The Message, by Diana Sudyka

On the Wild Edge in Iceland

By BROOKE HECHT

Picture a country hanging from the Arctic Circle, where at least 80 percent of the people leave room in their minds for the existence of elves, "Huldu-folk" (hidden people), or other netherworldly creatures; where wild means vast stretches of grayness: gray, craggy mountain peaks, gray gravel, and gray ash from yesteryear's volcanoes.

If you imagined Iceland, you guessed right. And I was heading north into that gray.

I drove on roads carefully designed by the Icelandic Road and Coastal Commission, around bends that intentionally avoid the presumed dwellings and churches of elves and hidden people. I felt grateful for the possible company of these sprites, as I sometimes drove for hours without seeing another human, much less a gas station.

I had landed in Reykjavik the day before, ready for the first field season of my Ph.D. research in ecosystem ecology. My bags were full of equipment that I hoped would help me unlock ecological puzzles about what made ecosystems flourish or fail. On the bus into town from the airport, a group of women—headed north for some adventure of their own—had clucked over me, concerned that I was venturing into this remote country by myself.

I wasn't as worried. There is really only one main road in Iceland, aptly called "Highway 1." Furthermore, I was looking for a forest—which I guessed would be hard to miss in this vast grayscape—a wild surprise of green life rising up from the ash.

I drove alone for two days, owing to the detour I chose to take around Snaefellsjokull. Known in these parts as the most beautiful glacier in the world, Snaefellsjokull is also the starting point for the expedition in Jules Verne's *A Journey to the Center of the Earth*. I was not seeking the center, however, but the edge: forest edges, to be exact—the treeline, the forest limit. A place that might span a few steps; a place where you could throw a small stone through an ecological doorway, with you standing in forest and the stone landing in tundra. These mysterious threshold zones hold clues to what makes a forest a forest and what causes a forest to reach a breaking point and give way to tundra.

When I arrived at my destination, a forested valley in northeastern Iceland, I became less puzzled by the Icelandic belief in elves. The gnarled birches had an aura of magic about them. The drops of dew on the ancient equisetum (commonly called "horsetails" for their soft, feathery look) seemed to await collection into tiny fairy cups. What struck me most particularly was the scale of the forest. It was as if I had drunk from the Alice in Wonderland "grow" bottle as I drove. Either I was much taller than I had been two days before or else I had arrived in a miniature woodland, a fine home for elves, trolls, and perhaps a fairy ring.[1]

The sheep that dotted some of the woodlands seemed normally sized, from my vantage point anyway. Trios of sheep (a mother and two lambs) are a regular sight across Iceland in springtime. There are a number of interesting points about Iceland and sheep, and here are four: (1) there is a distinct breed of Icelandic sheep (note that there is one breed of sheep, but thirteen different kinds of elves); (2) there are more sheep than people; (3) sheep run free, while forests are enclosed within fences; and (4) sheep have everything to do with Iceland's particular type of wildness.

A short time after arriving in Iceland, I learned that the sheep—and, to a lesser extent, their grazing compatriots (goats, cows, horses, and pigs)—have changed the Icelandic landscape so dramatically that, were the original Viking explorers to make landfall in Iceland today, they might believe they'd discovered a new island. When the Vikings arrived in Iceland, there were no native people and no four-legged inhabitants except the arctic fox. The land was not gray, but a lush green "from mountain to seashore," with "butter dripping from every blade of grass in the land"[2]

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In hindsight, it is easy to understand how newly introduced grazers would decimate the abundant vegetation that greeted the Viking explorers. As old trees fell, emerging seedlings were devoured, leaving little chance for new trees to grow beyond the reach of hungry sheep. Without vegetation, there was nothing to hold the soil underfoot. Where a horde of sheep had eaten its fill, the light volcanic soil simply blew away, leaving glacial till as the new terrain. The upshot was not so much a novel ecosystem as it was *ecosystem loss*, which comes with all the sadness that you might expect such a loss entails. This cycle (beginning with eating and ending with glacial till) continues in some parts of Iceland today.

If you know that Iceland had an influx of two-legged and four-legged creatures around 1,200 years ago, you also know that the present lack of color in many parts of this country is in fact a loss of color over this time period—and a story with many layers. I believed I would uncover important pieces of this story at the forest limit.

After spending one summer hiking every Icelandic woodland I could find, I honed in on three different birch sites. The forest limit zones of these three woodlands would become my study areas for the next few years. "Spend as much time there as you can," one of my dissertation committee members told me. "Drink your coffee there. Eat there. And just look." I don't believe I could have started my research with wiser words than those.

However, there are some things you cannot see. For example, as you hike to the forest limit—straight up—there are important changes in the leaves that cannot be seen with the naked eye. They need to be measured to be known, either with equipment in the field or back in the lab with carefully transported leaf samples. One such change that is important to this story is foliar nitrogen—the nitrogen in the leaves of the birches.

Imagine that you are hiking in a forested Icelandic valley and that you begin hiking up a mountain, through the forest, and toward the forest limit. As you take each step upward, foliar nitrogen levels climb higher with you. There is an important reason for this. The higher up on a mountain you are, the colder it is. The colder it is, the harder plants need to work to photosynthesize (i.e., make their food). Nitrogen is key to a plant's ability to photosynthesize at low temperatures.

So high levels of nitrogen at the forest limit are essential to survival. This is a pattern that is observed worldwide. I can picture the pattern of the graph in my head—foliar nitrogen increases with altitude like steps going up a staircase.

There is something else important to this story that could not be seen as I took those woodlands in, day after day, over the course of several summers, and that is the woodlands' history. What had happened here over the last thousand or more years since the Vikings' arrival? What about the last few hundred years?

As an ecologist, I was painfully aware of the stresses that ecosystems worldwide experience from grazing, climate change, and other human-imposed factors. What I wanted to know was this: Does a forest with a history of higher levels of disturbance have a more difficult time responding to additional stress than a forest with a lesser history of disturbance?

There was one way to find out. I would impose a disturbance on three woodland sites and observe the response. My three sites were strikingly similar birch woodlands, but they had a few important differences in their disturbance histories. My Site 1 (the forest in the valley in eastern Iceland that had me believing in elves) had not seen any serious sheep grazing for about a century. My Site 2, in a valley adjoining Site 1, was remarkably similar in all respects to Site 1, except that it had never been protected from grazing. My Site 3 was farther north—a harsher climate, a shorter growing season—and, like Site 2, it had never been protected from sheep grazing. These sites were on a gradient of stress from the least stress (at Site 1) to the most stress (at Site 3). Knowing how important nitrogen is to plant survival at high altitudes (and latitudes), I would track foliar nitrogen as my clue, using it as my insight into how the woodlands were handling stress.

I didn't know at the time that some of the ecological models concerning disturbance, ecosystem shifts, resilience (or lack thereof), and crossing of ecological thresholds were based on psychological models of human psychic breaks and breakdowns. But now it makes sense. At what point does the accumulation of disturbances become so profound that a person—or a forest—is no longer able to function?

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It is important to note that the prospect of disturbing the woodland sites was not an easy one for me. I was conflicted. I was studying forests because I loved them. Was it ethical to stress my subject and push it closer to the edge, even if my long-term goal was to understand (and even promote) ecosystem resilience? My advisor, Kristiina Vogt, comforted me: the forest disturbance would be minor and temporary. The ecosystems would bounce back.

With that reassurance, I bought a lot of sugar (actually, almost half a metric ton) for my disturbance experiment. While ecologist and forest service colleagues in Iceland questioned whether I was embarking on a homemade liquor and bootlegging project, the truth was that my unusually large sugar purchase had everything to do with nitrogen. A story from one of my fellow doctoral students, Michael Booth, can help me explain how.

Michael used to begin his forest ecology presentations with a picture of a forest upside down. The roots of the trees were featured on top and the leaves down below. His point? Much of what is running the show in a forest is under our feet. In any given handful of dirt, there are millions to billions of bacteria. And these microbes can be the tail that wags the forest dog, especially when it comes to nitrogen. While these bacteria play a key role in making nitrogen available to trees and plants in their preferred form, bacteria also need nitrogen for their own survival. Can you guess what happens to nitrogen in a handful of soil when there is a significant increase in the bacterial population? The answer: The microbes take the bulk of the nitrogen for themselves, leaving less nitrogen available for plants.

I wonder if a happy, healthy forest is one that has just the right number of microbes (whether that number would be in the millions or billions, I have no idea), such that the microbial community gets the nitrogen it needs while giving the trees and other vegetation the nitrogen they need. While notions of "balance" in nature are very out of fashion, to say the least, the concept seems applicable here. Too few or too many microbes would be a problem—from the perspective of the Icelandic woodlands, anyway. At both ends of the spectrum, there would not be enough nitrogen for the plants and trees.

So what does sugar have to do with this? I could use it as a free source of energy for microbes—put enough sugar into a handful of soil and one might even cause a microbial population explosion. If I spread a bunch of sugar at my forest limit sites, where the birch trees are already at their threshold of existence, would the woodland sites with the higher levels of stress have a harder time dealing with it?

I spent quite a bit of time spreading carefully measured quantities of sugar in selected "disturbance" plots at my study sites while leaving an equal number of plots as controls (without the sugar disturbance). I carried sugar by the backpack-full up to the forest limit, ever thankful to have a wonderful field assistant to help me with the haul. We spread the sugar in the woodlands by hand. As my advisor had shown me, it's all in the flick of the wrist.

We spent even more time gathering birch leaf samples to bring back stateside to the lab for nitrogen analysis. I packed thousands of leaves for transport in a huge box. (In accordance with my permit to transport biological material across international borders, the large box was marked "quarantined material," which made a few of my fellow air travelers quite nervous.) I subsequently spent a lot of time in a basement lab at the Yale School of Forestry and Environmental Studies, dropping small capsules of Icelandic leaf powder into a machine that resembled a clothes washer but was in fact a high-tech piece of equipment that would help me determine foliar nitrogen levels.

I was surprised to find that my study sites did not fall into the global pattern of increasing foliar nitrogen with increasing altitude. The location of the forest limit in terms of altitude was lowest at Site 1 (eastern "elven" forest protected from grazing), in the middle at Site 2 (eastern grazed woodland), and highest at Site 3 (northern grazed woodland). So I should have seen a stepwise increase in nitrogen levels from Site 1 to Site 3. In contrast to the expected trend of nitrogen levels climbing up as regularly as stairs, the nitrogen levels at my study sites dropped from Site 1 to Site 3 (with significantly lower nitrogen levels at Site 3 than either Site 1 or Site 2).

While this result offered me a new ecological puzzle right off the bat, my sugar disturbance shed some light on both this unexpected result and my original question about how sites with higher levels of stress handle additional disturbance.

At the eastern protected forest (Site 1), where there were lush layers of springy moss and no sheep, the sugar disturbance caused no change in the foliar nitrogen levels at the forest limit. In ecological speak, this site had "resistance" to the disturbance. However, at the two grazed sites (Sites 2 and 3, in the east and the north), the foliar nitrogen levels dropped significantly following the input of sugar—that is, these forest limit sites showed a lack of resistance to the disturbance. The foliar nitrogen levels took a significant step down at the eastern grazed forest (Site 2) following the sugar disturbance and dropped even lower at the northern grazed site (Site 3). In fact, the pattern was once again as clear as a staircase—only this time, nitrogen levels were going down.

Here was the answer to my question (Does a woodland with a history of higher levels of disturbance have a more difficult time responding to additional stress than one with a lesser history of disturbance?): yes. The woodlands carry those stress loads—memories of the stresses, so to speak—and this affects their ability to handle new stresses that come their way.

Maybe it was a coincidence that the highest levels of foliar nitrogen were at Site 1 (with the lowest stress levels) and the lowest levels of foliar nitrogen were at the disturbed "sugar plots" at Site 3 (with highest cumulative stress levels). But I don't think so. Here is why. More sheep equals more trampling. More trampling means less moss. Less moss means warmer soil temperatures (thick layers of moss keep soil cooler). Warmer soil temperatures mean increased microbial activity. Larger microbial populations mean less nitrogen for birch trees.

As a picture of these feedback loops began to emerge, I remembered the metaphorical story of the flapping butterfly wings that trigger a series of reactions, ending in a wild storm. Taking such a chain reaction further at my study sites, I knew that fewer (or no) plants mean no soil. No soil essentially means no ecosystem. While you might think that no ecosystem means no sheep, I saw—more often than I would have thought—sheep picking their way across a gray landscape of rocky glacial till with hardly a blade of grass in sight, and certainly none dripping with butter.

At this point in the story, it sounds like sheep are, for the most part, nothing but bad news for the birches. Moreover, the cards are stacked against the birches not only because sheep are eating them but also because sheep give microbes a leg up in terms of competing for the available soil nitrogen. However, if sheep are nothing but bad news, one piece of the puzzle doesn't fit.

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At the eastern protected site (Site 1), the moss layers were so thick that you could fling yourself backward into the moss (a moss "trust fall," so to speak) and land in a moss bed comfortable enough for even the pickiest of elves. A sturdy fence had excluded sheep at this woodland for a century, and the human footprint was similarly light. Is this site the most pristine? The most wild? I might be tempted to say yes, except for this: at this woodland, the altitudinal location of the forest limit was the lowest among the three sites.

The forest limit of the northern woodland (Site 3)—with plenty of sheep, the harsher climate, and a shorter growing season—definitely looked scrappier, lacking that lush layer of moss. This was not a good place for a moss trust-fall exercise—not a surprise, given that sheep trampling is not conducive to moss growth. The surprise was that this forest limit was located at highest altitude among my three sites. Despite the stresses present at this site, this woodland had managed to climb higher up the mountain than either of the other two sites. This struck me as an impressive feat. Even though I did not understand it yet, there was a consistent pattern: the forest limit at the eastern grazed forest (Site 2, with the middle-of-the-road stress of the three sites) had the middle of the road scrappiness (and moss layers), along with a middle-of-the-road altitude.

How could I solve this puzzle? The northern grazed site (Site 3) with the most stress (historical and current) had trees growing at the highest altitudes on the mountainside. With all that stress—at the higher altitudes and with the lower foliar nitrogen levels—one might wonder how these birches are surviving at all. But there they are. It's true enough that, at these higher stress levels, the birch trees are closer to their ecological breaking point. Add just the right amount of stress (especially in the form of competition for nitrogen), and the birches at this northern site would reach a threshold where they could no longer function. In contrast, the eastern protected woodland (Site 1) was buffered. Higher levels of foliar nitrogen left the trees some wiggle room for taking on additional stress; it was more of a birch safety zone. That being said, the protected woodland in the east did not extend up the mountain nearly as far.

At the grazed sites, perhaps the warmer soil temperatures allowed for expansion of the birch woodland into higher altitudes. While the warmer soils may have allowed the birch to exist at higher altitudes, the trees at the grazed sites are also at a higher risk for nitrogen competition (from microbes enjoying the warmer soils) and grazing (from the aforementioned sheep). In other words, the birches at grazed tree lines exist higher up on the mountainside, but at the same time, they live closer to their edge. While this may not be the safest route for the birches, it is perhaps worth the risk because the upside is pretty big: the chance at life.

It sounds familiar. Given the choice, I would rather be on the edge of human experience, certainly on the edge of human knowledge, and even tolerate the edge of emotional comfort, if it meant life. And does not history (our own and others') show that experiences on the edge can offer important insights into both what it means to be human and what it means to be one human in particular? For me, "living on the edge" is part of the daring—and the learning—that is central to the evolution of life.

There are many expressions of Iceland's wildness, and all these expressions depend on the presence or absence of sheep. Perhaps the most common depiction of the Icelandic wild involves Iceland's gray moonscapes, with sheep—and not trees. However, these starkly beautiful landscapes have crossed over an ecological threshold beyond which it is very hard to return. These landscapes are wild and wooly, but if you do not know how they came to be as they are, you may not be able to put your finger on the sadness that you might sense in the haunting gray vistas.

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One could argue that the lush, protected woodlands are Iceland's most wild places, despite the fact that they are enclosed by human-made fences. These sheepless woodlands offer wild green memories seemingly borrowed from the time of the Vikings and carried into the present day by their human—and elf—protectors. On the other hand, in some places, Icelanders ask the Icelandic Forest Service not to plant more trees. The chief of the Icelandic Forest Service, Þröstur Eysteinsson, told me that in such cases he hears the complaint that trees will "ruin the view." "They are optimists," Eysteinsson retorts, because it is, of course, no small task to restore a whole forest ecosystem anywhere, much less in such a harsh climate.

If I were to show you what I believe to be the wildest places in Iceland, however, I would take you to the forest limit, to a birch woodland populated with a good number of sheep and enough moss to satisfy the average elf. Mind you, this place would not have too many sheep, nor too many soil microbes, for that matter. I would take you to a place where birches breathe life into a landscape shared with sheep and their people, a place where the story told by both the sagas and the landscape itself is a story of life taking a chance—on the edge.

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NOTES

1. As noted by Þröstur Eysteinsson, chief of the Icelandic Forest Service (and one of my dissertation committee members), "Icelanders do not have the concept of the small winged creatures that English speakers call fairies." As for the elves, Þröstur says, "Our elves are human size and look like people, only better looking and better dressed."

2. Anonymous (thirteenth century), "Landnámabók" (Book of Settlement); in Íslendingasögur (Sagas of the Icelanders), vol. 1, ed. Gunny Jónsson (Reykjavik, Iceland: Íslendingasagnaútgáfan, 1946), 27.