

**SOCKEYE SALMON AND A WILD ALASKAN WATERFALL:**

**POSSIBLE LESSONS FOR DAM RETROFITS**

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**EXTENDED ABSTRACT ONLY – DO NOT CITE**

**Introduction**

Fish ladders have been used for hundreds of years to help migratory fishes move upstream past human-made obstacles such as dams. Even recent designs of these ladders appear to have given little consideration to the behaviors and leaping abilities of the fishes they are supposed to help (Clay, 1995). These inadequate designs seem partly a result of the paucity of information on the behavior and biomechanics of fishes as they leap.

In order to improve fishway design, one must understand fish leaping by studying both the kinematics of the behavior and the hydrological characteristics preferred by the fish. Stuart (1962) briefly described the kinematics of salmonid leaping but few rigorous analyses have ever been published. Stuart (1962) also outlined the physical characteristics of a pool and weir system used by salmonids but no wild waterfalls have been described to our knowledge. We hope to integrate biological considerations with the design and construction of

fish ladders by understanding the preferences, capacities and limitations of wild fishes leaping up natural stream obstacles.

## **Methods**

We analyzed aspects of the biomechanics of leaping in sockeye salmon, *Oncorhynchus nerka*, as they tried to pass the approximately 1 m high waterfall on Brooks River in Katmai National Park, Alaska, USA during their spawning migration (July 11-14, 1999). Digital video recordings were made of leaping salmon from distances of 21-24 m perpendicular to the flow of the stream. The camera was aimed at the base of the waterfall at an angle less than 5° from horizontal. Fish were tracked as they traveled through the air and kinematic parameters of the individual leaps were quantified. Individual fish positions throughout leaps were obtained using Scion Image version 3b. Mathematica version 3.0 software was used to calibrate video frames to real world units and to calculate leaping parameter values (i.e. angles and velocities). Video frames were calibrated using the gravitational constant of 9.8 m/s<sup>2</sup> and the recorded film speed of 15 f/sec. Leaping parameters were calculated based on ballistic physics (assuming a negligible effect due to air resistance) by applying best fit parabolic functions to the individual leap trajectories. Relative water depths were measured using video of bears wading across the river.

These results are summarized in the context of successful versus unsuccessful leaps and of calculated theoretical parameter values for successful leaps. A successful leap is defined as a leap originating below the waterfall and ending on or above the fall with the fish continuing up the stream (without immediately returning downstream). The theoretical model was constructed using Mathematica version 3.0.

## **Results**

The sockeye salmon we observed had an 11% leaping success rate (29 of 265 recorded leaps). Aerial kinematic parameters were quantified for 47 leaps (22 successful and 25 unsuccessful). These parameters include horizontal velocities, vertical takeoff and landing velocities, resultant takeoff and landing velocities, takeoff and landing angles, and distances between takeoffs and successful landings.

A theoretical model was constructed describing the relationship between the waterfall height and two leap parameters for a successful leap: <sup>1)</sup> distance between takeoff and successful landing and <sup>2)</sup> takeoff velocity. This model describes the minimum distance and velocity combinations required for a successful leap.

The salmon almost exclusively leap in a very specific and narrow region of the approximately 30 m wide waterfall. The few fish observed leaping outside of this region were all unsuccessful. The most notable difference between the area of leaping and the rest of the waterfall is the presence of a relatively large plunge pool with a large standing wave or boil at the base of the falls.

### **Conclusions**

The accordance of the kinematic data with the model and the low observed success rate suggest that the proportion of the salmon population arriving at upstream spawning tributaries is low under natural conditions (in the absence of human made obstacles). The restricted region of leaping activity suggests that the fish have very specific hydrological preferences for leaping. These preferences seem to include deep plunge pools that produce a standing wave as suggested by Stuart (1962).

We plan to conduct future studies correlating the hydrology downstream of waterfalls with leaping salmonid kinematics, both underwater and in air. These studies will include a range of plunge pool dimensions and over-spill characteristics that will experimentally investigate the preferences of migrating salmonids at stream obstructions. These results along with the theoretical model describing successful leaps may be used in the development of fish ladders to help maintain a natural passage rate of fishes up streams that contain human made obstacles.

### **References**

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