Healers. Edith Montgomery and Belinda Labrosse in the RCT research library, the largest collection of torture-related documents in the world.

Changing a Fish’s Bony Armor
In the Wink of a Gene

Genetic researchers have become fascinated by the threespine stickleback, a fish that has evolved rapidly along similar lines in distant lakes.

A sassy little fish—a mere 6 centimeters long—that can turn a threatening red, builds nests, and feuds with competitors is now becoming a star in research on genetics and evolution. Long a favorite of behavioral scientists, the threespine stickleback is garnering attention for what it can reveal about genes, morphology, and the speed at which a species can adapt. Half a dozen recent papers on sticklebacks show “all kinds of interesting things about the genetic and molecular basis of how organisms evolve,” says David Kingsley, a vertebrate geneticist at Stanford University.

This new research adds weight to a provocative idea that a little DNA—perhaps just a single gene—can control many traits that affect an organism’s ability to thrive; in this case, the gene may have enabled sticklebacks to evolve out of tight situations. Not only have sticklebacks adapted quickly to past and current environmental change, but several researchers have documented that they still retain a remarkable adaptive flexibility.

Since the 1930s, the prevailing view has been that evolution moves in a slow shuffle, advancing in small increments, propelled by numerous, minor genetic changes. But some have challenged this dogma, notably H. Allen Orr, an evolutionary biologist at the University of Rochester in New York. In 1992, he and his colleagues argued that just a few genes, perhaps even one, could power long-term change. Such change could rev up speciation. Lately, the Orr camp seems to be gaining ground, in part because of studies of sticklebacks, says R. Craig Albertson, an evolutionary biologist at the Forsyth Institute in Boston. He and others are finding that “simple genetic changes can have profound effects.”

Salty past
Kingsley is a convert to stickleback research. Five years ago he and his postdoctoral fellow Katie Peichel turned to it when they were looking for a way to add a touch of reality to their studies of the genetics of bone development. Neither lab mice, the subject of their previous work, nor labbred zebrafish offered much insight into the causes of natural variation in a natural setting. So Kingsley and his students searched for a species with a rich natural history literature and a lifestyle that would enable both field and lab studies. “The stickleback had everything we wanted,” he recalls. About the same time, zebrafish expert John Postlethwait of the University of Oregon, Eugene, was on a similar hunt, casting about for a fish with a well-known biology and an interesting evolutionary background in which he
could apply molecular techniques he had developed. He, too, landed the stickleback.

Both researchers were attracted by a huge body of knowledge on sticklebacks—at least 2000 scientific papers and seven textbooks—dating back to the 19th century. The fish’s fame increased in 1973 when Niko-laas Tinbergen won a Nobel Prize based in part on his studies of stickleback behavior, which is now the focus of perhaps 100 labs, according to Kingsley.

Another draw was the stickleback’s evolutionary history, which includes a major transition. Sticklebacks were once a solely saltwater species that migrated from the sea to streams and lakes to breed; as the glaciers retreated up to 22,000 years ago, some settled in lakes. Although they evolved to look very different from their ancestors, they often came to resemble their counterparts who were evolving in a similar way in lakes that are geographically distant (Science, 14 January 2000, p. 207). These lakes now are natural laboratories for evolutionary studies, says Susan Foster, an evolutionary biologist at Clark University in Worcester, Massachusetts: “These remarkably divergent populations have created a unique resource,” in part because freshwater and saltwater populations can interbreed.

Recently, molecular genetic studies have been added to stickleback science. Says Kingsley: “We are beginning to collect real data on the number and location of the chromosomal regions that control substantial evolutionary modification.” Those regions can control multiple characteristics.

**Armor is optional**

Genetic studies took off several years ago when the Kingsley and Postlethwait groups independently began to breed threespine sticklebacks from lakes with marine counterparts. The research teams have examined various geographic locations. In every population researchers have examined, from Japan to California to Iceland, they are finding the same thing: A gene or set of nearby genes is causing the loss of certain parts of the fish’s armor. “It’s remarkable,” says Postlethwait, that a single gene could exert such a large effect in so many different groups of sticklebacks. Along with armor, “a whole suite of bony characters is changing,” he says, including jaw shape and bones associated with protecting the gills. This is not what researchers had expected to find. But when they tried a breeding experiment, the same pattern emerged: Small DNA segments affected vast areas of bone and armor.

In one study, Kingsley and Stanford graduate student Pamela Colosimo crossed well-armored marine fish with fish from Paxton Lake in British Columbia. The lake fish had only the front plates—the first ones to form during development. Colosimo measured the pattern, number, and size of the plates in the progeny, then by genetic analysis pinpointed the stretches of DNA involved in plate formation. One area had the greatest sway, accounting for 75% of the number and distribution of the plates, she, Kingsley, and their colleagues reported in the 30 March online journal PLoS Biology. Changes in this stretch of DNA sequence caused a fivefold reduction in the number of plates, whereas three other stretches had a slight effect. The same small stretch of DNA proved equally influential when they studied freshwater fish from a California lake 1300 kilometers distant. Their geographic distribution virtually guarantees that the fish lost their plates independently, says Kingsley.

Similar findings have appeared in work by Bell and William Cresko, Postlethwait, and their colleagues at the University of Oregon. Using a different strategy, they narrowed the cause of a change in some of the body armor to a single gene. Cresko collected threespine sticklebacks from three lakes in Alaska at least 15 kilometers apart, as well as marine fish...
from two sites. After confirming that there were large, consistent differences between lake fish and sea fish, they performed breeding studies. In one experiment, they crossed marine and freshwater fish and found that the resulting offspring all had a complete set of armor and a fully formed pelvis—suggesting that the DNA, or allele, belonging to the marine fish overrode the effects of the allele of the freshwater cousins. In the second generation, the researchers saw that three out of four had a full set of this armor, confirming a dominant allele, they reported in the 20 April issue of the Proceedings of the National Academy of Sciences.

Next, the Oregon researchers tested to see if the altered pelvis and lateral plates of the lake fish were controlled by the same genes in each population. They expected the opposite: that the gene involved in armor loss would be different in the three groups because each had evolved that trait independently. But their surprising finding was that the alterations were always in the same gene. Dolph Schluter, an evolutionary biologist at the University of British Columbia in Vancouver, Canada, reached the same conclusion, this time with marine and freshwater fish from British Columbia and Japan. Although the DNA sequence has not been identified, “it could well be the same gene everywhere,” says Schluter, who is reporting these results in an upcoming issue of The American Naturalist.

Bell has found that, from an evolutionary perspective, this gene may change at lightning speeds. In the most recent issue of Evolution, he and his colleagues report on a case in Alaska where plates disappeared in most fish within a decade. The findings come from Loberg Lake near the Cook Inlet in southern Alaska, where in 1982, the Alaska Department of Fish and Game had prepared the water for restocking with salmon and trout by poisoning all the fish in it. Eight years later, Bell and his colleagues found that the sticklebacks were back, this time with plates, suggesting that they had come upstream from a saltwater inlet.

As Bell’s team sampled the lake for the next 10 years, taking note of the sticklebacks’ plate makeup, the number of armored fish declined. In 1990, 96% of the sticklebacks had the full suite of plates; in 1993, only 39% did. His crew spotted the beginning of this transition in 1991, noting that some individuals had just the front plates. By 2001, that variety represented 75% of the sticklebacks sampled. The number of plates also declined—from 33 to 32 in the fish with all their plates and from seven to six and a half in those with just the anterior ones. “It was obvious that things were changing very fast,” says Bell.

The results suggested that natural selection had taken its toll on the armored fish in just a few years. “That wouldn’t happen if you had to wait for new mutations to occur,” notes Postlethwait. Instead, he thinks the allele responsible for the loss of plates was present all along. But its effects were muted because it was recessive and rare in the population. “When you get into fresh water, [the situation] would change rapidly,” he explains. Fish that still carried the allele for plates didn’t thrive.

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