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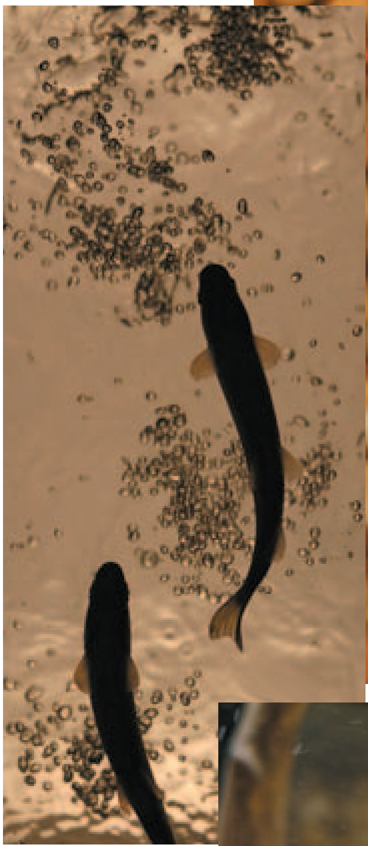
UP A CHOPPY RIVER

The Way of Trout



Rainbow trout streamline their bodies, folding fins back, when swimming actively (above, right) but in turbulent water allow their bodies to flap from side to side (above, left). Turbulence may also help explain schooling behavior (left).

STRANGE TO SAY, swimming through rough water may actually be easier than swimming across a calm pond. At least that's true for many kinds of fish, whose body structure allows them to capitalize on turbulence and use the water's energy to propel themselves forward by bouncing off eddies in an alternating side-to-side motion, like a sailboat tacking across a breeze.

This discovery, reported in a recent issue of *Science*, is the central finding of a doctoral dissertation by James Liao, a graduate student in organismic and evolutionary biology who became interested in fish as a child, during weekend afternoons fishing with his parents in Brooklyn's Prospect Park. In consultation with his adviser, professor of biology George Lauder, and Michael Triantafyllou and David Beal of MIT's department of ocean engineering, Liao inserted fine wire electrodes into the muscles of rainbow trout to measure their activity and, indirectly, the fishes' energy expenditure. Fish in choppy water, he determined, are not so much swimming as "going with the flow."

In general, when fish swim actively, they streamline their bodies, folding their fins back and fluttering their tails rapidly. When swimming through turbulence, they relax the fins so that their bodies flap from side to side, like a flag in the wind. The propulsive advantage is so great that fish actually seek out the turbulence created by a stationary stick or rock in a moving current.

Liao built computer models of the flag-flapping movement after spending hours observing fish swimming in tanks with artificial currents—"treadmills for fish," he says. A dusty powder of microscopic glass particles, which Liao added to the water and made visible with a laser, etched the currents. In a uniform current, the electrodes detected muscle activity along the entire body of the fish. But when he submerged a half-cylinder-shaped obstacle in the current, creating a pattern of whorls along both sides, the fish slalomed back and forth, going virtually limp. In the vortices created by the cylinder, the fish used only certain muscles near the head to position themselves. The flag-flapping motion requires minimal muscle activity—so minimal, in fact, that a dead fish, held in place in a turbulent current, ac-

Photographs by James Liao

tually makes the same motion as a live fish. The motion depends instead on the fish's skeletal structure and as yet undetermined connections of muscle and bone.

The relationship between turbulence and energy expenditure may also help explain why fish swim in schools. Two fish swimming forward, side by side, create a pattern of turbulence similar to that created by a single, fixed object in a moving current. This allows a third fish, swimming between and behind the pair, to exploit the energy they release into the water.

Liao's experiment used a very specific kind of turbulence—a single stick in the center of a rectangular tank with an artificial current—and fish that are the ichthyological equivalent of lab rats. But field observations have confirmed the lab results: Liao stuck cylinders into streams in Canada and observed the same behavior in wild trout and has recorded similar motions in species that do not school or live in flowing water. Anglers know that in real rivers, fish seek out "rest stops" behind rocks or sticks; the obstacles shield the fish from the current and the eddies on either side of the calm spot propel them forward. "It makes a lot of sense," Liao says. "If you're in a windstorm and you're behind a tree, you don't feel the wind as much."

His findings may help create better fish ladders, the tiered structures built alongside dams that help fish navigate rivers freely. Introducing turbulence could help make such ladders more fish-friendly. The research even mirrors work in a field as seemingly remote as robotics, where designers increasingly are imitating nature by making robots springy, rather than stiff. Flexible robots, like animals, can stabilize themselves with less energy than more rigid robots can, and they recover more easily from mishaps when moving on uneven surfaces—much like the limp fish bouncing off eddies. New insights into fish anatomy could also affect designs for robotic fish, which might prove useful in military or other tasks, such as surveying sewage plants.

Liao's work even has metaphorical implications. His findings debunk the image of heroic salmon fighting their way upstream to spawn. That swim against the current is probably easier than we thought. ~ELIZABETH GUDRAIS

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CROOKS TAKE EARLY RETIREMENT

Twigs Bent, Trees Go Straight

In a discussion of criminal-justice issues, former U. S. Attorney General Janet Reno once stated that the life trajectory for most criminals was essentially set by the age of three. Among criminal-justice professionals, an analogous theory is common: a young person with a low IQ who shows a high level of egocentricity and aggressiveness and exhibits poor self-control is likely to become a lifelong, career criminal.

But in a recent book, *Shared Beginnings, Divergent Lives: Delinquent Boys to Age 70* (Harvard University Press), Ford professor of the social sciences Robert Sampson and John Laub of the University of Maryland suggest instead that various environmental factors predict long-term behavior better than childhood risk factors. "Why do some juvenile offenders persist in committing criminal acts as they grow older and others desist?" asks Sampson. "Developmental child psychology doesn't really provide an adequate explanation."

Sampson and Laub revisited the classic 1949 study *Unraveling Juvenile Delinquency*, by Sheldon Glueck, Ph.D. '24, S.D. '58, the late Pound professor of law emeritus, and Eleanor Touroff Glueck, Ed.D. '25, S.D. '58. The Gluecks tracked 1,000 men born in Boston in the late 1920s or early 1930s: 500 were juvenile delinquents who had been committed to a correctional facility as teenagers or young men; a control group of 500 non-delinquent males attended public schools. The original research tracked subjects up to age 25, then followed up at age 32. Sampson and Laub extended this longitudinal study of the 500 original delinquents. "We followed them in three ways," Sampson explains: "by doing criminal history checks, examining death records and causes of death, and by conducting interviews." They managed to locate and interview 52 of the men, 35 years after they had last been seen, in the 1960s.

The study showed a dramatic drop in criminal activity among the original subject pool as the men aged. Between the ages of 17 and 24, a robust 84 percent of the subjects contacted had committed violent crimes. But when the men reached their forties, that number dropped sharply, to 14 percent; it fell to just 3 percent two decades later. Property crimes and alcohol- and drug-related crimes showed similar significant decreases. The average subject committed his first offense at age 12—but also desisted from crime from age 37 onward. "Any social or environmental factors that helped established positive routines played major roles in influencing future behaviors," says Sampson.

Marriage was particularly powerful in this regard. "Many of the men who were high-rate offenders in their youth were