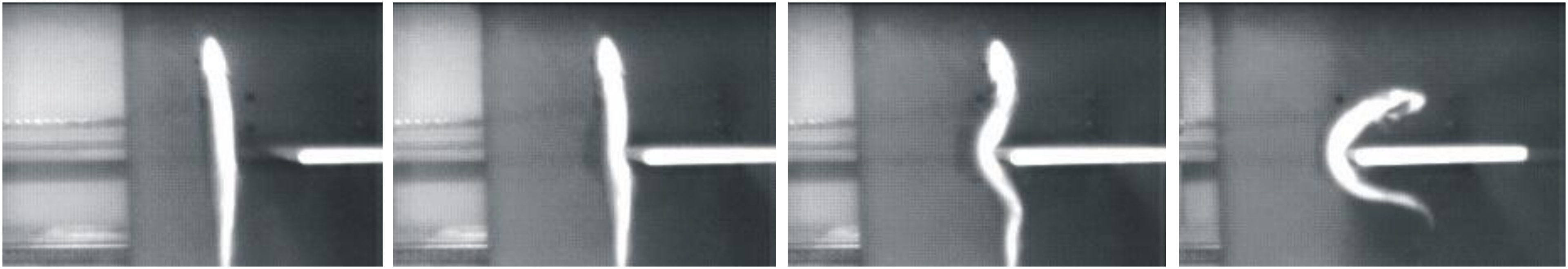
Conference on Environmentally-Enhanced Hydropower Turbines

DESIGNING LEADING EDGES OF TURBINE BLADES TO INCREASE FISH SURVIVAL FROM BLADE STRIKE



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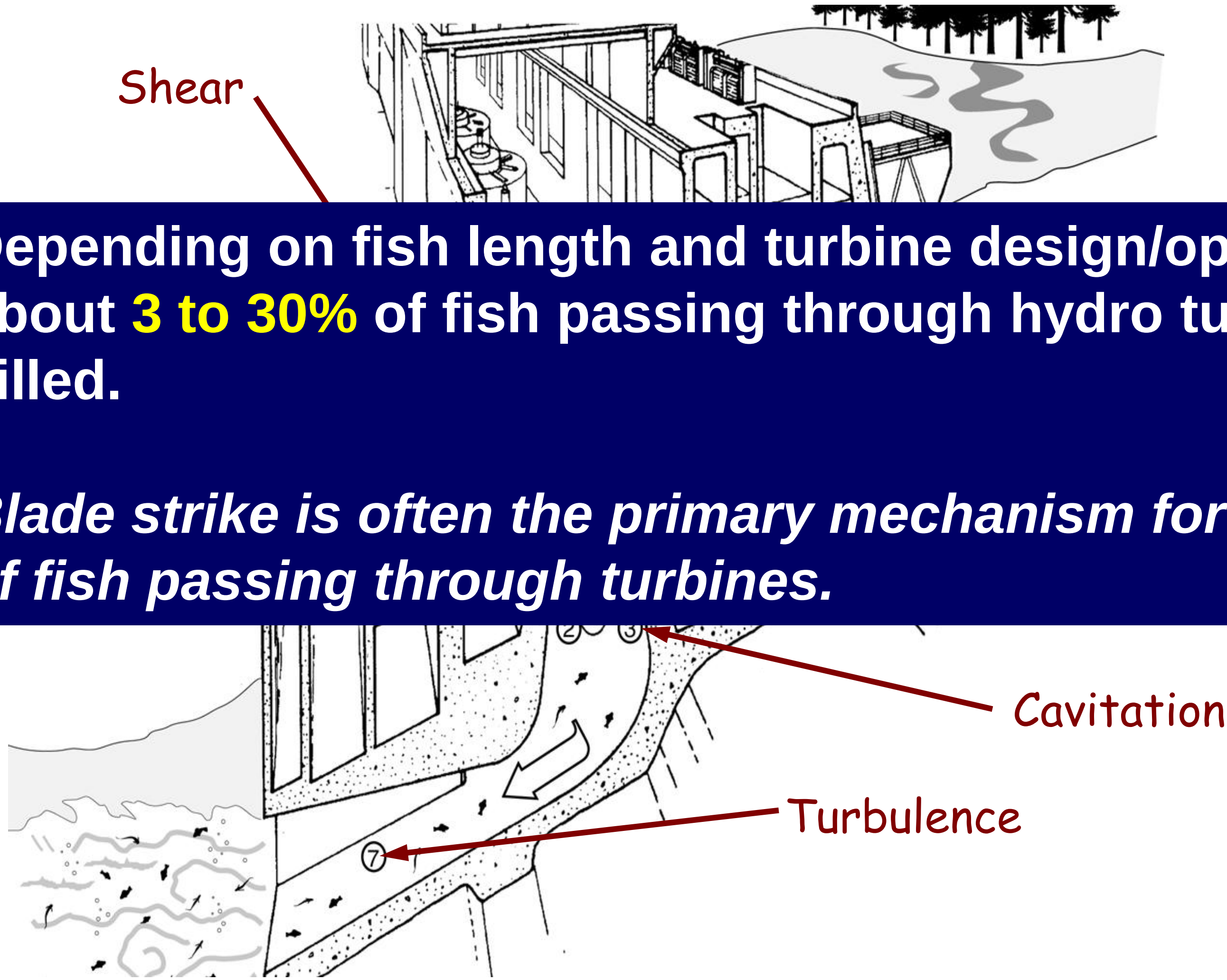
Fish Passage Through Hydroelectric Turbines



Depending on fish length and turbine design/operation, about 3 to 30% of fish passing through hydro turbines are killed.

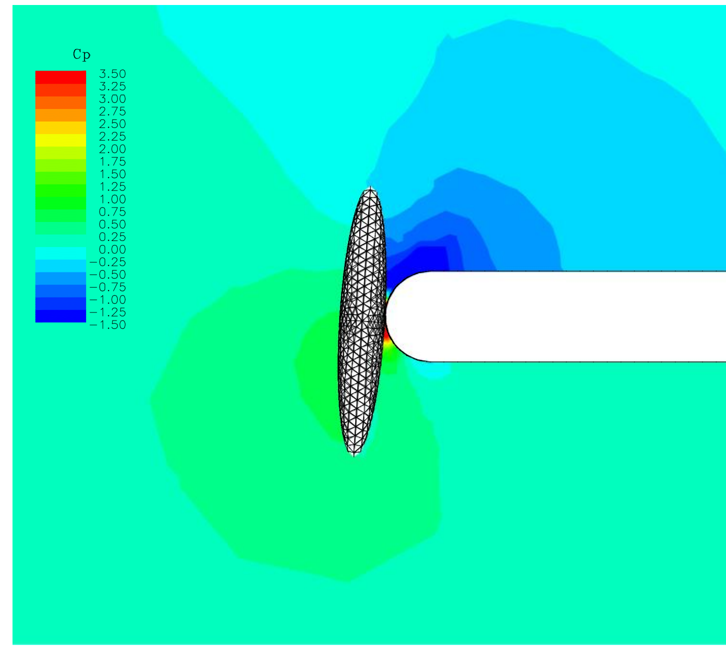
Blade strike is often the primary mechanism for mortality of fish passing through turbines.

Leading Edge Blade Strike Study

Evaluate how blade strike survival is affected by:

- Blade shape
- Blade thickness
- Impact (strike) speed
- Fish length
- Species

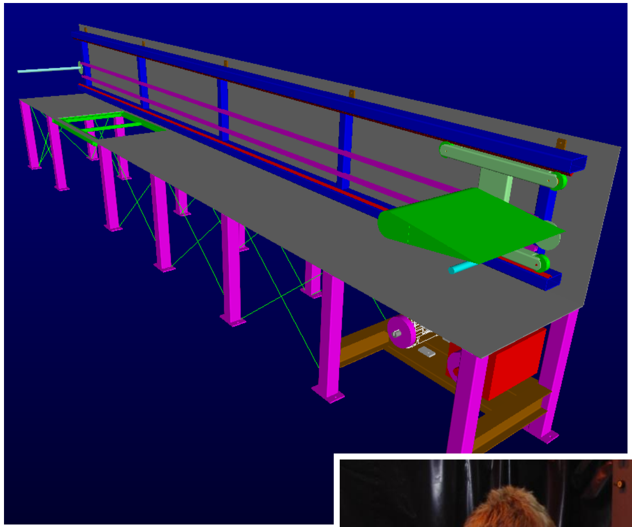
Numerical modeling was used to evaluate effects of leading edge shapes on flow patterns and fish impact.

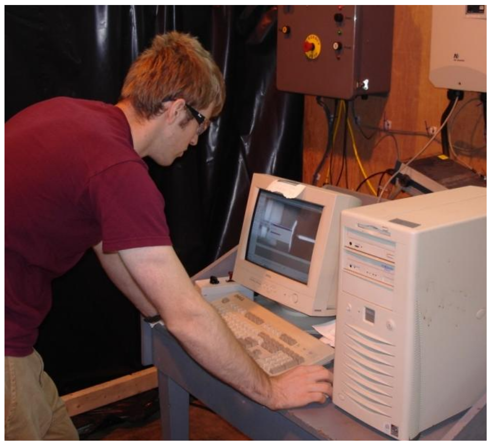


Using a semi-circular shape to enhance fish deflection, fish survival was evaluated for multiple blade widths, strike speeds, fish lengths, and species.

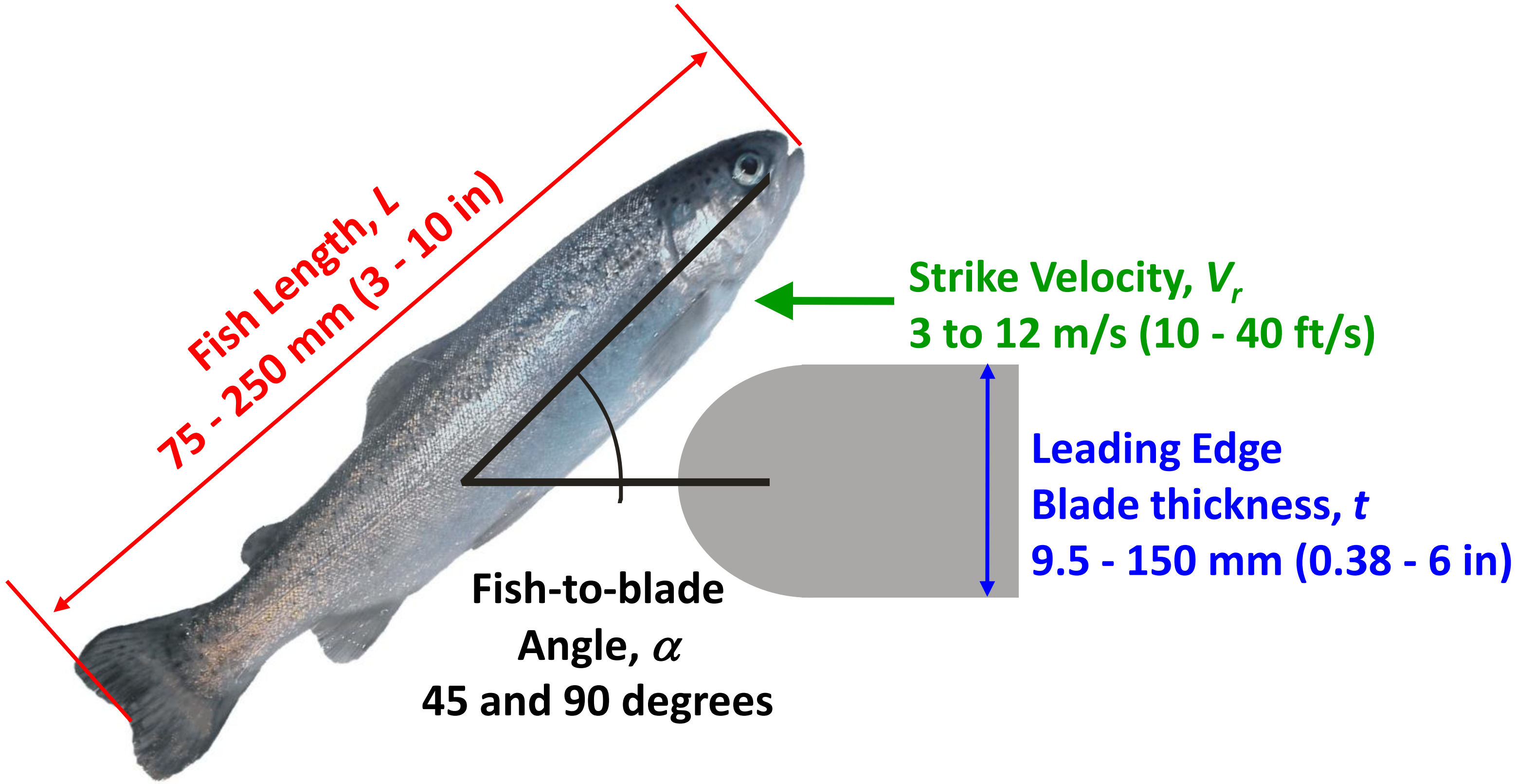
Methods *Laboratory Evaluation of Blade Strike*

- Linear facility:
  55 ft L x 3 ft W x 3 ft H
- Accelerate blade to strike speed, then stop!
- Record impact using high speed video system
- Examine injury and survival for each set of test parameters

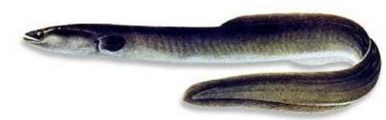




Methods *Test Parameters*



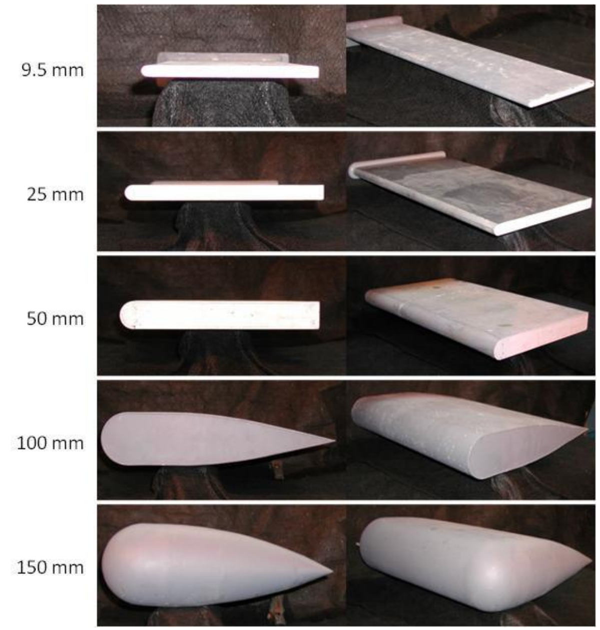
Test Species: rainbow trout, white sturgeon, American eel

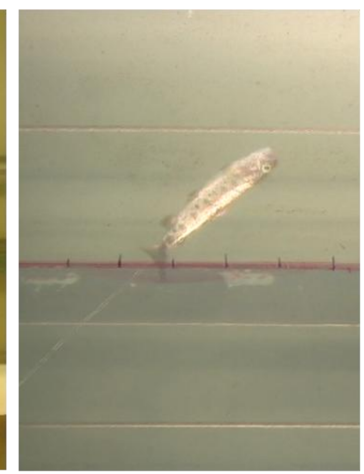


L/*t* ratio: 0.75 to 25

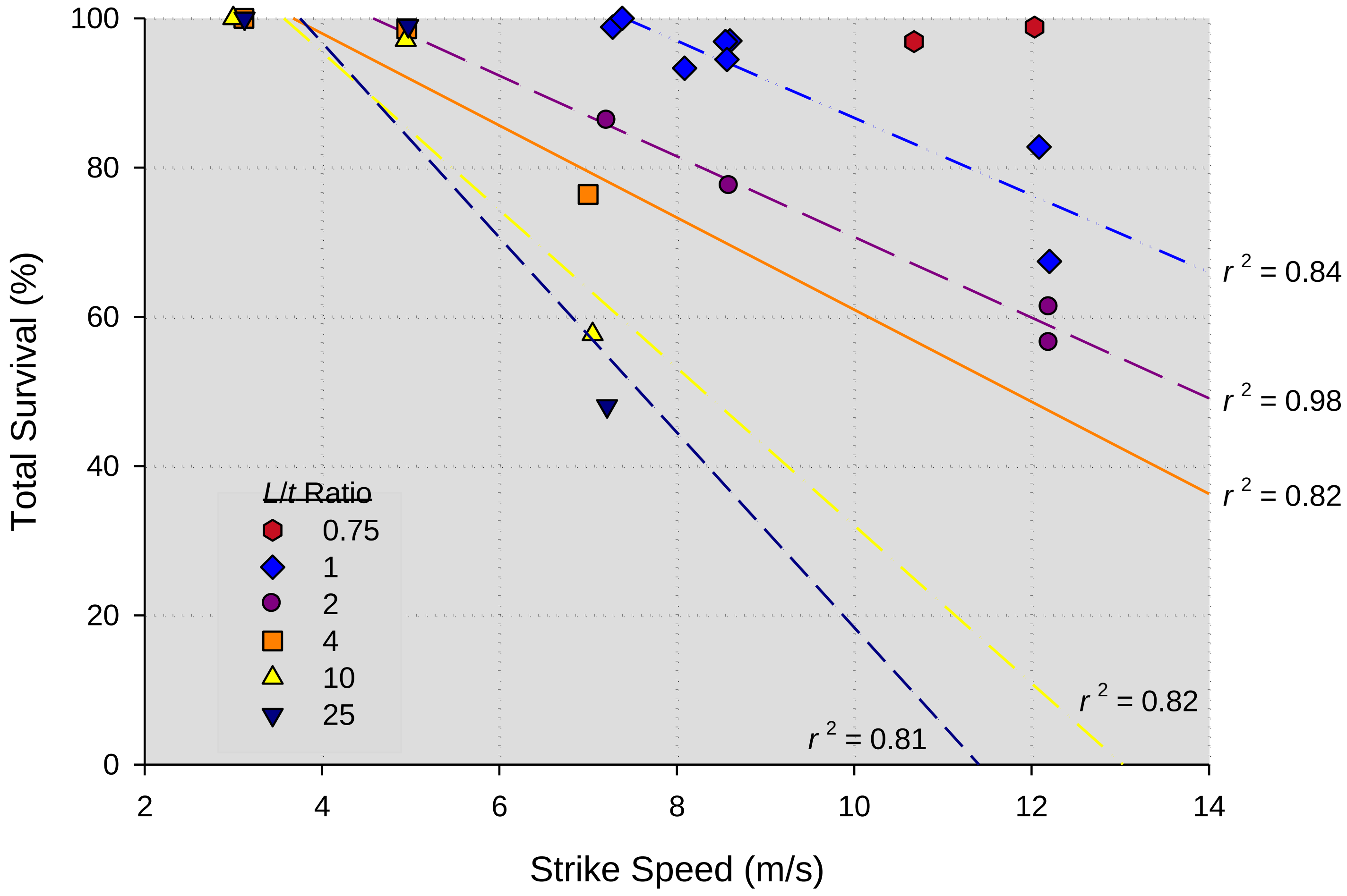
Methods Experimental Design

- 25 to 75 test fish for each combination of species, fish length, fish angle, blade thickness, and strike speed
- Following strike, recorded injury and immediate mortality (1 hr)
- Used high speed video to record fish orientation to blade (dorsal, ventral, or side) and location of blade strike along body (head, mid-section, and tail region)
- Held live fish for 96-hr delayed mortality period



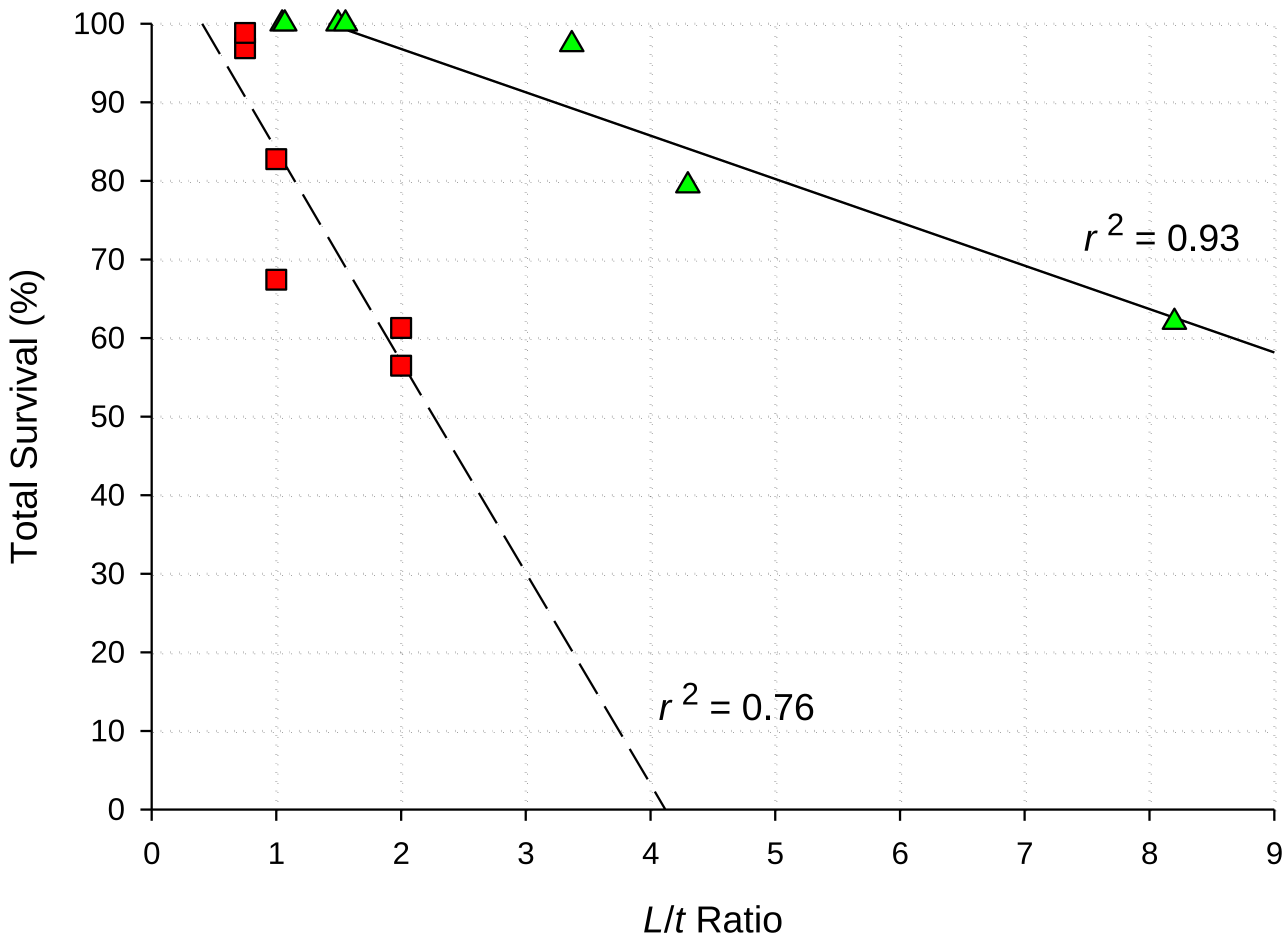


Results *Rainbow Trout Tests*

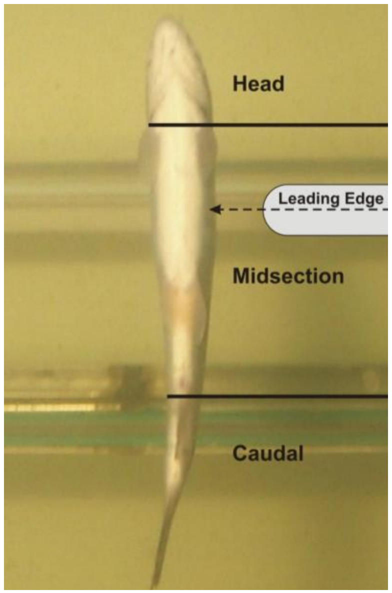


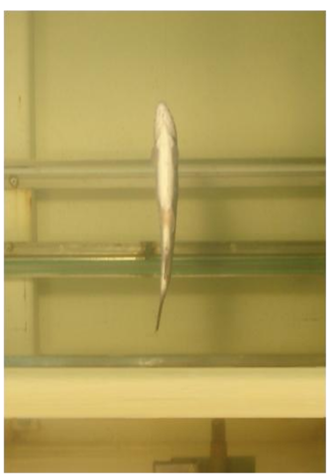
Results *White Sturgeon Tests*

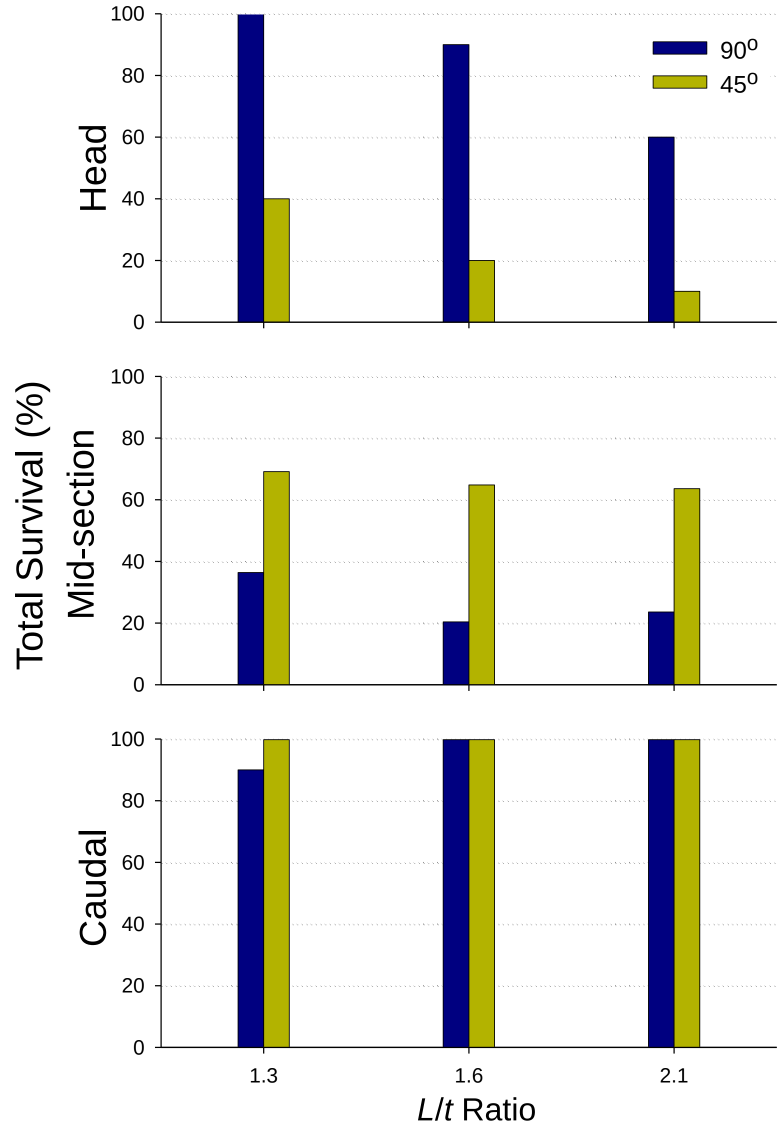
Strike Velocity = 10 – 12 m/s



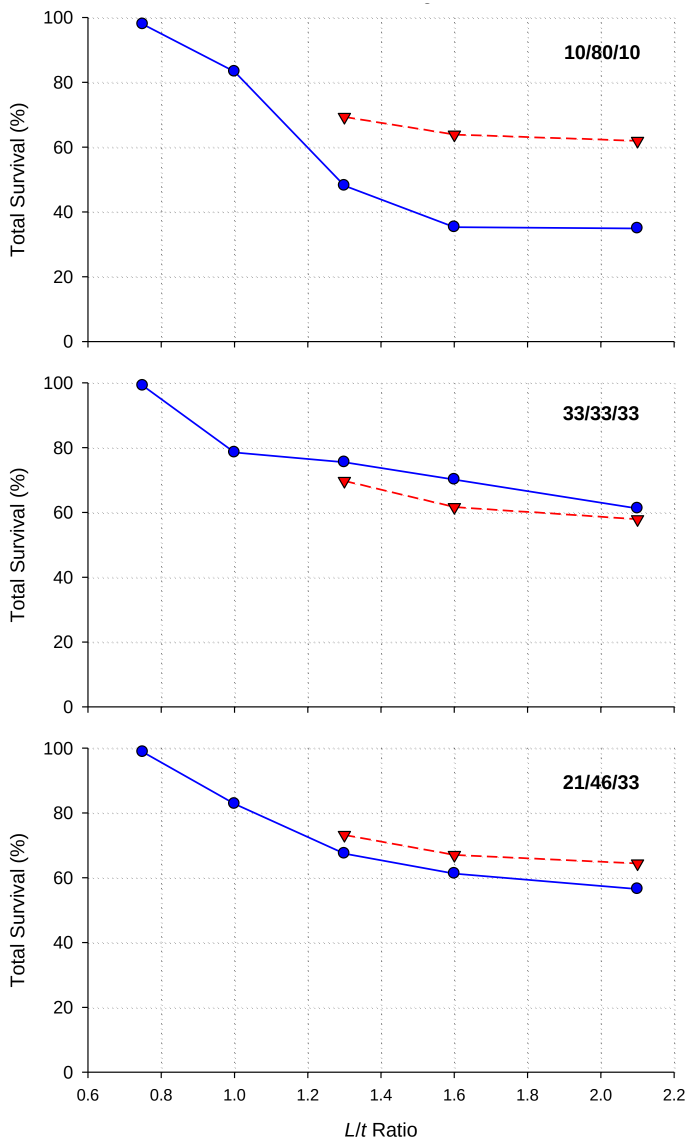
Results ***Effect of Strike Location and Fish Angle***





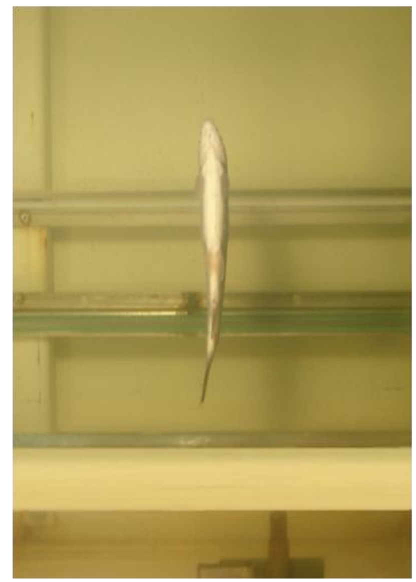


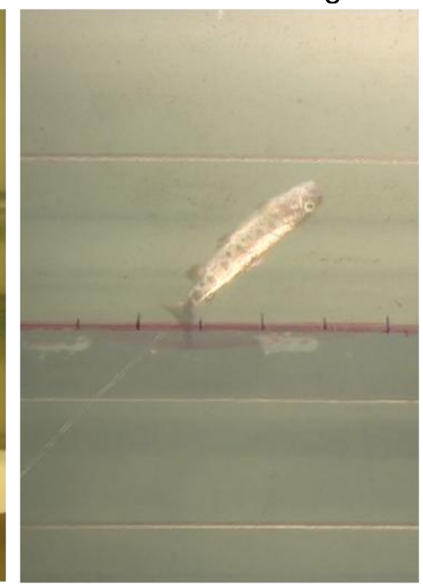
Results *Effect of Strike Location and Fish Angle*

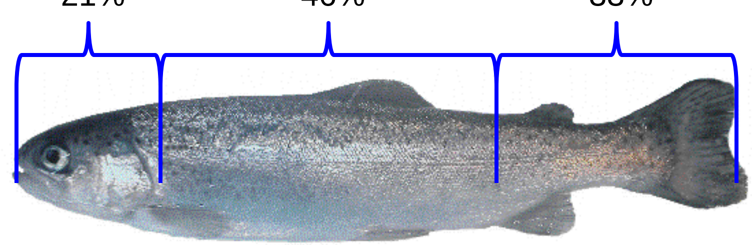


Strike Velocity = 12 m/s

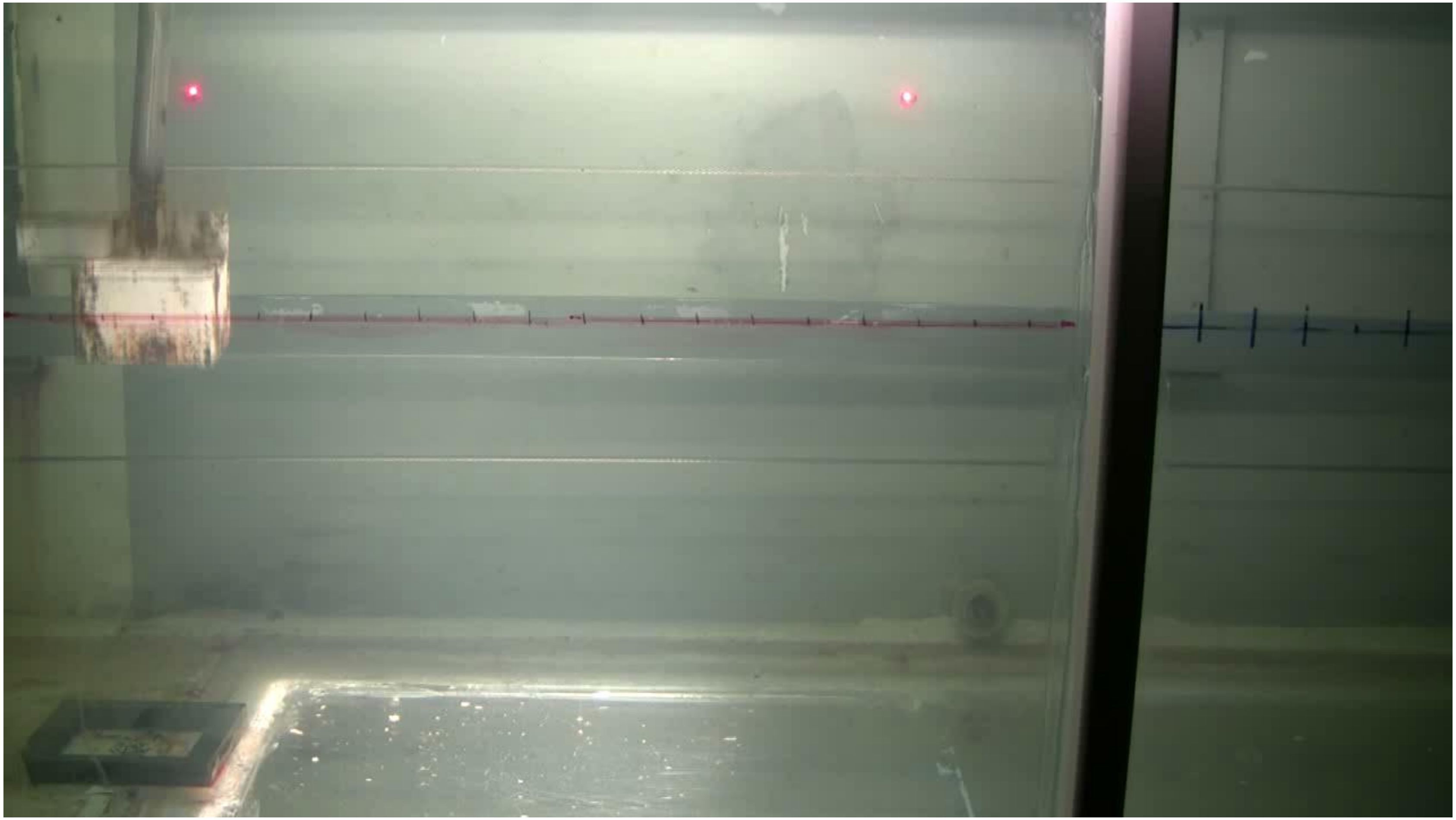
90^{o} fish angle   45^{o} fish angle





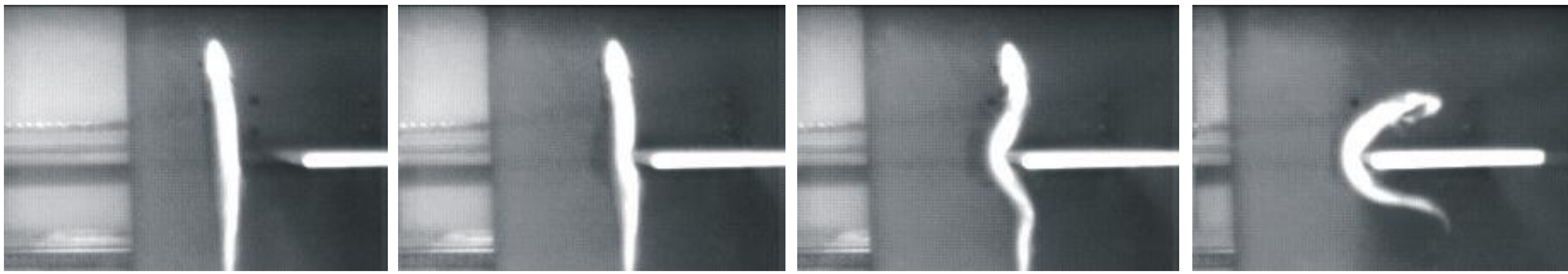


Video *Rainbow Trout – 45º*

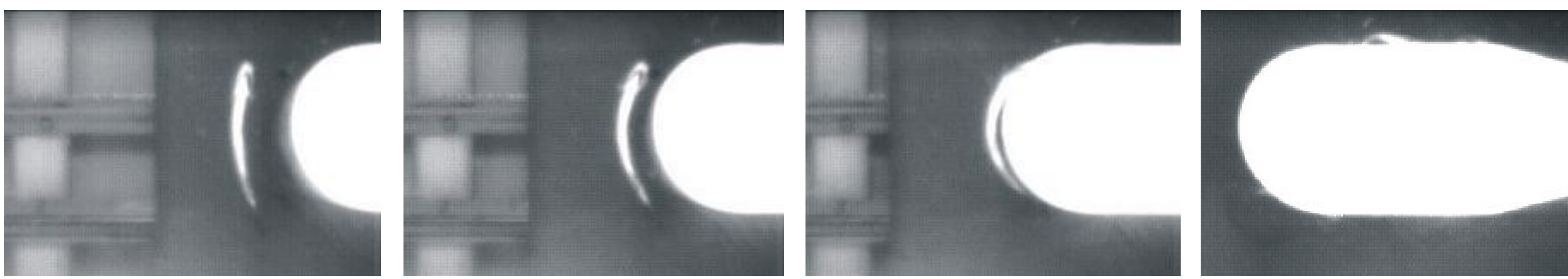


Hi-Speed Video

Fish L=250 mm; Blade t=10 mm; V=7.3 m/s

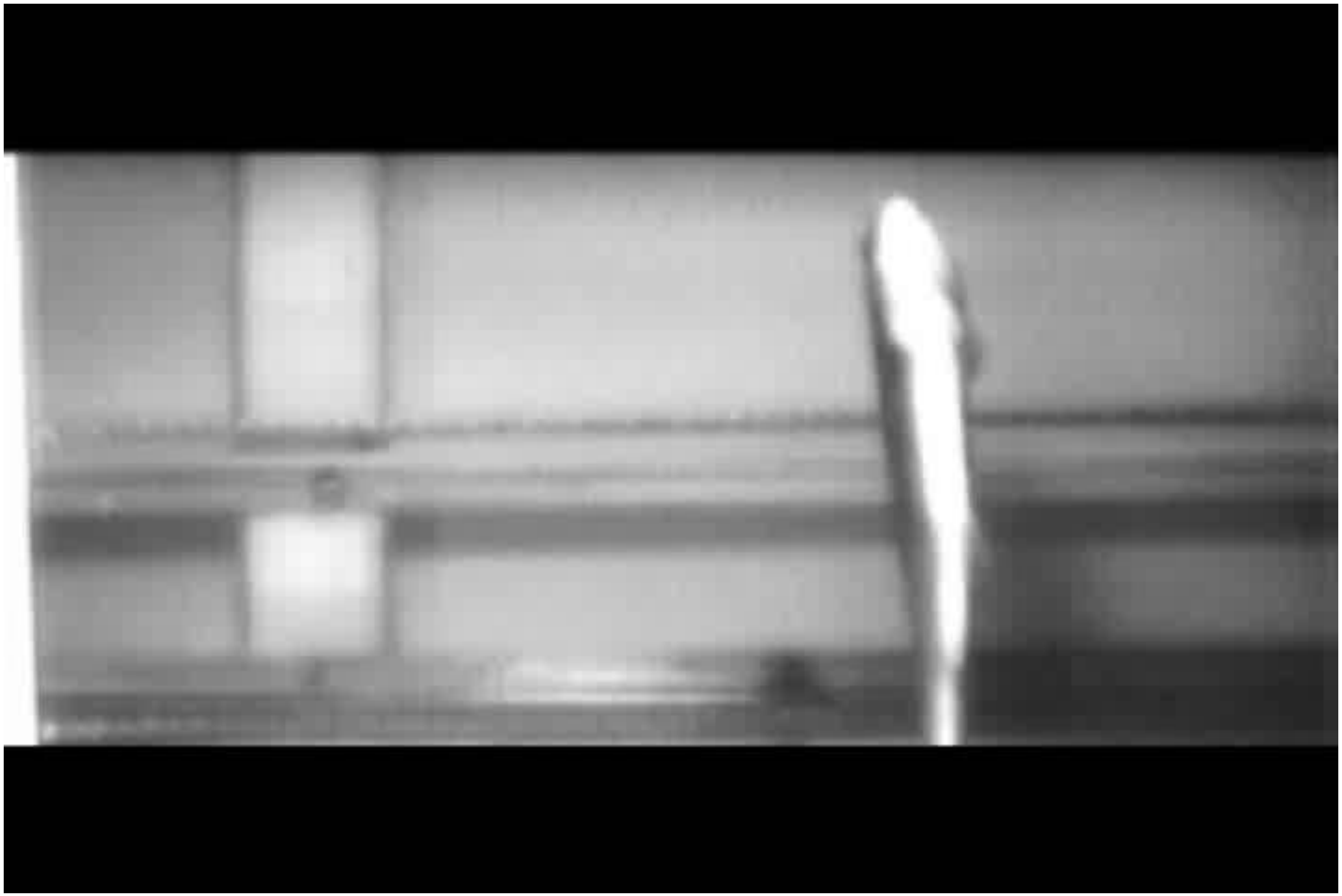


Fish L=150 mm; Blade t=150 mm; V=7.3 m/s



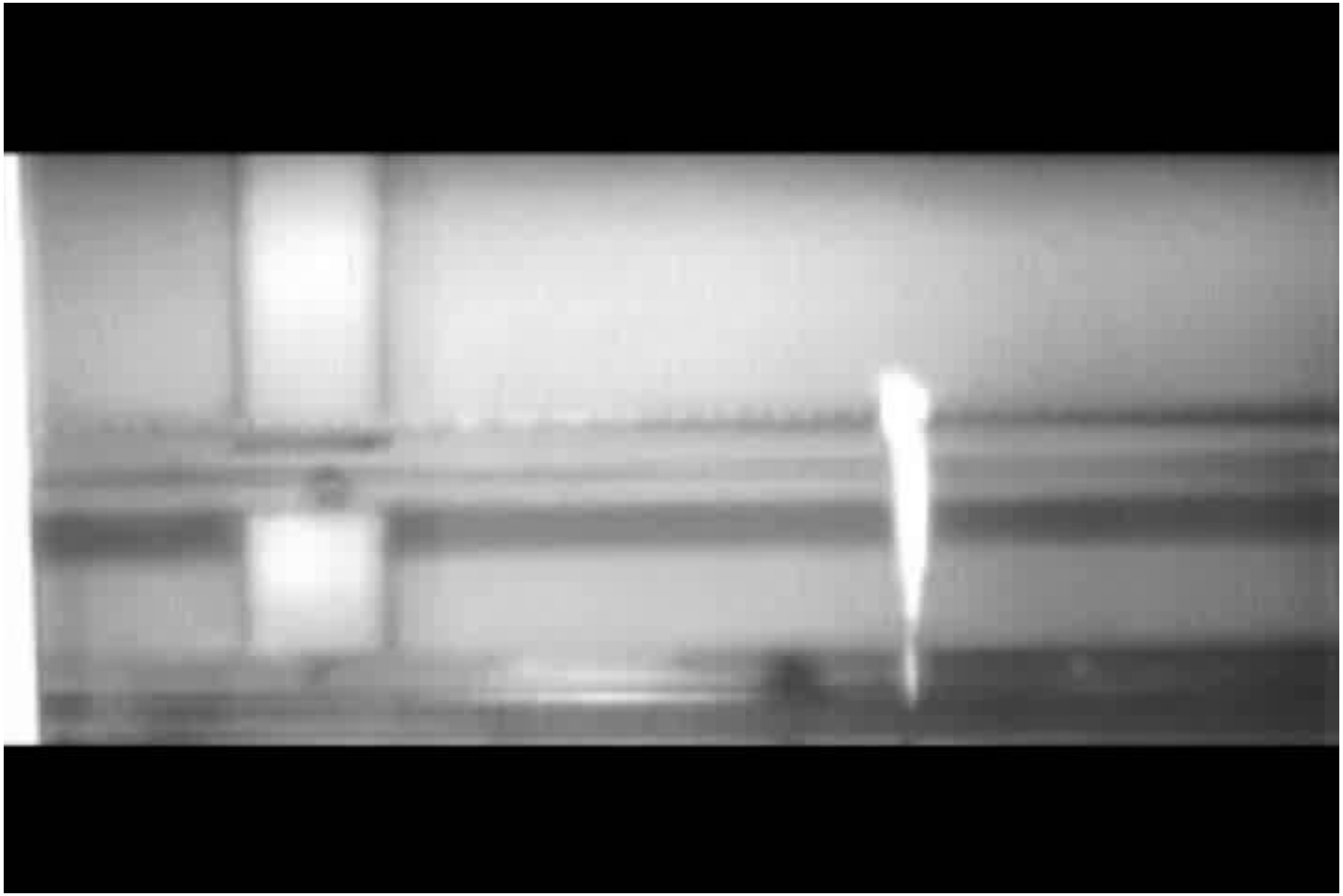
Hi-Speed Video *Rainbow Trout – 90°*

Fish L=250 mm; Blade t=10 mm; V=7.3 m/s



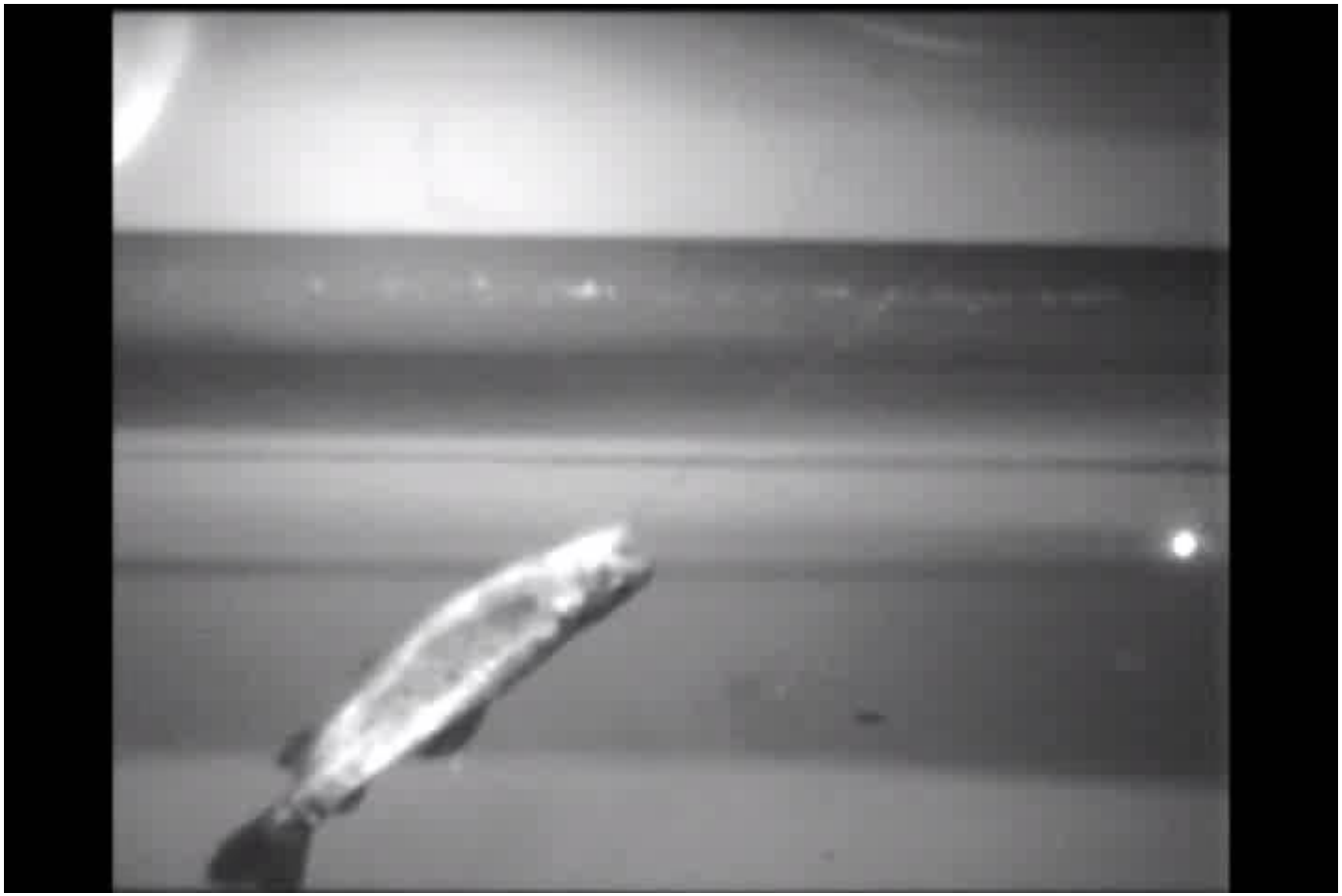
Hi-Speed Video *Rainbow Trout – 90º*

Fish L=150 mm; Blade t=150 mm; V=7.3 m/s



Hi-Speed Video ***Rainbow Trout – 45°***

Fish L=125 mm; Blade t=100 mm; V= 12 m/s



Conclusions and Implications

- ***Thicker (blunter) is better***: Strike survival is higher for thicker leading edges, particularly when fish length is similar or less than the blade thickness (*L*/*t* ratios <= 1).

- ***Slower is better***: Little or no mortality occurs at strike speeds of about 5 m/s (16 ft/s) and less and increases with velocity above this speed, particularly for *L*/*t* ratios >= 2.

- ***Being a sturgeon is better***: Strike survival of white sturgeon was higher than it was for trout. This is consistent with the results from the biological evaluation of the pilot-scale Alden turbine, which showed that turbine passage survival of sturgeon was significantly greater than it was for rainbow trout, coho salmon, smallmouth bass, and river herring. Sturgeon have a cartilaginous skeleton and no true scales.

Conclusions and Implications (continued)

- ***Turbine passage survival prediction***: The strike survival data can be incorporated into blade strike probability models to generate theoretical estimates of turbine passage survival.

- ***Fish-friendlier turbine design***: These data have also been used to improve the biological performance of the Alden turbine by increasing the leading edge blade thickness to 150 mm (6 inches), and can be considered in the design of other turbine types.

- ***Alden turbine performance***: The blade strike speed of the Alden turbine is in the range of 10-12 m/s. At these speeds, and with 150-mm thick leading edges, strike survival for fish passing through an Alden turbine will be greater than 80% for fish about 150 mm in length and smaller (including salmon smolts and juvenile shad and river herring).

- ***High turbine passage survival rates***: Because strike probability is low in the Alden turbine, overall survival is expected to exceed 98%.