Songbirds swap colorful plumage genes across species lines among their evolutionary neighbors

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Some bird species on neighboring tips of the evolutionary tree can interbreed, with interesting genomic results.

Kaleb Anderson

People typically think about evolution as a linear process where, within a species, the classic adage of "survival of the fittest" is constantly at play. New DNA mutations arise and get passed from parents to offspring. If any genetic changes prove to be beneficial, they might give those young a survival edge.

Over the great span of time – through the slow closing of a land bridge here or the rise of a mountain range there – species eventually split. They go on evolving slowly along their own trajectories with their own unique mutations. That's the process that over the past 3.5 billion years has created the millions of branches on the evolutionary tree of life.

However, new genome sequencing data reveals an unexpected twist to this long evolutionary story. It turns out that the boundaries between species on their own branches of this tree are a little more permeable than previously thought. Rather than waiting around for new mutations to solve a particular problem, interbreeding between different species can introduce ready-made genetic advantages.

Unraveling the story of life, one genome at a time

The author with a red-faced warbler (Cardellina rubrifrons), one of the wood warbler species included in the study.
Kevin Bennett

As an evolutionary biologist, I've been studying the stories written in the genomes of animals for over two decades. I focus mostly on colorful songbirds called wood warblers that hail from North, Central and South America. There are approximately 115 species in total, and they come in a dazzling array of bright colors.

Some of these birds might be familiar to you, such as the brilliant Blackburnian warbler (Setophaga fusca), which lights up the tops of the pine trees in the eastern forests of the U.S. and Canada during spring and summer. Other warbler species might be less familiar, like the pink-headed warbler (Cardellina versicolor), which lives only in the highlands of Guatemala and southern Mexico.

The story of these New World warblers was written within the past 10 million years or so – relatively recently in evolutionary terms. They're all, in effect, "evolutionary neighbors," sitting next to each other at the tips of the crown of the tree of life. In my team's most recent work, led by evolutionary biologist Kevin Bennett, we gathered a massive amount of data from warbler genomes – over 2 trillion base pairs, from nearly every species of warbler – to learn more about their evolutionary history.

We found that some species have unexpectedly leaped over evolutionary hurdles by sharing solutions to evolutionary problems. We are now learning from this kind of data that species aren't just vertical, evolutionary silos, as we once thought. Instead, there is much more horizontal "cross talk" among the branches of the evolutionary tree.

These warblers now join Amazonian butterflies, cichlid fish in Africa, as well as our own hominid lineage, as exemplars of this process of evolutionary sharing.

Nestlings in a hybrid zone between golden-winged (Vermivora chrysoptera) and blue-winged warblers (V. cyanoptera). Hybrid chicks that grow up to 'backcross' with one of their parent species can introduce new genes into the mix for a population.

Abigail Valine

How does evolutionary sharing actually occur?

Genetic sharing among evolutionary neighbors all happens through hybrids: the offspring produced when individuals from two species mate. Famous hybrids include offspring between polar and grizzly bears – affectionately called "pizzly" bears – as well as mules, the offspring of horses and donkeys.

But unlike mules, which are sterile and cannot reproduce, in instances of natural warbler hybrids, we think these rare offspring can sometimes "backcross": They breed with one of the parental species, ultimately moving genes across species boundaries. These hybrids are the genetic conduit by which genes are shared across the branches in the evolutionary tree.

But aren't we all taught in biology class that species can't interbreed with other species? Isn't that what helps define a species?

In reality, biology always has its exceptions and fuzzy edges. And this is one: Species result from the very gradual process of speciation, which typically takes millions of years. The taxonomic boxes we humans like to put around "species" don't typically capture the blurry borders around lineages early in this long process, when otherwise distinct plants and animals can still interbreed.

Indeed, my lab has described many interspecies and intergenus hybrids in warblers, including at least one arising from both. We've also identified "hybrid zones" between very closely related species, where hybridization is rampant.

And if the genes within these hybrids are beneficial in the recipient species, they'll spread – just like a new, beneficial mutation passed to an offspring. In this case, it's not just a single mutation but can be a whole new complement of mutations in multiple genes.

Wood warblers need particular genes to help them process and deposit certain pigment molecules in what they eat to make brightly colored feathers, like in this yellow warbler.

Marc Guitard/Moment via Getty Images

Shared genes solve 'evolutionary problems'

Our most recent work in wood warblers shows that the evolutionary solutions they're sharing are related to their coloration.

In this family of birds, we previously identified genes related to their carotenoid-based coloration. Carotenoid pigments give birds their brilliant orange, yellow and red plumes – colors that are exemplified by the aptly named yellow warbler. But birds, like all vertebrates, can't synthesize carotenoid pigments on their own. They need to obtain carotenoids from their diet and then chemically process them.

But processing carotenoids appears to be an evolutionary hurdle that not all birds have jumped and a rather difficult problem to solve. Our genome sequencing shows that these warblers have more shared carotenoid genes than other shared genes in their genome, and it's likely that different versions of carotenoid-processing genes improve the recipients' fitness.

One carotenoid-processing gene, called beta-carotene oxygenase 2, or BCO2, has been shared several times within this single family of birds. Moreover, BCO2 appears to be so popular that it shows second-order sharing: passing from one species to another, and then on to a third.

A sign of quality on the mating circuit

My colleagues and I think these genes are so popular because male warblers use these carotenoid colors to attract females that have a discerning eye. Male birds obtain carotenoids from the insects they eat. The idea is that the more colorful a male is, the higher the quality of its diet.

From across the forest, the males' rich carotenoid colors are signaling that they'd be good dads with good genes. Biologists call this kind of display an "honest signal." And if males obtain a new gene that allows them to process carotenoids more efficiently, it's likely to spread faster and farther into the species, as the brighter males will potentially have greater mating success.

Our research with warblers demonstrates how evolution can shuffle genes across the thin lines between species. These close evolutionary neighbors sometimes share DNA, including potentially beneficial mutations, by mating across the species lines defined by humans' classification systems.

We suspect that the more we look, the more we'll find this kind of borrowing among evolutionary neighbors. As we unravel the stories told in the genomes of nature's problem-solvers, it's likely we'll find that their threads are deeply intertwined.

David Toews works for Pennsylvania State University. He receives funding from The National Science Foundation.