A Climate Related Explanation for the Natural Control of Pacific Salmon Abundance in the First Marine Year

Richard J. Beamish, Rusty M. Sweeting, Chrys E. Neville, and **Korey Poier**

Fisheries and Oceans Canada, Pacific Biological Station,
Nanaimo, British Columbia, Canada

⇌⇌⇌⇌

Keywords: Ocean mortality, growth, competition, climate, coho

The belief that most natural losses of Pacific salmon occurred during the freshwater stage of their life cycle profoundly influenced how Pacific salmon were managed and researched in Canada for the past 50 years. It has only been recognized in the last few years that an understanding of the impacts of ocean habitat and climate are essential ingredients in the assemblage of considerations needed to manage salmon. We studied climate and ocean impacts on the productivity of coho salmon in the Strait of Georgia from 1996 to 2001. From September of 1996 to the end of 2001, we completed 27 surveys, 3,203 sets and sampled 123, 519 juvenile Pacific salmon (Table 1). Our study benefited from a managed fishing closure, an almost constant production of hatchery-reared coho that was approximately two times the production of wild smolts, and an abrupt increase in coho prey productivity in the Strait of Georgia in 2000. In the late 1990s, the total Canadian catch of all species of Pacific salmon declined to historic low levels. In the Strait of Georgia, coho marine survival declined from levels of 10–15% in the early 1980s to below 2% in the late 1990s. The number of adults produced declined from average abundances of 1.5 million in the 1980s[1] to less than 200,000 from 1996 to 1999[2]. The decline in production of coho and other species of salmon in 1999[2]. The decline in production of coho and other species of salmon in the 1990s followed a shift in large-scale climate indicators in 1989. The recent productivity increase was associated with another decadal-scale climate shift in mid-1998 (Beamish et al. 1998).

Productivity in the Strait of Georgia increased from 1999 to 2000, as indicated by a doubling of euphausiid biomass in 2000 (Fig. 1). Because euphausiids in the Strait of Georgia feed on phytoplankton (Parsons et al. 1969), there must have been an increase in phytoplankton. If phytoplankton production also doubled, there would be significant changes in productivity at lower trophic levels in 2000. As a consequence, coho and other

Fig. 1. Euphausiid biomass in the Strait of Georgia determined from hydroacoustic surveys in 1999 and 2000.
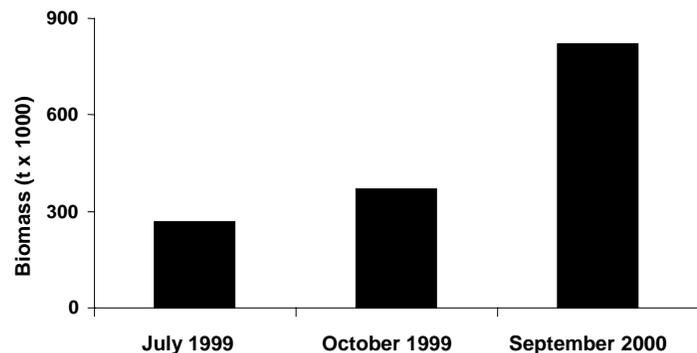

Table 1. Total catches (numbers) of ocean age 0 salmon from the Strait of Georgia surveys from September 1996 to November 2001.

Species	1996	1997	1998	1999	2000	2001	Grand Total
Chinook	1749	5674	3706	2789	4241	4254	22413
Chum	2748	7558	9064	7577	17818	8875	53640
Coho	2813	3370	2854	3635	6029	7331	26032
Pink	1520	138	4961	3	5592	79	12293
Sockeye	798	4920	659	1200	598	966	9141
Grand Total	9628	21660	21244	15204	34278	21505	123519

[1]Total number of adults was determined by dividing catch by the exploitation rate, less 11% to account for adults from United States sources.
[2]Total number of adults was determined by multiplying the estimated number of hatchery and wild smolts produced in Canada by the estimated marine survival.

Pacific salmon in the first marine year increased in size, fed more frequently, and contained larger volumes of prey in their stomachs (Fig. 2). The first evidence of improved marine survival occurred in 2001 for pink salmon and coho salmon as they spend only one winter in the ocean. Adult returns of pink salmon in 2001 were at historic high levels, following historic lows in 1997 and 1999. Preliminary marine survival estimates for coho show between a two and four-fold increase. The coho that returned as adults in 2001 were primarily from the faster growing individuals in the previous year. An analysis of marine circuli spacing in 2000 (the 1998 brood year) indicated that circuli spacing for the first 10 marine circuli was significantly larger in the coho that survived the winter compared to juveniles sampled in the previous year. The average spacing of the first 10 circuli of 50% of the fish returning in 2001 was equal to the average spacing of approximately 10% of the population in the previous year (Fig. 3). Scale circuli represent a permanent record of growth and circuli spacing is an accepted index of growth (Fisher and Pearcey 1990). Thus, it was clear that the faster growing coho in their first marine summer had significantly larger over-winter survival and hence contributed a greater proportion to the subsequent adult population. Because the abundance of juveniles in September of all years of the study was large relative to the total returns (Beamish et al. 2000), the late fall and winter mortality was an important contribution to the total natural mortality. The existence of this mortality, late in the first marine year, indicated that there were two major sources of natural mortality for coho: the well-known, early, predation-based mortality and this newly documented, later, growth-based mortality. The wide range in observed marine survival in the Strait of Georgia may indicate that growth-based mortality is more important than predation-based mortality.

Our study provides additional evidence of the validity of the critical size and critical period hypothesis proposed by Beamish and Mahnken (1999, 2001). The hypothesis proposed that the later growth-based mortality related to the requirement to store enough energy to survive metabolic demands over a period of reduced feeding in the late fall and

Fig. 2. Biological data for ocean age 0 coho captured in July surveys in the Strait of Georgia from 1997 to 2001, expressed as anomalies for the time series. A. Anomaly of average fork lengths. B. Anomaly of average percentage of empty stomachs. C. Anomaly of average prey volume in stomachs.
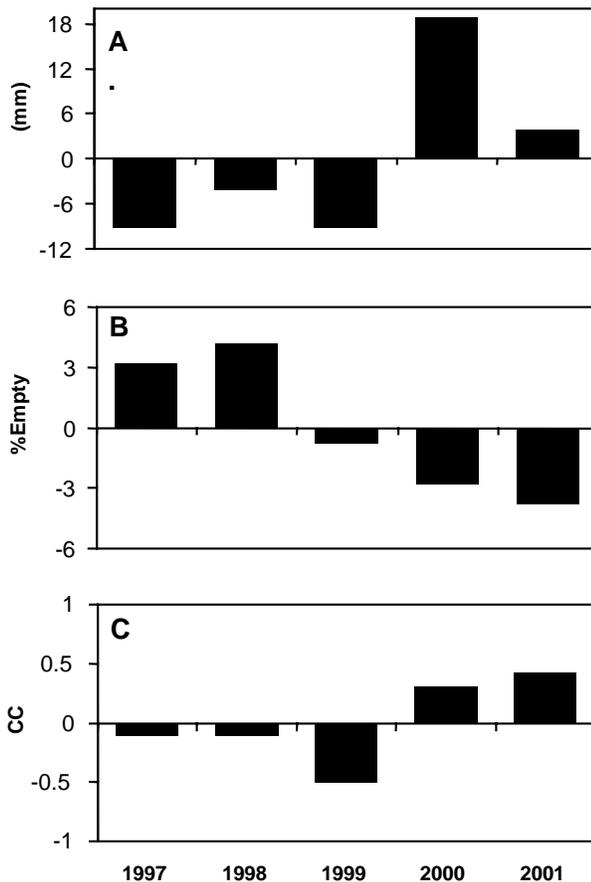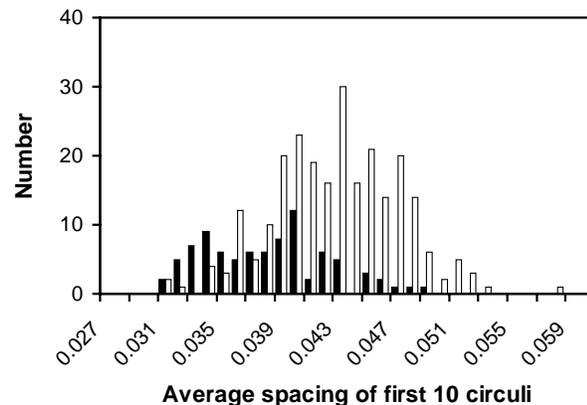

Fig. 3. Average spacing (in mm) of first 10 marine circuli for age 0 coho captured in 2000 (black bars, N = 87) and ocean age 1+ coho (open bars, N = 248) from the same brood year captured in 2001.

winter when there was a possible net deficit in energy. The beginning of he critical period was proposed to be more related to day length than to temperature, with the onset being at the fall equinox. A relationship between growth and natural mortality and a relationship between growth and ocean productivity is evidence that factors that reduce growth will contribute to increasing the natural loss of juvenile salmon in the ocean. Thus, during the periods of reduced prey abundance prior to the regime shift of 1998, competition from other coho and other species eating prey

similar to coho contributed to reduced coho productivity through increased marine mortality. It is evident that, under such conditions, adding more coho or other salmon that compete for similar prey would reduce growth and subsequently increase growth-based mortality. It is also evident that climate and climate change play a vital role in the natural regulation of coho abundance through impacts on the production of prey. The relative importance of predation-based and growth-based mortality may vary among ecosystems and among species. The concept of a growth-based mortality probably would apply to Atlantic as well as Pacific salmon. A linkage between marine survival and climate, particularly at the decadal scale, should warn salmon managers that greenhouse gas induced climate change will affect marine survival. This means that there is a possibility that the pollutants we emit into the atmosphere may be just as harmful to salmon as those that we dump into their spawning and nursery habitats.

REFERENCES

Beamish, R.J., and C. Mahnken. 1999. Taking the next step in fisheries management. *In* Ecosystem approaches for fisheries management. Proceedings of the 16th Lowell Wakefield Fisheries Symposium*,* Alaska Sea Grant Rep AK-SG-99-01, pp.1–21.

Beamish, R.J., and C. Mahnken. 2001. A critical size and period hypothesis to explain natural regulation of salmon abundance and the linkage to climate and climate change. Progr. Oceanog. 49: 423–437.

Beamish, R.J., G.A. McFarlane, D. Noakes, J.R. King, and R.M. Sweeting. 1998. Evidence of a new regime starting in 1996 and the relation to Pacific salmon catches. (NPAFC Doc 321) 21 p. Dept. of Fisheries and Oceans, Sciences Branch-Pacific Region, Pacific Biological Station, Nanaimo, BC, Canada, V9R 5K6.

Beamish, R.J., D. McCaughran, J.R. King, R.M. Sweeting, and G.A. McFarlane. 2000. Estimating the abundance of juvenile coho salmon in the Strait of Georgia using surface trawls. N. Am. J. Fish. Manage. 20: 369–375.

Fisher, J.P., and W.G. Pearcey. 1990. Spacing of scale circuli versus growth rate in young coho salmon. Fish. Bull. 88: 637–643.

Parsons, T.R., R.J. LeBrasseur, J.D. Fulton, and O.D. Kennedy. 1969. Production studies in the Strait of Georgia. Part II. Secondary production under the Fraser River plume, February to May, 1967. J. Exp. Mar. Biol. Ecol. 3: 39–50.