Evolution in the Cornbelt: How a Few Special Species Are Adapting to Industrial Agriculture

by

Conor J. Gearin

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Signature of Author: Signature redacted
Department of Comparative Media Studies/Writing
June 10, 2016

Certified by: Signature redacted
Marcia Bartusiak
Professor of the Practice of Science Writing
Thesis Supervisor

Accepted by: Signature redacted
Thomas Levenson
Professor of Science Writing
Director, Graduate Program in Science Writing

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ABSTRACT

Over the last 150 years, humans have wrought sweeping changes to the Great Plains. What was once the prairie is now the Corn Belt—row crops planted from fencerow to fencerow. What does this mean for the native wildlife, which evolved for millions of years to live only on the prairie? Here are the stories of three species—cliff swallows, western corn rootworms, and prairie deer mice—that natural selection has reshaped to thrive in the new agricultural landscape. With his finches, Charles Darwin read the record of evolution in the past. In the Corn Belt, today's scientists can see evolution in real time.

Thesis Supervisor: Marcia Bartusiak
Title: Professor of the Practice of Science Writing

1. Mice Where They Shouldn't Be

In an Indiana soybean field this past winter, Jacob Berl flipped over a cinder block, revealing the top of a little wooden box with a short length of black plastic hose sticking out of one side. Using a small crowbar, he popped off the lid. Inside, there was a pile of corn silk and soybean seed coats, and it rustled with life.

Berl reached in with a gloved hand, pushed the nesting material aside, and pulled out a female prairie deer mouse. The size and shape of a small Roma tomato, she had a russet-colored back with a darker streak down her spine, and a white belly—not unlike a deer. A few of her three-week-old offspring crawled around inside. Berl took a fecal sample from the mother to see what she had been eating.

Berl, a graduate student at Purdue University, was checking a grid of 36 artificial nest boxes, set 20 meters apart to attract deer mice looking for winter shelter. The air temperature that morning was 27 degrees, but it was the gusting wind that stung the most. Berl wore a heavy farmer-style tan bib and jacket. Even so, he drove a pickup truck with the heat turned on as he traveled from box to box.

He later found a pregnant female in one of the boxes. "She's pregnant in the middle of January. That's pretty remarkable," Berl observed. With a handheld yellow scanner, he checked whether the mouse had one of his microchips. There wasn't one—this was a new mouse to his grid. Using a large needle, he injected a microchip into the mouse's back and set her back into the box's tunnel entrance.

Historically, prairie deer mice didn't breed in the middle of winter. But the animals Berl was catching were not living in their historic prairie habitat. Instead, they were nesting cozily in the middle of industrial scale, high-input agriculture. Winter breeding is just one of the many ways this species has changed to adapt to its new home—the agroecosystem, a hybrid of the old grassland ecosystem and the giant farm fields sown on top of it. Berl is trying to figure out how the deer mice manage to survive in this changed environment.

I asked Berl if, while starting this project, he had expected to find this many prairie deer mice in the middle of crop fields. He said that, in fact, he hadn't been expecting to find any deer mice at all; he thought they needed a more natural prairie habitat. And yet here they were, in great numbers.

"One of my biggest curiosities is how the heck these animals survive in a place like this," Berl said. "This is literally just a dirt field, but somehow they're thriving out here."

Over the last 150 years, humans have wrought sweeping changes to the Great Plains landscape. What was once prairie is now the Corn Belt—a huge swath of our country where the majority of the landscape is devoted to long stretches of corn and soybean from fencerow to fencerow. Humans replaced a patchwork of prairie, oak savannahs, and streams with a carpet of row-crop agriculture in just a few generations.

What do these changes mean for Midwestern wildlife, most of which have evolved for thousands or even millions of years to live on the prairie and nowhere else? For many species, such as ground-nesting birds and large mammals, the arrival of agriculture meant disaster. But for a special few, it meant a new chapter in their ongoing saga of evolution. Like the special set of animals that have adapted to city environments, these species have evolved within our lifetimes to a landscape that humans have reshaped until it became nearly unrecognizable. And over the last thirty years, scientists have caught them in the process of evolution.

Here are the stories of three species—cliff swallows, western corn rootworms, and prairie deer mice—which natural selection has reshaped to thrive in the new agricultural landscape. One lived on the sandy cliffs of Great Plains rivers; the second, a relative newcomer, arrived alongside Stone Age humans; and the third has always lived deep in the prairie's heart. They all changed in order to live in their upturned environs, and the way they did so challenges the conventional view of farmland as relatively sterile and tamed. Instead, these animals live in a dynamic and still-evolving system, where humans are but one player. And the stories of how scientists discovered this evolution reveal that the natural world is still capable of surprising us. With his finches, Charles Darwin read the record of evolution in the past. The scientists of today can see evolution in real time, in response to the astounding changes we have made to the Great Plains.

2. Plowing the Plains

Driving around Missouri and Illinois, I'd often see a brown sign set in some yellow, un-mowed grass, labeled "PRAIRIE RESTORATION."[1] Given the tiny scale of this "restoration" compared to the nearly continental sweep of the original prairie, this sign always struck me as amusingly ironic. What exactly do we mean by prairie—and does it still exist in the same form as Native Americans experienced it before white settlement?

A prairie is a landscape in which the ruling vegetation type is grasses, not shrubs or trees.[2] For thousands of years, the central prairies kept up a dynamic balance with the eastern forests. Aldo Leopold, one of the first conservation biologists, called this relationship the "prairie war." The foot soldiers of the forests were the bur oaks, a species with a thick bark able to survive the prairie's wildfires. The bur oaks pushed the skirmish lines of the forests from the Great Lakes region to the southwest, only to fall back as dryer conditions favored the grasses.[3]

As you travel from east to west, prairie grasses get shorter—basically, due to a decrease in moisture as you get closer to the Rocky Mountains.[4] If you're driving on highway I-80, beginning in Illinois, you start with the tallgrass prairie remnants. In Nebraska you begin entering the mixed prairie region, where tallgrass and shortgrass species can both grow. Further west in Colorado (now you're headed west on I-76), you enter the shortgrass prairie.

However, when you make that drive today, you don't see much prairie. What you see is a lot of corn and soybean fields, plowed in neat rows, ticking past your window with unvarying regularity. Over the past 150 years, humans have upturned and reshaped the Great Plains.

"The tallgrass prairie is the most hammered," said Wayne Ostlie, a conservationist at the Minnesota Land Trust. He researched the history of the Plains in a 2004 study published in the *Wildlife Society Bulletin*. This is particularly true in north plains states like Minnesota, where only 2.4 percent of the tallgrass remains.[5] Mixed grass and shortgrass prairies have done a bit better for two reasons—their dryness makes them poor cropland,[6] and they are valuable as pasture for cattle.[7] They make up much of the 30 percent of the prairie region that remains unplowed. [8]

The changes started in earnest with the Homestead Act of 1862.[9] This allowed almost 1.5 million people to settle in the Great Plains and begin farming. However, operations were small scale. The plots granted by the Act were only 160 acres, and much of this was devoted to food for the settlers themselves and their animals. [10] These homesteaders planted a variety of crops—lots of wheat and corn, but also rye, barley, sorghum, oats,[11] and stretches of unbroken prairie to use as pasture for livestock.[12] Small-town journalists praised the diversity in planting as a wise economic decision over risking it all on a single crop.[13] There were more people than today actually living on the rural plains at that time.[14] Towns on the prairie were large, supporting civic organizations and newspapers. These communities needed food, and it had to come from nearby.[15]

Yet even with these new settlements, the bulk of the prairie survived. It took years to break a 160-acre plot with horse-driven plows. The prairie sod was thick and gnarly.[16] Prairie plant roots go deep—sometimes as far as 12 feet—to draw moisture from every soil layer.[17] In his book *On the Great Plains: Agriculture and Environment,* Geoff Cunfer tells the story of a homesteader who settled in Kansas in 1874.[18] It took a week to break just one acre of prairie sod. By 1885, he had only managed to plow a little over half of his plot. His family got by cultivating just a fraction of their land for sixty years.[19] Likewise, his neighbors left up to 45 percent of the original prairie on their plots standing, because they judged the land unworthy for planting but good for pasture and hay. By 1900, only 8 percent of the Great Plains had been turned over into cropland.[20]

Then came the first great technology that reshaped the Plains: the tractor.[21] Early tractors before 1900 were massive, steam-powered and train-like, costly and thus out of reach for most farmers.[22] But with the development of gasoline-powered engines, small and affordable tractors spread throughout the Plains, allowing farmers to break up the sod that had resisted them. The prairie's destruction progressed at the astonishing speed of twenty-five acres per day.[23]

At the same time, farms got much larger. Engineers and economists wanted to experiment with new business ideas, reshaping the Plains farm from a small, home-based trade to a commercial industry. Throughout the 1920s, the industrial farmers bought out the 160-acre homesteaders and set up factory-farms stretching for tens of thousands of acres.[24]

This all means that the Plains weren't changed gradually; in evolutionary terms, it happened in a flash, mostly between 1915 and 1925. There was no time for wild animals to transition comfortably.[25]

By the 1950s, the interstate highway allowed even more land to be devoted to cash crops. Since the local grocery store was now bringing in food by the truckload, there was no longer a need for Plains farmers to keep a small herd of livestock or to grow vegetables for their families.[26] The genetically modified corn and soybean revolution of the past twenty years only strengthened humans' grip on the agroecosystem further. By sewing toxic pesticides into the very tissues of the crops, we pushed pest insects into a corner from which they couldn't escape. We could finally manage the insect populations as precisely as we could manage the land.

Ostlie has seen many of these changes happen within his lifetime. He remembers when there were tallgrass stands still remaining near his family farm in Minnesota, and when farmers didn't plant just corn and soybean. As this prairie remnant vanished, he was drawn towards researching and conserving what little was left. After talking to him, I thought again about the "PRAIRIE RESTORATION" sign that I had chuckled at before. As pathetic as that roadside prairie was, it was my first exposure to what the grasslands used to look like. Such restoration projects might be the only time most people see anything resembling wild prairie. For better or worse, the cornfield now reigns supreme.

3. How to Build a Better Swallow

In late May 1996, two Ford F-150s rolled toward a roadway culvert in southwestern Nebraska.[27] Rain streaked the windows, and the biologists inside peered out with binoculars. [28] Some birds fluttered around gourd-shaped nests made of mud and straw attached to the underside of the culvert, but many others sheltered inside the nests. They were all starving to death.[29]

A six-day storm was keeping the cliff swallow colony from foraging successfully for flying insects, its only food source. The biologists did not dare get out and walk closer, because that would flush the swallows from their nests, causing them to lose more of the valuable energy stores keeping them from starvation.[30] Dead swallows lay in the mud under the culvert.[31]

For fourteen years, Charles Brown, Mary Bomberger Brown, and their team of students had been studying the cliff swallows around Ogallala, Nebraska.[32] Cliff swallows are small songbirds with dark wings, a chestnut-colored throat, blue back, orange rump, and a white forehead patch.They live in large colonies of up to 6000 nests. In the age of Napoleon, John J. Audubon dubbed them the "Republican" swallow, after seeing the complex societies they form to raise their young.[33]

While Audubon saw the species confined to natural rocky outcroppings, in the 20th century the species began colonizing highway overpasses, bridges, and culverts in Midwestern farmland. These features became more common over the last century as humans built up the network of roads and infrastructure needed for maintaining large farms and transporting produce to market. It was a win-win for cliff swallows. And because they have a highly social lifestyle, with nests clustered close together in colonies, the species is ideal for studying how social systems evolved in animal populations. Brown and Bomberger Brown, once married, have dedicated the bulk of their career to the Ogallala cliff swallows and continue to co-write papers on them.[34]

But while they began by asking how the swallows evolved over the millennia to their current state, those rainy days in 1996 caused them to ask a new question—are the birds changing into new forms right in front of us?[35]

It had rained that long only twice in the past 123 years—and overnight frost didn't help, either.[36] And they knew how sensitive the swallows were to weather events that kept them from catching insects on the wing.[37] "I always sort of live in fear of these events during the first half of the field season, because you can lose a lot of your study animals," Brown said. The birds could usually go without food for the typical 2-3 day spring rainstorms. This one was different. “When it got to four days, I started to get worried,” Brown said. “When it reached six days, I knew we were seeing something that was very unusual.”

When not driving by the colonies from a safe distance in their pickups, the biologists contemplated their lot from the comfort of the dining lodge and cabins, wondering as it rained just how much data they were losing—how many adult breeding birds, how many nests they could no longer study?[38]

From the bay windows of the Cedar Point Field Station, they looked out over Lake Ogallala, which lies below a dam across the North Platte River.. They saw birds trying to fly out over the lake, hunting desperately for any insects still on the wing in the rain. On the seventh day, after the storm subsided, they saw the grotesque results. Swallow corpses lined the lakeshore like a bathtub ring.

The team pulled on their boots to further survey the casualties. They found dozens of bodies under the road bridges where the birds nested. Many more starved inside the nests and were harder to see. Brown surmised that others fell into Lake Ogallala and were lost to science. The biologists collected as many dead swallows as they could.[39]

Looking at the bands on the dead birds’ legs, they realized they were collecting individuals they had known for up to ten years.[40] “Some of them were old friends,” said Bomberger Brown.

The researchers estimated that 53 percent of the population had been wiped out, leaving nearly half the nests empty.[41] “It was obvious we were having a major mortality event,” Brown said.

But the die-off became a different kind of bounty for the scientists. One of evolution’s favorite sculpting tools is death, and that spring in Ogallala, death was all over the place. This calamity made Brown wonder: did the birds that died in the storm differ in their body plan from the survivors? To answer that question, the team needed a new piece of equipment. A maintenance worker at the field station soon hammered out a large cedar chest, putting in Pacific-brand house insulation boards to keep its contents cold. It was a mass sarcophagus for cliff swallow corpses.[42] Over 1800 cold bird bodies went into the box. To compare these carcasses to lfiving birds, the team put up mist nets between two poles to catch the survivors and measure them.

Bomberger Brown, who is skilled in preparing museum specimens, thawed the cliff swallows in the box and measured every single one. After adding in the surviving swallows, she and the team ended up measuring a total of 2,866 birds.[43] She found that the survivors had larger bodies on average than the birds that died. The larger body sizes probably allowed those swallows to store more fat and retain more body heat to survive the long storm.[44] They also tended to be more symmetrical, making for more efficient flight.

But more interestingly, the surviving birds had shorter wing and tail feathers on average. This advantage is less immediately obvious. But Brown thinks it isn't an accident. Perhaps the flying insects available during the bad weather were harder to catch and called for sharper turns than the swallows ordinarily needed to perform.[45] Those cliff swallows with shorter wings and tails, which make for more acrobatic flight, were able to catch these bugs. They had an advantage.

The shorter-winged cliff swallows, in other words, were favored by natural selection. This means that while the storm was putting pressure on the swallows, the shorter-winged ones had a better chance of surviving than the longer-winged ones. And because they survived, they could reproduce and pass on their genes. It's the same process that, over thousands and millions of years, shaped tunas into ever more streamlined torpedoes, favored the fastest reproducing rabbits, and rewarded the wolves with the best sense of smell.

We usually think of natural selection as happening long ago. But here, the cliff swallow team had documented it taking place in real time.[46] They began, like Darwin, asking how cliff swallows evolved to the way they are now—why the swallows developed the complex social structures and nest colonies that structure their lifestyle.[47] But while working out this riddle, they watched evolution unfolding right before their eyes.

"We learned to see things differently, to see and think about things more broadly," said Bomberger Brown. "1996 was a watershed. It was a big deal."

It caused them to start thinking differently about another set of data they had been collecting over the years. Brown makes a point of picking up every single dead bird of any species the team comes across, said Amy Moore, who has worked with him for ten years.[48] And without question, the car stopped every time someone spotted a dead swallow.[49]

Living near country roads, cliff swallows tend to get hit by cars. Often they will stand on the road surface until a car comes and then try to escape at the last minute[50]—much like tree squirrels do in forested areas. The result was a predictable toll of dead swallows on the roadsides every year, the victims of windshield collisions. The team scoured the same roads year after year, keeping their search efforts consistent over the decades.

They ended up with 104 dead birds in all, but interestingly, fewer appeared to be collected in recent years.[51]

They also collected a second set of dead swallows. Sometimes in the course of catching birds with mist nets, some swallows had "little bird heart attacks" or died for other accidental reasons, Bomberger Brown said. The researchers took advantage of this unfortunate occurrence and preserved each expired bird. They collected 134 of these in total.[52]

From these two sets, the researchers were able to make a meaningful comparison. The birds that died by accident during netting weren't collected for any particular trait—they essentially died at random. This means, theoretically, that they're an accurate representation of the general population. To make sure of that, the team checked whether the measurements of the birds that died during netting were any different than their measurements from the birds that survived. They were the same.

Looking back at their three decades of specimens, the researchers confirmed their hunch that they had been collecting fewer and fewer road-killed birds with each passing year. Of their 104 road-killed birds, most of them came from the earlier years, when they found about 20 birds per year. The number fell to around 10 in the late 1990s, to just a 2-4 in recent years. And over the same period, the population of cliff swallows nearly doubled. So, it wasn't just that there were fewer swallows around to get hit.

Brown wondered if there might be something behind the decrease in roadkill. Rather than the birds just getting cleverer, could their bodies be changing somehow to help them get out of the way?

When Brown first assigned Moore to help crunch the numbers on the thirty-year dataset, she was skeptical that they'd find any meaningful trend. Though people drive fast in the rural roads of Ogallala, Moore thought there wasn't a high enough volume of traffic to force natural selection in just three decades.

But when they graphed the length of the swallows' wings against the years, they found something extraordinary. The general population of swallows' wings had decreased in length fairly smoothly over the thirty years, falling from 109 millimeters to 106. Meanwhile, the road-killed birds tended to have wings over 109 millimeters. While this change might appear negligible, small changes in wing shape can have strong effects on flight physics. The researchers already knew from the earlier study about the effect of the storm that shorter wings tend to help swallows maneuver more sharply.

While this finding was exciting, the work had just begun. The team had many alternative explanations to rule out, each one requiring a search for relevant data. Could the population of mammal scavengers have increased, taking away more birds before the team could find them? While they didn't have information on the Ogallala population of scavengers, they knew that skunk numbers in all of Nebraska had fallen, so that explanation was unlikely. Could there be fewer cars driving on the roads, resulting in less collisions? No, traffic had held steady. And in fact, the use of SUVs had increased in recent years. Their huge windshields could increase the chance of a bird-strike. Yet roadkill decreased even though there were more large cars on the road. Had the team searched different lengths of road over the years? Again, no—the total distance they surveyed each year remained the same.[53]

And a final question—could the birds just be learning from their peers' mistakes to avoid cars, as squirrels never seem to do? The researchers knew from a study in the '90s that cliff swallows aren't great at learning from each other. For example, they don't seem to get better at catching flying insects after watching other swallows doing it successfully. That makes it improbable that the population had learned road safety. [54]

After going through all of these potential confounding factors, the researchers felt confident in concluding that what they had seen was natural selection on wing length within their lifetime. [55] This characteristic was so beneficial that it came to be dominate within the population fairly quickly.

Here's the story the researchers believe they've uncovered: since swallows often stand on the road surface or fly low over it, they need to be able to launch quickly into the air. While longer wings allowed for more efficiency during flight, there was a big trade-off: the extra length kept the birds from taking off quickly enough from the road surface. Birds with shorter wings tended to survive those encounters and pass on their traits. As the population's wings became shorter, swallow take-offs could be more vertical and acrobatic, up and away from the oncoming Hummer. [56]

In evolutionary terms, this represents a rapid shift, happening in the space of an academic career rather than in geologic periods of thousands or millions of years. Brown and Bomberger Brown published a paper on this surprising outcome in *Current Biology* titled, "Where Has All the Roadkill Gone?" [57]

Looking at classic examples of evolution such as orchids, natural selection seems like a mechanism for making a species more and more graceful. In the co-evolutionary partnership between a particular orchid and its butterfly, the flower's long tapering opening and the insect's long unrolling proboscis have become more and more elegant with time.

With the cliff swallows, evolution was not a matter of grace. The ancestral cliff swallows started off more like stealth bombers, with long, narrow wings. With the arrival of country roads, SUVs, and 70-mile-per-hour speed limits, though, they needed a different design. Natural selection sculpted them into a new form, but not necessarily a more beautiful one. The wings got shorter and stubbier, the flight more daredevil.[58]

What we got, Bomberger Brown said, was basically the crop-duster model of a cliff swallow. [59]

But there was a potential downside to the cliff swallow's adaptation—that crop duster had to fly all the way to South America. Cliff swallows are long-distance migrants, spending their winters along the Rio Paraña, a grassland river much like Nebraska's River Platte, near the borders of Argentina, Uruguay, and Paraguay. Once natural selection tricked out the population with barnstorming wings, they might have just puttered out halfway to the wintering grounds.

But fortunately, even with the shorter wings, the swallows have continued to leave Nebraska in the fall and return from South America in the spring, traveling thousands of miles. For now, their wings let them handle both the challenge of migration and the challenge of car-dodging. In other words, the swallows seem to have found the sweet spot in an evolutionary balancing act.[60]

This adds to a precious handful of examples of modern evolution that scientists have been able to document. In fact, it's so rare to witness such rapid changes that the best-known example required a return to the birthplace of evolutionary theory: the Galapagos Islands. Peter and Rosemary Grant of Princeton University studied Darwin's finches since the 1970s, and watched the beak size and body size of the birds shift in response to changes in their food supplies.[61]

However, there's a caveat to make. While Brown and Bomberger Brown feel confident they've documented natural selection, they don't yet have direct experimental evidence showing that it has happened. An experiment is the gold standard for documenting evolution—even though Darwin didn't use one with the Galapagos finches, nor did the Grants when they returned to the islands in the 20th century.

The environmental conditions an animal grows up under can have an influence on physical traits. For example, the bones of a human child who exercises frequently tend to grow larger than in a sedentary child—the bone tissue responds to the stress of exercise by growing thicker.[62] A pine tree growing at the top of a mountain replaces its needles less frequently than one growing in the valley to cope with the lower humidity at high elevations.[63] Neither of these differences in the two populations of the same species have to do with genetics, but with the environmental conditions in which the individuals developed.

To sort this out, scientists use experiments. In one standard test for evolution, the two populations are moved to an environment somewhere between the two extremes—called a common garden—and are bred through a couple generations to see if the differences in their traits really are passed down to offspring consistently. If their genes really have evolved, the offspring would look the same as their ancestors and unlike the other population. If the genes hadn't changed, but had just been expressed differently in different places—nurture rather than nature—the two populations would start to look similar in the common garden.

Brett Sandercock, who studies grassland birds at Kansas State University, said that figuring out whether a population is currently evolving or has evolved recently "is a really hard question to get at with birds" because they're hard to corral for experiments. They wouldn't want to hang around in a common garden.

"You pick up a white-crowned sparrow in Texas and take it to California—it can actually navigate and go back home," Sandercock said. For this reason, more work on evolution has been done with fish, which an experimenter can keep contained in a pond, or with plants—much less prone to escaping than songbirds.

Sandercock also noted that while the cliff swallow has adjusted well to the new agroecosystem, the story is different for most other grassland birds. This is especially true for ground-nesting species. In the historic condition of the plains, there were almost no trees or shrubs around to use for a nest. Accordingly, many prairie songbirds like grasshopper sparrows and bobolinks,[64] as well as gamebirds like the prairie chickens, have always made nests within grassy cover and cannot adopt a different strategy. It would require an entirely different life-history, not just translating the same strategy to a new situation, as with the cliff swallow.

"If you convert [the land] to soybean or corn, that's it," said Sandercock. "It's not suitable."

While their Plains habitats changed dramatically, cliff swallows found a way to live on in the larger landscape by colonizing highway overpasses. And as they enter new habitats, it's possible that the swallows will continue evolving.

Cliff swallows are on the move. They're following the highway system towards the Atlantic. They've made appearances in New Jersey and Maryland, [65] though they don't yet breed in the East in large numbers.[66]

They might not need new adaptations, since Maryland's highway bridges aren't so different from Nebraska's. But the small groups that enter new habitats might have a slightly different genetic makeup that has consequences over time. This is called the founder effect: a break-off group that moves into a new habitat will randomly have different frequencies of traits than the source population. The result is that the two populations' traits begin to look different, as the generations progress.

For example, Bomberger Brown said, cliff swallows in the desert Southwest have dark foreheads, while cliff swallows in the Great Plains have white foreheads. That's probably not an adaptation to new conditions—it might just be that the groups that colonized the two habitats happened to look a little different at first, by random chance. Then, since the two groups stopped breeding, the difference became more pronounced over time. Even though it's not a useful adaptation, this is still a kind of evolution. Much of evolution is random and has nothing to do with natural selection and "survival of the fittest."

The eastward march of the swallows poses an interesting question for conservationists. How do we feel about a native North American species gradually moving across the continent, from one highway bridge to another? It's a less obvious case than, for example, the House Sparrow, which was introduced from Europe and has since been busy stealing woodpecker nests across the United States. The cliff swallow was here from the start—but now, it's benefiting from the changes that humans are making to the landscape.[67]

One reason we can feel good about this species' spread is that they probably won't disturb local bird communities—in fact, they might fill a missing role. They occupy a nesting habitat—concrete structures—that few other birds want. And Northeastern fly-catching birds such as phoebes and kingbirds haven't been doing well lately.[68] This means that cliff swallows could pick up the insect-catching slack in eastern ecosystems.

Bomberger Brown doesn't feel bad at all about the cliff swallows' advance. "I like cliff swallows. So I think they should take over the world," she said. "We've always sort of laughed that cliff swallows and cockroaches will inherit the earth.

4. Resistance

The cliff swallow found a way to survive a battle it couldn't win outright. When the prairies were plowed and paved, it found itself taking on cars' windshields. It was an unequal matchup, and the swallows rolled with the punch rather than standing their ground. They found a way to live on in the larger landscape by occupying underpasses and dodging the cars. But this next story of modern evolution involves a species that's in a battle it could actually win. In this case, it might eventually be us who have to adapt to the animal, rather than the other way around.

The western corn rootworm is an oval-shaped yellow beetle with black stripes. [69] It's about a quarter of an inch long. It belongs to the leaf beetle family, the chrysomelids. This might not sound like a portrait of a resistance fighter. But this species has been engaged in 5,000 years of guerilla battles with farmers in the Americas. And in recent years, the low-level skirmishes escalated into an all-out ground war for the Corn Belt.

The beetle's larvae are the shock troops in this conflict. They're where the rootworm beetle gets its name. Masters of underground sabotage, the larvae feed on and tunnel into corn roots, stunting growth and nutrient uptake.[70] But there's combat in the open air, too—the adult eats pollen, leaves, and corn silk, preventing fertilization of the kernels.[71]

The rootworm has done more than any other Great Plains species to erode the myth of our superiority over the environment and unravel our confidence in manipulating the agroecosystem to suit our wishes. The story of how the rootworm stood its ground against farmers armed with the newest weapons of biotechnology reveals how humans are just one force in this landscape, one that has lost as well as won. In fact, these days, the rootworm seems to be gaining the upper hand.

When you take the viewpoint of the rootworm's ancestors, moving through their evolutionary path over the last 100 million years, the reasons why this species dove into the modern conflict with humans in the Corn Belt becomes clear.

The forebears of rootworms evolved alongside the flowering plants, the angiosperms, back in the days of the dinosaurs. As the flowering plants first bloomed and spread in the Cretaceous period, they offered a huge new untapped source of food. The leaf beetles followed them all over the world, feeding on the plants' soft parts.[72] Each type of beetle developed a specialty. One lineage developed a taste for elm trees,[73] another cucumber plants.[74]

One group of leaf beetles in Central America specialized in eating a broad-leafed grass called teosinte. It's a relative of modern corn, but basically unrecognizable to someone expecting Fourth of July corn-on-the-cob. Its triangular seeds come in a narrow husk and have thick brown coats. On the ground, they look like gravel.

About 10,000 years ago, Native Americans bred teosinte into a more edible form, with softer, larger seeds—early corn plants.[75] They began growing these plants extensively. This abundance made the species an even better target for the rootworms, which became a common and belligerent resident of cornfields. But because the beetle had lived in Central America for millions of years, a suite of parasites and predators had also evolved to keep the insect in check—and they still do today.[76,77]

Native Americans eventually spread their corn crop north, reaching into the far western Great Plains. The western corn rootworm followed, but in small numbers, with a population limited to Colorado. There, the beetle was more of a problem—the species had few natural enemies in the northern part of the continent. But because the corn planting stayed limited, the rootworm's numbers stayed small as well.[78] For at least 5,000 years, the rootworm was a pest of corn crops but not an all-out destroyer.

But when white settlers plowed the Great Plains in the 1900s, planting corn from the Rocky Mountains to Indiana year after year, the Colorado rootworms rose up and went on the offensive. Where once there were small patches of corn surrounded by diverse prairie grasses, seemingly endless fields of their host plant (both their supermarket and their nursery) stretched to the horizon. As in the Cretaceous, a tremendous new source of food had appeared, and it was time for the rootworm to invade.[79]

The species rolled across the continent in a merciless blitz—quite a punch for an animal the size of a fingernail. By 1930, it had reached Nebraska's state line. In the 1940s, rootworms devastated crops in the center of that state. The next decades saw their fastest advances. In 1964 they had reached the heart of Iowa, and the invasion wave hit Indiana in 1970.[80] They completed their march to the sea in 1983 when they entered New Jersey.[81] Since then, rootworms have caused over a billion dollars in crop losses each year, chewing corn roots to tatters.[82]

Not even oceans have restrained them. Thought to have stowed aboard an aircraft carrying harvested corn, a fifth column of rootworms reached behind enemy lines and began an invasion of central Europe in the 1990s.[83]

Not keen on losing to a tiny beetle, the farmers fought back. They recognized one of their mistakes—planting corn in the same field year after year gave rootworms a stronger foothold. As a defense, the farmers began rotating their crops, planting soy in a cornfield every other year or so. A field of bright green soy leaves looks pleasant to us, but for rootworms, it's the equivalent of scorched earth warfare. Soy is a completely different plant from corn. Rootworms are so well adapted to corn that they can't live on another plant. They're like fish out of water in a soybean field. It's one of the only things that limits them.

Or so scientists thought until 1987.[84]

That year, biologists found a rootworm-ransacked cornfield in Illinois—even though the year before, the field had been rotated with soybean.[85] The soybean plants hadn't starved them out. Less than twenty years had passed since the rootworms first invaded the state, and they had already managed to adapt to crop rotation.

It only got worse. 1995 was a particularly rough year. In Illinois and Indiana, rootworms destroyed over half the corn crop.[86] The rotation strategy seemed beaten.

This meant that rootworms were starting to live on soy plants, not just corn.[87] Biologists caught the beetles in soybean fields, and they were eating soybeans. And not just that—the rootworms could now lay eggs in soybean fields.[88] Given that they've had such a strong relationship with corn-related plants for so long, this behavioral shift was remarkable.

If crop rotation couldn't do the job, then what? Agronomists turned to developing a new arsenal of weapons: genetically modified crops engineered to produce toxins throughout the plant's tissues. Scientists wanted to make the entire corn plant poisonous to its pests—while still safe to eat for humans.

A pesticide taken from a bacteria species, called Bt, showed promise for this project. The chemical was only toxic to pest insects, not to humans or to the beneficial predator insects that eat pests. It had been popular with organic farmers as a spray for years.[89]

Researchers were hard at work in the late 1980s trying to make crops genetically engineered with Bt genes that would code to produce the needed toxins for large-scale agriculture.[90] By 1995, the Environmental Protection Agency (EPA) cleared a Bt corn poisonous to pests other than the rootworm.[91] Both Monsanto and Syngenta quickly rolled out models.[92] It wasn't until 2003 that Bt corn specifically engineered for western corn rootworm control at last entered the market. U.S. farmers leapt at this chance to defeat the rootworm once and for all. Like many of the early 20th century changes to the Great Plains, this one too was rapid. By 2009, 45 percent of corn plants in the U.S. were already Bt-engineered.[93]

However, this strategy of trying to use Bt corn as a silver bullet was playing to the insect's greatest strengths. The rootworm has its evolutionary history in a never-ending arms race with its host plants. As it turns out, plants invented pesticides millions of years ago. They're called phytochemicals—compounds made by the plant and stored in its tissues to discourage animals from eating them. This is where we get caffeine, cocaine, and the oak tannins that give red wine its subtle character; they're all meant to disgust or even kill herbivores.[94]

The ancestors of corn had their own set of pesticides. And if rootworms wanted to keep eating the plants, they needed to develop a corresponding set of enzymes in their gut capable of disarming the pesticides.

And on it went, for millions of years: the corn ancestors would develop a toxin, at first probably wiping out many beetles. But the few mutant beetles able to break down the toxin lived on and thrived. Thanks to natural selection, the balance would tilt the other way. Like Cold War enemies racing to build ballistic warheads and missile defense systems, the balance never became so untenable that one side completely lost. The beetles were doing something good for the plants, after all—keeping their populations in check so that they would not become too large and crash. What wolves do for deer, rootworms did for corn ancestors.

This fine balance ended when humans entered the fray. In creating corn plants with a single powerful pesticide but no genetic variation, we shut down the corn's ability to evolve and took over responsibility for developing new chemical weapons. The rootworms, on the other hand, had no such restriction. The chemical machinery in their guts worked as well as it ever had.

"These things are very well adapted to overcoming various chemicals and nasty toxins," said Jeff Fabrick, a biologist with the U.S. Department of Agriculture.

Bruce Tabashnik, a biologist at the University of Arizona, said that among pest insects, there are 'studs' and there are 'duds' at resisting pesticides. The western corn rootworm is definitely a stud.[95]

There were concerns about Bt resistance from the beginning. Scientists worried that if farmers planted entire fields with Bt crops, the most resistant rootworms would survive and quickly take over. Instead, Tabashnik and several other biologists strongly recommended that the EPA require farmers to leave part of their fields free of Bt corn. These "Bt refuges" would leave a safe haven for rootworms that could still be killed by the Bt-engineered corn. While Bt crops on the rest of the field would kill all but the toughest beetles, the refuge would make sure that a large population of weaker beetles would stick around, diluting the influence of the resistant ones. Writing a book called *Now or Never: Serious New Plans to Save a Natural Pest Control,* the group of biologists told the EPA that every cornfield should have at least 50 percent of its area free of Bt.

The EPA did not follow that advice. From 1995 to 1997, having a Bt corn refuge of up to 20 percent was purely voluntary.[96] It was not until 2000 that the EPA required a minimum 20 percent refuge for all Bt corn fields,[97] but that percentage was still much smaller than the recommended one.[98]

In 2009, a group of scientists led by Aaron Gassmann of Iowa State caught rootworms throughout Iowa and tested them in the lab. They found that in six years, some of the populations had already developed robust resistance. It was the first example of field-evolved resistance to Bt-engineered corn.[99]

Tabashnik said the intense natural selection going on in the fields made evolution basically inevitable. The Bt corn kills a good chunk of the rootworm population at first—up to 95 to 99 percent. "That sounds good, and it's good in the short term," said Tabashnik. "But it's the worst case for evolution of resistance. It favors the fastest evolution of resistance." Only the most resistant rootworms are left, and they quickly take over the population.

This makes me wonder—can we ever find a way to keep pace with the rootworm's evolution?

Here's the thing: since humans took control of selecting which corn plants make it to the next generation, we also took over the corn's job of developing new toxins to discourage insects. Actually, not just the toxins, but the entire role (usually performed by a whole ecosystem) of keeping these beetles in balance with everything else. The problem is that unlike a natural ecosystem, we don't have millions of years to perfect this balance. We have to find a way each and every season, because we need the corn now. We can't deal with the amount of death required for natural selection to give us better adapted corn. That would mean that only a tiny fraction of a cornfield—the ones with the best natural toxins for discouraging rootworms—would survive a rootworm infestation. Then, given enough time—a long time—that fraction would reproduce and eventually recover. But since we need a corn harvest every year, we can't just let natural selection take its plodding course as it once did. Instead, the entomologists I talked to believe in integrated pest management—the use of a whole set of tools, used responsibly to keep pests at manageable levels, rather than relying on one silver bullet.

Still, even our best tools are limited. A new generation of pesticides involves targeting specific genes in the pests, a technique called RNA interference. Inserting a genetic substance called RNA into the plant, the modified crop actually attacks selected genes in the insect to stop producing certain enzymes it needs to survive. Unlike with more traditional pesticides, which are similar to natural plant toxins, the rootworm has no history resisting this kind of assault. It can't suddenly develop a way to destroy the RNA before it causes harm or replace a gene knocked out by the RNA. Or can it?

Blair Siegfried, an entomologist at the University of Florida, has studied the rootworm for much of his career. He's optimistic about RNA interference—but he also knows how tough the enemy is. "I wouldn't bet against the rootworm," Siegfied said. "If you look at the history of the insect, going back into the 1950s, just about every control tactic that has ever been deployed against this insect has eventually failed. ... I think we're a long way off from saying that we have the upper hand in dealing with this insect."

Pests like the western corn rootworm are the perfect challenge to our assumption that any ecosystem can be mastered, given the right tools. Even elaborate combinations of our finest tools are not always enough to stop resistance studs like the rootworm. What this means to me is that even the agroecosystem, the place we've shaped to our own ends, is not under our yoke. There's a quarter-inch beetle that nearly has us beaten.

5. Written in Bone

While rootworm beetles evolved to live in the new Plains habitat, they had a head start: they specialized in eating the corn that now dominates the land. In contrast, prairie deer mice now face an ecosystem totally unlike the one in which they had specialized to live. And unlike cliff swallows, they didn't try to hang on elsewhere in the landscape but changed to live in a drastically altered habitat. Natural selection gave them a way to reinvent not just their body plan but their entire way of life—in just the past 100 years.

* * *

Brent Danielson doesn't like studying cornfields. A wildlife biologist at Iowa State University, he'd much rather be researching animals in less corrupted landscapes like western forests or intact prairie. [100] "I like it wild," he said.[101] But a friend cued him into an ecological mystery occurring on cropland that was too good to pass up.[102]

A friend in the agronomy department at ISA, professor Matt Liebman, told Danielson that he'd uncovered something intriguing while studying weeds in agricultural fields. Something was killing off many of the weeds in his study area by eating their seeds before they could germinate. To narrow down what was scavenging, Liebman left some of the seeds as bait, surrounding them with mesh with differently sized holes. This scheme showed the animal getting to the seed was bigger than a cricket but smaller than a rabbit—most likely, a mouse. But he had no way of knowing whether this was just a few clever mice or a large population focusing on this food source. He called on Danielson for backup.[103] The mammologist could put numbers on the mouse population and determine how much they were interacting with the agroecosystem.

Danielson found that it was the prairie deer mouse, a species native to Iowa. The prairie deer mice don't carry the heavier headgear of their cousins, the white-footed mice, whose jaws can handle big tree nuts. Instead, deer mice specialize in eating only small insects and tiny wildflower seeds, some of which are as small as a pinhead.

As Danielson understood it at the time, the mouse needed intact prairie habitat, however limited, to survive. There was nowhere else that provided this prairie mammal with its special diet. He knew that some of them probably nested in corn fields and nibbled at corn kernels. But by and large, the species had to be surviving primarily on the edges of fields, in hedges and fencerows. There was no way, he thought, that they were living on crop fields in large numbers, which are routinely torn up by tilling, cultivation, and harvesting.[104]

Still, the deer mouse's success at handling weed seeds in the fields made Danielson wonder—was this species better adjusted to life on a cornfield than he had imagined? In particular, he wondered if they were benefitting from what's called waste grain. When farmers harvest fields, a few corn kernels inevitably fall to the ground. If they germinate, they become feral corn, which is a particularly frustrating pest. Since corn is genetically modified to resist herbicides like Round Up, you can't go out and kill feral corn with conventional sprays. They require special treatment. Sometimes, a disorderly crowd of feral corn stands in the middle of what ought to be a soybean field.[105]

"That's what my grandfather would call dirty beans," Danielson said. It's a sign that the farmer did a poor job in harvesting the previous season and left corn kernels behind. "Dirty beans are embarrassing. Your neighbors will talk about you and say nasty things."[106]

If the deer mice were taking care of farmers' dirty beans for them, that would be a new example of the benefits of hosting native species on agricultural land—and, more interesting for a wildlife biologist, a new example of a plains species adjusting to the agroecosystem.

First, Danielson and his team tried to put numbers on the extent to which the mice used the corn fields versus the edges. For two years, they used live traps, a small aluminum box with a spring-loaded door on one end. They placed the traps in lines at set distances from the edge. At night, as they searched for food, the mice were drawn to the bait in the traps. This wasn't a great method for keeping the mice alive, though. Because of how cold it can get in a cornfield at night, many mice froze in the aluminum boxes before the team could set them loose.

"It was brutally hard on the mice. It is Antarctic out there," said Danielson. It wasn't easy on the biologists, either—the traps had to be checked right at dawn.

They compared how many mice they found at different points along the trap line. What they found surprised them. On both corn and soybean fields, they trapped mice more frequently at ten and fifty meters into the field, and rarely caught them on the edges.[107]

It went against Danielson's original expectation, but on further reflection, it made sense. "They don't like the edges—that's where the predators are," he said. Animals like coyotes hunt from the cover of hedgerows and ditches, and birds of prey keep watch from poles. For a deer mouse, it turns out the safest place to be is right in the middle of high-intensity agriculture.

Next, the biologists wanted a closer look at these cornfield burrows. After trapping mice, they covered them in bright fluorescent dye and let them loose. At night, they returned with a black-light to follow the glowing path of the mouse back to its home. The trails led not *away* from the cornfields but *to* their very hearts. Finding an abandoned burrow, the team took a can of insulation foam from the hardware store and sprayed it into the entrance, about as wide as a half-dollar. After letting the foam set, they unearthed the space it had filled. [108]

Danielson showed me a couple of these foam-filled burrows in his office. There was a circular den about the size of a gourd, and a slightly winding tunnel leading out of it. The species had transplanted its burrow, perfected over millions of years under the prairie grasses, to a completely unfamiliar environment. [109]

"Most wildlife in cornfields, they live on the edges, they live in a roadside ditch," said Danielson. "Not this species." And they weren't just hanging on—they seemed to be thriving in large numbers. [110]

This lifestyle is not without its drawbacks, Danielson explained. "If that's their living room, it goes upside down on them four, five, six times a year," he said. Probably, a few of them die from this. But plenty make it through. [111]

This was strange. What allowed the mice, which are evolutionarily fine-tuned for the prairie, to succeed in a completely different ecosystem?

The team was tired of unintentionally killing mice through live-trapping. One of the graduate students suggested they use nest boxes instead. Rather than trapping the animals at night on the surface, these small wooden boxes are buried just under the surface and closely mimic the mice's normal burrows. The den space is rectangular but similar in volume to the mouse-built version. The biologists lined it with cotton to encourage nesting. A short length of plastic tubing connected the box to the surface. The team buried the nest boxes throughout their fields at regular one-meter intervals.[112]

It was a much more enjoyable method for both mice and scientists. In the winter, the mice took to the artificial dens in large numbers, in groups of three to seven. "They're happy as clams in there," said Danielson. "Life is good." And to the biologists' delight, they could check the traps at any time of day. Since deer mice lower their body temperature during the winter to save energy, they are very lethargic when scooped out of a nest box on a January afternoon. "They move in slow motion, which makes our life even easier," said Danielson. He and his students had no problem counting the mice in the box, slipping on an identifying ear tag, and going on their way. [113]

The nest boxes allowed them to see the architecture of the deer mice's life on a cornfield. Given two nearby nest boxes, a group of mice will use one as their bedroom and the other as a pantry. In the pantry boxes, the team found enough groceries for the entire winter and then some. The mice's life during winter consisted of just scooting between these two nest boxes—not unlike a college student laying low for winter break. [114]

But what was stored in the boxes was lots of corn and soybean. Historically speaking, prairie deer mice have small jaws specialized for grass and wildflower seeds. Compare that to closely related mice like the white-footed mouse, which has large jaws that can handle acorns and hickory nuts as well as smaller fare.[115] While the prairie deer mouse's dietary switch might seem like a small difference from our perspective, it's a little like a human going from eating only apples to eating only watermelons and cantaloupes, Danielson said.[116]

Yet the benefits of this shift were clear. The biologists found newborns in the nest boxes in the middle of January. Winter breeding had never before been documented for the prairie deer mouse. It seemed that the energy boost they got from the grain stores allowed them to produce an extra set of offspring each year. [117]

How could a species that evolved to eat tiny seeds handle this amount of heavy grain? Did their jaws adapt to handle this new diet? John Doudna, a graduate student for Danielson, made this question a focus of his dissertation.[118] And it meant the team had to kill some more mice. [119]

As with the cliff swallows, figuring out whether the species had evolved meant comparing specimens before and after the landscape change, to see if there was a change over time. While Doudna and Danielson did not have the benefit of thirty years of data, as the cliff swallow researchers did, they were able to make use of a different kind of resource.

The field work of 19th century mammal biologists consisted of trapping, shooting, and collecting animals wherever they could find them.[120] The result is that our country's natural history museums are packed with the carefully preserved furry fruits of these labors. To see what Midwestern prairie deer mice looked like before intense corn and soybean agriculture, Doudna and Danielson borrowed specimens collected before 1910 from the Smithsonian, the Chicago Field Museum, and two universities. The 150 specimens from these collections gave them snapshots of the deer mouse populations from over 100 years ago near six towns: Ames, Iowa; Manhattan, Kan.; Emerado, N.D.; Waseca, Minn.; and Shabbona, Ill.[121]

The team went to these same towns in the summers of 2012 and 2013 to set mouse traps in the fields. They gathered around 40 mice at each spot, for a total of 160. They cleaned the skulls using special beetles[122] that clean the soft tissue off of dead animals while leaving the bones intact—the same beetles used by taxidermists to prepare animal skulls for display.[123] The beetles chewed through the rotting flesh and revealed the hard bone below.

To test whether the jaws had changed, the researchers took close-up images of each mouse skull, new and old, next to a millimeter ruler for scale. On the computer, they added digital points along the landmarks of the jaws. When measuring distances this small, even tiny differences in how they positioned or rotated the skull for the picture could cause an error in their measurements. With help from a program called *geomorph,* they removed the effect of these differences in the skulls' positions.

When they finished crunching the numbers, they saw that the modern mice had larger mandibles—lower jaws—than the historical mice. The upper jaws of the current-day mice, and the locations of the jaw where bite muscles attach, had also increased in size significantly. And larger, tougher hardware meant that the muscles had also increased in size, probably making their bite force much greater.

By itself, this finding might not be surprising. A number of studies have shown that you can get a mouse's mandible to grow larger just by giving them a diet of tougher food as they grow. An individual's set of genes give it some wiggle room, called plasticity, to change depending on the environment in which it develops. Again, think of the children who exercise more and develop thicker bones.[124] In other words, this finding alone didn't tell the team that the mice had definitely evolved. And in fact, some biologists aren't fully convinced that the Iowa State team found signs of evolution. It's an argument that happens often in biology: are animals (including people) the way they are because of nature or nurture?

However, the case for evolutionary change—nature rather than nurture—is convincing in this case. To be sure they were seeing natural selection and not just environmental effects, Doudna and Danielson considered other information. One important piece of the puzzle was when the modern mice had been collected.

The team captured mice in the summer. Most individuals in the species don't make it past their first year, so these mice were entering their first winter. The biologists know from studying the mice's stomach contents that they focus on eating insects during the summer and eat few seeds. What this means is that the mice they caught were not exposed to big grains like corn during their development.[125] The mice didn't have the chance to eat big seeds to pump up their jawbones, allowing nurture to take precedence over nature.

"We're pretty sure it is genetic," Danielson said. "We're being very conservative about assigning genetics to any of those [jaw] dimensions." [126] He said the evidence of natural selection here is "written in hard bone."[127]

Doudna and Danielson's study came out in the online journal *PLOS One* in 2015.[128] In this paper, the two researchers also pointed to another piece of recent evidence: the cliff swallow story. The observation that cliff swallow wings had shortened over three decades due to natural selection supported the idea that mouse jaws could evolve to be more robust over a century.

When Danielson finished his study, he gave his nest boxes to Jacob Berl at Purdue, who Danielson now helps advise along with Purdue professors. I joined Berl in the field this January as he checked the boxes in both corn and soybean fields. While he hasn't looked at jaw morphology yet, it struck me how much of what Berl saw in Indiana matched what Danielson observed hundreds of miles west in Iowa. The prairie deer mice near Purdue reach their highest densities right in the middle of crop fields. They breed in winter, sometimes more than once. Groups of mice tend to stash grain in one nest box and shelter in a nearby one.

Indiana was a frontier outpost for the tallgrass prairie region. The Prairie Peninsula, the eastward reach of the plains, extended through central Indiana into Ohio.[129] But overlaid on the map of the historic Plains is the modern Corn Belt and its agroecosystem. This region stretches from Nebraska to Ohio, directly replacing most of the tallgrass region. The challenges faced are similar throughout: corn or soybean from fencerow to fencerow.

Danielson draws a measure of hope from the story of this native mouse species adapting to the cornfield. "They're doing better out there than back when this was a native prairie," he said. "These mammals ... have really adapted well. I mean incredibly well—to a landscape that is absolutely nothing like what they used to be in."

Danielson thinks this tells us something about what other dramatic changes to the world, such as global warming, might mean for native species.

The Midwest's distance from the coasts has insulated the region from climate change so far—but that might be about to change. June 2015 was the wettest in recorded history for Missouri,[130] and Iowa just had its wettest winter in 100 years.[131] If things continue as they are now, storms will become more frequent and more severe. But maybe we've underestimated the ability of Plains wildlife to adapt to these coming changes.

"These species aren't as helpless as we maybe make them out to be," Danielson said. "Most of our estimates of what the future will bring or what change will bring is built around the idea that the animals themselves are frozen, that they can't change and adapt—when in fact, a lot of them can. And certainly, a lot of them have."

Brown and Bomberger Brown told me something similar about the cliff swallows—if they had adapted as a result of one intense storm, perhaps more frequent intense storms will just be more of the same for the birds.

But what does it mean for conservation to have a changed version of a native species? Danielson said that in some sense we have lost species. "We could say our prairie deer mouse is lost. It's not the same deer mouse that we used to have," he said.

And yet, it strikes him as more important that we still have the species with us in some form. "We're causing them to change, but they're still with us. And I think that's a really good thing," he said.

I find myself agreeing with Danielson. To me, there is something thrilling about a wild mouse succeeding in a habitat we assume is under strict human control. It suggests to me that whatever humans do, no matter how many casualties there are among other species, there will always be some organisms able to adapt and survive in new ways.

Without forgetting the damage our natural world is now experiencing, these three survivor stories are worth considering. Maybe we have underestimated the potential for animals to adapt to the changes we're making to the Earth. This isn't to say we should stop trying to restore landscapes and keep polluting—especially since we're probably much less able to adapt our lifestyles to climate change than, say, a deer mouse or rootworm. But what it does mean is that natural selection isn't broken. It didn't stop working when we built coal plants or ripped up the prairie grasses. We humans are just one more evolutionary challenge to wildlife, and there are species capable of dodging us, doing battle with us, and coexisting in harmony with us. Maybe that could provide us with a much-needed dose of humility.

Nonetheless, we've forced species to adapt within the last century. That, too, ought to give us pause. It shows definitively that the world we've created is different than the one we were given, the one that multiple species had evolved to live in for millions of years.

We're passing the Earth's wildlife through a sieve, and not every species is going to make it through. If we want to ease the pressures on wild populations, we need to find a way to relax our stranglehold on the oceans, the forests, the marshes—and not least, the plowed and wounded prairies.

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[26] Cunfer, 38.
[27] Interview with Mary B. Brown, 2 Nov. 2015.
[28] Interview with Mary B. Brown, 2 Nov. 2015.
[29] Interview with Charles Brown, 29 Oct. 2015.
[30] Interview with Mary B. Brown, 2 Nov. 2015.
[31] Interview with Amy Moore, 2 Dec. 2015. The ground under the culverts is usually muddy.

[32] See: Brown, Charles, and Mary Bomberger Brown, 2013, "Where has all the road kill gone?" *Current Biology* 26:R233-R234. The first paragraph notes that the cliff swallow study began in 1982 (1996-1982 = 14 years.)
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