FISH TALK
By Nick Hughes and Bill Hauser

Sensible Salmon (continued)

One of the most important economic decisions *(choices to save energy)* a migrating salmon makes is how fast to swim *(to find a good pace for a marathon*). Rather surprisingly analysis suggests there is a single ground speed that minimizes the cost-per-unit- distance traveled, irrespective of current speed *(in other words, there is an optimal point-to-point swimming speed regardless of the current speed of the river).* The cost-minimizing *(optimal)* ground speed for a 2.5 kg *(5.5 lb*) sockeye salmon is predicted to be about 0.5 m/s *(20 inches, or 1.7 feet, per second)* and the cost minimizing *(optimal)* speed for a 25 kg *(55 lb*) chinook about 0.8 m/s *(32 inches, or 2.7 feet, per second).* Of course fish that are in a hurry to reach the spawning grounds may swim faster, but generally fish should time their entry into the river to allow upstream migration at the most economical *(optimal)* speed, especially when their migration is a long one.

The energy needed to maintain this ground speed will depend on the speed of the current, and, all else being equal, salmon should swim upstream close to the bank or the stream bed, where friction reduces current speed. *(Drag caused by the "roughness" of the bottom materials and shore causes the current to slow down.)* They should also take advantage of local flow reversals in back eddies *(You have noticed that sometimes there are small counter currents in the water. Fish can use these currents to help them swim upstream.)* and the oscillations in current speed associated with tidal fluctuations *(incoming tides)* in downstream reaches. One fascinating new discovery by Scott Hinch and Em Standen *(two fish researchers)* at the University of British Columbia demonstrates that salmon can also extract energy from the small-scale flow reversals associated with turbulence *(caused by roughness and boulders).* The relative importance of this energy subsidy appears to decrease with increasing current speed, but, in slow water, fish may pay less to swim upstream than they would in still water *(Small-scale upstream currents are more valuable at lower average water velocity and in the lowest velocities, the upstream components may balance-out the downstream component.).* Fish themselves generate a trail of spinning vortices as they swim *(as a body passes through water, it creates it's own turbulence),* and its likely that members of a group can extract energy from these if they swim in the correct formation *(fish traveling in schools create turbulence that can help other members of the school swim upstream more easily).* As a result the lead fish should have a higher tailbeat frequency and shorter stride length (distance covered per tailbeat) than trailing fish. *(The tails (i.e., propellers, of the leading fish – or a fish traveling alone - must work harder than the trailing fish to cover the same distance.)*

Current speed is not the only factor that determines the cost of maintaining the cost-minimizing *(optimal)* ground speed. Wave drag may also be an important consideration. This is the drag that is generated when a fish swims close enough to the surface to create waves. *(The surface causes drag, just as the bottom does.)* The cost of generating these waves can be considerable, when the fish swims rapidly immediately under the surface the total drag it experiences may be five times higher than if it swam at the same speed well submerged. *(It is five times harder for a fish to swim just under the surface than to swim deeper in the water.)* Experimental work suggests that fish should swim at least three body diameters beneath the surface to avoid wave drag. *(The* *optimal swimming depth for a fish that is 5 inched high, from belly to back, is 15 inches below the surface.)* If we allow for an additional body depth between the fish's midline and the river bed then the minimum water depth required to avoid wave drag should be about four body diameters, this is about 0.7 m *(28 inches)* for a 2.5 kg *(5.5 lb*) sockeye and about 1.5 m *(60 inches, or, 5 feet)* for a 25 kg *(55 lb*) chinook. As a consequence large fish should swim upstream further from the banks and in deeper water than smaller ones, even if they have to swim against faster water as a result. *(This is the reason why chinook salmon migrate farther from shore than sockeye salmon.)* One rather fascinating aspect of wave drag is that hydrodynamic theory suggests the waves generated by different fish can cancel out, reducing or eliminating wave drag. *(Fish create turbulence as they swim, but the turbulence caused by one fish may cancel out the turbulence of a nearby fish; thus, there should be an optimal spacing between members of a school.)* According to this theory there is a particular horizontal spacing, and submergence depth at which this cancellation is likely to be most effective. It would be interesting to know if fish exploit this effect.

These are just some of the tricks that salmon may use to minimize their energy expenditure *(conserve energy for a long migration)* while migrating upstream. I hope reading about them will add to your enjoyment next time you are watching salmon making their way home.

(In summary: Salmon feed in the ocean to store energy to migrate up rivers to spawn. As they swim up river, they must expend energy to overcome the speed of the water current. Interestingly, for each different-sized fish there is a particular, optimal, over-the-ground migration speed that requires the least amount of energy expenditure. Water velocity in a uniform reach of a stream channel is not uniform; it is fastest near mid channel and about six-tenths of the depth above the bottom, it is slowest near the shore and bottom and surface drag slows the current, too. Salmon can select the optimal position in the stream channel, based on their size, where they find optimal current velocity to conserve energy.

In addition, salmon can take advantage of turbulences caused by bottom and surface drag and by other migrating salmon in the same school. Thus, sockeye salmon migrate closer to shore, in shallower water than chinook salmon; and, there is an advantage to migrating in a school rather than an individual. Dr. Hughes did not discuss this, but I suggest that this also implies that there is an advantage when different individuals in the same school are approximately the same size.

Bottom line: Salmon migrate in schools of similar-sized individuals and smaller-sized salmon migrate closer to shore than larger-sized salmon so they can conserve energy for successful spawning.)