Evolution and the Environment

The second symposium in a series draws educators

OKSANA HLODAN

Why are amphibians declining on all continents where they are found? How important is it to conserve wild relatives of food plants like cassava, on which millions of people around the world depend? What are the evolutionary processes that generate biodiversity, and what are the ecological processes that maintain it? Have climate changes in the distant past created opportunities for speciation, or are radiations influenced more by interactions between species? Is it possible to win the ongoing race between human ingenuity and evolving pathogens?

These were some of the challenging questions addressed at a symposium for biology teachers called "Evolution and the Environment." AIBS cosponsored the day-long event at the National Association of Biology Teachers (NABT) annual meeting last fall in Milwaukee, Wisconsin. Invited speakers provided updates from research on the connections between evolution and environmental change. An afternoon workshop, moderated by symposium cosponsor Biological Sciences Curriculum Study (BSCS), followed the presentations. The symposium and workshop were also sponsored by NESCent (National Evolutionary Synthesis Center).

Symposium speakers Barbara Schaal and Anthony Barnosky share ideas during the conference. Photograph: Oksana Hlodan.

Plant evolution

Appropriately enough, the symposium kicked off with a presentation on plant evolution. Pamela Soltis, curator of the Laboratory of Molecular Systematics and Evolutionary Genetics at the University of Florida, Gainesville, spoke on the role that floral and other changes played in spurring radiations and diversification. The green plants are a clade of about 500,000 species, whose ancestry can be traced back nearly a billion years. Near the origin of the clade is a basal split with streptophytes on one branch and chlorophytes on the other. The basal streptophytes eventually gave rise to angiosperms about 130 million years ago, possibly earlier. Today we have over 300,000 species of flowering plants on Earth.

Soltis gave an overview, based on molecular studies of chloroplast, mitochondrial, and nuclear DNA, of the phylogenetic position of the angiosperms among the green plants, showing the major angiosperm clades and thereby inferring the possible patterns of radiation. She suggested some of the key innovations, processes, or structures that may have contributed to increased diversification, not across the angiosperms as a whole but as applied to specific clades. Her list of possibilities includes vessels, closed carpels, genome duplications, synorganized flowers, and nitrogen-fixing symbioses—all occurring at different levels of the angiosperm tree. For example, the development of vessels for conducting water may have allowed angiosperms to move into different types of habitats and diversify. It may also have been an innovation that led to the basal radiation within the angiosperms. "Are there microevolutionary processes, such as mutation, drift, and selection," Soltis asked in conclusion, "responsible for generating these macroevolutionary patterns? Or are there other things involved in generating these large-scale patterns that we see associated with radiations?"

Barbara Schaal, professor of biology and genetics at Washington University Medical School, St. Louis, Missouri, and vice president of the US National Academy of Sciences, focused on cassava, a tropical plant that is also known as manioc. "Evolutionary biology has a lot to say about applied issues," Schaal said, "such as the evolution of disease resistance, the design of vaccines, and very importantly, the interaction between humans and their food plants." Cassava is the primary staple crop for 600 million people around the world. In sub-Saharan Africa, it is the primary source of calories. Globally, it's the sixth most important crop in agricultural production. Though the root is cooked for eating or ground into meal, here in the United States we know it mostly as tapioca.

Cassava is among the 98 Neotropical species in the genus *Manihot*, which scientists think arose relatively recently on the geological time scale. Evolutionary studies show that cassava in the Americas was domesticated in the southwestern part of the Amazon basin. The varieties of cassava used by the indigenous people of this region have many unique and important traits that have potential for enhancing the nutrition of people throughout the developing world. But cassava has generally been understudied by the scientific community. "It's analogous to an orphan drug," explained Schaal. "It has in the past been considered an orphan crop. An orphan crop is one that doesn't have enough economic stimulus associated with its growth, harvest, and commerce."

Schaal stressed that maintaining wild species is extremely important because wild relatives of crop species contain agriculturally important genes, such as genes for disease resistance. In the process of domestication, genetic bottlenecks occur. On average, only 20 percent of the variation found in the wild ancestor of a crop is actually passed through the bottleneck. Crop species, therefore, don't have the reservoir of genetic variability for crop improvement. Species closely related to a crop can be used to generate the necessary genetic variability because they can be crossed with the crop.

Animal evolution

It's easy to understand why food crops are important, but perhaps it's less obvious why we should care about amphibians,

AIBS Education Chair Gordon Uno, of the University of Oklahoma, co-organized the symposium and gave the opening remarks. Uno (left) talks to Bob Melton, a teacher at W. Putnam City Schools, Oklahoma City, Oklahoma. Photograph: Oksana Hlodan.

whose populations are declining. Andrew R. Blaustein, an ecologist from Oregon State University, Corvallis, presented a historical perspective of amphibian population declines, an in-depth view of one of the causes, and a look at how the problem is approached in the Pacific Northwest. In terms of biodiversity, all three components—genetic, species, and ecosystem diversity—are in trouble right now. Seemingly adaptive behaviors that have persisted in amphibians for millions of years appear to be putting amphibians in harm's way in today's environmental conditions. Three major hotspots for extinctions are the western United States, Central America, and northeastern Australia. The golden toad, for example, was last seen in Costa Rica in 1989. Blaustein agrees with the hypothesis that a fungus is killing many amphibian species in the area because climate change is stimulating an increase in the fungus.

Amphibians are important in ecosystems as both predators and prey. They are sensitive to toxic substances and fight back with substances of their own. Because they are "hopping drugstores," scientists study them from a pharmacological point of view. Why are these significant animals in trouble? Habitat destruction, global climate change, ultraviolet (UV) radiation, acidification, pollution, introduced exotic species, and pathogens all play a role. Blaustein's own fieldwork showed that frog embryos were developmentally arrested in streams in the wild. When reared in the lab in the same stream water, the embryos from these streams survived and matured. He concluded there was nothing wrong with the water in the streams; the UV radiation from sunlight was the source of the problem.

Is today's ozone depletion different in its effects on amphibians than at other times in evolutionary history? Blaustein asserted that UV radiation is increasing and hitting the Earth's surface at greater levels than in the past. We know that UV light can cause DNA damage, mutations, and cell death. Why don't frogs evolve a mechanism to protect themselves? Blaustein gave multiple answers: "Evolution is limited by historical constraints, adaptations are often compromises, not all evolution is adaptive, selection can only edit existing variations, and evolution takes time." Blaustein also noted that some frogs are resistant to UV radiation and others are better at adapting to it because they have improved their ability to repair UV damage.

Jonathan B. Losos, an evolutionary biologist and chair of the environmental studies program at Washington University in St. Louis, Missouri, introduced his talk this way: "My main message is that if we want to understand biodiversity, we need to know two things: What are the evolutionary processes that generate this diversity? What are the ecological processes that maintain diversity in communities around us?" He noted that some people don't realize that we can do experiments to test evolutionary questions in natural settings. To demonstrate, Losos presented his field and lab experiments with *Anolis* lizards, of which there are 400 described species found mostly throughout Central and South America.

Losos's research on *Anolis* species in the Greater Antilles—Cuba, Hispaniola, Puerto Rico, and Jamaica—illustrated the experimental nature of evolution on all these islands. As they radiated through the islands, *Anolis* species partitioned the environment on a fine scale, so that one species lives exclusively on a tree trunk near the ground, another in low-lying grassy areas, another in twigs, and yet

The BioQUEST Curriculum Consortium's lead investigator, John Jungck (right) of Beloit College, Wisconsin, is shown speaking with teachers. Symposium co-organizers Jungck and AIBS Education and Outreach Manager Susan Musante (not pictured) introduced the speakers. Photograph: Oksana Hlodan.

another up in the canopy. Six such habitat specialists, or ecomorphs, have been recognized. The twig species of one island looks almost identical to its counterpart on another, living and behaving in much the same way.

Why does each island have the same set of habitat specialists? Are *Anolis* species more closely related by island or by specialty? Evolutionary trees built from DNA sequences from each of the island species showed that *Anolis* lizards have evolved separately on different islands. "The phenomenon of convergent evolution, where species evolve the same characteristics if they occupy the same environmental situation, was known by Darwin," said Losos. "It's an old concept. But convergence of entire communities is much less well documented. The *Anolis* [radiation] is one excellent example, with entire communities evolving four different times on four different islands." This raises other questions: Why are they evolving the same characteristics on each island? Is there some adaptive basis for it? How do their characteristics affect their capabilities? Does competition drive species to use different resources, leading to adaptive radiation?

In experiments on small lizard-free islands, Losos has attempted to find some answers. He has documented differences in survival rates between competing species, for example, that are accompanied by habitat shifts. "Given enough time," Losos said, "these differences in natural selection will lead to evolutionary differences."

Anthony D. Barnosky, a vertebrate paleontologist and curator of the Museum of Paleontology at the University of California–Berkeley, took a more sweeping approach to environmental issues. The past 70 million years can be divided into chunks of time that are defined by the assemblages of mammal species alive at the time. Fossil records show, Barnosky noted, that periodic turnovers are followed by radiations of new species. What drives these large-scale speciation patterns? Some researchers argue that climatic changes stimulate evolution; others see interactions between species as more important than climate change in accelerating natural selection. Barnosky presented both sides.

Looking back about 750 to 1150 years ago, scientists find an example of a fairly recent climate change, a time when global temperatures were about one degree Celsius warmer. Sequencing of DNA extracted from fossil bones dating to that time provides a glimpse into genetic changes occurring in mammalian populations, showing different kinds of change depending on a mammal's life history. This period, however, did not yield a speciation event. Will a more prolonged period of climate change or a larger climate change, or both, lead to new species? Or put another way, do evolutionary effects of climatic change manifest at different levels of the biological hierarchy, depending on the rate and magnitude of the climate change? Ice age data and studies using tools such as morphometrics and molecular clocks show that a cyclical climate change sustained for 100,000 years did not cause pronounced speciation events, even though mammalian populations experienced dramatic genetic and morphological changes. What about an even larger, more significant event? The mid-Miocene climatic optimum, sustained for millions of years, had the most pronounced speciation in mammal groups that have been studied.

Barnosky concluded, "Scale is really very important when talking about evolutionary processes. You always have to be explicit about what you're trying to test and how you're trying to test it, and oftentimes when you have contradictions, it comes down to people doing things either by mismatching scale or talking about two different scales." He continued, "The other thing we've learned is that if you have geologically very rapid changes, you get tremendous evolution at the population level, but in order to get speciation, you really have to stabilize that climatic state for hundreds of thousands or millions of years to give enough time for the isolating mechanisms to result in speciation events." So what does that mean in terms of regenerating biodiversity today? It's not going to happen in the next hundred or two hundred years. Mammal speciation, said Barnosky, does not occur that fast.

Evolution's fast lane

Marine ecologist and molecular geneticist Stephen Palumbi, of Hopkins Marine Station and Stanford University, intrigued the audience with his approach to teaching evolution. "I discovered that I got the most reaction to things that mattered most in the daily lives of the students: when you are staring at yourself in the bathroom mirror trying to decide if you are too sick to go to work, when your children are born, when you're reading a newspaper and thinking 'Can [this disease] kill you?'" Without evolutionary science, Palumbi explained, we could not understand how HIV becomes so deadly, how to win the arms race with bacterial diseases, or how to prevent the next flu pandemic. The value of science is that it is explanatory and predictive, leading to the possibility that technology will enhance societal well-being. "Being able to watch things happen, test them, pose hypotheses, and get answers is a part of the living machine that science really is." Watching evolution happen over various scales of space and time is not only possible but critical in agriculture, medicine, and biotechnology.

"What we have [in medicine]," said Palumbi, "is an arms race in our efforts to find a new antibiotic, develop it, deploy it, and use it." Not only does the ongoing evolution of antibiotic-resistant pathogens affect human health, but there are costs involved. Enhancing the action of penicillin-type drugs by combining them with clavulinic acid, which inhibits the resistance mechanism bacteria have against penicillin, raises the cost 5 to 20 times per dose. Why does it cost so much to treat AIDS? The human immunodeficiency virus mutates 10,000 times faster than we do. We have to treat this disease with multiple drugs that work in different ways, not just to quell the virus but also to stop its evolution.

We're also in an agricultural arms race—with insects. Over the last century, the number of insect species known to resist some form of pesticide has gone from 1 in 1908 to well over 500 today. For example, in Central America, mosquito susceptibility to DDT was almost 100 percent in 1960, but after 20 years of treatment with the pesticide, mosquito populations evolved so that their susceptibility was down to about 5 percent. Some species have evolved resistance to several pesticides. "Evolution by natural selection is such a strong force in our current world," said Palumbi, "it could do such damage that not teaching about it is like not teaching engineers about gravity."

Speaker Stephen Palumbi explains an idea to an informal gathering of teachers. Photograph: Oksana Hlodan.

Teaching aids

Jerry L. Phillips, science educator and project director for BSCS, provided educators with resources and strategies to teach material covered in the speakers' presentations. He and Mark Bloom, a colleague from BSCS, took the audience through suggested activities, including those that could help students understand what distinguishes science as a way of knowing from other approaches. Two new resources from AIBS and BSCS, the video *Evolution—Why Bother?* and the book *Evolutionary Science and Society: Educating a New Generation,* were also highlighted (*www.aibs.org/bookstore/*). Both were generated from the first symposium that AIBS and BSCS held at the 2004 annual NABT convention. A student activity book to accompany *Evolutionary Science and Society: Educating a New Generation* is forthcoming from BSCS and will include a CD-ROM of the proceedings of the symposium. The organizations expect to convene a third evolution symposium on the topic of macroevolution at the 2006 NABT annual meeting, to be held in October in Albuquerque, New Mexico.

Oksana Hlodan (e-mail: ohlodan@aibs.org) is the editor of ActionBioscience.org, *an education resource of the American Institute of Biological Sciences.*