

Macroevolution: Alive and Well

In Sticklebacks

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Kindly provided by the author.

Creationists remind us often about the alleged inability of evolutionary biologists to directly demonstrate macroevolution. They grant that microevolutionary change might be possible, but moths are still moths, dogs are still dogs, frogs are still frogs, etc. Now they'll have to add a new example to their tiresome litany – the threespine stickleback. Only this time, they will be confronted with an example of macroevolution in action that they cannot easily dismiss.

So what's the basis of my enthusiasm? Three papers, one in *Science*, one in *Nature*, and one in the *Proceedings of the National Academy of Science* (Colosimo *et al.*, 2005; Shapiro *et al.*, 2004; and Cresko *et al.*, 2004) appeared in 2004 and 2005 showing that dramatic morphological changes have appeared *independently* in a number of populations of freshwater threespine sticklebacks that have all evolved since the end of the last glaciation (i.e., between 9,000 and 14,000 years ago). Some (perhaps even most) of these populations are thought to be new species. This phenomenon, known as *parallel speciation* (Rundel *et al.*, 2000), is remarkable in its own right, but is not the subject here.

The subject is the rapid morphological change that has accompanied the probable speciation events. The marine ancestors of the freshwater populations of sticklebacks have: 1) a series of bony dermal plates (i.e., body armor) that extend the lateral length of the trunk all the way to the tail fin; and 2) pelvic spines that are part of the pelvic appendages of these fish (homologous to tetrapod hindlimbs). *The remarkable observation is that these structures, both body armor and pelvic spines, have been repeatedly lost in multiple populations of freshwater sticklebacks.* Even more surprising, some of these populations are in locations as distant from each other as Alaska and Iceland (Shapiro *et al.*, 2004). There is no question about what we have here. This is major morphological change that has taken place in about 10,000 years, not just once, but a number of times! If this isn't macroevolution by any reasonable definition of the term, I'll eat my evolutionist's hat.

But the story gets better, much better in fact. As this work has gone forward, the investigators have combined the techniques of classical genetics and modern molecular genetics to identify the genes involved in these changes and to elucidate the probable ways in which gene function has been altered to produce loss of body armor and loss of the pelvic spines. The genes are inherited in a pattern that is largely consistent with classical Mendelian rules. Furthermore, both the gene that controls body armor and the gene that controls the pelvic spines turn out to be developmental regulatory genes. This is precisely what the emerging field called "evo-devo" (i.e., the evolution of development) has predicted we would find to be the genetic basis of macroevolutionary change (e.g., see Goodman and Coughlin, 2000; Pennisi, 2002a, 2002b).

In the case of the body armor, the relevant gene encodes Ectodysplasin, a cell signaling protein known to be involved in regulating the development of dermal scales and a variety of ectodermal structures (Colosimo *et al.*, 2005). The alleles of this gene that are involved in armor loss appear to have altered regulatory regions. These alleles are already present at very low frequencies in marine populations, but become fixed due to positive selection in the freshwater populations (Colosimo *et al.*, 2005).

In the case of the pelvic appendages, the primary gene involved is called *Pitx1* (Shapiro *et al.*, 2004). As these authors point out, this same gene is involved in hindlimb development in tetrapods (e.g., mice that carry a double recessive lethal form of the gene show greatly reduced hindlimbs and a pronounced left-right asymmetry in this reduction; the same left-right asymmetry is seen in the stickleback pelvic appendage). In sticklebacks with reduced or absent pelvic appendages, the *Pitx1* protein is not altered; rather, the expression of the gene is drastically reduced, but only in the pelvic appendages and the tail fin. The observation strongly suggests that this is a regulatory mutation.

Were it not for the pressure that is being applied to biology teachers by creationists, this article might be one of mainly academic interest. But that pressure is increasing significantly because to the recent surge in activity of “intelligent design” creationists who cry out for us to “teach the controversy” (e.g., see Scott and Branch, 2003). A central part of this alleged “controversy” is the supposed impossibility of macroevolution. The direct experimental demonstration of the specific genetic basis of a documented macroevolutionary change thus becomes very significant to biology teachers as well as to research scientists. By the way, this example also shows clearly that macroevolutionary changes are accomplished using classic microevolutionary mechanisms to alter the frequencies of developmental regulatory alleles.

Furthermore, the example is pedagogically useful. While the three referenced papers themselves are probably too difficult for most high school students, there have been several popularized summaries of the work aimed at less specialized readers (e.g., see Gibson, 2005; Pennisi, 2004). Some of the illustrations that contrast the marine ancestors with the freshwater descendants lacking body armor and pelvic appendages are quite spectacular. At least in the case of the Cresko *et al.* (2004) article, these full-color illustrations can be directly downloaded from the P.N.A.S. website as PowerPoint slides for teaching: <http://www.pnas.org/cgi/content/full/101/16/6050>. One of these slides is even arranged to show the Mendelian pattern of inheritance of the traits. The cited URL will take you directly to a full-text version of the Cresko *et al.* paper so that you can scroll through and pick the illustrations that might seem appropriate for your classroom.

The results that I have presented here are merely the tip of a giant “evo-devo” iceberg that is providing remarkable new evidence in support of the theory of evolution. The field of evolutionary developmental genetics is emerging as a field that is generating empirically testable hypotheses about molecular pathways of evolution that organisms have followed to reach their present state. Finding out about this evidence will be challenging for the classroom teacher. Creationists will continue to “spin” their own interpretations of the evidence. Nevertheless, it is my hope that this article will be seen by “evo-devo” researchers who will recognize the importance of sharing their findings with teachers in future issues of *The American Biology Teacher*.

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