# BEHAVIOUR, AND PHYSIOLOGICAL RESPONSES OF ADULT SOCKEYE (*ONCORHYNCHUS NERKA*) SALMON EXPOSED TO SIMULATED ESTUARINE CONDITIONS AND HYPOXIC SALT WATER.

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## Introduction

Persistent hypoxic conditions exist in the sub-halocline waters of the Somass River estuary at the head of 45 km-long Alberni Inlet, British Columbia. These conditions are related to a naturally-slow flushing rate and the input of effluent from a pulp and paper mill. Over the last forty years the oxygen demand of the effluent, which is discharged into the freshwater lens of the highly stratified estuary, has contributed in a decline in the dissolved oxygen concentrations of these surface waters by an average of 1 $mg \cdot L^{-1}$ from pre-discharge conditions. Over the same period the corresponding decline in the deeper sub-halocline waters has been about 4 $mg \cdot L^{-1}$; a reduction of almost 60%.

The progressive deterioration in the quality of the habitat used by aquatic organisms in Alberni Inlet, and especially the concern about valuable salmon resources, have prompted reviews by federal and provincial government agencies and the forest products industry. All parties are endeavouring to understand the biological effects, and improve the quality of the upper inlet waters; this research project was initiated in response to these objectives.

The significance of the concern over the well-being of salmon is exemplified by events that occurred in 1990 during the annual migration of sockeye salmon (*Oncorhynchus nerka*) through Alberni Inlet and the Somass River to their spawning areas in Great Central and Sproat Lakes. During this summer, warm and stable climatic conditions elevated the temperature of surface waters in the Somass River and estuary to the extent that the migration of adult sockeye was delayed 2-8 weeks. Sonar records revealed that the fish were holding at depth in the cooler (11-12°C) hypoxic salt water, rather than continuing their migration through the warmer, less saline but more oxygenated surface waters. Over 100,000 adult salmon were lost, and it is likely that the cumulative effects of prolonged exposure to the adverse environmental conditions at the head of Alberni Inlet, and increased infection by parasitic copepods (*Lepeophtheirus salmonis*), contributed to their demise.

We employed a continuous-flow Water Column Simulator (WCS) to mimic conditions that adult sockeye salmon experience during their spawning migration through the vertically-stratified estuary of the Somass River. This technique was applied as a preliminary step towards understanding the possible physiological consequences of this seemingly maladaptive behaviour.

## Methods

Adult sockeye salmon (ages $4^+$ and $5^+$) were captured by commercial seiner in Alberni Inlet and transferred to sea water holding facilities at the West Vancouver Laboratory 5 weeks prior to experimentation. The fish were held in a 15,500 L outdoor tank in which the depth of water equalled that in the WCS. The tank was continuously supplied with air-equilibrated salt water (10.8-13.9°C; 26.0-27.2‰ salinity) at 100 $L \cdot min^{-1}$ resulting in 90% replacement within 3 h. We conducted six consecutive 5.5-d experiments with individual fish, during the natural migration period of these stocks through Alberni Inlet.

To minimize handling and osmotic stress, the sockeye were rapidly (5 min) transferred to the WCS in 20 L brackish water (salt water:fresh water ratio 1:1.5) containing metomidate (0.5 $mg \cdot L^{-1}$), under low light (dusk) conditions. Within the WCS, normoxic fresh water (0.74 m depth) overlay, and was separated from, normoxic salt water (1.5 m depth) by a well-defined and narrow (4 cm deep) halocline. The temperature of both water layers was 12°C, within the range of that in the holding tanks. A natural photoperiod was maintained by controlling the output of a metal halide source which transmitted light through a centrally-positioned Light Pipe™ providing equally-distributed illumination over the water surface.

On the third day following transfer to the WCS, we determined the swimming speed and ventilation rate (opercula openings$\cdot min^{-1}$) of the experimental fish under normoxic conditions. The following day the same determinations were made under progressive salt water hypoxia (6.5 h). During a return to normoxic conditions (3.5 h) the temperature of the freshwater lens was gradually raised to 20°C (similar to that of the Somass River), creating a bithermal normoxic condition. The identical protocol which produced progressive hypoxia in salt water under isothermal conditions was repeated, and the responses of the fish determined.

Continuous video recordings using a high resolution camera with peak sensitivity in the near infra-red coupled to a time-lapse video recorder were used to document fish behaviour in the WCS 4500-L plexiglass aquarium. Recording at night was accomplished under illumination by red light (680-760 nm, peak at 705 nm).

## Results

It was our expectation that the experimental conditions would elicit responses in the adult sockeye that would assist our understanding of their behaviour in Alberni Inlet. We anticipated an avoidance response to hypoxic salt water and movement to normoxic fresh water under isothermal conditions, and that the extent of this response would be diminished by the presence of warmer fresh water under the bithermal regime which typified conditions in the estuary of the Somass River.

Under normoxic fresh and salt water conditions during daytime, the fish remained in the deeper sea water, but moved upwards at night and made transient excursions into fresh water. The imposition of short-term hypoxic conditions in salt water during daytime did not elicit a definite avoidance response. The fish exhibited little displacement from their positions in salt water until the dissolved oxygen level decreased to about 3-4 $mg{\cdot}L^{-1}$ (51-69 mm Hg $pO_2$). The fish maximized gill ventilation rate (respiratory compensation) however, rather than directly avoiding the stressful conditions, they increased the frequency of movements (8 to 145 excursions) into the freshwater layer. They continued to spend the majority of time (>90%) in hypoxic salt water. Elevations in ventilation rate (from about 40 to a maximum of 105 opercula $openings{\cdot}min^{-1}$) began when dissolved oxygen concentrations dropped below 5-6 $mg{\cdot}L^{-1}$ (85-104 mm Hg $pO_2$), and decreased only slightly in response to the brief excursions of the fish into normoxic fresh water or to the halocline.

The presence of approximately 1-2% Somass River water did not result in behaviour different from that displayed when 100% well water comprised the freshwater layer. Furthermore, warming the surface fresh water to 20°C, as occurred in the freshwater lens of the Somass River estuary, had only a slight inhibitory effect on the duration and frequency of excursions to this water layer when compared to the movements of fish under stratified but isothermal (12°C) conditions and salt water hypoxia.

An ancillary direct transfer experiment demonstrated that these salmon could physiologically tolerate fresh water for at least 18 days, indicating that their motivation for "habitat" selection, especially under hypoxic stress, was behavioural.

## Conclusion

It was concluded that the behaviour displayed by the sockeye salmon in response to short-term exposure to hypoxic conditions in salt water could result in an additional energy expenditure for these non-feeding adult salmon. We speculate that prolonged exposure to hypoxic waters, in addition to contributing to mortalities, could result in reduced spawning and production of progeny.

**Our laboratory experiments confirmed field observations of the behaviour of adult sockeye salmon which must reside or pass through regions of sub-optimal water quality in Alberni Inlet. We did not observe the expected avoidance responses to hypoxic salt water and it is possible that inherent behavioural traits may, in fact, be maladaptive in this location. By choosing to remain in the hypoxic deeper salt water rather than benefit from movement into the more oxygenated surface waters, they potentially jeopardized health and survival.**