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Exceptionally Poor Survival of Chinook Salmon Entering the Strait of Georgia in 2007 is Consistent With the Synchronous Poor Survival of Other Pacific Salmon and Pacific Herring

by

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Abstract

Indices of marine survival of eight populations of Chinook salmon entering the Strait of Georgia identified the ocean entry year 2007 as a year of generally poor survival. Marine survival was exceptionally low for the Harrison River population which is the largest Chinook salmon population in British Columbia. The low survival is consistent with the poor survival and poor growth of the other species of Pacific salmon and juvenile Pacific herring that reared in the Strait of Georgia in the spring of 2007.

Introduction

It was shown in Beamish et al. (2012) and Thomson et al. (2012) that Pacific herring *Clupea pallasii* and Pacific salmon *Oncorhynchus* spp. rearing in the Strait of Georgia had exceptionally poor survival or growth or both in 2007. The historically poor survival of sockeye salmon *O. nerka* resulted in an unexpected poor return of adults in 2009. This poor return not only resulted in a cancellation of the commercial fishery, it also stimulated the Canadian Government to hold a judicial inquiry to determine the reasons for the poor return and historically low abundance.

Pelagic trawl surveys from 1998 to 2009 showed that 98% of the fish in the surface 30 m of the Strait of Georgia in the spring and early summer were juvenile Pacific herring and Pacific salmon. Beamish et al. (2012) identified a synchrony in the poor survival and poor growth of these juvenile Pacific salmon and Pacific herring in the surface waters of the Strait of Georgia in 2007. The synchronous response of these species indicated that there was a common cause which they proposed was related to a reduction in the prey species for these fish. Thomson et al. (2012) reported that the poor food production was likely due to unfavourable wind and runoff conditions in the spring of 2007. Wind forcing, river discharge and surface stratification were highly anomalous and appeared to be the cause of the poor food production. The winter of 2006-2007 was characterized by heavy rainfall resulting in high runoff from many rivers flowing into the Strait of Georgia. The numerous days of rainfall also reduced the amount of sunlight. At the same time there was a delay in the spring transition that was associated with a continuation of the southerly winds. In the winter on the west coast of North America, winds are from the south and, on average, about mid April there is a reversal with the winds blowing from the north. This change in direction is called the spring transition and was delayed by one month relative to the mid April long-term mean. This delay would result in winds continuing to blow northward up the strait, helping to retain the fresh water and reducing the surface salinity. A model estimate of the depth of the mixing layer showed that the shallow depth was unprecedented over the years 1980 to 2010 (Thomson et al. 2012). Additionally, satellite-derived chlorophyll data showed an early and short-lived plankton bloom (Thomson et al. 2012) that would not be expected to result in high productivity in the spring. The increased surface stratification early in 2007 would reduce vertical mixing, resulting in less entrainment of nutrient-rich deeper water, limiting the duration and vertical depth of the upper layer productivity. Reductions in plankton production probably greatly reduced the abundance of the typical prey species consumed by the first feeding Pacific herring larvae and the juvenile Pacific salmon when they entered the Strait of Georgia.

The paper by Beamish et al. (2012) did not include marine survival estimates for Chinook salmon *O. tshawytscha*. In this report we use an index of marine survival of hatchery-reared Chinook salmon that enter the Strait of Georgia to show that marine survival of Chinook salmon was generally poor to exceptionally poor for the fish entering the Strait of Georgia in the spring of 2007. Thus, it is clear that all four species of Pacific salmon (sockeye, chum *O. keta*, coho *O. kisutch* and Chinook salmon) that entered the Strait of Georgia in 2007 had very poor marine survival.

Methods

The survey methodology and trawl design has been published (Beamish et al. 2000, Sweeting et al. 2003). The depth of the net when fishing was approximately 15 m and was fished in 15 m intervals with the head rope at or near the surface and then at 15 m depths. Beginning in 1998, standardized survey track lines were used with sampling dates mostly in early July and a survey lasting 9-10 days (Figure 1). Juvenile Chinook salmon were captured at depths deeper than other juvenile Pacific salmon with relatively large catches to a head rope depth of 45 m and a habitat depth of 60 m (Beamish et al. 2011). There were catches in deeper water, but the numbers were relatively small. Juvenile Chinook salmon were measured for fork length and, when possible, for weight.

The index of marine survival was developed using coded-wire tag (CWT) recoveries and is a standard reference used by the Chinook Technical Committee (CTC) of the Pacific Salmon Commission. The methodology is described in Appendix 2 (www.psc.org/pubs/TCCHINOOK88-2app2.pdf) of the 1988 Chinook Technical Committee report to the Pacific Salmon Commission (www.psc.org/pubs/TCCHINOOK88-2.pdf). The procedure produces an index of hatchery survival from release in fresh water to the age-3 cohort in the ocean when the fish first become vulnerable to the fishery. CWT recoveries in the fishery are used in a cohort analysis to reconstruct the size of a population in the second ocean year. The population size at age-3 is then determined. As all hatchery fish are ocean type or sub-yearlings, age 3 fish would be in their second year in the ocean. For brood years that still have fish alive in the ocean, the procedure uses estimates of natural mortality and CWT recoveries to reconstruct cohorts back to the age-3 cohort. The marine survival index is the number of CWTs in the age-3 population divided by the number released. The survival rate indices are a relative measure of survival that includes total fishing mortalities and escapements as well as some mortality that may occur in fresh water after the fish are released from the hatchery. The brood years until 2007 or ocean entry years to 2008 would be complete.

Results

Survival estimate indices were available for 8 populations of Chinook salmon that enter the Strait of Georgia (Figure 2). The populations vary in size from the very large Harrison River fall Chinook salmon to the very small Puntledge River Chinook salmon, as indicated by the escapement estimates from 1998 to 2008 (Table 1). Marine survival estimates for the ocean entry year 2007 were poor in most of these populations. Exceptionally poor survival occurred for four of the largest populations that entered the Strait of Georgia in 2007 (Chilliwack, Harrison, Nicola, and Quinsam rivers; Figure 1). Two populations had poor survival (Cowichan and Puntledge rivers; Figure 1) and two had average survival (Big Qualicum and Lower Shuswap rivers; Figure 1). The most exceptional drop in survival occurred in the Harrison River fall Chinook population where there was almost a magnitude decline between the 2006 and 2008 marine survival estimates.

The length and weight of the Chinook salmon sampled in July 2007 were anomalously smaller than other survey years (Figure 3). An estimate of condition using weight (g) divided by the cube of length (mm) times 100,000 showed that the fish in 2007 had exceptionally poor condition (Figure 3C). There was a declining trend in the anomalies of length and weight over the study period (Figure 4). There was no significant relationship ($P \leq 0.05$) between fork length or condition of the samples collected in the July trawl surveys and the individual population marine survival estimates (Table 2).

Discussion

The Fraser River watershed is the largest producer of Chinook salmon on Canada's Pacific coast. There are an estimated 114 populations (Candy et al. 2002) that produce juveniles that enter the Strait of Georgia. The Harrison River population is the largest in the Fraser River drainage and one of the largest naturally-spawning Chinook salmon populations in the world. All eight populations of Chinook salmon had lower survival in the ocean entry year 2007 than in 2006. In six of the eight populations, marine survival improved for the ocean entry year 2008. In three populations, Chilliwack, Harrison and Quinsam rivers, the marine survival in the 2007 ocean entry year was exceptionally poor. The Fraser River watershed is the largest producer of Chinook salmon on Canada's Pacific coast. There are an estimated 114 populations (Candy et al. 2002) that produce juveniles that enter the Strait of Georgia. The Harrison River population is the largest in the Fraser River drainage and one of the largest naturally-spawning Chinook salmon populations in the world. The extremely poor survival of the juveniles that entered the Strait of Georgia in 2007 represents a major loss of Chinook salmon as the population is so large. The failure of the brood year for the Harrison River population and the generally poor survival of the other index populations indicates that the spring of 2007 was a year of generally poor survival for juvenile Chinook salmon. It is important to note that the estimates of survival are not without error that was not determined. Thus, differences among populations may have less relevance than the general trend. Length, weight and condition were also anomalously poor for the samples of juvenile Chinook salmon collected in the July 2007 surveys. The poor growth and poor condition is an indication that the juvenile Chinook salmon were stressed and most likely not finding adequate prey. We know from samples collected in other years that the juveniles of the eight populations in this report rear in the Strait of Georgia. For example, in 2010, in the July 4-23 surveys, it was shown that the Harrison and Chilliwack populations were commonly

found in the Strait of Georgia, although the relative abundance was less than might be expected (Beamish et al. 2011).
The declining trend in length and weight in recent years is an indication that there is a persistent cause that is gradually affecting the growth and ultimately the survival of the Chinook salmon. As the length and weight measurements are made within the Strait of Georgia, the reason for the declining trend would be within the Strait of Georgia.

We did not find a relationship between length and condition of the juvenile Chinook salmon we sampled in the July surveys and the individual population survival estimates. A difficulty with this comparison is that the lengths and weights are for all populations within the Strait of Georgia and not for the specific populations that have marine survival estimates. We suspect that an average marine survival estimate for all wild and hatchery fish entering the Strait of Georgia from 1998 to 2007 would have a declining trend in marine survival anomalies. The ocean entry year 2005 was also a period of generally synchronously poor ocean survival. Unfortunately, marine survival estimates are missing for two of the eight populations for the ocean entry year 2005. The major causes of the mortalities remain to be determined but there is no doubt that in years like 2005 and 2007 there are more mortalities than in other years.

In June-July 2008, there were 148 juvenile Chinook salmon that were tagged with acoustic tags (Neville et al. 2010). DNA from 74 of these tagged fish showed that four of the eight populations in Table 1 were in the sample. Only two of the 148 fish were detected leaving the Strait of Georgia, one through Johnstone Strait and the other through Juan de Fuca Strait. If the results in 2008 were indicative of the behaviour in 2007, it would indicate that a large percentage of juvenile Chinook salmon remained, and probably died within the Strait of Georgia. This is another indication that conditions within the Strait of Georgia directly affected the survival and in some years these conditions are more extreme, resulting in larger mortalities.

Beamish et al. (2012) concluded that the synchronous poor growth and survival of virtually all fishes in the surface waters in the spring of 2007 in the Strait of Georgia most likely was an extreme in the natural variability of the factors that normally affect the survival of juvenile Pacific salmon and Pacific herring in the early marine period in the Strait of Georgia. In this report, we show that the generally poor or exceptionally poor survival of Chinook salmon entering the Strait of Georgia in 2007 is consistent with that conclusion. Pacific herring and sockeye salmon that entered the Strait of Georgia in 2007 had historic low marine survivals. Survival of chum salmon was poor and coho salmon survival was also poor, although the survival of coho salmon was already quite poor. In this paper we show that Chinook salmon survival was also generally very poor. The physical conditions that caused the poor survival, described in Thomson et al. (2012) were extreme, indicating that the synchronous events in the winter and spring of 2007 probably reduced the prey available to the juveniles when they just started feeding in the Strait of Georgia through to the early summer. The exceptionally poor survival of virtually all major species of fishes in the surface waters of the Strait of Georgia in the spring of 2007 probably is an example of an extreme in the natural variability in marine survival.

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Chuck Parken and Gayle Brown provided the marine survival estimates compiled through the Pacific Salmon Commission. Lana Fitzpatrick helped prepare the manuscript.

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Table 1. Estimates of the numbers of spawning fish (total escapements of "adult" sized fish with no jacks or catches within the river included) from 1998 to 2008 to indicate the approximate relative size of the populations in this study.

Year	Nicola River (spring run)	Shuswap River (summer run)	Cowichan River(fall run)	Big Qualicum River (fall run)	Puntledge River (summer run)	Quinsam River (fall run)	Harrison River (fall run)	Chilliwack River (fall run)
1998	1,824	16,703	5,858	5,826	246	4,740	188,425	81,512
1999	8,281	24,765	6,110	5,521	362	8,256	107,016	77,217
2000	8,309	28,061	6,638	6,761	653	8,211	77,035	43,163
2001	9,105	51,984	5,015	9,441	1,747	14,608	73,134	68,247
2002	13,022	54,578	4,115	6,726	1,137	13,047	89,968	58,852
2003	14,630	21,379	3,356	6,279	929	7,289	247,121	54,111
2004	10,257	17,177	2,721	6,559	826	10,064	135,895	54,682
2005	6,164	18,133	2,467	7,621	2,979	7,670	88,580	34,211
2006	5,211	59,328	1,775	12,652	994	9,494	50,942	41,635
2007	1,126	16,168	2,175	7,270	1,147	6,694	79,176	23,865
2008	4,534	15,161	2,015	5,260	510	6,436	41,603	35,914

Table 2. The relationship (R^2 and P) between the fork lengths (mm) and condition (L / W^3 X 1,000) for samples collected in the July trawl survey and the individual population marine survival estimates for 1998 to 2008.

Population	Fork length		Condition	
	R^2	P	R^2	P
Big Qualicum River	0.26	0.09	0.06	0.42
Chilliwack River	0.31	0.06	0.28	0.08
Cowichan River	0.07	0.43	0.03	0.60
Harrison River (Fall)	0.01	0.78	0.05	0.50
Lower Shuswap River (Summer)	0.17	0.18	0.00	0.99
Nicola River (Spring)	0.25	0.10	0.07	0.41
Puntledge River (Summer)	0.07	0.38	0.02	0.66
Quinsam River (Fall)	0.04	0.54	0.28	0.07

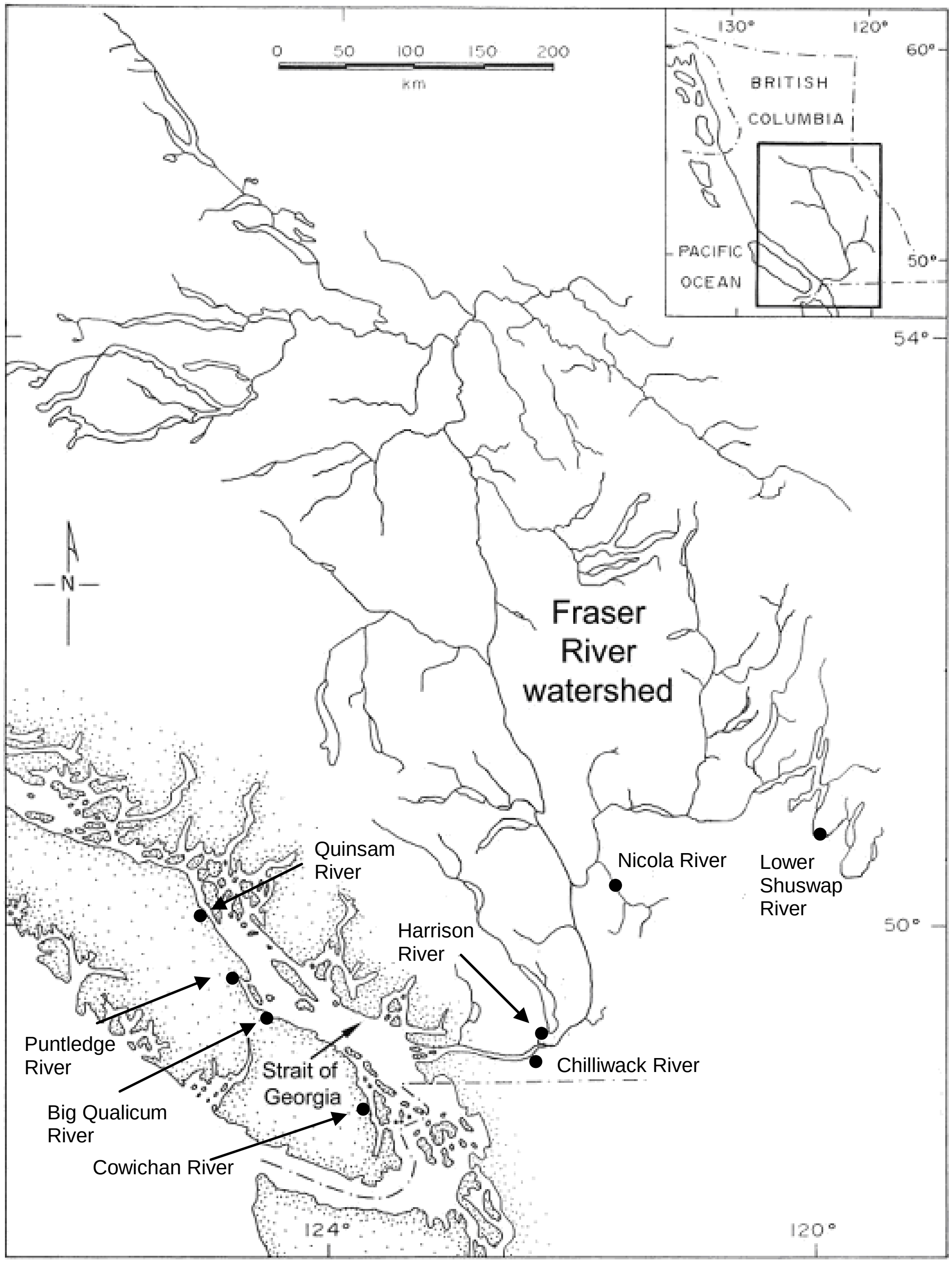

Figure 1. Map of British Columbia showing the location of the eight rivers in the report.

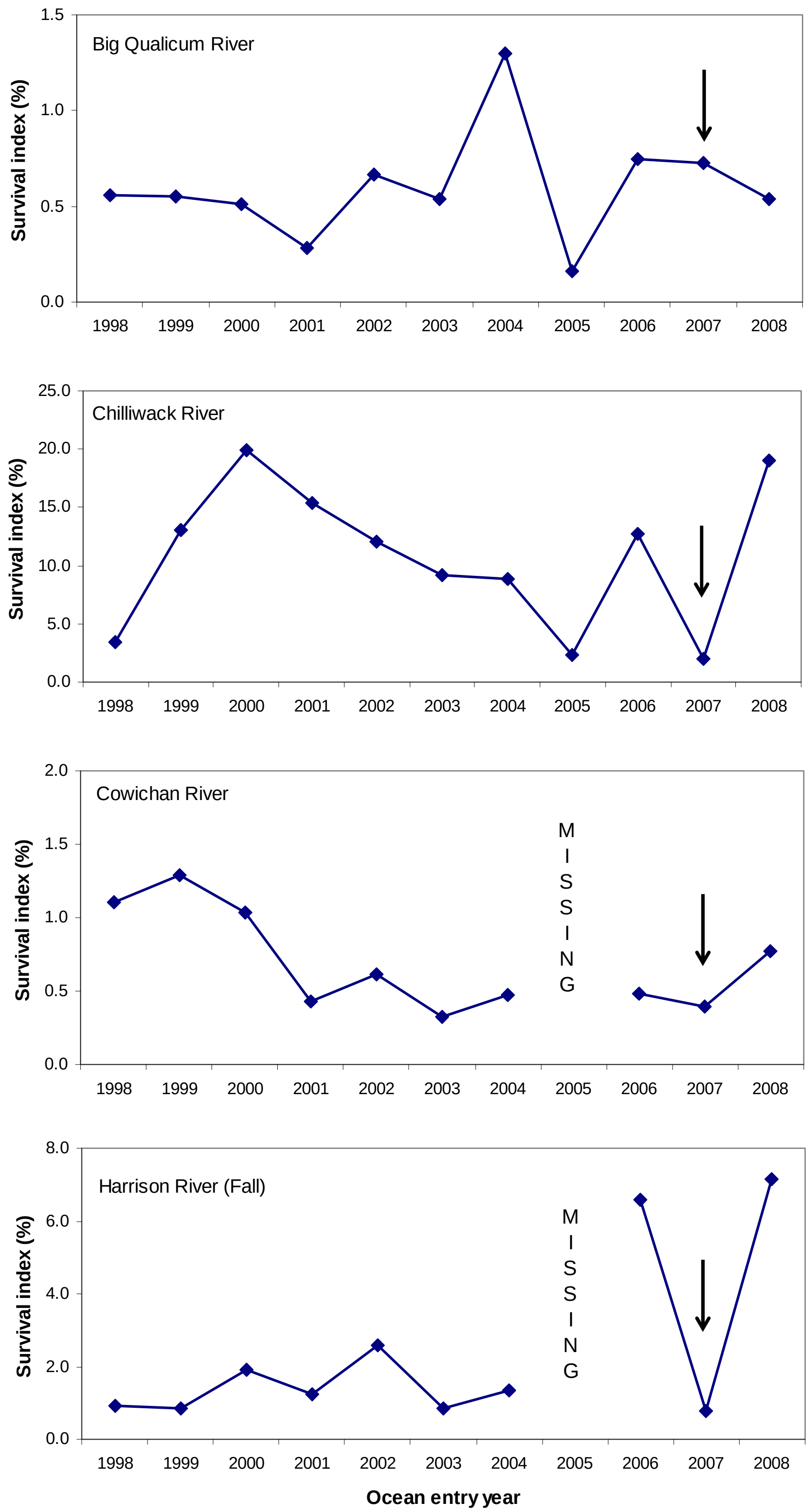

Figure 2. Survival indices for Chinook salmon for selected Fraser River populations from 1998 to 2008 ocean entry years. The arrow highlights 2007.

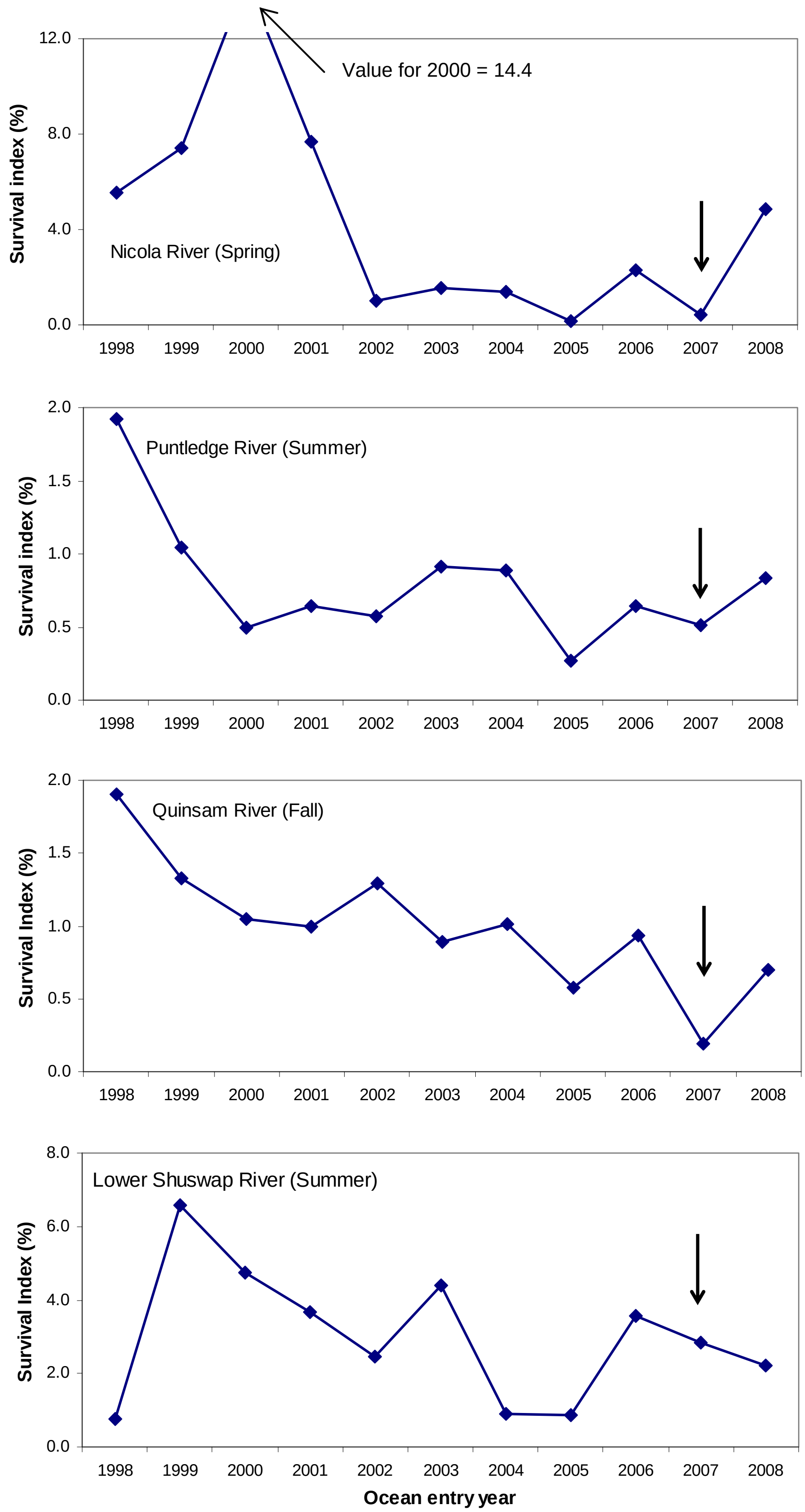

Figure 2 (Continued). Survival indices for Chinook salmon for selected Fraser River populations from 1998 to 2008 ocean entry years. The arrow highlights 2007.

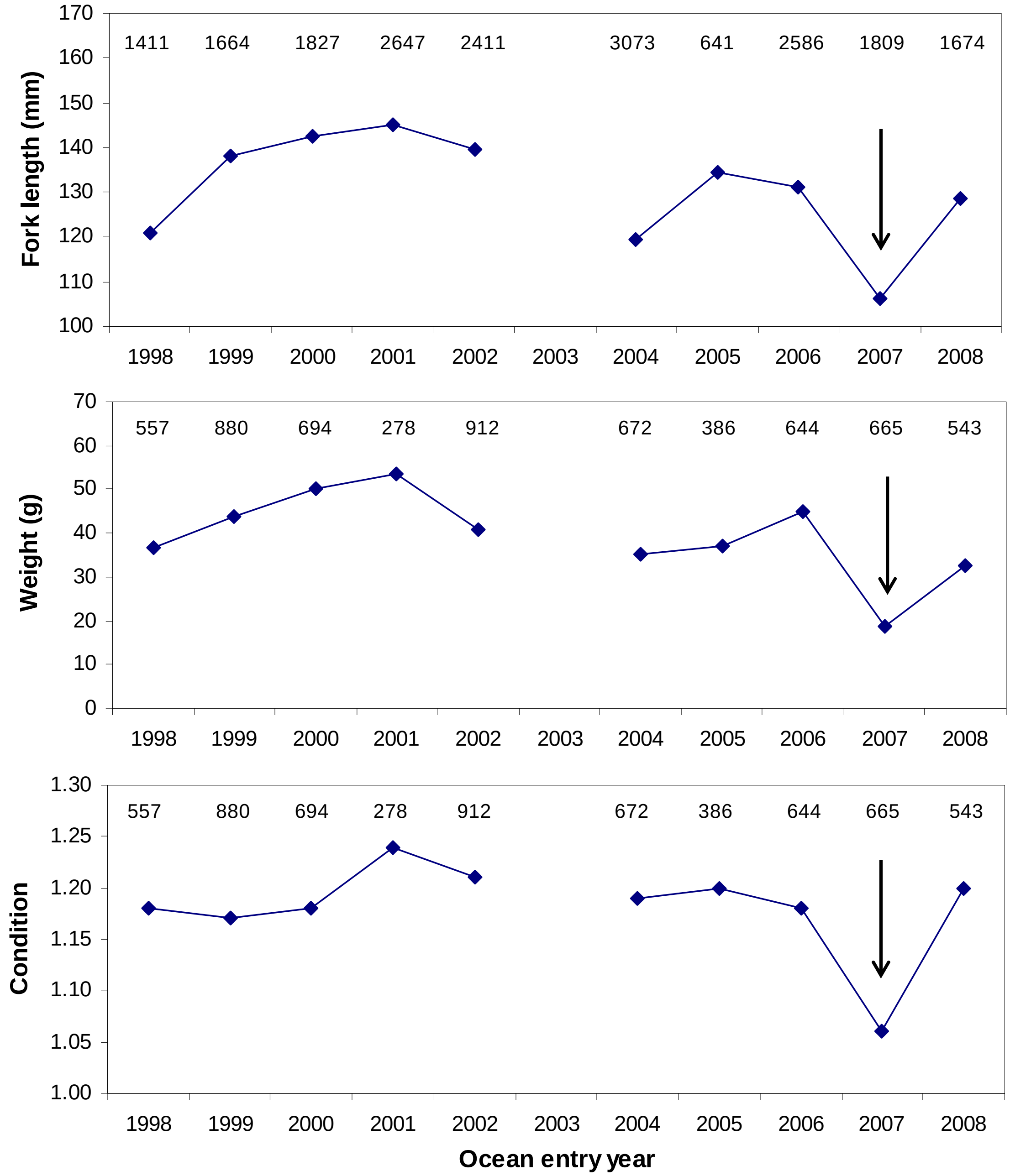

Figure 3. Length, weight and condition of juvenile Chinook salmon from the trawl surveys in the Strait of Georgia in July 1998-2008, showing the anomalous small size, weight and poor condition in the ocean entry year 2007. The N values are shown above each point. (From Beamish et al. 2012)

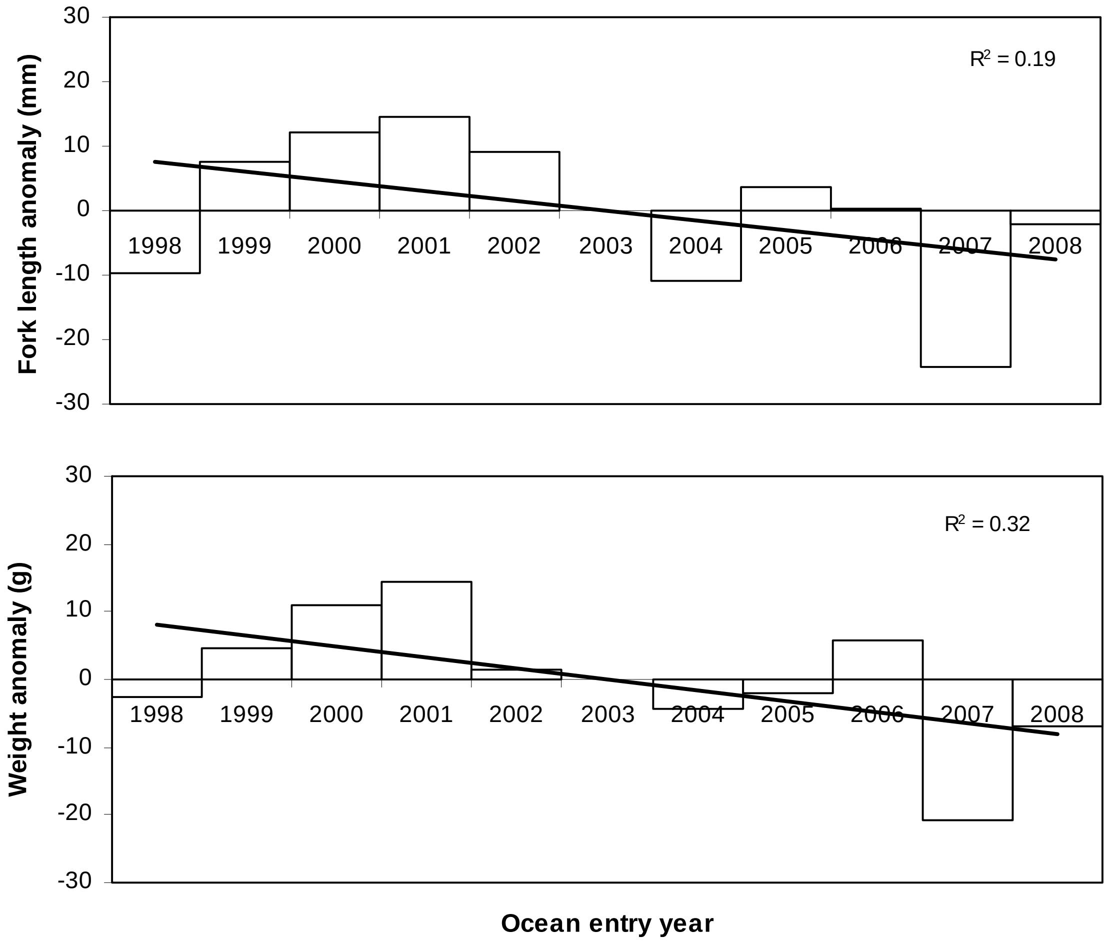

Figure 4. The anomaly of the length and weight of juvenile Chinook salmon from the trawl survey in the Strait of Georgia in July, showing a declining trend from 1998 to 2008.