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This Week's Citation Classic

Brett J R. The respiratory metabolism and swimming performance of young sockeye salmon. *J. Fish Res. Board Can.* **21**:1183-226, 1964. [Fisheries Research Board of Canada, Biological Station, Nanaimo, British Columbia]

The rate of oxygen consumption was determined for stepwise increases in steady swimming speed of young salmon, up to fatigue levels. The tests were conducted at temperatures from 5° to 24°C in a tunnel respirometer designed to produce fine turbulent flow of uniform cross-section. This provided an empirical model of swimming energetics, over the full range of tolerable temperature and swimming capacity. [The *SCI*® indicates that this paper has been cited over 125 times since 1964.]

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"This was the first study on the exact metabolic energy expended by a streamlined fish (salmon) for any given swimming speed within its capacity. By use of a hydrodynamically stable water tunnel, it reproduced the equivalent of the classical treadmill used for determining the energy cost of locomotion in terrestrial animals.

"It all began in 1957 when a proposal was made to build a series of hydroelectric dams on the Fraser River, British Columbia, the major salmon river of the Canadian west coast. This posed a lethal threat to the free passage of fish that annually migrate by the thousands both upriver as adults and downriver as fingerlings. Government research programs on an unprecedented scale were instituted to determine the potential consequences and seek solutions to the dramatically altered flow patterns that would result. Increased support made it possible to proceed in our physiology lab with the development of apparatus that had formerly been beyond our means. This included a recirculating, highly controlled, tunnel respirometer by which we proposed to simulate and consequently predict the metabolic costs associated with velocity and temperature changes in river and reservoir. By good fortune a naval expert on water tunnel design was available so that biological requirements could be matched with hydrodynamic insight. The tunnel included an electrified downstream grid that served to prevent any lazy behaviour from obscuring physiological capacity.

"The very first tests of the new respirometer were not a little disquieting—fish were either electrocuted (an isolation transformer was needed), intoxicated (from residual plastic solvents), or so excited that no relation between imposed velocity and energy expended could be established! The small crowd that had assembled for the first demonstrations melted away in sympathetic disillusionment. Slowly each fault was corrected. The persevering patience of technical assistants outlasted the limited flippant behaviour of fish that really could steady down and display their true form.

"Hydrodynamic theory on the energy required for an undulating body to move through a moderately viscous fluid had deduced that fish or whales could not swim against the velocities and over the distances observed. Named after its distinguished originator —Gray's paradox — this contradiction was the source of much conjecture and debate in the literature. By establishing the power-performance relation for a fish of stated size and form, the hydrodynamicists at last had a true measure of energy expended for known performance. This early story is reported in an article in *Scientific American.*[1] An extensive treatise on the more recent findings, both biological and hydrodynamic, has served to remove the mystery of the paradoxical swimming efficiency.[2] Fast swimming fish reduce their form drag greatly by allowing skin drag to carry back along their surface diminishing the internal energy of the trailing wake.

"The dams on the Fraser River have not been built. No effective solution for maintaining the salmon resource could be devised. However, no escape seems possible from the creeping menace of pollution. The respirometers (now small and large) have proven to be useful tools in assessing sublethal stress by determining what concentration of a pollutant just begins to make inroads on the respiratory metabolism of a salmon working at top sustained speed."

1. **Brett J R.** The swimming energetics of salmon. *Sci. Amer.* **213:**80-5, 1965.
2. **Webb P W.** Hydrodynamics and energetics of fish propulsion. *Bull. Fish. Res. Board Can.* **190**:1-158, 1975.