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OVERCOMING OBSTACLES TO EVOLUTION

Evolution and Biogeography: Leading Students in Darwin's and Wallace's Footsteps

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Abstract Exploring life's diversity and geography's effect on it was central to Darwin and Wallace's parallel discoveries of evolution. Those discoveries required the two to overcome their own misconceptions about species and biology. By helping students to see the world through the eyes of explorers and placing life's diversity into a geographic context, teachers can help students overcome those same barriers to the acceptance of evolution and deepen students' appreciation of biodiversity.

Keywords Biogeography · Teaching evolution · Charles Darwin · Alfred Russel Wallace

"I begin to feel rather dissatisfied with a mere local collection, little is to be learnt by it," a young Alfred Russel Wallace wrote to Henry Bates in 1846. He and Bates had been collecting beetles in Wales, winning minor scientific reputations from their reports of a few rare specimens, but he hungered for a broader perspective. "I shd. like to take some one family, to study thoroughly—principally with a view to the theory of the origin of species" (Raby 2001, p. 28).

His desire to travel was spurred in part by tales of an earlier generation of naturalists, men like Charles Darwin, whose journey around the world from 1831 to 1836 had earned him scientific fame, but also by the explorers who had earlier inspired Darwin, especially Alexander von Humboldt and Joseph Banks (Holmes 2008; O'Brian 1997).

A year after Wallace wrote that letter, he and Bates were collecting specimens in the Amazon for sale to museums and collectors back in Britain. In the next decade, Wallace traveled on to collect in the Indo-Australian Archipelago, selling specimens to many scientists. Among his customers was Charles Darwin, who was secretly developing his theory on the origin of species.

But Wallace, too, was working on such a theory independently, hitting on the crucial insight while ill with fever. In 1858, when Wallace sent Darwin a draft of his paper sketching his theory, Darwin was astonished at the similarities to his own secret work. Working on opposite sides of the globe, these two world travelers had developed nearly identical theories.

It is significant that the theory of evolution by natural selection was formulated by naturalists who had undertaken voyages of discovery. Much of the earliest evidence for evolution came from looking at the patterns of biological diversity across space. Seeing the scope of global biodiversity, and tracing how geography seemed to drive diversity, helped Darwin, Wallace, and other explorers in "Darwin's Armada" (McCalman 2009) overcome prior misconceptions about biology.

Before he embarked on the *Beagle*, Darwin was inclined, like most scientists of his day, to regard species as distinct. But his experiences on board were to shake that belief. As he sailed away from the Galápagos in 1835, Darwin considered the different species of mockingbird he found on each island. He wrote in his journal, "When I see these Islands in sight of each other, & possessed of but a scanty stock of animals, tenanted by these birds but slightly differing in structure & filling the same place in Nature, I must suspect they are only varieties," rather than widely separated species. Darwin added, prophetically, "If there is the slightest foundation for these remarks the zoology of Archipelagoes will be well worth examining; for such facts would undermine the stability of Species" (Keynes 2000). This was a key moment in a conceptual transformation that led to Darwin's theory of evolution.

Wallace had far more opportunity to see the power of islands in person than did Darwin. Where Darwin spent only five weeks in the Galápagos and a mere ten days in the Indo-

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Australian Archipelago, stopping only at Tahiti, Wallace lived in the archipelago for eight years, exploring and collecting on many islands. These islands are still central to biogeographic research and contain many of the world's undiscovered species (Lohman et al. 2011), making them the perfect place for Wallace to pursue his theory on the origin of species. While there, he developed not only a theory of evolution but also the foundation of modern biogeography. Yet his first discoveries, and the great insight which eventually yielded his theory of evolution, came earlier in his life, from metaphorical islands of the Amazonian rainforest.

In the Amazon, Wallace was struck by how different the species inhabiting the opposite sides of rivers often were. "During my residence in the Amazon district I took every opportunity of determining the limits of species, and I soon found that the Amazon, the Rio Negro and the Madeira formed the limits beyond which certain species never passed," Wallace (1852, p. 110) explained, presenting several examples from monkeys he had collected, before adding, "I have only referred to the monkeys, but the same phænomena occur both with birds and insects, as I have observed in many instances." Reflecting on these observations, he asked (p. 109): "Are very closely allied species ever separated by a wide interval of country?"

His question was not entirely new, but it flipped the traditional form of the claim. In 1761, Buffon observed that geographically distinct areas with similar environments nonetheless have different assemblages of species. Buffon's Law is the first principle of biogeography (Lomolino et al. 2010) but focuses on the *differences* between species assemblages. By considering instead where *similar* faunas can be found, Wallace took a key step in developing his theory of evolution.

While in Sarawak, in modern Indonesia, Wallace (1855) expanded that observation into his own law of biogeography, deduced from his observations of geography, geology, and biology: "Every species has come into existence coincident both in space and time with a pre-existing closely allied species." The core of Wallace's law of biogeography was the recognition that geographical distance was related to chronology. Species found close together are likely to share their common ancestor more recently than species found farther apart. By looking at islands in the Indo-Australian Archipelago, Wallace could see the results of recent speciation on those that were nearer one another. Islands that were more distant from one another would contain species that had been on separate evolutionary trajectories for longer.

The resulting branching pattern of similarities between islands and species on them is characteristic of evolutionary trees, and of the hierarchy of traits that biologists use to reconstruct evolutionary history. Three years later, Wallace grafted a version of natural selection to this model of common ancestry, mailed the resulting paper to Darwin, whose friends arranged for Darwin's and Wallace's papers on evolution by natural selection to be read at the Linnean Society in 1858, and modern evolutionary biology was born.

Biogeography thus aided the founders of evolutionary theory to overcome the obstacles standing in the way of their understanding of evolution. Biogeography can be just as effective at overcoming those obstacles for students today.

The greatest challenge many students face in understanding evolution is what Wallace faced in 1846: they haven't seen the sort of diversity that calls for explanation in terms of evolution. The world most students encounter seems to contain organisms in discrete categories: squirrels and rabbits, robins and sparrows, grass and daisies, oaks and pines. They are unlikely to notice that two ladybird beetles actually represent different species or that there are several species of grass in their lawn, let alone to recognize that there are two local species of chipmunk which can only be distinguished by dissection or DNA analysis. What diversity they notice represents groups that are quite distinct, with differences so large that it is impossible to imagine how their members could share a common ancestry.

As a result, students today, much like Darwin in 1835, tend to see species as distinct entities. Presenting students with a similar experience of the often subtle differences between species can similarly shake this misconception. When they realize how low the barriers can be between different species, they can place lessons on speciation in a more accurate context. Rather than imagining that speciation means turning lions into tigers, or bears into cows, or fish into humans, they will see that speciation involves a subtle divergence in the evolutionary trajectories taken by populations. Because the Galápagos mockingbirds were still early in their divergence, Darwin was able to recognize the process. Students today can learn similar lessons by examining the subtle differences between species on neighboring islands. The Evolution and Nature of Science Institute has a lesson plan in which students compare lizards in the Canary Islands (http://www.indiana.edu/~ensiweb/lessons/island.html), while Understanding Evolution offers a lesson plan looking at *Anolis* lizard biogeography in the Caribbean (http://www.ucmp.berkeley.edu/education/lessons/anolis/teacher_directions.html).

Being able to trace biological history on a map made evolution clear to Wallace, and there's no reason the same can't happen for students today. It may be impossible to take students on their own circumnavigation, but the Beagle Project (http://hmsbeagleproject.org) aims to build a replica of the *Beagle* and sail it along Darwin's original route, using the tools of modern biology to conduct new research and connect students to that research over the internet and in person (James 2009). Museum collections, expedition live-blogs, and other resources make it ever easier for students to interact directly with the world's biodiversity in its geographic context. This is the raw material of evolution and biogeography, with which they can rediscover the evolutionary principles that Darwin and Wallace found a century and a half ago, and hopefully gain a deeper respect not only for science, but also for the natural world.

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