As winter sets in, porcupines converge on places like The Crevice—places that are often easy to spot on a topo map. Here it's the evergreen leaves and twigs of hemlock that keep porcupines fed through winter. In the summer any porcupines up at The Crevice are more likely to be digging for underground false truffles than eating hemlock needles. But in winter they climb high up in the trees, as far out on a branch as is safe, and feed on hemlock. With their sharp front teeth—four rodent incisors—they cut through the twigs. They munch on some leaves, then let the twigs fall.

Porcupines are choosy about which hemlocks they feed on—individual trees within a species vary in their taste due to genetics, site conditions, and defensive compounds. When you come across the one-foot-wide rut in the snow marked by the blunt, pebbly textured feet of a plodding animal and dribbled with piney-smelling green pee, follow it. It will lead you through the forest, past hemlock after hemlock, until you reach the one hemlock, the tastiest of all, where the porcupine feeds day after day, year after year. Perhaps this one tree is also particularly easy to climb.

Hemlock twigs are littered around the base of the tree, each about the size of Japanese foldable fans, maybe a bit larger, but feathered with tiny, dark green hemlock needles. Pick up one of these branches and you'll see the broken end, a bit thinner than your pinky, showing the characteristic 45-degree angle cut of a large rodent. Looking up in the tree, we see denuded branches with strange tufts of green at the ends but no green along the lengths. The teetering porcupine, afraid of venturing out too far on each branch, prunes it like pom-poms on a poodle.

INVADERS

I'm worried about the porcupines at The Crevice. Not because of shovel-wielding landlords but because the woolly adelgid is killing

Figure 8.4.
Hemlock woolly adelgid.

off our hemlocks up and down the eastern United States (fig. 8.4). For millennia the aphid-like insect has feasted on hemlocks in the western United States, Japan, and China. Those hemlocks evolved ways of defending against the insect, and the trees don't seem to even notice when they're covered with the white fluff. However, the two species of hemlocks in the eastern United States didn't evolve alongside woolly adelgid. So when people accidently transported some woolly adelgid from Japan to Virginia in the mid-twentieth century, the eastern hemlocks' nightmare began.

Over the course of eighty years, woolly adelgid spread to Georgia, Maine, and beyond. Hemlocks down south have been particularly hard hit—like the forests of snags we encountered when searching for chestnut. Luckily for the Northeast, the introduced strain of woolly adelgid came from southern Japan, where the climate is relatively warmer. The invading adelgids aren't adapted to the cold. So up north, when we get a hard winter, it kills off the

Figure 8.5. Elongate hemlock scale.

adelgids, holding them at bay. But as the planet warms and our winters become less severe, the adelgid will inevitably march farther northward.

The good news for hemlock is that, unlike with American chestnut, hemlock isn't that valuable for timber. Which means that timber companies haven't rushed to cut down all the hemlocks before they die—as they did with chestnuts. Hopefully, there will be a handful of hemlocks that, due to just the right set of genes, survive the first wave of adelgids. The next generation of hemlocks would then inherit these genes as they start to reclaim the forests.

Over the past year I've hiked up this mountain many times to photograph adelgid for the chapter's opening image. But I've failed every time to find a single adelgid—is this good news? Instead of adelgid, all I find are heaps of another tiny invasive pest: elongate hemlock scale (fig. 8.5). I've been told that the scale doesn't kill the hemlocks as directly as the adelgid, but there is a complicated interaction with the insects competing against each other and both draining the tree's resources. At a recent Woodsy gathering, I was venting my frustration at failing to capture an adelgid photograph. Then Jesse reminded me of how the last couple winters the polar vortex has slipped down into New England causing weeks of negative temperatures. Those cold snaps must have driven the adelgid back, however temporarily.

The porcupines at The Crevice are rooting for the hemlocks to survive. Having tracked many a porcupine around here, I came to the belief that porcupines depend almost entirely on hemlock in the winter. But the truth is that porcupines can eat pine needles, sugar maple twigs, basswood buds, beech bark, oak bark, and more. Out in New Mexico, Charley and I found a porcupine crossing through the sandy desert at White Sands National Monument, far from any hemlocks.

Biologist Uldis Roze has spent years following porcupines around, naming individuals and getting to know them. Porcupines, he found, all have individual tastes. Two porcupines living side by side might eat very different things. The porcupine Uldis named Rebecca, for instance, loved basswood, whereas Finder loved beech, Squirrel loved sugar maple, and Moth loved hemlock. Why? Well, one reason might be that these trees all have toxic defensive compounds, and the microbes living in the porcupines' guts have to be specially trained to break down these compounds. If Rebecca suddenly started eating hemlock, her gut bacteria might revolt, and she'd be unable to process the tannins that hemlock produces.

So although I think of porcupines as only eating hemlock in the winter, that's only true of the porcupines I know—the ones who tend to hang out in hemlock-rich areas in winter. Even if we lose all our hemlocks, porcupines as a species will survive, but perhaps not the ones I know.

Figure 8.6. Hemlock removal experiment: (a) girdled hemlocks surrounded by black birch, and (b) student Nia Riggins sampling ants in the understory.

EXPERIMENTAL FORESTS

This summer I followed Sydne and three students in to one of the experiments at Harvard Forest. We walked through a young stand of hemlocks casting a dark shadow into the open forest understory. Then we encountered a sudden shift. Now we were clawing our way through a bright green sea of black birch saplings. Above, the sky was full of dead hemlocks. At the base of each tree, the trunks were encircled by the grooves of a chainsaw.

Sydne and the students fanned out to collect pitfall traps—little plastic vials sunk into the soil and filled with soapy water—to study the ants that fell in. This forest is a simulation of what would happen if woolly adelgid killed off all our hemlocks. Instead of millions of tiny fluffballs sucking at the needles, researchers had girdled the trunks to cut off the flow of sap (fig. 8.6).

Hemlock is a typical old-growth species—slow growing, long lived, and shade tolerant. Young hemlock saplings will hang out for decades in a forest understory, slowly growing to take their turn in the canopy. In the dark shadow of a hemlock forest, mid-successional species such as oaks can't survive.

There is an early successional species, black birch, which is also often associated with old-growth hemlock stands. In a stand of hemlocks, one of the ancient trees crashes down. A tiny seed of black birch finds its way onto the fresh dirt around the upturned hemlock roots. The young tree quickly shoots up into the gap, lives for maybe a hundred years, and dies. Meanwhile another hemlock is slowly working its way up for its own 500-year life in the forest.

With the hemlocks gone from the system, everything shifts. Sunlight pours in. Cool streams become warm streams. Moist soil becomes dry soil. Even the ants, as Sydne has found, are profoundly different.

After Sydne and her students finished collecting the first twenty-five ant traps, we walked through a fenced-in area to collect more traps. The fence was built to keep moose and deer out.

Deer are another species, like porcupines, that gather together in hemlock forests in the winter. The dense needles of hemlocks make great shelter, and snowpack is thinner under hemlocks. More often than not, when I find a winter deer bed, shaped like the imprint of a two-foot-long lima bean melted into the snow, it's underneath a hemlock. The same is true of moose beds, though the lima bean is even bigger, as is the sheltering tree. After a good sleep under the hemlocks, deer will wander in search of food. If there's not too much snow on the ground, and if there are some good oaks around, the deer might be able to scrape up acorns from the forest floor. But when the snow is too deep or icy for hooves to reach the acorns below, deer, like porcupines, will feast on hemlock needles and bark.

In some places, where you exclude deer, the forest is completely different. In graduate school I had a little project studying how salamanders on islands in lakes are different from salamanders back on the mainland. On the mainland, I'd walk through open forests with scattered hobblebush shrubs. When I'd get in my boat and float over to the islands, I'd encounter impenetrable thickets of American yew. Yew is a favorite of deer, who presumably devoured it all on the mainland but never visited those islands.

What's the role of deer in a forest? In addition to eating vegetation, they eat acorns. Deer presence thus reduces populations of mice, who also rely on acorns. Mice, more so than deer, are the key vector for Lyme disease, so fewer mice means less Lyme disease. Mice also eat spongy moth larvae. So when mouse populations crash, spongy moths explode and eat up all the oaks. This means fewer acorns, and so fewer deer. It makes my head spin, and we haven't even brought in the predators like foxes and coyotes yet. These are the kinds of complex interactions that researchers with fences around the country have been working out for decades. However, at Harvard Forest it turns out that the populations of deer are so low that the forest inside the deer fences is basically identical to the forest outside the fences.

These big experiments are just a few of the many strange things in the woods at Harvard Forest. Harvard Forest is part of a network of Long Term Ecological Research sites around the country focused on doing research that requires a long investment in a place. For instance, up at a sister site in New Hampshire—Hubbard Brook—researchers have been studying the various parts of a single watershed from all different angles for decades. Recently, Hubbard Brook researchers brought out firehoses in the dead of winter and simulated an ice storm. The trees, coated with glistening ice, began to snap. What snapped when and how will the trees recover? The answers to these questions will be used by weather forecasters to predict ice storms and by ecologists to predict how forests will respond to climate change.

Figure 8.7. Trees felled by windstorms: (a) pines knocked down in the 1938 hurricane in New England, lying parallel to each other, and (b) blowdown from a 2006 tornado, photographed in 2009, showing varied log orientation. (b: MassGIS, Fugro Earthdata, Inc.)

Elsewhere on the Harvard Forest property is a hurricane simulation. Audrey Barker Plotkin, a forester and ecologist, recently took me and two students there to sample falling leaf litter. This was the day before the town where I live—home to the mountain of conglomerate that holds The Crevice, the porcupines, the oak forest, and the hemlock forest—was to hold a big parade celebrating the town's 300th anniversary. On the drive out to the hurricane simulation plots, Audrey told us about how, eight years ago, they celebrated the twentieth anniversary of the hurricane experiment. To which I asked, "Did you have a parade?"

Twenty-eight years ago Harvard Forest researchers drove out into the forest armed with a huge steel cable and a powerful winch. In one two-acre area, they toppled 276 trees, all toward the northwest—which, according to the researchers' calculations, is the di-

rection of the strongest hurricane-force winds in this region. Although humans always seem surprised and devastated when hurricanes hit, the forests are used to them. At Harvard Forest, researchers figure that each tree in the forest should expect to be hit with some sort of damaging hurricane winds every decade or so. Every hundred years or so, the winds are going to be so bad that much of the forest will be flattened—as happened in the "Great New England Hurricane" of 1938 (fig. 8.7).

In the control plot, where researchers left the trees untouched, Audrey led us into a forest of red oaks. They were decent-sized, but not huge, and all pretty similar to each other. It struck me as a sort of young, boring forest—with a predictable history typical for the region. In the 1800s it was a farm. It was abandoned. Pines grew in. An oak understory began. The pines were cut. The oaks took over.

Figure 8.8. Hurricane experiment at Harvard Forest: (a) hurricane simulation plot, and (b) control plot.

But over in the hurricane plot, it was more interesting (fig. 8.8). In some ways the forest looked much older—almost like an artificially created old-growth forest. There was structural complexity—something more typical of older forests. In undisturbed old-growth forests, the trees don't all die, or start growing, at the same time. Individual trees fall over while their neighbors stand tall, creating a little gap in the canopy. This creates a tapestry of new gaps, older gaps that have been filled in, and old trees still holding their ground. And on the floor of an old-growth forest you'll find big logs in all stages of decay.

In the hurricane simulation there are logs lying all over the ground. Instead of the dominant trees all being the same size, like

in the control plot, there are two size classes in the canopy. There are, of course, all the young trees that have grown up in the last twenty-eight years since the simulated hurricane touched down. But then there are scattered trees that lived through the hurricane. Relative to the rest of the forest, these trees are huge. Even compared to the trees in the control plot—which are the same age—the trees that survived the hurricane are bigger. That's because, twenty-eight years ago, all their competition was wiped away. Left alone to soak up all the sunlight and soil resources, these trees grew like mad.

It's neat to see a forest with old-growth characteristics around here, as most of our forests are still recovering from the massive land clearing over the past few centuries. And it's not just the trees—the animals, too, were cleared from this region due to the lack of forests, intense game hunting, and high bounties on predators. We lost heath hens, passenger pigeons, and sea mink—gone forever. We lost all our wolves and cougars—although they survived elsewhere. We lost almost all our bear and deer, and they have since rebounded from holdout populations, with the help of active management aimed at restoring their populations. We lost all our beavers—but then the state reintroduced them further west in the 1930s and 1940s. By the 1970s, beavers had spread up and down the Connecticut River Valley, and by the late 1980s they had repopulated most of the state.

Standing out in the forest with Audrey and the students, I inspected some of the red oak logs that were pulled down twenty-eight years ago. How do they compare to the logs in the bright forest up on top of our hill where I took the *Field Naturalists*? I'd brought my laptop out to the hurricane plot so that I could look up all the Harvard Forest data on each numbered log we encountered. I pulled up a photo of the logs from the bright forest to compare the amount of decay in those logs to the ones in the hurricane plot. It was hard to say, but they could have been somewhere around the same age.

Well, maybe the logs in the bright forest are a bit older. To explain my reasoning, I told Audrey that the forest in my book chapter is an oak-hickory-hop hornbeam forest. "Yup," she said knowingly. These types of forests, which grow on south-facing slopes, are characterized by hot, dry conditions. In contrast, the moist conditions of the forest in which we were now standing make a much better place for moss and critters to grow on and in the logs, which therefore deteriorate much faster.

Audrey pointed out the root ball of one of the upturned trees in her plot. When the tree was tipped over, the living roots held fast to the soil and rocks, transporting a huge pile of dirt out of the ground. Where the tree once stood was now a big pit. To the side, where the exposed roots came to rest on the ground, now sat a big mound of dirt (fig. 8.9).

Then Audrey pointed out another log. This one, however, had no pit or mound at its end. The roots at the base of the tree all seemed to have broken off close to the trunk. This was not a tree that the researchers pulled down. Audrey had a theory. If trees are weakened or already dead when they fall over, their roots break off. Sometimes the trunk snaps above the base, and sometimes the break occurs just underground. Without roots clinging to dirt, such falling trees don't make pits and mounds. It's when the lives of healthy trees are cut short by a violent storm that the roots are strong enough to create a pit and mound.

So what role do these pits and mounds play in the forests? Armed with a tape measure and clipboard, Audrey has been crawling for years through the old hurricane experiment measuring the dirt piles. "Charismatic micro-topography," we joke. Over the last two decades, Audrey and other researchers followed the erosion of individual pits and mounds as the mounds slowly grew lower and wider and the pits slowly filled with leaves and soil.

Pits and mounds are a common feature of old forests. Depending on the local climate, they can last for a few decades or a few thousand years. Collectively, pits and mounds on the forest floor record generations of trees growing, falling, and rotting into the earth. In temperate forests, if you don't see pits and mounds, you have to wonder, why not? Often it's because the land was once cleared and plowed flat by people. The floor beneath virgin old-growth forests is typically an irregularly undulating surface of pits and mounds in various stages of decay.

Out in the hurricane experiment, Audrey watched over the years where little seeds landed in the dirt on top of the mounds, sprouted, and grew up into small saplings. For most trees, especially black birch, those mounds are the best place in the forest to

Figure 8.9. (a) Pit with breeding wood frogs next to a freshly tipped-up root ball of a tree in Pennsylvania: wood frog egg masses appear as dark splotches emerging from the water, near the fresh dirt. (b) An old pit and mound in Tennessee.

grow. It's prime real estate high above the competition, with exposed soil that isn't smothered by leaves, and a rotting tree below to provide nutrients to the growing sapling. Plus black birch is an early successional species that needs light to grow, like the light that pours in through the gap in the canopy where the old tree once stood. These little gaps where trees fall are why old-growth forests aren't simple monocultures of late-successional species.

After many decades the old, toppled tree and its root ball rot away to almost nothing. But the aging black birch still keeps a record of the mound it sprouted on. The birch stands on a set of funny spread legs that emerge from different points in the ground and fuse together a few feet up to form the main trunk. Enclosed by these legs is an empty space—the shape of the old root ball. In some forests,

like those of the Pacific Northwest, the whole trunks of fallen trees become prime real estate for sprouting trees, such that trees often grow in lines marking the location of old “nurse logs” (fig. 8.10).

Audrey concluded that the mounds themselves promote diversity in the forest. Without the mounds, species like black birch wouldn’t have a place to grow in the forest. The pits, however, seem less exciting to Audrey. In the Harvard Forest hurricane simulation, most young trees didn’t like to grow down in the pits.

But, as a herpetologist, I love the pits. I root around through the layers of leaves trapped in the pits hoping to find an overwintering box turtle or a hiding ring-neck snake. In lowlands in early spring, I leap from pit to pit, hoping to find some filled with water. Hearing a cackling sound echoing through the forest, I home in on

Figure 8.10. Nurse log in the Smokies.

one water-filled pit overflowing with breeding wood frogs. Without these pits where would all the reptiles and amphibians go?

DISTURBANCE

At last the *Field Naturalist* students have arrived at the answers to the little mysteries.

The circle of moss? That's the mound from the root ball of a tree that toppled long, long ago and has completely returned to soil.

That dead sapling? You can see exposed growth rings where for several years the bark tried to heal over a wound, creeping sideways across the stem. In fact, that thick scar is the only bark that's still attached to the tree—the rest of the bark below and above has sloughed off. Hemlocks do that. A few other species do also, but the feathery twigs tell us it's hemlock. So what injured it? A porcupine? Porcupines do like hemlocks, at least in winter. But a little sapling like this—exposed on this hill—doesn't scream porcupine. It's such a skinny trunk, and there's no evidence of angled cuts on the branches. Moreover, there's only a small portion of the stem that actually shows evidence of scarring.

No, this tree doesn't seem like it died because something ate it. The lone hemlock sapling in a hardwood understory. At the top of a hill, in a forest littered with acorns, and a short walk from the cover of much denser hemlock. This is a perfect place for deer to hang out in winter, and the sapling is a perfect signpost on which to make a territorial claim. This is a classic, albeit very old and weathered, marking sign of a male deer thrashing his antlers against the sapling.

What do we see in those understory hemlocks? For one thing, there's a sharp horizontal line. Above the line, a sea of green hemlock needles. Below the line, a dark void. This is the browse line of a voracious herd of deer, out of nuts, munching every needle within reach. The other pattern worth noting is that, while the understory is all hemlock over there, the canopy, as told by the leaf litter, is all hardwoods. If left alone, succession would turn that little hardwood stand into hemlocks.

The branches on the ground? Looking around, branches of that size, shape, and degree of decay are littered about this forest. They came from the tree tops and were all brought down at once. In an ice storm—a particularly bad one ten years ago.

The rotting log? That's where a tree fell. What else is there to say? Well, a close look at the wood shows that it's a red oak for starters. Also, there are several other logs of the same size, with the same amount of decay, all lying in the same direction. Three root balls are visible in the top left photo of the chapter's opening image, and, like the shadows of the setting sun, the logs are all pointing eastward. That suggests that a great gust of wind toppled the trees at once. A hurricane? A tornado? A winter nor'easter? A summer thunderstorm?

A tornado would scatter trees willy-nilly. The rotational forces of a hurricane moving north up through New England typically topple trees to the west around here. A winter storm moving in from the Northeast would also knock trees down toward the west. But thunderstorms, which tend to march from west to east, tend to knock trees over toward the east. So, chances are, a strong gust, known as a microburst, from a severe thunderstorm knocked these red oaks down. I'd guess that these trunks have been lying here maybe thirty or fifty years, so that storm would have happened in the late twentieth century.

Looking at the roots on these overturned trees, they don't seem to have made a mound around them when they died. No, they seem to have broken off near the base when they fell. Were they already dead when that storm hit? Well, it was nearly forty years ago, in

1981, that the spongy moth outbreak killed off Bill Patterson's oaks on the other side of the slope. I bet they killed these oaks too.

But there's more that these oaks have to tell. The trunks are all forked. That suggests that these were the regrown stems of trees that had been previously cut down. Looking at the size of the forked trees, I'd guess they'd been growing for maybe a hundred years or more, which would put the logging event in the mid-1800s.

How big were the original trees that were cut down? If we estimate the centers of the base of each trunk on the tree, the distance between them is about the original diameter of the earlier trunk that was cut down—since the new sprouts start growing from the edges of the cut stump. In this case the original trees were about two feet in diameter. So these original oaks probably started as acorns in the mid-1700s.

HEADING HOME

As Juno and I stare at the hemlock slice in our living room, ticking off the decades, our count takes us past 50 rings, past 100 rings, then past 200 rings. The ring at the center of this slice of hemlock formed in the year 1776, around the time that the red oak on the hill above was a young sapling. The oak was felled twice since then, while the hemlock just kept growing older. And, as I remember, this slice of the hemlock wasn't cut from the base of the tree but from fifteen feet up along the trunk. It likely took the hemlock several decades to reach that high, making the tree well over 250 years old. Older, perhaps, than all the old towns around here. It's probably time for this forest to have a parade in its honor.

So why is this old hemlock here? There are two answers to this question. First, this north-facing slope makes for prime hemlock habitat. Although these trees can live in a variety of settings, this is one that they're especially good at. The oak forest above, especially the part with no understory hemlocks, faces south, catching the hot, dry sunlight all day. That hill of oaks casts its shadow onto this hemlock ravine. Thus, it is dark and relatively humid here—great for hemlocks.

Up on the hilltop the trees are short. In part it's because the dryness makes for difficult growing conditions. But it's also because the trees up there take a beating from the elements. When storms hit, ridges often take the brunt of the wind—although not always. And from freezing to baking, the temperatures are more extreme up there. The protective snowpack melts faster on the sunny ridges, leaving roots in the soils exposed to damaging cold at night.

The hemlocks in the ravine, however, are sheltered. Beyond just the weather extremes, the steep slopes have also protected this forest from humans. On such steep slopes, logging is difficult. Farming is even harder. Plus, although hemlock was historically prized for tanning hides, if you try to make a board out of it, the wood tends to fall apart. So loggers in this area would have left hemlock alone.

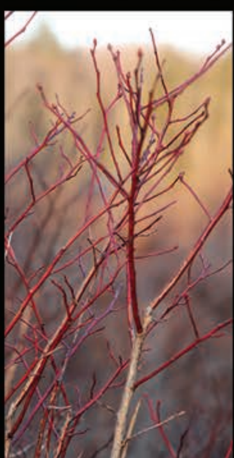
This is the truth of most remaining old-growth forests. They are in the hard-to-reach places. That's why, when we were looking for chestnuts in North Carolina old growth, we had to travel up the Tail of the Dragon—that ludicrously sinuous road—to get there. And that's why I put in the extra effort to push the children up this mountain. In the Northeast, old growth is often concentrated on steep, north-facing slopes of hemlock. Having survived the centuries primarily because people were uninterested in these forests, the arrival of woolly adelgid is suddenly threatening the ancient hemlocks. Indeed, the hemlocks here at this site are falling apart, and it's not clear how much longer they will last.

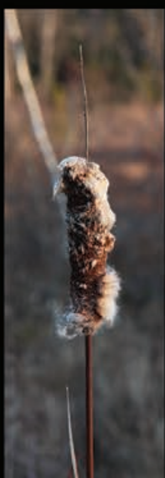
The sun is gone from this valley now. Back in the stroller, Juno and Alder huddle together for warmth like hibernating snakes as we roll down the mountain.

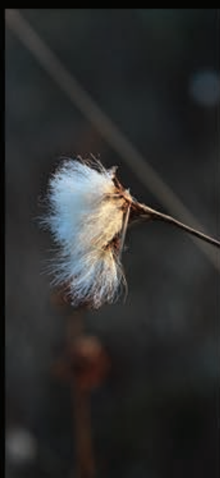
MAJOR LESSONS FOR INTERPRETING A LANDSCAPE

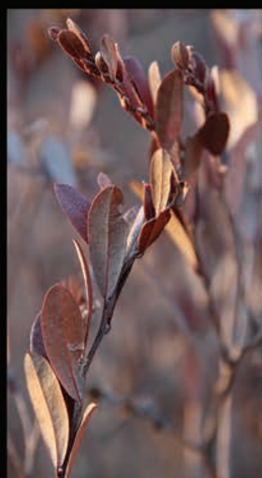
- What are the disturbance dynamics in your site? Think about windstorms, herbivores, pathogens, and so on.
- Where are the local microhabitats that support wildlife through winter or the dry season?
- How does topography drive patterns in your landscape at large and small scales?











(overleaf)
Figure 9.1. A clearing in the forest.

9. Relics

I'm staring at a footprint. It's big and obvious. There's a long, alternating string of them that continues for perhaps twenty yards or more. The track size and stride length aren't too different from my own. But my feet don't make the slightest impression in this firm litter of hemlock twigs and needles. I'd have to really twist and dig in with my heels. Is this what I think it is?

I wander off, then return. I search for a bit. Then right there on the trail I find a big tree that's been gouged all over. An hour before, on my hike in, I had breezed right by it, along with all the mangled saplings that surround the tree. It's what trackers call a "whammy tree." The string of footprints leads right to it.

This is the ritual trail of a bear. "Ritual" because the bears methodically slip their feet into the same footprints each time they visit the tree, twisting with each stomp to rub in their scent. As I tell my kids, it's where the bears come to dance.

What a perfect spot for this sign: in the center of a low, long, forested hill that juts like a peninsula into a surrounding habitat. When I was sleeping a few feet away in my old debris hut—now nothing but dirt—I wonder, was this sign here the whole time?

It's now time to head for that other habitat.

Wandering among six-foot boulders beneath a dark hemlock canopy, I catch sight of light pouring into the forest up ahead. I cut down a short slope, scratch my way through a wall of dense

Figure 9.2. View of dead snags on south end of clearing.

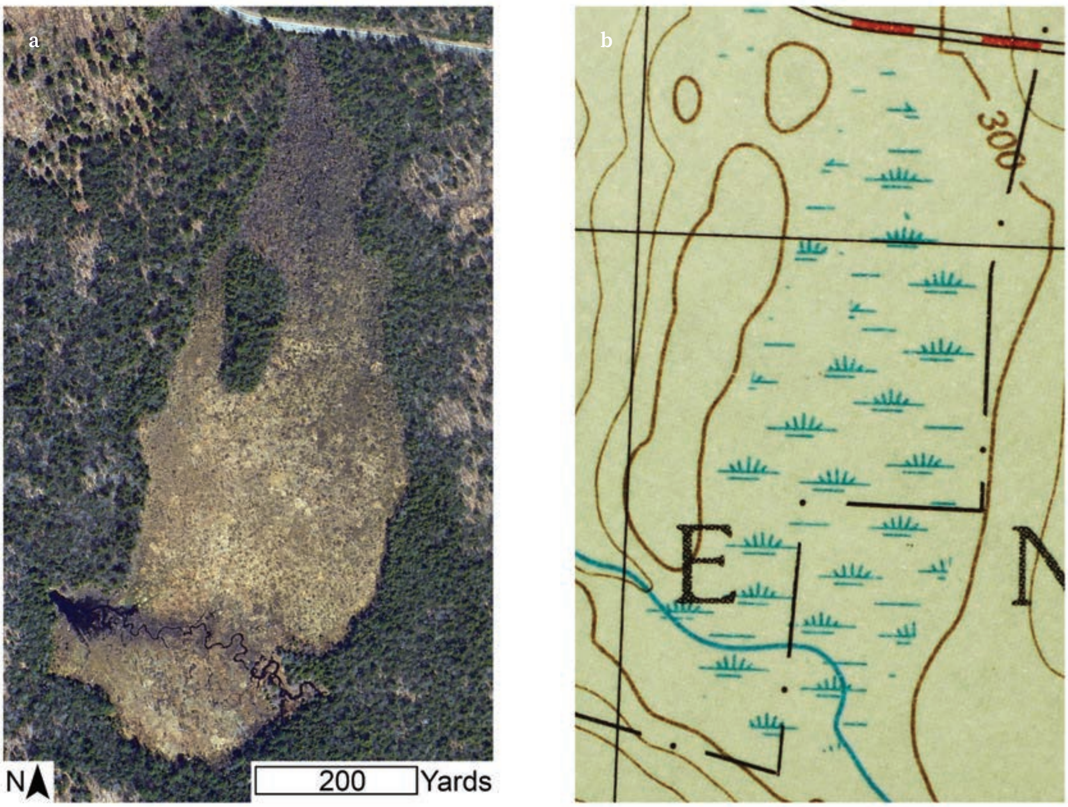
shrubs, and am confronted with an expansive view (fig. 9.1). What is this place, and why is it so starkly different from the surrounding forest? After soaking up the warm sun on this chilly December afternoon, my gaze turns to the forty-foot dead trees standing about. On the far side of this clearing, there is an entire ghost forest of these snags (figs. 9.2 and 9.3). Why are there so many tall dead trees but none alive?

What is a clearing? Having lived most of my life in the eastern forest, I expect to see trees wherever I go. When I find myself in a place without trees, I naturally wonder what is holding them back. Is it from logging? Cattle? Fires? Floods? Hurricanes? If we venture across North America west to the Great Plains, desert, or mountain biomes, trees are naturally prevented from growing by combinations of lack of water, grazing mammals, fire, and other forces.

Perhaps if you come from Nebraska, the sight of forest might cause you to wonder what is holding back the prairie—a fair question. Try planting a prairie here in the East and leaving it alone. As we saw at Maggie's Forest, succession will eventually bring in an army of trees that block the sun and wreck your prairie. To keep your prairie, you must regularly disturb the landscape by unleashing cattle, mowers, or fire into the field to kill off the tree saplings.

Trying to maintain an open field in the eastern forest can be like trying to maintain a yard of big water-loving trees in the Desert Southwest. However, that's not to say that such trees never occur naturally in the deserts—if you go down by a river, you will find stands of cottonwoods. The same is true in the eastern forests—if you know where to look, you will find natural meadows.

Figure 9.3. (a) Aerial photo of the chapter site, and (b) topographic map of the chapter site. (a: MassGIS, Sanborn LLC; b: USGS)



This site reveals a complex pattern of vegetation types and heights spread about in organic clumps. I don't see uniform vegetation, neat lines, logging stumps, fences, or heavily worn trails. This suggests that we are looking at a natural clearing in the forest, not one of human creation.

CATTAILS

Do you see the cattail peeking out of our chapter-opening image? The sight of cattails transports me to their signature habitats: nutrient-rich marshes inhabiting backwaters of streams, on the shores of lakes, and in artificial retention ponds. I close my eyes and see myself on a sunny winter day clambering through a nearly impenetrable cattail stand. As I step carefully forward in my imagination, I hear the crackling sounds of brittle stalks breaking while snow crunches between my boots and the ice-covered water. Without warning the ice breaks, jamming against my shins as I drop through to the mud below. My boots fill up with water. When I stand still, the water warms in my socks. But with every step my boots make a sucking sound, and I feel cold on the soles of my feet from new water rushing in.

I plod along the meandering trail of swimming muskrats. Muskrats love the taste of cattail just as I do. The spring stalks taste exactly like cucumber. But it's the winter seed heads that to me are the most magical part. My students begin giggling with delight as they pluck at the firm brown corndogs. Out of this tight bundle, golden velvet masses of a quarter million seeds explode into the wind. It's that texture I love. Each seed is fashioned like a helicopter, with a payload suspended beneath a whirl of blades that unfold as the seed crawls out of the mass. The seeds tumble out like so many clowns packed in a car. How did they all fit in there? The furry floating clowns now completely fill the air. They coat my nose and tickle it, causing my head to recoil with a shiver as I open my eyes and return to the present.

This image before me bears little resemblance to the landscape I saw when I closed my eyes.

Yes, this cattail seems to be telling us that water is to blame for the lack of big trees here. To survive with roots under water year round, trees need special adaptations, such as the snorkel-like "knees" of mangroves that stick up above the waterline to help the roots breathe. Such trees are not abundant in this region, so when soils are deeply waterlogged all the time, there are usually no large trees—as in many lakeside marshes.

Indeed, ask the small white pine sapling on the right side of this chapter's opening image why it is a sickly yellow color. This pine may say that it found purchase in dry soil for a few years next to the big rock, but now it's too big to grow sufficient roots without drowning. But weren't there big trees and woody shrubs in the Great Swamp? In that case the water was held at the surface by a layer of clay, "perched" above the natural groundwater level. The water layer was thin, seasonal, and, during the wet season, tree roots could find air in little mounds above the water layer or conceivably even in air pockets beneath the clay layer. The lack of trees where I am standing now may mean that this wetland is deeper and more permanent than our tupelo swamp.

But this is not the dense cattail marsh I waded through in my memory—there are only a few scattered emissaries of this species. What other friends can we find here to offer more clues?

PITCHER PLANTS

To my eye the most striking species is the pitcher plant in the foreground of our chapter-opening image—seen as a rosette of red leaves beneath dried flower stalks. Here we meet one of those incredible carnivorous species that few realize live among us. The "pitchers" are hefty leaves that have been modified to hold water.

I imagine shrinking down to fly-size and perching on the pitcher lip. Peering down over the edge, careful not to fall, I can see insects floating in the dimly lit water near the bottom. Many of these insects were drawn in by the sweet nectar on the rim of the pitcher. Looking to my left, I see an ant, about my size, drinking that sugary liquid. That nectar looks so yummy and barely within reach. I stretch my arm out to grab just a little taste of the delicious nectar. Teetering, I make a quick adjustment to my balance and bend down to steady myself on the lip of the pitcher. But my feet slip, and I find myself scrambling to hold on to the downward-pointing hairs that line the walls of the pitcher. After a moment of panic in mid-air, I splash into the water.

I come up gasping and begin to tread water among the other floating bodies. Slowly, these prey are being consumed by the digestive juices secreted by the plant. Some are consumed by the other organisms who call the pitchers home. Enclosed by maroon walls, here is an entire gloomy food web of bacteria, protists, nematodes, fly larvae, ants, spiders, and their acquaintances. I'm not the first vertebrate to fall in here; researchers out of Harvard Forest recently reported that this species of pitcher plant consumes newts on a somewhat regular basis. In fact, the last time I took my students to this wetland, they tore open a pitcher, just one, and shrieked in horror and delight when a rotting redback salamander corpse came rolling out (fig. 9.4). That could be me.

To a pitcher plant the critters it consumes serve as vitamin pills. When your doctor says you're not eating enough calcium, she may advise you to take some calcium supplements. Ancestral pitcher plants found themselves in nitrogen-poor environments, and so Dr. Evolution prescribed nitrogen-rich insects, to be taken only when needed. If we sprinkle a little nitrogen fertilizer on the

Figure 9.4. Salamander eaten by pitcher plant, found by *Field Naturalist* students.

roots of this plant before us, she will stop growing pitchers. No more nitrogen deficiency? No more need to swallow insect pills.

Why would any wetland soil lack nutrients? When a wetland receives most of its water from rainfall, it doesn't enjoy the nutritional benefit of groundwater percolated through rich soils. This results in an acidic, nutrient-poor wetland perfectly suited for sphagnum moss (fig. 9.5). Sphagnum, in turn, enhances the acidic conditions of the water, with its complex minute structures acting as cation exchange surfaces and releasing more hydrogen ions

Figure 9.5. Close-up of sphagnum moss.

into the water. Thus, an acidic bog is formed, making a home for pitcher plants and other leafy carnivores (fig. 9.6).

A bog is a type of peatland—a wetland that develops layers of organic peat because the rate at which plants grow is faster than the rate at which plants decompose. Peatlands are thus important global carbon sinks. The peat itself is primarily composed of sphagnum moss, with new life growing on top of old, dying layers. Long harvested and burned as a source of fuel, peat has been promoted as a renewable energy source by advocates in peat-rich countries like Finland. However, peat grows very slowly, at about 1⁄10 of an inch or so per year, hardly fast enough to be considered a sustainable source of energy.

There are many different types of peatlands, occurring in varied places and contexts—from tropical forests in Malaysia to Venus-flytrap-harboring wetlands in the Carolinas to the boreal string bogs of Labrador. Their formation can unfold in multiple ways. Sometimes they begin as isolated basins, such as kettle ponds—

which are holes left in the landscape by giant chunks of melting ice dropped by retreating glaciers (see pond in fig. 3.2). Sphagnum may begin to grow across the pond surface and slowly transform open water to a mat of wet vegetation. Sometimes bogs form from parts of wetlands that become hydrologically isolated from the rest of the wetland. Sometimes a sphagnum wetland may form by piling up layers and creeping out across dry land. In some places acid-forming bedrock or mine tailings will trigger formation of bog-like communities.

Standing in this spot and then looking down, you might be surprised to find that, where you thought you were standing on solid ground, your feet have sunk a few inches into a squishy wet mat of sphagnum. Holding a long stick, the *Field Naturalist* students probe

Figure 9.6. Thread-leaf sundew eating a bluet in New Jersey.

the surface out beneath that mysterious forest of dead snags. The stick easily slides down into the sphagnum five feet or more before stopping.

Once when I was surveying a small pond for salamanders, I stepped onto what seemed like solid ground only to find myself suddenly waist deep in layers of sphagnum. My first attempts to wriggle out caused me to sink even deeper. After a few panicked minutes, I managed to reach a nearby branch and drag myself back out to solid land. With less luck, perhaps I would have become another of the many "bog bodies," buried in peat and discovered thousands of years later, preserved by the extreme acidic conditions that inhibit decomposition within the wetland.

Slowly growing peat not only preserves bodies and stores energy but also maintains a historical record of the conditions present when the layers formed. Digging deeper and deeper corresponds to looking farther and farther back in time. This is how paleoecologists, inspecting pollen grains stuck in the layers of peat, can reconstruct the past—like Margaret Davis mapping the movements of tree species over the past 20,000 years.

In January, on a −6°F day, David Foster took me for a walk out to a couple of swamps at Harvard Forest. David, the esteemed director of Harvard Forest, is an expert in reconstructing ecological histories, and I wanted to learn about his work coring bogs. On the walk out I figured I'd try to impress him with some of my own expertise, so I dropped to my knees to sniff some yellowish snow.

"Gray fox," I said to David.

He looked back, stone-faced. I persisted.

"You know the smell of red fox?" I asked, eagerly filling in the silence. "Red Fox is skunky; you'd smell it from far away. Gray fox is milder, more like fisher, if you know fisher pee."

Unimpressed, David told me that he hadn't had much experience in smelling pee. So I shifted gears and pointed out some fisher tracks crossing the road.

David walked me through a spot where dozens of dead chestnuts were leaning up against hemlocks—as they had been since 1913. Just before the blight hit, a researcher had carefully marked and measured all the chestnuts in this forest to understand what characteristics would allow a tree to survive the blight—assuming some would survive while others wouldn't. Then the blight hit, and every single chestnut died.

At last we reached the wetland called "Hemlock Hollow," which looked to me like a small vernal pool. Decades ago, when David first arrived at Harvard Forest, one of his students made bathymetric measurements of the pond and discovered a deep bed of sediments below. So they took some sediment cores. Back in the lab, the samples showed a layered sequence from which they were able to date back an 8,000-year chronology. In a neighboring wetland David pulled another core out that went back nearly 12,000 years.

The sediments in these layers showed how the ponds had evolved. The deepest layers in the basin were sand, from the recently departed glaciers. Then bluish-gray clay and green pond bottom algae reflected calm, open waters. Then peat showed when each pond had filled in to become forested wetlands. Digging many more cores, Rebecca Anderson later continued this work and showed that after the ponds had turned into forested wetlands, sphagnum crept out over the edges as the wetland expanded laterally uphill.

Wedged into these sediments was ancient pollen which had landed on the water's surface before sinking to the bottom, and which now tells the story of the broader landscape. Looking through the microscope, David picked out the species of pollen in each layer, matching it with radiocarbon dates. While hemlock has been dominant in the forests surrounding these wetlands for about 8,000 years, it was only in the last couple thousand years that chestnut has been around. The deepest layers showed an open land of sedges—tundra following the retreat of the glaciers.

Just above these, about 10,000 years ago, the landscape was dominated by spruce—like the forests we now find north of us today.

Spruce, like the little lone tree now standing at the left of our chapter-opening image, just beyond the pitcher plant, not far from the cattails. I wonder, is that a black spruce or a red spruce? Here, south of the northern boreal forest, black spruce occurs primarily in acidic bogs, whereas red spruce occurs in more neutral wetlands.

Whenever I see a black spruce in this state, I can hear Charley mumbling in my head about dwarf mistletoe—we better go over and take look to see if we can find it. This tiny parasitic plant is related to common mistletoe but stands no more than an inch tall. If we find dwarf mistletoe, we can report the occurrence of a species on the state's endangered species list. Its rarity is largely because the primary local host, black spruce, occurs so infrequently here—farther north, dwarf mistletoe is considered a pest species that managers target for eradication. But in this state, dwarf mistletoe is known from only twenty current locations, although perhaps the low number of records relates to the fact that it is easily overlooked, and too few people stomp out into bogs to inspect black spruce branches.

Over at the spruce, the dark, shiny needles, the reddish twigs, and the lack of old cones suggest this is a red spruce. No mistletoe here.

So what should we call this place? A bog? We see sphagnum moss and pitcher plants. If we come back in the summer, we will also find carnivorous sundews, which have withered by December. That's not to mention the tawny cottongrass visible in the chapter-opening image, which, like most other cottongrasses, is usually another indicator of acidic or nutrient-poor wetlands. But instead of black spruce, we've got red spruce. And don't forget the cattail. Remember how we said cattails are typical marsh residents and that marshes are defined as nutrient-rich wetlands? Also have a look at the dense stand of *Phragmites*, or common reed—the invasive type here. This is not a typical bog species. Finally, look at the aerial photo (see fig. 9.3a)—the wetland is bisected by a distinct stream channel. This does not appear to be a pure, hydrologically isolated bog dominated by bog-only species. Rather, it is more of a patchwork of bog species and other species. This, then, would fall more in the category of a fen. A fen is a type of peatland that has some groundwater inputs and outputs, providing more nutrients than would be available for plants growing in a bog.

CORNUCOPIA IN A FEN

Beyond their sheer beauty, fens are important homes to a rich set of species, with plenty for everybody. Notice the animal trail cutting through the vegetation in the chapter-opening image. The dense vegetation of such wetlands supports dense populations of small animals, which in turn attract many predators like foxes, coyotes, bobcats, weasels, and others. Large herbivores such as deer and moose will come down to feed on the sedges. Perhaps the moose who pooped on the log came down to sleep in the cold, wet sphagnum. At the southern extent of their range here, moose must resort to such tactics to stay cool enough in this relatively warm climate.

On the far side of this fen is a nice crop of wild cranberries, and the red stems of the highbush blueberry promise bushels of sweet blueberries in summer. I spent one summer wandering this very fen, gorging on blueberries until my belly was full, all the while following fresh tracks of bears who were doing the same. Toward the end of that summer, Charley and I spent a couple days camping out, feasting on nothing but cucumber-flavored cattail stalks, bamboo-like reeds, and other wetland plants. When we awoke by our dwindled campfire in the morning, Charley turned to me and asked, nonchalantly, “Hey, did you see the bear?” I looked up in

Figure 9.7. Bald-faced hornet collecting wood fibers from an old fence—note the stripe of freshly exposed wood above it.

time to see a berry-filled mass of poop falling out, about twenty feet from us, as the large bear casually walked past, never breaking stride. I'm not sure if it was the swampy aftertaste from the previous day's forage, the smoke, or the presence of the bear, but in the same moment Charley rolled over and puked.

With all this life around, even those standing dead trees support a variety of critters. Many people seem to believe that deadwood should be cut down and removed—an outlook that drives me crazy. I view deadwood as the most important and most beautiful habitat that trees provide, depended on by many creatures. Consider cavity-nesting species such as woodpeckers, chickadees, owls, and flying squirrels. Or the bears that tear the wood apart to eat the grubs living inside. If we look closely at the snags in this fen, we will see light marks—just like the little marks on the fence post in Caleb and Maya's yard—where wood fibers were stripped, rolled into balls, and carried by wasps back to their nests (see fig. 1.1). The fibers were then chewed up and mixed with saliva to make wasp paper, which was used to construct the nests that protect the developing eggs and larvae. This is just one of the little creatures making good use of those beautiful snags (fig. 9.7).

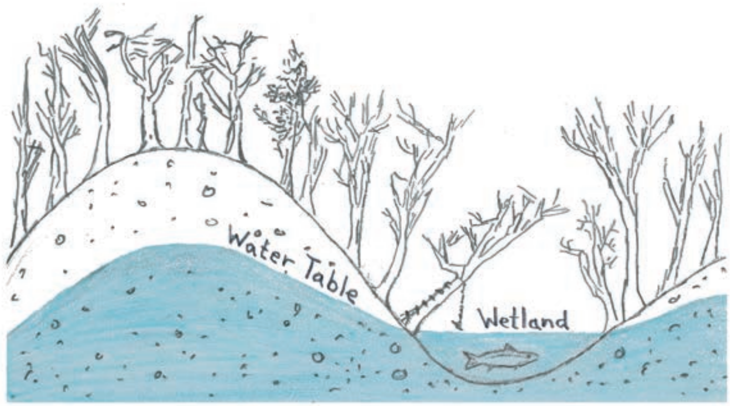
But back to the question that started us off: What is the story behind those snags? What is the history of this landscape? If you notice in figure 9.2, the branches on the dead trees are arranged in the classic, evenly spaced whorls that indicate pines—likely white pines. A white pine will grow one whorl of branches for each year that it's alive. So we can count backward and estimate the age of these trees, keeping in mind that many of the whorls have broken off by now. By my count, those trees were maybe around sixty-five years old when they died. Given the density of pines, this seems to have been a stand of mostly white pines, following the pattern of white pines invading an old field after it was abandoned. So what happened to the stand of early successional white pines?

WATER LEVELS

Perhaps you've guessed that rising waters killed the trees. Sure, but why did the waters rise?

Let's take a closer look at how water levels are controlled in a wetland that we suspect is at least partially fed by groundwater. When it rains, some water is taken up by tree roots. If it is a particularly heavy rain, some water may flow rapidly downhill on top of the ground surface. The remainder of the water soaks into the ground and filters down to the water table. The water table is the

Figure 9.8. Simplified version of a water table.



line below which all open pores in between soil or rock are filled with water. If you dig a deep hole, your hole will fill in with standing water to the height of the water table.

As a general approximation, if you look at a profile of the landscape in cross section, the water table follows the overall contours of the land, but with less exaggerated features (fig. 9.8). Beneath a big hill, the water table profile looks like a small hill. As you go further and further downhill, the water table gets closer to the surface. That's a good thing to remember if you're ever in a bind and really need to dig a hole to find water—the water table should be closest to the surface at the lowest point on the landscape. Where the water table intersects the ground surface, you find a river, pond, lake, water-filled hole, or maybe a fen.

If we wanted to raise the water levels of a wetland, one approach would be to increase the amount of water flowing in. Short of causing more rain to fall, if you covered the porous ground with impervious pavement, more surface runoff will flow directly downhill, bypassing the groundwater. This is why streams and wetlands across urban and suburban landscapes become overloaded with runoff and gouged by flash floods—we've removed nature's system for rain absorption.

Another way to increase water flow would be to cut down the trees uphill from the wetland. With fewer trees sucking up groundwater, there will be more groundwater to feed the wetlands. This is why reservoir managers seeking to maximize water in their lakes will often cut down surrounding trees. This concept, I believe, also explains what I found one May day when I went to survey a population of rare marbled salamanders in a small vernal pool. Instead of water and happy larvae, I found an expanse of dry, cracked mud with small, rotting bodies baking in the sun. I think the trees had leafed out too early—before the salamanders were ready to leave the pond. If a warming climate means trees begin to leaf out earlier and earlier, I wonder if we might find more and more populations of salamander larvae baked in the sun.

The other way to raise the water levels in a wetland is, of course, to let less water escape. Once in a wetland, water stays there until it either evaporates, seeps further down through the ground, or flows out through a surface channel. It may be hard to control the evaporation from the surface or groundwater flows, but you could plug up outflowing streams with a dam. Looking at the landscape surrounding this wetland, we see no logging, parking lots, or other evidence for a recent change to the water coming downhill. This leaves us with the explanation that perhaps would have been your initial hypothesis—there must have been some sort of dam put in downstream to raise the water levels and kill the trees.

AGING A WETLAND

Looking at those trees, we might guess that they've been dead for several decades, if that. So perhaps this place was a forest until someone dammed up the stream in the last thirty years or so, right? But wait, how old is this wetland?

Thinking about the number of habitat specialists—pitcher plant, sundew, cranberry, cottongrass—I'd guess that this natural community must have taken quite some time to form. Consider the process of dispersal, using a classic ecological island metaphor. If you construct a new island by dumping a huge pile of dirt in the middle of the ocean, at first there will be no species. You must then wait for species to colonize the island, sending seeds or propagules from other nearby land. If you come back to check on your island, the number of species occupying it will depend on a few factors. In general you will see more species on bigger islands, on islands closer to other landmasses, and on islands that have existed for a long time. This basic line of thought underlies the theories known as "Island Biogeography Theory" and "Metapopulation Theory" that are central guides for conservation planning.

The same ecological thinking applies to terrestrial "habitat islands," such as a park in the middle of an urban metropolis. If you want your urban park to contain high native biodiversity, keep it big and try to protect nearby native species to act as a source for dispersing individuals. With the salamanders in my dissertation, the most important determinant of whether we'd find salamanders breeding at any given pond was not whether there was salamander habitat right around the pond but whether there was salamander habitat a mile away from the pond. That's the scale of metapopulations. If, a mile away, all the forests around the pond had been cut down, it didn't matter whether or not there were awesome forests right around the pond—there would be no source of salamander colonizers to maintain a population at the pond. All that prime salamander habitat would be devoid of salamanders.

Although, connectivity isn't always good. At a recent conservation conference, researcher Molly Bletz stood at the front of the room and described a trip she took to Panama a few years back.

She and fellow researchers were surveying for frogs. As they walked out into the tropical rain forest, they were expecting to be greeted by hundreds of frogs hopping and calling from leaf litter, puddles, trees, and bryophytes. That's what previous researchers had found. But now Molly found only two lonesome frogs chirping worriedly.

At another conference I'd heard a similar story about salamanders in Guatemala. Walking up a pristine forested mountain, untouched by logging or development, researchers flipped logs that in the decades prior had been teeming with salamanders. Now most of the species were completely gone. From an amphibian perspective these had become ghost forests.

Like Native American communities decimated by smallpox, the frogs and salamanders were killed off by a disease from another continent. In this case it was a fungus known as chytrid.

After telling her story Molly went on to describe her current work on US salamanders. The United States is a global hotspot for salamander diversity, and so far they are disease-free—or at least free of this particular disease. But, as we speak, there is a wave of a new chytrid fungus that is sweeping through Europe, wiping out their salamanders. Our salamanders—especially the newts, which are among our most abundant species—are highly susceptible to that fungus.

Chytrid fungus is spread across continents by the pet trade, where many species—including several frogs—commonly carry the salamander disease without suffering from it. With legal battles still raging over whether we can ban trade of these disease-carrying species, all it takes is for one child to grow tired of her fungus-infected pet and dump it in some nearby pond; that could spark the mass die-off of our salamanders.

After her talk I approached Molly to learn more about the looming threat to our salamanders. I asked her, is this a case where connectivity is bad? In response she told me an anecdote about the devastation of the European fire salamanders. The new chytrid fungus was first discovered in a small town in the Netherlands that had lost most of its salamanders to the disease. This was the country's largest and most well-known population of fire salamanders. The town's forest, once crawling with salamanders, was now empty. But, it turned out, there was one previously unknown population a half-mile away in a tiny scrap of forest surrounded by developed lands and farm fields—which function as barriers to salamander movement. And this isolated forest patch was full of healthy salamanders. Likewise, across Europe, forest patches that are surrounded by busy highways are escaping the epidemic. Had tunnels been in place to help salamanders cross beneath these roads, chytrid fungus may have hitched a ride across. In these cases the roads had saved the salamanders. Habitat fragmentation was good.

Still, perhaps because I don't study diseases, I'm mostly of a mindset that fragmentation is usually something to fight against. I think about a small pond in a tiny forest in the middle of a giant cornfield and see isolated salamanders with no way to get help from the outside world. Eventually, something is likely to wipe out the population. If not disease, then perhaps drought, flood, fire, frost, inbreeding, or predators. I imagine they're going to need an occasional colonizer to keep them going.

Metapopulation theory applies to an island in the middle of an ocean, a park in the middle of a metropolis, a forest patch in the middle of a cornfield. How about a fen in the middle of a forest? Suitable pitcher plant habitats are few and far between in the forests around here, and so I imagine we must wait a long time before a pitcher plant seed happens to land in any newly formed fen. How long? Dispersal is one of the most difficult ecological processes to quantify, since it's based on rare events and tiny objects. So it's hard to say how long it took this community to form—but my sense is it didn't happen overnight.

Remember also that we seem to be standing on top of five feet of sediment. If that sediment is all peat, which grows only 1⁄10 of an inch or so a year, then to build up that much peat should take many hundreds of years. So we'd guess that this fen has been around a long time. But those trees have only been dead a few decades. Perhaps, then, this place has been a wet fen for a very long time, except during a dry spell long enough for a forest to begin to grow.

FOUR-LEGGED SUSPECT

So what may have caused a dry spell in this basin that ended thirty or so years ago? Remember from Chapter 8 our discussion of all the animals that once roamed our landscape before they were killed off by people? There's one mischievous friend whom hunters had eradicated from our area by 1700, but then by the late 1980s had repopulated most of the local landscape thanks to intentional reintroduction: beaver (figs. 9.9 and 9.10).

Before humans were making ponds and lakes left and right, beavers were the primary source of large standing bodies of water throughout much of their range. Ducks, newts, turtles, moose, otters, and a host of others have long depended on beaver ponds. I am often amazed at the volume of water that beavers can hold back with a single dam.

A few years ago I was trailing a moose with a South African animal tracker who had come to New England to trade tracking knowledge. We came on a typical beaver dam, about seven feet high, and he asked, "Who made this?" He thought we were joking when we told him it was made by an animal. It took much convincing, and eventually he just stood there with his mouth open shaking his head. After seeing the beaver's work and later seeing shoe-sized holes drilled in a tree by a pileated woodpecker, he remarked, "This is incredible; your animals are so big here!" Words

Figure 9.9. Beaver dam, with a lodge visible in the background.

I never would have expected from a South African tracker. I suppose true appreciation comes from perspective.

So one theory would posit that beavers have historically played an important role in maintaining high water levels here in this basin. Upon beaver extirpation, the land dried a bit and a forest began to take hold, until the beavers came back to flood the land again. On our aerial map (see fig. 9.3a), at the southwestern edge of the wetland, we see evidence of a dam—though not necessarily that of a beaver—where standing water backs up at the outflow of a meandering stream. Looking closely at the rest of the stream, you can pick out the location of three other smaller dams where the water is backed up—almost certainly made by beavers. But could beavers be the only story behind this wetland?

I often think of beaver-made landscapes as free-form and dynamic. A beaver family will move in and construct a pond, only to eat all their favorite trees and see the ponds fill in. Out of food, the

Figure 9.10. A tree felled by a beaver.

beavers then abandon the pond, the dam breaches, and the trees regrow until other beavers come back a decade or two later. At the larger scale there will be many different patches along the stream, resulting in a shifting mosaic of habitat. At one location there may be a brand new pond. Downstream there may be a pond that was recently breached. Further downstream there may be an old beaver meadow that was a pond fifteen years ago. Such a patchwork of continual change provides great diversity to a landscape.

Looking at the aerial photo, our vast wetland has well-defined edges and extends far beyond the beaver-plugged stream at the south end. This suggests to me that there is something deeper going on here—a static, larger-scale process that defines the basin in which this wetland resides. This isn't just an arbitrary place along a uniform stream where a beaver happened to construct a dam. The shape of the underlying landform seems conducive to holding standing water.

DEEPER PAST

What shaped this basin? Did you notice the big boulders in the wetlands, like the ones on which the *Field Naturalist* students in figure 9.2 are eating lunch? Remember also, as we first entered this landscape, the big boulders scattered in the forest? Where did they come from? These are known as glacial erratics. Chunks of mountains further north that glaciers plucked off and carried southward. To be true erratics these boulders would be made of entirely different rock than the bedrock beneath us—a feature that is useful in charting how glaciers moved. As the glaciers retreated, they left behind rocks of all sizes. Rather than being completely randomly distributed, these glacially deposited rocks are often formed into distinctive patterns—streamlined drumlin hills, sinuous eskers, giant moraine piles, and the dam that created the ancient glacial lake.

If we were to walk through the forest right along the western edge of our wetland, we would encounter dozens of big boulders extending in a north-south line the length of the wetland. Have a look at the topo map (see fig. 9.3b). What does it say to you? It's hard to work out the exact flow of ice and water beneath the glacier 15,000 years ago. But whatever pattern of flow caused this line of boulders, my understanding is that the line of boulders and the underlying mound of till may be what now dams up this basin.

This basic process—of glaciers interrupting the flow of water—is central to the ecology of the region. Staring at aerial photos of Massachusetts, conservationist Matt Burne once circled over 30,000 vernal pools in the state. That didn't include the ones that didn't show up in the photos—the true number is probably double that. The abundance of ponds is, in large part, the result of a landscape that doesn't shed water well. Perhaps water-resistant bedrock helps also.

Where I grew up in Tennessee, beyond the reach of glaciers, we boast that the only natural lake in the entire state is Reelfoot Lake, formed in 1812 when the Mississippi flowed backward into a hole opened up by the New Madrid earthquakes. Maybe you can find other natural bodies of water besides beaver ponds and Reelfoot Lake in Tennessee, but nowhere near the density found in New England. In Tennessee, streams and rivers have been carving up the landscape for millions of years, creating well-developed drainage networks. No matter where you are on the Tennessee landscape, there is almost always a path that will take you downhill to the ocean without interruption, thanks to the long, hard work of water. In New England glaciers repeatedly ravaged water's engineering by arbitrarily dumping vast amounts of unsorted till hither and thither. The salamanders have thanked the glaciers ever since.

In this fen where I am standing, water was perhaps first trapped here when the glaciers retreated. At that time perhaps there was a full-fledged lake before the sphagnum mat grew over it. And perhaps the lake was ringed at one point by the ancestors of the spruce in our opening image. If so, the spruce did not colonize this fen. Rather, this fen is all that's left of the magnificent spruce-dominated forest that used to grow all around us.

MAJOR LESSONS FOR INTERPRETING A LANDSCAPE

- How do wetlands form near your site? What species depend on them?
- Where are the "habitat islands" in your area, and how do organisms disperse among them?
- What ecosystem engineers, like beavers, exert outsized influence on your landscape?
- Does your site show any evidence of sudden shifts in conditions—like a dramatic and sustained change in water level?