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Fish May Show How Nature Diversifies



Image Title: A marine stickleback with skeletal structures shown in red. These fish have undergone a remarkable evolutionary radiation in thousands of coastal streams and lakes of the Northern Hemisphere. Freshwater populations with different sizes, shapes, and numbers of spines, plates, and other characteristics are being interbred for genetic studies of natural variation in recently evolved species. - Katie Peichel, Pam Colosimo, and David Kingsley (HHMI and Stanford University)

Although the threespine stickleback fish has been celebrated on the currency of the Netherlands and been a star of a pioneering 1928 French documentary film, the fish has found its most receptive audience with biologists, who have been studying it for more than 100 years. In what may be its most important role yet, the stickleback is being used as a model by researchers at the Howard Hughes Medical Institute (HHMI) at Stanford University to track the genetic changes that define a species, a puzzle that until now could not be tested experimentally in vertebrate animals.

In the December 20, 2001, issue of the journal *Nature*, HHMI investigator David M. Kingsley, HHMI associate Catherine L. Peichel and their colleagues at Stanford, the University of Wisconsin, Eau Claire, and the

University of British Columbia, report the creation of a genetic map of the fish that will make it possible for Kingsley's lab and others to tie behavioral, ecological, morphological and physiological differences among the various species of sticklebacks to changes in the genome.

"We see this as our chance to find out how many genetic changes it takes to evolve new traits," said Kingsley. "Using this method we can ask which genes or developmental pathways nature uses to create a new species."

The scientists were able to study the molecular evolution of the threespine stickleback due to its recent evolution since the end of the last Ice Age, which occurred 15,000 years ago. When the giant glaciers melted, they created thousands of lakes and streams in North America, Europe, and Asia. These waters were colonized by the stickleback's marine ancestors, which adapted to life in freshwater. The spiny fish, which are one- to six-inches long, were remarkably successful in adapting to various niches in their new habitats.

"The fish have evolved so recently that it is still possible to carry out crosses between the new species using artificial fertilization," said Kingsley. "This makes it possible to use genetics to study the number and location of genetic changes that are responsible for evolutionary change."

The isolated pockets of sticklebacks have created thousands of evolutionary experiments, he added. By studying the genetic variation among various species, Kingsley said it should be possible to discover how evolution generates new species adapted to life in different environments.

As a first test of the new genetic map, Kingsley and his associates crossed two species of sticklebacks that live in Priest Lake in British Columbia. One species inhabits the grassy, murky lake bottom near shore, while the other lives mainly in the open water. The two species don't interbreed in the wild and look dissimilar. The species that lives near shore, for example, has less body armor and a thicker body. The species that lives in open water more closely resembles the ancestral form, which still lives in the open ocean, and has larger eyes, a longer snout and jaw, and more numerous gill rakers for filter feeding.

When the researchers looked at the spectrum of skeletal changes between the species, they saw two phenomena. First, they discovered that different chromosome regions control the development of different parts of the fish skeleton. Even parts of the skeleton that are in close proximity to each other are controlled by different regions of the genome.

"This makes sense because when you think about the diversity of size and shape among different animals, it is clear that vertebrates have to be able to independently modify the size and shape of individual skeletal features," said Kingsley.

Second, the researchers discovered that the longest spine on the fishes' back and the single spine projecting from its belly, whose lengths are highly correlated, are also linked genetically in a single chromosome region.

“The fish use these spines for defense against predators,” said Kingsley. “The total length of these spines sets the cross-sectional diameter of the fish, which helps determine whether or not they get eaten by predators like trout. Having both spine lengths controlled by the same genetic region may help explain how the fish achieve useful modifications of these functionally related skeletal structures.”

The overall results point to many different chromosome regions that affect specific aspects of skeletal anatomy in sticklebacks and reveal a flexible genetic system for independent modification of the size and number of different feeding and armor structures, the authors report. But perhaps more important, said Kingsley, is the creation of a resource that will help bring together a large body of ecological work with the tools of modern genomics to create a new major model organism for the study of evolution of species.

“There is a lot of interest right now in comparative genomics,” said Kingsley. “But for most of the species proposed to be studied, the timescale of evolutionary divergence is enormous, making it difficult to sort out which genetic changes are truly responsible for species differences. In contrast with the sticklebacks, this genetic approach lets the organism tell us where the relevant genes are. Rather than betting on a favorite gene being important, we let the fish tell us which chromosome regions we should pay attention to. Those regions can then be studied in detail to identify the molecular basis of evolutionary changes in vertebrates.”