COURTESY OF JONATHAN B. LOSOS

The author, arranging an experiment on evolutionary ecology, sizes up an uninhabited stretch of Great Abaco Island, in the Bahamas.

What Darwin Got Wrong

By JONATHAN B. LOSOS

BIOLOGISTS HAVE LEARNED that it usually doesn't pay to bet against Darwin, yet year after year, my colleagues and I return to the warm breezes of the Bahamas to study the evolutionary adaptation of lizards to novel environmental pressures—as it takes place in nature, in the present moment. And we're not alone. Today studies of evolution in action have become a cottage industry. In the mountains of Trinidad, for example, a multidisciplinary team is investigating how guppy populations are evolving in the presence of predators; in the sandhills of Nebraska, geneticists have built enclosures the size of hockey rinks and filled them with mice, looking for the genes responsible for allowing them to survive on different-colored soils.

I doubt it ever occurred to Darwin to observe evolution directly, even though he was a pioneering experimenter in many other areas. He was remarkably prescient in his views on topics like evolution by natural selection, the basics of how coral atolls form, and the role of earthworms in soil aeration, but in this particular case—the speed of evolution—he was dead wrong. And for more than a century, scientists followed his lead, thinking that evolution occurs at a glacial pace, too slow to observe or to affect everyday life.

But we now know that when natural selection is strong, evolutionary change can occur very rapidly. Fast enough to observe in a few years—even within the duration of a typical research grant.

You can't really blame Darwin. Back in the middle of the 19th century, there were no data on how populations change through time. Darwin drew his conclusions from conventional wisdom about the pace of geological transformations and Victorian sensibilities about the appropriately slow rate of innovation in modern life. Ideas began shifting early in the 20th century, when laboratory experiments on fruit flies demonstrated that populations could evolve quickly when subjected to strong selection pressures. But those results were not thought to pertain to natural situations, in which selection was expected to be weaker and less consistent through time.

It wasn't until the latter half of the 20th century that field data started rolling in, and they showed that what happens in nature isn't so different from what occurs in the lab. Examination of specimens of the famous peppered moth collected in the 19th century revealed rapid change in wing color, from speckled white to black, as pollution darkened the skies and trees of Industrial Age England (an example

Continued on Following Page

Continued From Preceding Page

resoundingly confirmed in a recent study); shortly thereafter, field studies of Darwin's finches demonstrated equally rapid change in more-pristine habitats. Soon a legion of researchers was out studying natural populations, measuring the intensity of selection on individuals and the rate at which populations changed from one generation to the next.

So we now know that natural-selection pressures are surprisingly strong—and that evolution can occur swiftly. But does it matter to anyone except evolutionary biologists? Turns out that it does. In myriad ways, rapid genetic change has consequences—primarily, but not entirely, negative. Just as important, the brisk pace of evolutionary transformation fundamentally alters our conception of how the natural world works and how to study it.

LET'S START WITH rapid evolution's consequences. The most obvious effect is that it allows species to circumvent our efforts to control them. Various insect and rodent species have an annoying habit of eating our crops. In response, we have developed all manner of pesticides to kill the marauders, stop them from reproducing, or persuade them to eat something else. But time after time, those efforts fail for one simple reason: natural selection. New pesticides are initially extremely effective, but they set the stage for evolution because any mutation that helps get around the pesticide's effects would be an enormous advantage. (Note that environments don't induce mutations that are favorable, but given enough mutations, a beneficial one is likely to occur by chance.) Sure enough, such mutations quickly sweep through the population, rendering the pesticide ineffective. An estimated 500 to 1,000 species are known to have evolved resistance to our chemicals, and the way they do so is highly varied. Some species develop behaviors to avoid exposure to the toxins, others sequester or excrete them, yet others degrade the chemicals or change the molecular pathway they attack.

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Humans provide another cornucopia for exploitation: seven billion bodies that are a resource for parasites and the disease organisms they carry. And just as with crop marauders, natural selection is allowing the enemy to win again and again: Mosquitoes have evolved resistance to many pesticides, many of our antibiotics have been rendered impotent by evolutionary change in the bacteria they treat, and many once-conquered diseases are resurgent.

Even as pests and disease organisms use rapid evolution to defend themselves against our efforts to control them, nature is turning the tables in other ways, going on the evolutionary offensive as new and deadly organisms adapt to feast on us. AIDS, hantavirus, SARS, Nipah, MERS: Those are just a few of the new diseases that have emerged as micro-organisms incorporate mutations that allow them to make the leap from animal hosts to humans. Once that jump has occurred, an evolutionary battle ensues. The human immune system works to counter our invaders, and in response, natural selection continually sifts through newly arising mutations within the micro-organism's population to overcome the defenses. The result is periodic outbreaks, as happen every year with influenza. HIV is particularly adept: An extremely high mutation rate means that new variants of the virus are continually emerging within an infected person's body, defeating efforts of the immune system to control them.

But enough about pests and diseases—the effects of rapid evolution have a far greater reach. Humans are changing the world in ways that promote rapid evolutionary change. Take commercial fishing. Fishermen prefer larger fish; smaller ones are often thrown back or slip through mesh nets. The result is strong selection favoring smaller size and, no surprise, that's what evolves. Atlantic cod, for example, have decreased 70 percent in size in the past century. Such small fish lead to reduced harvests, exacerbating the problems of overfishing.

Another area in which rapid evolutionary change is worsening human-caused problems involves the global plague of invasive species that is causing extinctions, disrupting ecosystems, and imposing enormous economic costs. In many cases, rapid adaptation to new conditions plays an important role in the success of these invasive species. For example, the purple loosestrife, a water-loving plant native to the Old World, has had a devastating effect on wetlands in North America. Its spread over the past 100 years from its introduction, along the eastern coast of the United States, to central Ontario has in large part been the result of the evolution of an earlier flowering time, an adaptation to the shorter growing season in the North. More generally, the commonly observed "lag phase," in which a newly introduced population remains localized and uncommon before bursting out and expanding its range rapidly, has been attributed to a waiting period during which natural selection adapts the population to local circumstances.

Those examples notwithstanding, rapid evolution does not always work to our detriment. Sometimes newly arisen adaptations ameliorate the damage we have caused. Plants that can grow on soil contaminated with toxic metals, aquatic invertebrates that can feast on the huge amounts of algae produced when lakes are polluted by fertilizer (the process of eutrophication), predators that adapt to coexist with toxic toads that have been introduced from elsewhere—all are evolutionary success stories of species able to change rapidly enough to tolerate, and sometimes even take advantage of, our altered world.

A pressing question now is whether species will be able to adapt quickly enough to global climate change. In eons past, species have faced climate change and survived in two ways. One has been to shift geographic distribution, moving northward and upward as the world heats up, southward and downslope when a chill sets in. That strategy may have worked well in the past, but in today's world, the intrusion of highways, cities, and agricultural fields makes such moves extremely difficult.

The other way of surviving climate change has been to adapt to new conditions. But climate change is now occurring at a rate 10 times faster than any time in the past 65 million years. Whether species can adjust quickly enough remains to be seen. Many theoretical models suggest that the climate will change too much too quickly, and that many species will perish. Indeed, documented examples of successful adaptation are still few. Yet natural selection has overcome previous challenges we've thrown its way, so it's probably premature to give up on evolutionary rescue.

FOR SCIENTISTS the realization that species are evolving all around us leads to a fundamental reconsideration of how nature functions—and opens up entirely new avenues for its study. In the past, we have distinguished between "ecological" and "evolutionary" time. Ecological time is what happens among species in the here and now: They compete for resources, prey on one another, sometimes work together. These interactions have consequences, causing populations to wax and wane and individuals to shift their resource use and alter their behavior. But until recently, scientists viewed species as fixed entities in ecological time. Only over much longer evolutionary time can species evolve in response to interactions and changing conditions.

As a result, evolution did not need to be considered when understanding how ecosystems function. Want to know whether predator and prey species will be able to coexist, or whether the predator will eat the prey into extinction? All you need is information on consumption rates, birthrates, effects of density, and other demographic factors. No need to assess the extent to which prey evolve antipredator adaptations or how predators evolve in response. In the ecological moment, evolutionary change is not a pertinent factor.

That view is now flying out the window as evolutionary ecologists realize that evolution can often occur at a pace comparable to that of ecological change. In the time it would take wolves to eat a nonevolving caribou population into extinction, evolutionary adaptation in the caribou may occur to decrease the predators' effectiveness, transforming the outcome of the interaction. Indeed, in recent years an increasing number of studies has shown that year-to-year evolutionary change plays a large role in determining how population levels of species respond to altered environmental conditions.

Moreover, those adaptations may have far-ranging effects on the ecosystem. Work on that point is still in the early stages, but a number of convincing case studies are emerging. For example, the alewife is a small fish that, like the salmon, lives in the ocean but returns to freshwater streams to reproduce. The construction of dams throughout the northeastern United States in the past several centuries has trapped some of these fish upstream, forcing them to adapt to a year-round freshwater existence. To specialize on more-abundant small prey, these landlocked populations have evolved smaller mouths, a change that decreases their impact on larger aquatic invertebrates. But larger invertebrates eat more themselves, so their increase affects the next-lower level of the food chain, leading to a decrease in the common photosynthesizing plankton species that they eat.

THIS IS A NEW WORLD for evolutionary ecologists. We are just beginning to understand how often and to what extent incorporating evolutionary change alters predictions on the outcome of ecological interactions. Early indications are that the answer is "frequently."

And that is affecting how we conduct our science. Once, evolutionary biology was primarily an observational, historical science, in which ideas about what happened in the past were drawn from a wide array of data such as fossils, evolutionary trees of species' relationships, and inferences drawn from measures of present-day natural selection. But now that we know we can study evolution as it occurs, scientists are looking for its signal everywhere, and often finding it.

And the results are unexpected. Multiyear studies have revealed that natural-selection pressures may be much more variable than once thought, favoring, for example, large size in one year and small size in the next. As a result, even though populations may evolve quickly, the net result may be little change over long periods of time. The textbook example is the 40-year study of Darwin's finches in the Galápagos, which revealed that natural selection is highly variable in strength and direction: Heavy rains one year lead to an abundance of small seeds that favor birds with small beaks; a few years later, a drought results in a lack of small seeds and selection for larger beaks. Back and forth, back and forth, evolution proceeds as climate oscillations push beak size first in one direction and then in another. The net result over multiple decades is little overall change.

The rapidity of evolution also means that we can directly test hypotheses by manipulating the environment, thus applying the same experimental method that has been so successful in many other areas of science. Laboratory experiments on evolution have been conducted for nearly a century, and recent work has been epic in scale—one continuing study has monitored evolving colonies of bacteria for 50,000 generations over the past 25 years.

This work has been enormously important in advancing understanding of genetics and the evolutionary process. The challenge now is to take this approach from the lab to the field. The types of organisms studied in the field tend to live longer than those studied in the lab, requiring years for even a few generations to pass. And they are often bigger, requiring cages larger than test tubes, sometimes substantially larger: steel walls to enclose populations of field mice in Nebraska, an array of 20 swimming-pool-size ponds to hold stickleback fish in Vancouver.

Without a doubt, the classic in this genre is research on wild guppy populations in streams in Trinidad. Extraordinarily beautiful and fecund, guppies are known to anyone who's walked into a pet store. But what isn't so well known is that in nature, most guppies are nondescript: Flashy fish stand out and are snapped up by larger, predatory fish. Occasionally, however, guppies are found in areas that do not have predators. There they are much more colorful, bespeckled with vivid spots and stripes, tails ornately adorned. The reason? Females prefer showy males, for causes we don't fully understand. To directly test predation's role in shaping the fish's color and pattern, researchers in the late 1970s transplanted several guppy populations to nearby pools above waterfalls, where neither the guppies nor their predators had existed. The evolutionary response was immediate, as the guppies evolved not only a vibrant wardrobe, but also larger body size and delayed reproduction—traits that are favored when expected life spans are longer. All in less than four years.

Back in the Bahamas, we—like many other research groups—are trying to emulate the guppy team's success. Our experiment, too, focuses on the effect of predators. In our case, we mimic natural colonization by moving ground-dwelling predators from one nearby island to another; our prediction is that the presence of these predators will drive the lizards into the bushes, forcing them to adapt to an arboreal existence. In turn, such adaptations could have cascading effects through the ecosystem, as the newly adapted lizards start preying upon previously inaccessible insects. Will evolution follow the charted course? Early results suggest yes, but we've encountered an unexpected difficulty—hurricanes keep disrupting the experiment, adding a confounding and uncontrolled factor to our study.

And that, of course, is both the peril and the promise of field studies of evolution. Nature is rambunctious, messing with the precision and control that experimentalists crave. Yet this volatility is the reality of the natural world—storms perturb, colonizing species rampage, heat waves follow deluges—and natural populations must contend with all of that. Increasingly, we are realizing that evolution by natural selection is how they do so. ■

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Researchers find the brown anole, a species common in the Caribbean, useful in studying evolution because of the lizard's ability to adapt rapidly to environmental conditions.

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