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Changing trends in the rearing capacity of the Strait of Georgia ecosystem for juvenile Pacific salmon

by

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Abstract

There was an increase in the abundances of juvenile Pacific salmon (*Oncorhynchus* spp.) in the Strait of Georgia following the 1998 regime shift, indicating that the productive capacity for juvenile salmon had improved. Abundances particularly improved for juvenile chum and pink salmon (*O. keta* and *O. gorbuscha*, respectively), with subsequent returns of adult pink salmon to the Fraser River being at historic high levels. Abundances of juvenile coho and chinook salmon increased in 2000 and 2001, but have declined since 2001. In July 2005, the abundances of juvenile coho (*O. kisutch*) and chinook (*O. tshawytscha*) salmon were the lowest in the 9 years of surveys, whereas juvenile chum abundances were the second highest observed. These fluctuations in production appear to be related to ocean entry times in relation to timing of the spring bloom of productivity. The timing of the spring bloom relates to a number of short-term and long-term climate and ocean conditions that currently are being studied.

INTRODUCTION

The Strait of Georgia is the most important rearing area for juvenile Pacific salmon (*Oncorhynchus* spp.) on Canada's Pacific coast. Most of the juvenile Pacific salmon in the Strait of Georgia originate from the Fraser River, but there are salmon from numerous smaller rivers that flow into the Strait. We have surveyed the Strait of Georgia in the early summer since 1997 using the same mid-water trawl (Table 1). We were fortunate to start our surveys prior to the 1998 regime shift and thus were able to detect an increase in the carrying capacity of the Strait of Georgia for Pacific salmon in 2000 (Beamish et al., 2000a, 2000b). Initially, it appeared that the carrying capacity had increased for all Pacific salmon (Beamish et al. 2004) but, beginning in 2002, the early summer abundances declined for juvenile coho (*O. kisutch*) and chinook salmon (*O. tshawytscha*).

In this report, we summarize the survey abundance estimates for the early summer surveys from 1997 to 2005. We use coded-wire tag data to measure the marine survival of coho and chinook salmon that reared in the Strait of Georgia as juveniles. The marine survival estimates and the survey abundances show that the Strait of Georgia ecosystem is changing. A profound change occurred in 2005 with exceptionally poor abundances of coho and chinook, but very good production of chum salmon.

METHODS

The gear and survey design have been described previously, as have the swept volume abundance estimates (Beamish et al. 2000a). Marine survival estimates were made using coded-wire tag (CWT) data from the Mark and Recapture Program (MRP) reference database (Kuhn et al., 1988). Hatcheries mark a small number of their released fish with coded-wire tags. Estimates of the number of adult fish with CWTs are divided by the release number to provide an estimate of marine survival. Fork lengths were to the nearest millimetre.

RESULTS

Abundance estimates for the early summer surveys from 1997 to 2005 are presented in Table 2. In 2005, estimates of both coho and chinook juvenile abundances were the lowest in the data series. Juvenile chum abundances, on the other hand, were the second highest, surpassed only by the exceptional 2000 level. Average catch per unit effort (CPUE) was closely related to marine survival for both coho and chinook salmon (Figures 1,2). Average fork lengths for the five major species of juvenile Pacific salmon are shown in Table 3 and the anomalies of fork lengths are shown in Figure 3. In the 2005 survey, all four species showed large increases in average size compared to 2004. For both chum and sockeye salmon, the average lengths were the largest observed since the onset of the study. For juvenile coho, the 2005 average size was the second highest on record, whereas the average size for the juvenile chinook salmon was similar to the long-term mean size.

Estimates of abundance of juvenile sockeye salmon were the second lowest in the data series in 2005. The abundance of sockeye salmon would be expected to relate to the escapement which fluctuates significantly according to the well-known four year dominance cycle for this species (Foerster 1968; Ricker, 1950, 1997). We compared our abundance estimates with the escapement two years earlier that produced the juvenile fish (Figure 6). If the 1997 estimate is omitted, there is a general agreement between the size of the escapement and juvenile abundance. Sea surface temperature and salinity measurements show a trend to warmer and less saline waters since the late 1980s (Figures 4,5).

DISCUSSION

Our study started in 1997, thus there were only three years of data prior to the changes observed in 2000. However, there was an increase in production of all species of juvenile Pacific salmon beginning in 2000 and following the regime shift in 1998. Thus, it appeared that the carrying capacity had returned to levels observed after the 1977 regime shift. The abundances for chinook, coho, chum and pink salmon in 2000 were exceptionally large, much larger than the average from 1997-1999. Abundances for all five species were much lower in 2002, particularly for chum salmon. Abundances recovered in 2004 except for coho that remained at the lower, pre-regime shift abundance levels. Estimates for sockeye salmon (*O. nerka*) abundances are more difficult to interpret but if the 1997 value was omitted there was a relationship between the size of the escapement and survey abundances. Our early surveys occurred late in the migration of juvenile sockeye salmon out of the Strait of Georgia, thus we would not expect a close relationship between abundances and escapement.

The change in the Strait of Georgia ecosystem in 2002 was associated with inter-annual variability and generally poor marine survival for juveniles of all species of Pacific salmon. The changes in 2002 appear to relate to ecosystem wide changes and perhaps even larger scale changes outside of the Strait of Georgia. The changes in 2005 were different as chum abundances were exceptionally large while coho and chinook abundances were exceptionally poor. Juvenile coho and chinook salmon generally enter the Strait of Georgia later than chum juveniles. It is probable that an earlier production of particular prey could favour improved productivity of salmon species that entered the Strait earlier. The timing of the spring bloom is related to the density stratification of the water column which, in the Strait of Georgia, is influenced by freshwater discharge from the Fraser River as well as winds, temperatures and sunlight. There are trends in the surface salinity and temperature of the Strait of Georgia that could be altering the timing and/or persistence of prey preferred by chum and pink salmon. Decreases in coho and chinook salmon survival could occur because of decreased production of preferred prey, from competition, or from both. Traditional explanations for changes in marine survival would be that marine mortality was caused by predation. However, our surveys also sample for potential fish predators (adult chinook and coho salmon, spiny dogfish, *Squalus acanthias*, walleye pollock, *Theragra chalcogramma*, etc), and there has been little change in fish predator composition that would support an interpretation of increased predation. Our study has shown that major changes in juvenile Pacific salmon survival occur in the Strait of Georgia in relation to trends in climate and ocean conditions. Currently, the ecosystem is more supportive of pink and chum salmon than coho and chinook salmon.

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Table 1. Time of year and number of sets for the early summer surveys for juvenile Pacific salmon in the Strait of Georgia.

Year	Timing	Number of sets
1997	June 17-20, July 06-11	69
1998	June 30 – July 09	95
1999	June 30 – July 08	98
2000	July 11 – July 20	85
2001	July 07- July 15	89
2002	July 02 – July 11	93
2003	NO SURVEY	-
2004	July 04 – July 13	105
2005	July 14 – July 21	81
RANGE	June 17 – July 21	69-105

Table 2. Abundance of ocean age 0+ Pacific salmon in the Strait of Georgia in early summer surveys from 1997 to 2005. Depth strata used in the abundance estimate are shown in parentheses. The lower and upper interval is ± 2 standard deviations.

	Abundance	Lower Interval – Upper Interval
CHINOOK (0-60 metres)		
1997	4,730,000	1,810,000 – 7,660,000
1998	4,460,000	1,200,000 – 3,650,000
1999	3,880,000	3,050,000 – 5,760,000
2000	7,870,000	3,160,000 – 12,710,000
2001	5,840,000	4,120,000 – 7,658,000
2002	3,630,000	1,800,000 – 4,200,000
2003	NO SURVEY	
2004	8,130,000	4,486,000 – 6,886,000
2005	1,660,000	962,000 – 2,358,000
COHO (0-45 metres)		
1997	1,650,000	350,000 – 2,970,000
1998	2,820,000	1,510,000 – 3,350,000
1999	3,420,000	2,220,000 – 4,570,000
2000	10,960,000	6,600,000 – 15,840,000
2001	9,270,000	6,240,000 – 12,680,000
2002	2,750,000	2,130,000 – 3,870,000
2003	NO SURVEY	
2004	4,790,000	2,836,000 – 5,156,000
2005	820,000	535,000 – 1,105,000
CHUM (0-30 metres)		
1997	1,970,000	800,000 – 3,150,000
1998	10,270,000	3,530,000 – 18,470,000
1999	7,420,000	1,300,000 – 14,400,000
2000	26,220,000	7,330,000 – 46,660,000
2001	11,800,000	9,001,000 – 19,471,000
2002	1,310,000	500,000 – 3,500,000
2003	NO SURVEY	
2004	15,308,000	8,636,000 – 22,364,000
2005	17,480,000	10,175,000 – 24,825,000

PINK (0-30 metres) [1]		
1998	4,170,000	1,626,000 – 5,774,000
2000	7,550,000	3,184,000 – 11,616,000
2002	3,220,000	2,211,000 – 4,969,000
2004	7,130,000	2,504,000 – 11,667,000
SOCKEYE (0-30 metres)		
1997	7,300,000	1,721,000 – 12,959,000
1998	1,040,000	44,000 – 1,396,000
1999	1,330,000	520,000 – 2,140,000
2000	530,000	103,000 – 937,000
2001	1,620,000	1,548,000 – 2,952,000
2002	260,000	197,300 – 400,000
2003	NO SURVEY	
2004	3,500,000	358,000 – 6,746,000
2005	485,000	307,000 – 663,000

[1] Juvenile pink salmon are rare in off numbered years.

Table 3. Mean fork lengths (mm) ± SD, with sample size (N), for juvenile Pacific salmon captured in the Strait of Georgia in early summer surveys from 1997-2005. Pink data are shown only for even years, when abundances are high.

	CHINOOK	COHO	CHUM	PINK	SOCKEYE
1997	140 (33.8) (1585)	159 (22.5) (520)	122 (25.6) (907)		115 (10.7) (1580)
1998	121 (36.9) (1411)	173 (23.3) (1220)	123 (15.0) (1206)	119 (13.6) (1432)	86 (17.8) (371)
1999	139 (37.4) (1664)	168 (22.3) (1639)	116 (19.4) (1227)		120 (17.5) (640)
2000	144 (36.9) (1994)	200 (23.4) (3361)	128 (18.0) (2609)	118 (12.6) (1985)	117 (17.3) (464)
2001	146 (32.3) (2211)	185 (21.0) (2957)	130 (17.5) (2192)		133 (12.9) (857)
2002	136 (28.8) (1994)	169 (22.7) (1887)	115 (15.2) (1067)	112 (15.5) (2335)	124 (15.0) (248)
2003					
2004	120 (37.0) (3073)	179 (28.2) (2257)	123 (25.1) (2915)	116 (15.5) (1465)	108 (16.1) (609)
2005	134 (26.8) (641)	191 (24.3) (414)	153 (14.3) (2692)		147 (14.9) (363)
Overall	181 (36.0)	134 (26.6)	129 (22.8)	116 (14.9)	118 (19.8)

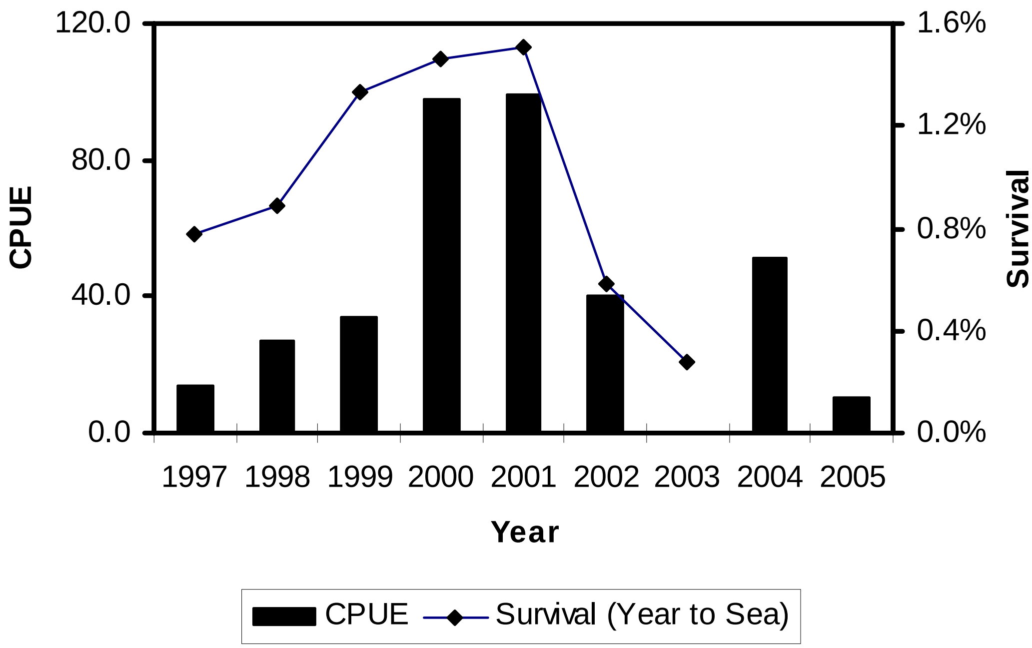

Figure 1. CPUE of juvenile coho salmon from the early summer surveys in the Strait of Georgia and resulting marine survival.

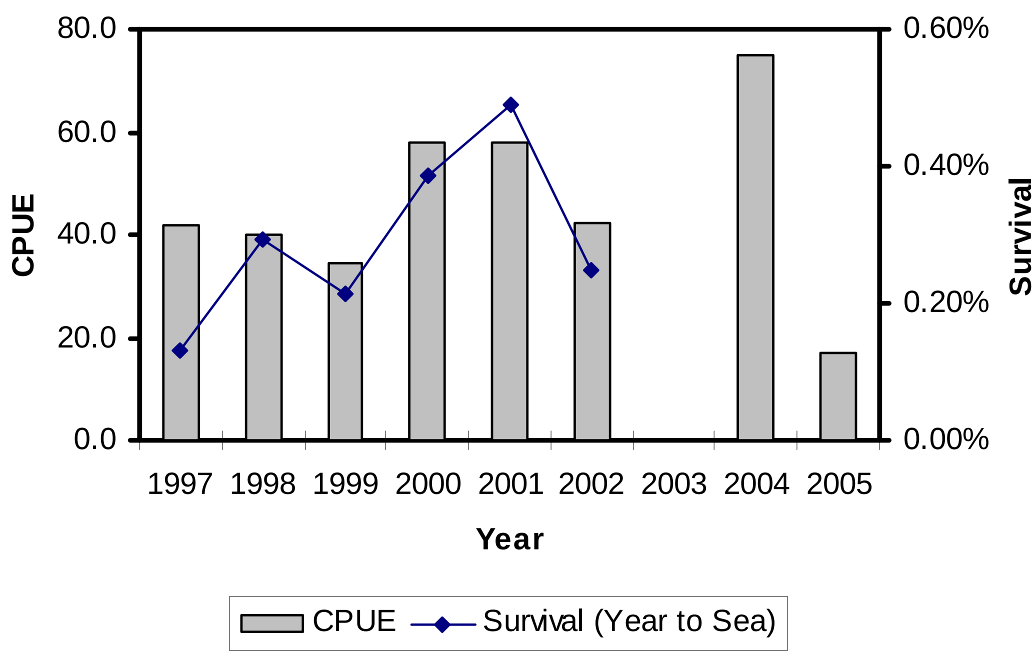

Figure 2. CPUE of juvenile chinook salmon from the early summer surveys in the Strait of Georgia and resulting marine survival.

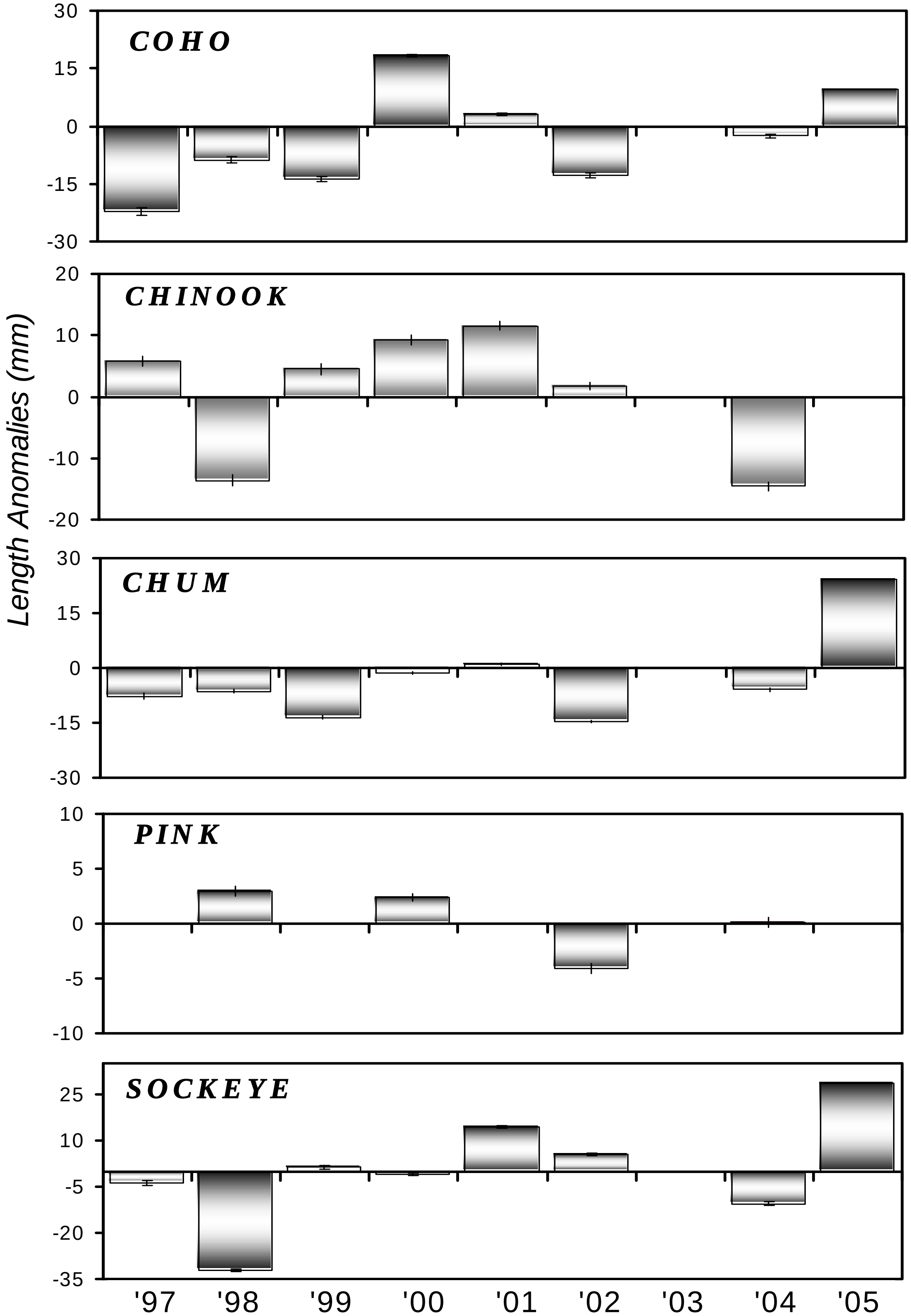

Figure 3. Fork length anomalies (in mm) of juvenile Pacific salmon from July surveys against the 1997-2005 average for each species.

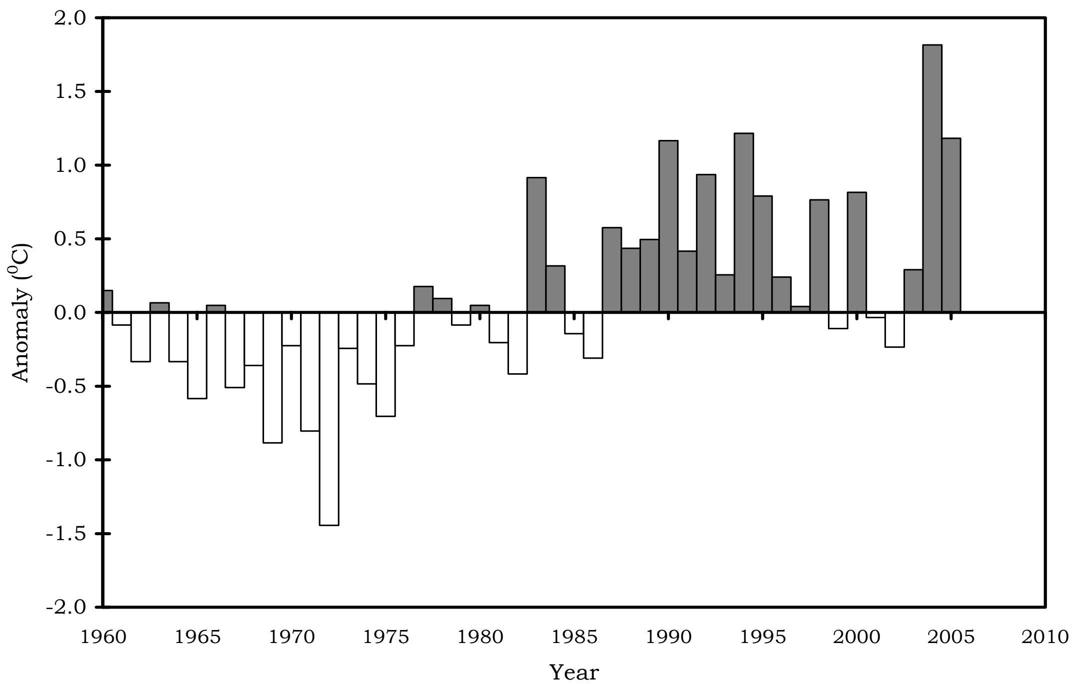

Figure 4. Anomalies of surface temperature in April for the Strait of Georgia using lighthouse temperatures (data available at IOS, Sidney, B.C., mean from 1960-1997).

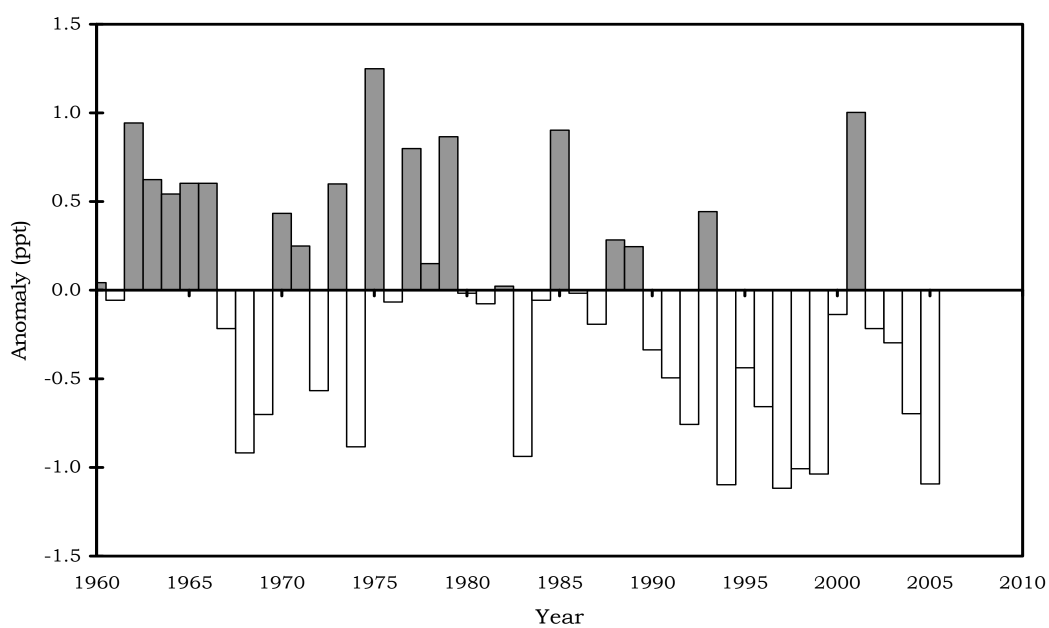

Figure 5. Anomalies of surface salinity in April for the Strait of Georgia using lighthouse salinities (data available from IOS, Sidney, B.C., mean from 1960-1997).

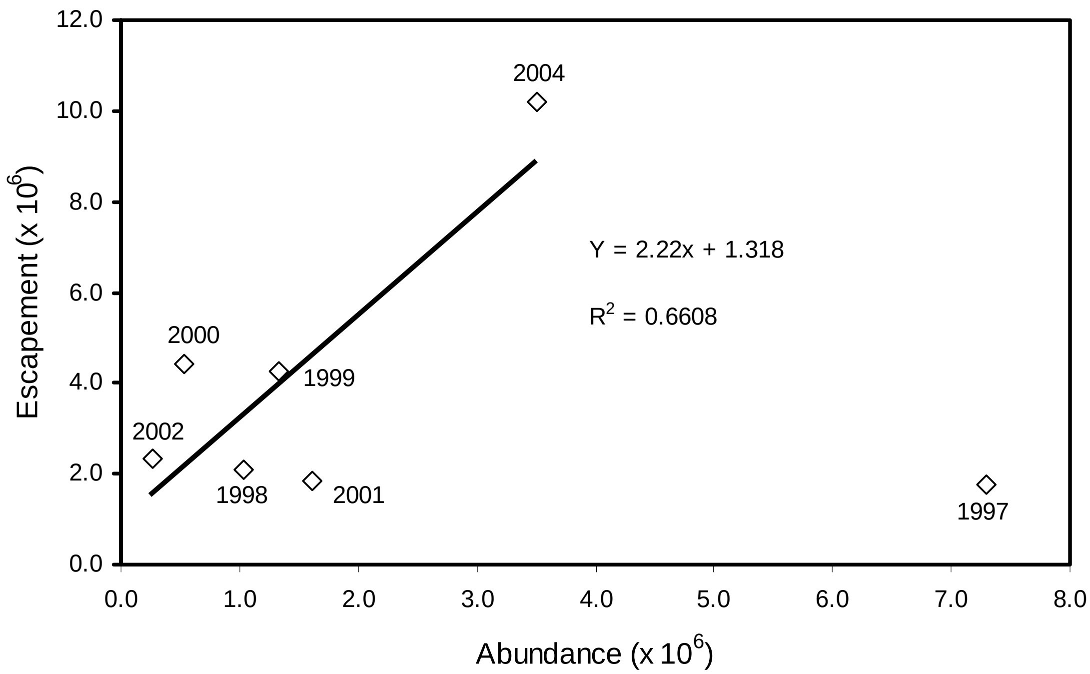

Figure 6. Abundance of juvenile sockeye salmon compared to escapement two years earlier. The regression excludes the 1997 estimate.