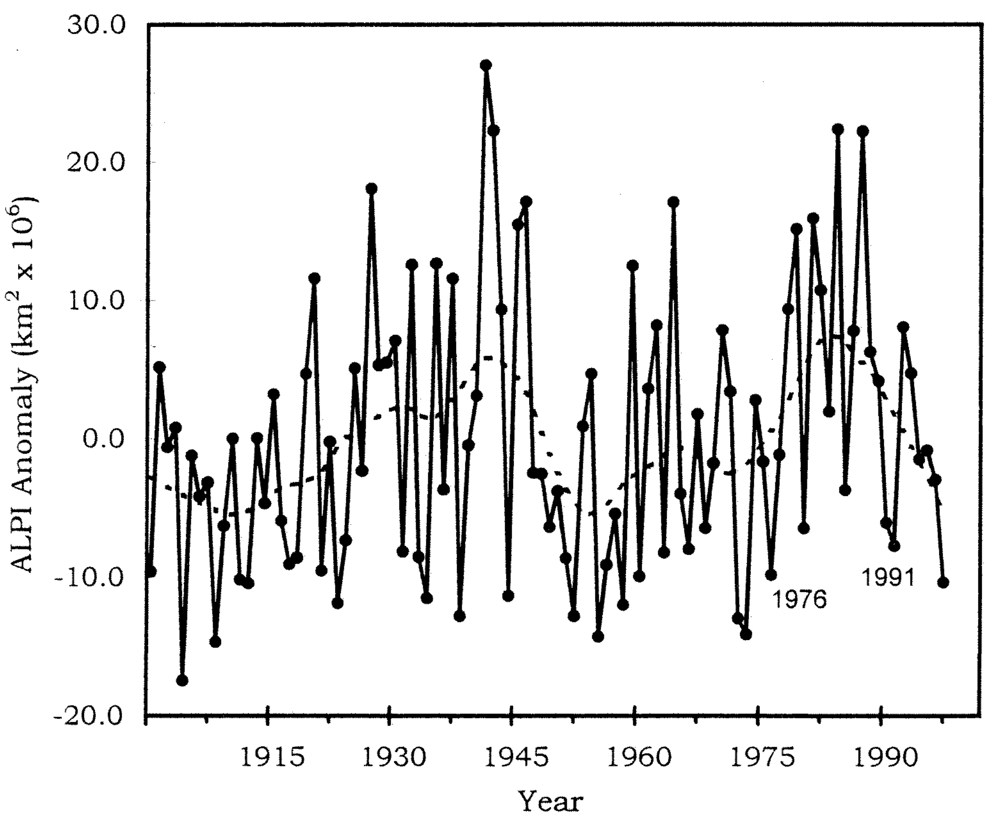


Fig. 10 **The Aleutian Low Pressure Index (ALPI) (Beamish et al. 1997) showing the period of intensification after 1976 and the period of weak lows in the 1990s.**



DISCUSSION

The largest abundance of chum salmon in British Columbia is produced in the Fraser River and it is these chum stocks plus the stocks in other rivers flowing into the Strait of Georgia that rear in the Strait of Georgia. The early studies of Healey (1982) indicated that these chum juveniles gradually leave the Strait during the summer months. The observation in our study that large numbers of chum salmon remained in the Strait of Georgia as late as November, indicate that the behaviour of chum has changed. A difficulty with our method of comparison of our catches with chum catches in other studies is the changing abundance of chinook and coho. It is true that catches of chinook were higher in the 1970s than in the 1990s, but Beamish et al. (1995 A) have shown that there actually was an increase in chinook smolt production relative to the 1970 levels as a consequence of hatchery production. Beamish et al. (1995 B) showed that increases also occurred for coho. However, these increases for both chinook and coho were associated with higher marine mortality rates. Despite the difficulties in quantifying the abundance changes, the results of the comparisons of catches of chum juveniles relative to the combined coho and chinook catches and the earlier observations of Healey (1980) of few chum late in year, indicate that relatively large numbers of chum are remaining longer in the Strait of Georgia than in the past. As we do not have observations in the 1980s, it is not possible to determine when chum salmon started to remain longer in the Strait of Georgia, thus it is possible that more chum remain in the Strait because of the increased releases of hatchery-reared chum salmon. However, except for 1992 and 1994, the total releases from Canada have not changed since the late 1980s, and as other species such as pink and sockeye are also found later in the year (Table 5) it is probable that the behaviour change is real.

The numbers estimated from the swept volume method are preliminary estimates as the accuracy of the determination is unknown. However, the abundance estimate may be conservative because it is unlikely that the net catches 100% of the fish in front of the net. There are other difficulties with the estimate that are associated with the patchiness of the distributions of chum and the estimated habitat depth of 30 m. We examined the accuracy of our swept-volume abundance estimates by comparing similar estimates for coho with total catch and escapements of coho from previous years. The November estimates of 563,000 coho is approximately 1/3 of the total catch and escapements reported in 1994. As a high percentage of coho caught in 1995 were outside of the Strait of Georgia it is possible coho were moving out of the Strait in the late fall and early winter. Our estimate of 563,000 coho or about 1/3 of the 1994 catch and escapement, therefore, is within an expected range of abundances. We suggest that this indicates that the abundance estimates for chum juveniles, also, are within the range of the actual abundances.

Our estimate of the contribution of the juveniles to future catch and escapement was based on an assumption that by November, 95% of the marine mortality had occurred and the total marine mortality would be 98%. When the total returns become known in 1998, we will be able to determine the validity of these assumptions. If we compare the estimated future catch of chum in the Strait of Georgia of 184,000 to previous Strait of Georgia catches of 446,000, it is apparent that a significant number of juvenile chum are remaining longer in the Strait. If only the 1995 catches were compared to the estimated future returns , then the catch of juveniles in the Strait of Georgia in 1995 when they eventually are fished could represent 3 times the catches in 1995. We assumed that the marine mortality prior to the November survey was 95%. The basis for this assumption was the common assumption that most marine mortality occurs shortly after salmon enter the ocean. Even if we were to use an estimate of 50% marine mortality by the November sampling period, the abundance of chum salmon would still equate to a high percentage of the subsequent catch if the future catches remain about the level of the 1995 catch. The numbers of chum estimated to remain in the Strait, therefore, appear large relative to the previous catches and escapements.

The reason for the change in behaviour is unknown, however it coincides with a change in the ALPI index about 1989-1990. Another change at about the same time was the earlier beginning of the increased Fraser River flows and a general increase in sea surface temperatures. We speculate that the longer residence time is related to these physical changes which may have improved feeding conditions.

An important observation from this study is that the behaviour of chum salmon changed. If it is valid to assume that the change in chum salmon behaviour results from changes in the ecosystem, then we need to look at ways of detecting when ecosystems change. We also need to recognize that multi-year behaviour trends can change. Decadal-scale variability, therefore, may be an important component of salmon population dynamics.

REFERENCES

Bax, N.J. 1983. The early marine migration of juvenile chum salmon (*Oncorhynchus keta*) through Hood Canal - its variability and consequences. Ph.D. thesis. University of Washington, Seattle, WA. 69 p.

Beamish, R.J. 1996. Synchrony of abundance trends of chinook and coho populations off Oregon, Washington, and in the Strait of Georgia in comparison with trends in all-nation catches of Pacific salmon. NPAFC Doc. 199, 24 p. Fisheries and Oceans.

Beamish, R.J., A. Cass, C.M. Neville. 1997. Production of Fraser River Sockeye salmon (*O. nerka*) in relation to decadal-scale changes in the climate and the ocean. Can. J. Fish. Aquat. Sci. (in press)

Beamish, R.J., B.E. Riddell, C.M. Neville, B.L. Thomson and Z. Zhang. 1995(A). Declines in chinook salmon catches in the Strait of Georgia in relation to shifts in the marine environment. Fish Oceanogr. 4:3, p. 243-256.

Beamish, R.J., C.M. Neville, J. Rice, Z. Zhang, 1995(B). Factors affecting the marine survival of coho salmon in the Strait of Georgia. Pacific Stock Assessment Review Committee (PSARC) Working Paper S95-4. Pacific Biological Station.

Department of Fisheries and Oceans. 1996. An assessment of Canadian enhanced salmon production, 1977-1994. Document submitted to the Annual meeting of the North Pacific Anadromous Fish Commission (NPAFC), Tokyo, Japan. September, 1996. 20 p.

Godin, J.G.S. 1982. Migrations of salmonid fishes during early life history phases: daily and annual timing, p. 22-50. *In*: E.L. Brannon and E.O. Salo (eds.). Proceedings of the Salmon and Trout Migratory Behaviour Symposium. School of Fisheries, University of Washington, Seattle, WA.

Healey, M.C. 1980. The ecology of juvenile salmon in Georgia Strait, British Columbia, p. 203-229. *In*: W.S. McNeil and D.C. Himsworth (eds.). Salmonid ecosystems of the North Pacific. Oregon State University Press, Corvallis, OR.

Healey, M.C. 1982. Timing and relative intensity of size-selective mortality of juvenile chum salmon (*Oncorhynchus keta*) during early sea life. Can. J. Fish. Aquat. Sci. 50: 291 p.

Salo, E.O. 1991. Life history of chum salmon (*Oncorhynchus keta*), p. 231-309. *In*: C. Groot and L. Margolis (eds.). Pacific salmon life histories. UBC Press, Vancouver, BC.

Thomson, R.E. 1981. Oceanography of the British Columbia Coast. Can. Spec. Pub. Fish. Aquat. Sci. 1456-1466.

Thomson, R.E. 1994. Physical Oceanography of the Strait of Georgia-Puget Sound-Juan de Fuca System. *In*: Wilson, R.C.H., R.J. Beamish, F. Aitkens and J. Bell [eds.]. Review of the marine environment and biota of Strait of Georgia, Puget Sound, and Juan de Fuca Strait: Proceedings of the B.C./Washington Symposium on the Marine Environment, January 13-14, 1994. Can. Tech. Rep. Aquat. Sci. 1948: 398 p.

Whitmus, C.J., Jr. 1985. The influence of size on the migration and mortality of early marine life history of juvenile chum salmon (*Oncorhynchus keta*). M.Sc. Thesis. University of Washington, Seattle, WA. 69 p.

Yin, K.D., P.J. Harrison, S. Pond, and R.J. Beamish. 1995. Entrainment of nitrate in the Fraser River estuary and its biological implications. 2. Effects of spring vs neap tides and river discharge. Estuarine Coastal and Shelf Science 40:529-544.