But like Goldilocks and the Three Bears (one must have been Smokey himself), there is a fire frequency which is "just right," and here diversity abounds. Creation of a mosaic of patches by mid-frequency burning creates wildlife habitat and maintains forest health, while fire suppression does not.

When the ice went out on the Kickapoo the next spring I called the gaging station and an electronic voice informed me that the river was in flood. So I jumped in my car and drove down to see what the mosses looked like now. The river was chocolate brown with dissolved farmland. Logs and old fenceposts were pushed along in the torrent, bumping against the cliff. My red paint markers were nowhere to be seen. By the next morning the waters had receded as quickly as they had come and the aftermath was revealed. The *Fissidens* had emerged unscathed. The mid-level mosses were sodden with mud and battered by the logs and the pull of the water. A few more bare patches had been made. The *Conocephalum* had not been submerged long enough to die, but it was torn away in great swaths, hanging from the cliff like ripped wallpaper. Its flat loose form had made it particularly vulnerable to the pull of water, while *Fissidens* was unaffected. The open patches created by the removal of *Conocephalum* made temporary habitats for a new generation of mosses which would persist there until *Conocephalum* gathered its strength and returned. These are the species which are not able to compete with *Conocephalum*, nor to withstand the frequent flooding. They are fugitives between two forces, living in the crossfire between competition and the force of the river.

I like to think of the satisfying coherence in that pattern. Mosses, mussels, forests, and prairies all seem to be governed by the same principle. The apparent destruction of a disturbance is in fact an act of renewal, provided the balance is right. The Kickapoo mosses had a piece in telling that story. Sandpaper in hand, I look at the splotch of red paint on this old blue canoe and decide to let it be.

Choices

My neighbor, Paulie and I communicate mostly by shouting. I'll be outside unpacking the car and she'll stick her head out of the barn and yell across the road, "How was your trip? Big rain while you were gone, the squash in the garden are going crazy—help yourself." Her head pops back into the barn before I can answer. She takes a dim view of my gallivanting around, but keeps a good eye on the place while I'm gone. While I'm out stacking firewood or planting beans, I'll catch sight of her blaze orange cap and call across the road to her with news of a downed fenceline I discovered up by the pond. Our shouts carry the shorthand affection we have for each other. Over the years it's been a telegraph from my side of the road to hers, carrying messages of kids growing up, parents growing old, breakdowns of the manure spreader, and news of the killdeer nesting in the pasture. On 9/11 I ran from my TV to the barn where we hugged and cried for a short moment until the feed truck arrived and brought us back to the immediate need of calves to be fed.

My old house and her old barn, in the little town of Fabius, New York, were once part of the same farm, starting way back in 1823. They share the shade of the same big maples and are watered by a common spring. We've brought them back from the brink of decay together, so it's fitting that we, too, are friends. Sometimes, when the weather is nice, we stand with arms folded in the middle of the road to talk, shooing barn cats out of the road and holding up traffic, which consists of the occasional haywagon or the milk truck. Our dirty work gloves are pulled off as we soak up the sun and the talk and are pulled back on again as we turn away. On the rare occasions when we do talk on the phone she forgets she's not hollering from the barn and I have to hold the phone a foot from my ear.

As observant neighbors we know a lot about each other. She just shakes her head and laughs over my field seasons spent earnestly investigating the reproductive choices of mosses. All the while she and her husband Ed are milking 86 head, raising corn, shearing sheep, and building a heifer barn. Just this morning, we met down at my mailbox and had a moment to talk while she was waiting for the AI man. "Artificial Intelligence?" I asked with a raised eyebrow. This cracked her up, one more sign of the detached ignorance of her neighbor, the professor. The white panel truck splashed over the potholes to the barn, a picture of a bull on the side. "Artificial Insemination," she shouted over her shoulder as we walked back into our worlds on opposite sides of the road. "Your mosses may have reproductive choices, but my cows sure don't."

Mosses do exhibit the entire range of reproductive behaviors from uninhibited sexual frenzy to puritanical abstention. There are sexually active species churning out millions of offspring at a time and celibate species in which sexual reproduction has never been observed. Transexuality is not unheard of; some species alter their gender quite freely.

Plant ecologists measure a plant's enthusiasm for sexual reproduction with an index known as reproductive effort. This measure is simply the proportion of the plant's total body weight which is dedicated to sexual reproduction. For example, our maple tree allocates much more of its energy to production of wood than to its tiny flowers and helicopter seeds that twirl to the ground on the breeze. In contrast, the dandelion in the pasture has a very high reproductive effort, with much of the plant's mass tied up in yellow flowers, followed by drifts of fluffy seeds.

The energy allocated to reproduction can be spent in a variety of ways. The same number of calories could be used to make a few large offspring that the parents invest in heavily. Alternatively, some are more profligate, spending their energy on a large number of tiny, poorly provisioned offspring. Paulie has strong opinions on those who have children that they don't adequately support. One of the barn cats, a long-haired beauty named Blue, seems to take the attitude that kittens are a disposable commodity. She has litter after litter, but can't be bothered to nurse them and leaves them to fend for themselves. Mosses

like *Ceratodon* take the same approach. On a patch of disturbed ground along the cow track to the barn, the leaves of *Ceratodon purpureus* are barely visible under the dense swath of sporophytes it produces all year long. But each spore is so small and poorly provisioned that, like Blue's kittens, it has a vanishingly small chance of surviving. Fortunately, there is among the barn cats a paragon of good mothering, Oscar. She's the old lady of the haymow, and carefully tends her single litter, and willingly adopts Blue's orphans as her own. For this, Oscar earns a place at the milk dish at milking time.

Paulie would approve of a moss like *Anomodon*, growing on the shaded rock wall behind the barn. This species delays its spore production until later in life, preferring to allocate its resources to growth and survival, rather than unfettered reproduction.

The two strategies of high and low reproductive effort are usually associated with a particular environment. In an unstable, disturbed habitat, evolution will tend to favor those species that produce many small highly dispersable offspring. The unpredictable nature of the habitat, like the *Ceratodon* near a cow path, means that the adults have a high risk of dying by disturbance, and so it is advantageous to reproduce quickly and send your progeny off to greener pastures. The destination of those wind-blown spores is unknown, but is likely quite different from the path edge of the parents. Sexual reproduction also conveys a strong advantage by mixing up the parents' genes into new combinations. Every spore is like a lottery ticket. Some will be good combinations, some will be bad, but the gamble pays off with millions of offspring spread randomly over the landscape. One will surely find a patch of ground where its novel genetic formula will bring it success. Sexual reproduction creates variety, a distinct advantage in an unpredictable world. However, sexual reproduction also incurs some costs. In creation of egg and sperm, only half of the parents' successful genes are passed to the offspring, and those genes are shuffled in the lottery of sexual reproduction.

In her muddy boots and manure-spattered jacket, Paulie doesn't fit the white-coat image of genetic engineering, and yet she is working at the forefront of its application. A Cornell grad, she has bred an award-winning herd of Holsteins with impeccable genetic pedigrees. Rather than lose this hard-won genetic advantage by mating her best cows with any old bull, she is using artificial insemination and then transferring the identical embryos to surrogate mothers in the herd. In this way, she will develop a herd with little variability, perpetuating the successful genotypes that would have been scrambled by ordinary sexual reproduction. Such cloning is a recent development in dairy production, but mosses have been doing it since the Devonian era.

Reproductive strategies that limit variation and preserve the parents' favorable gene combinations are commonplace among the mosses. The rock wall behind the barn has been undisturbed since the first farm owners built it 179 years ago. In such a steady, predictable habitat a steady, predictable way of life is most successful. The *Anomodon* mat that lives there has had nearly two centuries to prove that it bears a genetic makeup well suited to that particular spot. Energy devoted to frequent sexual reproduction would essentially be wasted here, by producing wind-blown spores of potentially unfit genotypes, which would simply be lost on the wind. In a stable, favorable environment, it is better to invest that energy in growth and clonal expansion of the existing long-lived moss, preserving the tried and true genotype, like pedigreed cows.

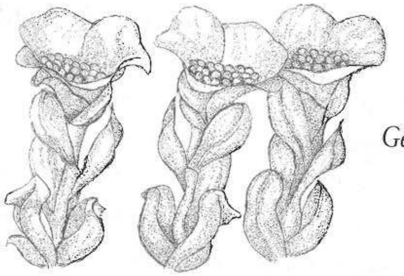
Natural selection is constantly acting upon the pool of individuals that make up a population, and only the most fit survive. Burying generations of barn cats who never learned to cross the road, or stillborn calves, clearly reveals the hand of natural selection. On such occasions, Paulie brushes off the loss with a practiced line. "If you're going to have livestock, you're going to have deadstock." Despite her bluster, Paulie's menagerie tells a different story. Not all of her animals are the cream of the crop. One stall is home for an old cow, blind now for many years. Her name is Helen. She's a good old girl and with the time-honored nose-to-tail guidance system she stills goes out to pasture with the others. And then there's Cornellie, the orphaned lamb whom Paulie brought home in diapers to sleep by the woodstove until it was big enough to survive. But, in nature, there is rarely a Paulie who spares the unfit from the scythe of natural selection. So I've been looking at the reproductive choices made by mosses in light of natural selection. Which choices result in survival and which are steps toward extinction?

Chance and our choices have brought Paulie and I together, converging for some reason on this old hill farm. Something about the way the house nestles in the hill sheltered from the wind, or the way the morning sun pours over the meadow. She fled the expectations of Boston family and chose the intense flavor of farming over a career as an animal physiologist. I flew here like a homing pigeon after a sad divorce with the fervor to start again, on my own terms. Our dreams have found a home here. Paulie recreates her self-sufficiency every single day and revels in the company of animals. And here my microscopes can share the table with blackberry pies.

Up in the hemlock swamp at the top of our pasture, the woods are fenced from grazing. Paulie is mowing hay in the adjacent field, the tractor rumbling along. I wave to her as I duck under the barbed wire and into the woods. A few steps into the trees and a hush descends with the green filtered light. The hemlock timbers which built my house and Paulie's barn were cut here generations ago. The old logs and decaying stumps are covered with one of my very favorite mosses, *Tetraphis pellucida*. I know of no moss more charged with well-being than *Tetraphis*. Its young leaves are luminous as dewdrops and swollen with water. The species epithet *"pellucida"* reflects this watery quality of transparency. Its sturdy little shoots are clean and simple and stand upright in a hopeful sort of way. Each stem is no more than a centimeter tall with a dozen or so spoon-shaped leaves arranged like an open spiral staircase ascending the stem.

In contrast to most mosses, which have adopted a particular lifestyle and stuck with it, *Tetraphis* is remarkable for its flexibility in making reproductive choices, sexual and otherwise. *Tetraphis* is unique in having specialized means of both sexual and asexual reproduction, standing in the middle of the road of reproductive options.

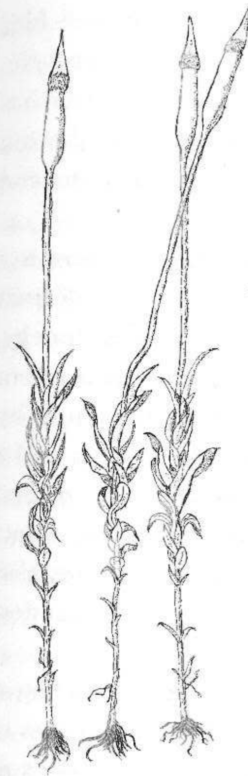
Most mosses have the ability to clone themselves from broken-off leaves or other torn fragments. These bits of debris can grow into new adults that are genetically identical to the parents, an advantage in a constant environment. The clones remain near the parents and have little ability to venture into new territory. Cloning by dismemberment may be effective but it is a decidedly crude and random way to send genes into the future. *Tetraphis* however, is the aristocrat of asexual



Gemmae cups of Tetraphis pellucida

reproduction, possessed of a beautifully sculpted design for cloning itself. When I kneel to look closely at the patches of *Tetraphis* on the old stumps, I see that the surface of the colonies is sprinkled with what look like tiny green cups. These gemmae cups, formed at the ends of the upright shoots, resemble miniature bird's nests, complete with a clutch of tiny emerald eggs. The nest or gemmae cup is a circular bowl made of overlapping leaves and nestled within it lie the egg-like gemmae. Each gemma is a roundish mass of only ten to twelve cells, which catch the light and shimmer. Already moist and photosynthesizing, each gemma is poised to establish itself as a new plant, cloned from its parent. It rests in the nest, waiting. Waiting for an event that will propel it away from its parent, where there's room to grow and start its own family.

When the skies darken and the thunder rolls, the time is at hand. Great big raindrops pelt the forest floor, and ants and gnats dive into mosses for shelter, lest they be squashed by the momentum of the raindrops. But sturdy little *Tetraphis* waits expectantly, for it is designed to harness the power of a raindrop. When a gemmae cup receives a direct hit, the raindrop breaks loose the gemmae and propels them outward, leaving the nest empty. The gemmae can be splashed up to fifteen centimeters away, which isn't bad for a plant only one centimeter tall. In a favorable location, the gemmae can regenerate an entire new plant in the span of a single summer. In comparison to spores, which are at the mercy of a fickle breeze that deposits them anywhere, a rock or a rooftop or the middle of a lake, gemmae are more likely to land in the same neighborhood as their parents. As clonal propagules, the gemmae carry a combination of genes that has already proven successful on this stump.



Sexual shoots of Tetraphis pellucida bearing sporophytes

In contrast, the spores produced by the sexual mixing of the parents' genes are a myriad of genetic combinations, a powder of potential sent off to seek its fortune in the unknown realm beyond the stump. There are other patches of *Tetraphis* on the very same stump which are the cinnamon color of old redwood. They take their rusty tint from the dense swath of sporophytes which rise from the green shoots below. Each sporophyte ends in a capsule shaped like an open jar. The mouth of the jar is ringed with four rusty teeth, from which the name *Tetraphis* ("four teeth") is taken. When the capsule is ripe, millions of spores will be released onto the breeze. The product of sex, the spores will carry the shuffled genes far from their parents. While these spores have the advantage of variety and distance, their success rate is exceedingly small. The tiny spores, even when carefully sown on a suitable site like another hemlock stump, yield only one plant for every 800,000 spores sown. There is clearly a tradeoff between size and success. The gemmae are hundreds of times larger than spores, and hundreds of times more effective in generating new plants. The large size and active metabolism of the gemmae, in comparison to spores, give them a higher chance of success. In experiments, I've found that one in ten gemmae survive to establish a new plant.

I can hear that the sound of the hayrake has stopped and Paulie comes down the sun-dappled path to see what I'm up to, grateful for a respite from the summer sun. I hand her my water bottle and she drinks deeply, wiping her mouth on the back of her hand and bending down to sit on a hemlock stump. I show her the two kinds of *Tetraphis*, the asexual colonies with reliable "stay at home" gemmae and the highly sexual colonies, sending their adventurous offspring off on the breeze.

She just nods her head and laughs. It's a story she knows very well. Her daughter, so very like her mother, has decided to stay on and work the land alongside her parents after college. Her oldest son, however, has flown the nest to become a teacher at the other end of the state, having no interest at all in days that start with milking before sunrise and end long after the cows come home.

When I look at logs and stumps covered with *Tetraphis*, there is a striking pattern. The two forms, gemmae and spores, occur in distinct patches, almost never intermingling. Since each reproductive strategy, clonal and sexual, is usually associated with a very different environment and with individual species, I wonder at the cause of this pattern. Why should the same species adopt a clonal lifestyle in one patch and a sexual lifestyle in another on the very same stump? Why does natural selection allow two opposite behaviors to coexist in the same plant? This question led me into a long and intimate relationship with *Tetraphis*, one of fascination and of respect where *Tetraphis* taught me a great deal about doing science.

I suspected right away that the cause of the reproductive patchiness was some aspect of the physical environment. Perhaps differences in moisture or nutrients in the decaying wood caused different forms of reproduction. So I laboriously measured environmental factors to see which one was correlated with either sexual or clonal behavior. I lugged around a pH meter, a light meter, a pyschrometer, and bagged samples of decaying log to take back to the lab for an analysis of moisture and nutrients. Months of expectant data analysis later, I discovered that there was no correlation whatsoever. There seemed to be no rhyme nor reason to *Tetraphis'* reproductive choice. But if there's anything that I've learned from the woods, it's that there is no pattern without a meaning. To find it, I needed to try and see like a moss and not like a human.

In traditional indigenous communities, learning takes a form very different from that in the American public education system. Children learn by watching, by listening, and by experience. They are expected to learn from all members of the community, human and non. To ask a direct question is often considered rude. Knowledge cannot be taken; it must instead be given. Knowledge is bestowed by a teacher only

when the student is ready to receive it. Much learning takes place by patient observation, discerning pattern and its meaning by experience. It is understood that there are many versions of truth, and that each reality may be true for each teller. It's important to understand the perspective of each source of knowledge. The scientific method I was taught in school is like asking a direct question, disrespectfully demanding knowledge rather than waiting for it to be revealed. From *Tetraphis*, I began to understand how to learn differently, to let the mosses tell their story, rather than wring it from them.

Mosses don't speak our language, they don't experience the world the way we do. So in order to learn from them I chose to adopt a different pace, an experiment that would take years, not months. To me, a good experiment is like a good conversation. Each listener creates an opening for the other's story to be told. So, to learn about how *Tetraphis* makes reproductive choices, I tried to listen to its story. I had understood *Tetraphis* colonies from the human perspective, as clumps in various stages of reproduction. And I had learned little by doing so. Rather than looking at the clump as an entity, I had to recognize that the clump was simply an arbitrary unit that was convenient for me, but had little meaning for the moss. Mosses experience the world as individual stems and to understand their lives I needed to make my observations at the same scale.

So I began the laborious work of inventorying the individual shoots in hundreds and hundreds of *Tetraphis* colonies. I took pains to see every patch of *Tetraphis* I sampled as a family of individuals. Every single stem was counted, and every shoot was categorized by its gender, its stage of development, and its mode of reproduction, gemmae or spores. I wonder how many shoots I've counted in all—probably millions. A dense colony of *Tetraphis* can have three hundred shoots per square centimeter. And then each colony was marked. I found that the plastic cocktail swords which impale olives in martinis make the best markers. They won't decay and the bright pink plastic makes them easy to locate the next year. And besides, I like to imagine the conversations of hikers who encounter mossy logs decorated with swizzle sticks.

The next year, I went back and found each of the marked colonies and counted them again. In notebook after notebook, I recorded the changes in their lives. And then again the year after that. Slowly, with my knees in the duff and my nose on the stump, I was starting to think like a moss.

I think that Paulie would be the first to understand this. Making a living as a dairy farmer on a few hilly acres is a tough proposition. She has been successful because she knows her herd, not as a clump, but as individuals. There's not a numbered ear tag on the farm; she knows every cow by name. She can spot when Madge is ready to calve, just by the way she walks down the hill. The time spent to know their habits and their needs gives her a competitive edge over the industrial-scale dairy farmers.

My notebooks record the fate of each patch, a changing census of the tiny moss community. With patient watching, and no direct questions, year by year, *Tetraphis* began to tell its own story. Colonies on bare wood start out with sparse and widely scattered shoots, a community with plenty of elbow room. In these low-density patches of fifty individuals in a square-centimeter sample, virtually every shoot bears a gemmae cup at its tip. The falling gemmae grow into more thrifty young shoots and by the time I return the next year the stems have gotten crowded. In colony after colony, I notice a remarkable pattern. With crowding, the gemmae disappear. There is an abrupt switch from making gemmae to making female shoots. Crowding seems to trigger the onset of sexual reproduction. With a populous colony of females and scattered males, it's not long before sporophytes appear. The colony has transformed itself from the vibrant green of gemmiferous shoots to the rusty color of spore production. When I return the next year, the colony has become even more crowded, approaching three hundred stems per square centimeter. This high density seems to trigger a radical shift in sexual expression. Now, the only shoots produced are male, with not a female or a gemmiferous shoot in sight. We discovered that *Tetraphis* is a sequential hermaphrodite, changing its gender from female to male as the colony gets crowded. This switching of gender with population density had been observed in certain fish, but never before in mosses.

In trying to piece together *Tetraphis'* story, I wanted to be sure that I understood what was going on, that the choice of having sex or making

gemmae was really determined by the density of the colony. If that were true, then if I could change the density, the mosses should change behavior. Perhaps I could ask an indirect question, and perhaps they would answer. To ask the question in the language of mosses, I took a cue from Paulie's woods.

A few years ago, when she needed cash for the new heifer barn, she decided to harvest some trees from her woodlot. She shopped around carefully for a logger committed to low-impact harvest, someone who would take good care of the woods. They cut timber in winter, scattering their openings, and made a clean job of it. In the springs that followed, the thinned woods had a carpet of snowy white Trillium and yellow trout lilies blooming under the leafy canopy. The lowered density had let in more light and rejuvenated the old stand.

Like a logger in miniature, I sat poised with fine forceps over the old, dense *Tetraphis* patches. One by one, I plucked out single shoots of *Tetraphis*, stem by stem, until the density was reduced by half. And then I let them be, returning the next year to observe if they had given me an answer to my question. The unthinned patches of *Tetraphis* remained male and had started to turn brown. But the patches where I'd opened the moss canopy by thinning were green and vibrant. The holes I'd made in the *Tetraphis* turf were being filled with thrifty young shoots, bearing gemmae cups at their tips. The mosses had answered, in their own way. Low density is a time for gemmae, high density for spores.

The transformation to being male appears to have adverse consequences. Over and over, I observed that the dense male patches were starting to die back, becoming dry and brown. These tired male colonies, spent with reproduction, were then easily invaded by other mosses on the log. Sometimes, I'd find the telltale swizzle sticks in a patch where old male colonies of *Tetraphis* had disappeared, obliterated by the advance of carpet mosses. Why would *Tetraphis* adopt a sexual lifestyle that seemed to doom it ultimately to fail, headed for local extinction?

On many occasions, I'd return to a familiar stump only to find that the carefully marked patch of *Tetraphis* had vanished. In its place was a clean, bare surface of newly exposed wood. Scrambling around on my knees, I found the patch of *Tetraphis*, still impaled by its cocktail sword, at the base of the stump, where it had tumbled in a small avalanche of decayed wood. These stumps and logs were a landscape in motion. The process of decay and the activity of animals were constantly causing the logs to fall away, piece by piece. The stumps looked like small mountains, forested by mosses, with a talus slope of decayed chunks lying like fallen boulders at their base. Blocks of old wood fell away, carrying their surface cover of *Tetraphis* and creating the bare places I'd noticed. And what became of such open spaces, these patches of new wood? Looking closely, I could see that they were sprinkled with gemmae, little green eggs that had splashed into the gaps in the old *Tetraphis* cover. In the aftermath of disturbance, the seeds were sown for the next wave of *Tetraphis*.

When I stop by the barn to buy a carton of fresh brown eggs, Paulie is just coming back from a meeting. We stand there in the sun, admiring the morning glories climbing up the side of the old silo. She heard some talk of opening a casino over in the next county and we laugh about the unwary throwing their money away on chance. "Heck," she says, "we don't have to go to the casino to gamble. Farming is like blackjack, year in and year out." Milk prices are notoriously unreliable, and feed costs can triple from one year to the next. Farm income can fluctuate like clouds passing over the sun, but college tuition only goes up. That's where the Christmas trees come in, and the sheep and the feed corn. To buffer against uncertainty, Ed and Paulie run a diversified farm. The cows are the mainstay but in years when milk prices are down, maybe the lamb market will pay the kids' tuition, or maybe the Christmas trees. They survive in an era of disappearing family farms by a resilience rooted in flexibility, where stability comes from diversity.

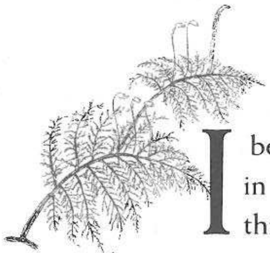
It's the same for *Tetraphis*, a moss that is hedging its bets in an unpredictable landscape where a landslide of decay can disrupt years of steady growth. It achieves stability in an unstable habitat by freely switching between reproductive strategies. When the colony is sparse and there is lots of open space, it pays to be clonal. The gemmae can occupy the bare wood more quickly than any spore and maintain a competitive advantage against other moss species. But when it gets crowded, the only offspring that have a chance are spores. And so sexual reproduction is begun, to produce spores of divergent genetic makeup

that will be blown away from the parents in their dwindling habitat. It's a gamble that any spore will land on a suitable log and be able to start a new colony. But it's a sure thing that without disturbance the colony will become extinct if it stays in one place.

The other mosses of less imaginative reproduction are slowly creeping closer, ready to engulf little *Tetraphis*. But *Tetraphis* has chosen its habitat well, taking full advantage of the rot which reliably causes disturbances to the log. Just about the time that the spent colony of *Tetraphis* is about to succumb to competitors, the face of the log peels away in a landslide of decay, exposing fresh new wood as it eliminates a patch of competitors and *Tetraphis* as well. If *Tetraphis* had to rely on spores to colonize these open spaces, its competitors would more often win the race for space. But just a few centimeters away stands a patch of *Tetraphis* in its clonal phase. With the next rain, gemmae are splashed into the opening and rapidly produce a new patch of vibrant green shoots. Decay renews the open space, and in accord, *Tetraphis* renews itself. *Tetraphis* plays both sides of the game, producing gemmae for short-term profit and spores for long-term advantage. In this changeable habitat, natural selection favors flexibility rather than commitment to a single reproductive choice. Paradoxically, those species adapted to a specialized lifestyle come and go, but *Tetraphis* persists by keeping its options open and maintaining its freedom of choice.

Maybe it's the same with our old farm, persisting now for almost two centuries. Generations of other women before us have shooed barn cats out of the road, planted lilacs, and raised their children under these maples. The old bull has been replaced by the AI man, and the cistern by a well. But the world is still unpredictable and still we survive by the grace of chance and the strength of our choices.

A Landscape of Chance



I believe it was the silence that woke me, an unnatural quiet in the silvery half-light before dawn, the hour of wood thrushes' songs. As I rose through the clouds of sleep, their absence grew alarmingly real. An Adirondack morning usually arrives to the accompaniment of veeries' and robins' songs, but not on this day. I rolled over to look at the clock. 4:15. The light outside suddenly shifted from silver to steel and thunder grumbled in the distance. The aspens turned up their leaves to flutter stiffly in the stillness, giving their rain call in the silence left by the birds. They must be hunkered down, I thought, in anticipation of the rain. Around here they say, "Rain before seven, done by eleven." I'd probably get to go canoeing after all. I snuggled back under my covers to wait it out. That's when the pressure wave hit the cabin like an axe against a tree.

Jumping out of bed, I ran to shut the cabin door, which had been suddenly flung open by the force of the wind. The cabin windows looked out onto a lake frothing and churning like the ocean, under a sky which had turned a sickly shade of green. The paper birches on the shore were bent nearly horizontal, their thrashing gyrations caught in the strobe of lightning, white on white, as a curtain of electricity advanced across the lake. The big pine over the porch began to wail and the windows seemed to press ominously inward. I herded my small daughters to the back of the cabin. We cowered in anticipation of shattered glass and splintered pine, small and speechless before the storm.

The thunder rolled and rolled, like a long freight train roaring by, then leaving silence in its wake. The sun rose over a placid blue lake. But still there were no birds. Nor would there be for the rest of that summer.

On July 15, 1996, the Adirondacks woke to a landscape battered by the most powerful storm ever recorded east of the Mississippi. Not a tornado, but a microburst, a wall of convective thunderstorms riding a

pressure wave off the Great Lakes. Trees were snapped and uprooted in swaths of blowdown that took every tree. Campers were pinned in their tents and hikers stranded in the backcountry, where trails disappeared under piles of timber thirty feet high. Helicopters were dispatched to carry them to safety. In a single hour, vast tracts of shaded woodland became a jumble of torn trees and upturned soil, exposed to the glare of the summer sun.

Such land-clearing events are rare, but forests exhibit remarkable resilience in the face of disaster. I'm told that the Chinese character for catastrophe is the same as that which represents the word opportunity. And the blowdown, while catastrophic, presented opportunity for many species. Aspens, for example, are perfectly adapted to take advantage of periodic disturbances. Quick growing and short lived, aspens produce light wind-blown seeds that sail away on cottony parachutes. In order to travel fast and far, aspen seeds come with minimal baggage. They can live for just a few days, and will die unless they germinate. An aspen seed that lands on an undisturbed forest floor hasn't a chance of success. Its tiny rootlet, the key to self-sufficiency, cannot penetrate the thick leaf litter and the dense canopy shades out the sun it needs. But, in the aftermath of the storm, the forest floor has been churned up into a tumult of logs and soil thrown up by uprooted trees. In the full sun, on clean mineral soil, the aspen seedlings will be the first to colonize the devastation.

Storms such as this one come perhaps once in a century, but the wind blows nearly every day, rocking the canopy trees and weakening their hold in the soil. The predominant cause of tree mortality in the northern deciduous forest is windthrow. Gravity always wins in the end. In frequent storms, or under winter's load of ice, individual trees come crashing down with great regularity, like pendulum strokes of the ecological clock. Even on a calm day, you can sometimes hear a tree groan and lean with a whoosh to the ground. The fall of a single tree punches a hole in the canopy and a shaft of light follows it to the forest floor. These small gaps don't provide enough light for aspens to get started, but there are other species poised to take advantage of someone else's demise. Yellow birch, for example, thrives on the small mound of earth thrown up by single treefalls and quickly establishes, growing up along the column of light to meet the maples in the canopy. The mound eventually erodes away, leaving the birch standing on stilt-like roots. Yellow birch is generally considered to be a "climax" species, a member of the dominant triad of the mature beech-birch-maple forest, and yet its very presence is due to disturbance. Without treefall, yellow birch would disappear, and the triad would be diminished. Paradoxically, disturbance is vital to the stability of the forest.

A forest's resilience after disturbance lies in its diverse composition. A whole suite of species is adapted to disturbance gaps of different types. Black cherry comes in to intermediate size gaps where the soil has been exposed, hickory into small gaps on rocky soils, pine after fires, striped maple after disease. The landscape is like a partially completed jigsaw puzzle in varying shades of green, where holes in the landscape can be filled with one particular piece and no other. This pattern of forest organization known as gap dynamics is known in forests around the world, from the Amazon to the Adirondacks.

There is something reassuring about these patterns which speak of order and harmony in the way things work. But what if the forest is composed of "trees" only a centimeter tall? Are the same dynamics of gap creation and colonization also played out at a micro-scale? Do the rules for assembling the jigsaw puzzle of a landscape also apply to mosses? Part of the fascination of working with mosses is the chance to see if and when the ecological rules of the large transcend the boundaries of scale and still illuminate the behavior of the smallest beings. It is a search for order, a desire for a glimpse of the threads that hold the world together.

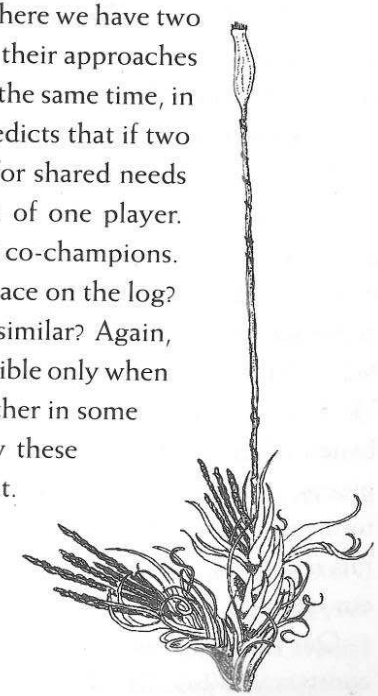
The trees that come crashing to the forest floor will soon become mossy logs. Like the forest above it, the moss turf is a patchwork of many species. And if you're down on your knees with your nose poked into the earthy smell, you'll see that the moss carpet is not unbroken green. There are gaps here, too, little openings in the turf where the wood shows through like bare soil after a windstorm. The dominance of the climax species is temporarily interrupted here, providing a microhabitat for any quick-thinking opportunists.

G. Evelyn Hutchinson, a pioneering ecologist, spoke eloquently of the living world as "the ecological theater and the evolutionary play."

This decaying log is a stage, and the scenes take place in the gaps, where the colonists act out their drama.

Tetraphis pellucida is here, its life intertwined with the forces of disturbance. Like aspen, it cannot renew itself without space free from competition. When disturbance opens up a new gap, its gemmae are there to quickly colonize the space. As the gap gets crowded, *Tetraphis* shifts to sexual reproduction, manufacturing the spores that will carry it away to a new gap on some distant log. Spore production happens just in the nick of time, before the carpet mosses encroach on the gap and *Tetraphis* perishes beneath them. Colonizing these short-lived gaps is essential. In the absence of disturbance, *Tetraphis* would not survive.

But *Tetraphis* is not alone. The other player in the evolutionary drama is *Dicranum flagellare*. *D. flagellare* shares many traits with *Tetraphis*. It, too, inhabits decaying logs. Like *Tetraphis*, it is small, short lived, and easily outcompeted by the large carpet mosses. Like *Tetraphis*, it relies on growing in the open spaces provided by disturbance. Like *Tetraphis*, it has a mixed reproductive strategy. So here we have two species, unrelated but quite similar in their approaches to life. They occupy the same logs, at the same time, in the same forest. Ecological theory predicts that if two species are very similar competition for shared needs will eventually lead to the exclusion of one player. There will be a winner and a loser, not co-champions. How then do the two species share space on the log? How do they coexist if they are so similar? Again, theory predicts that coexistence is possible only when the two species diverge from one another in some essential way. I was intrigued by how these two gap colonists divided up the habitat. Perhaps they used parts of the gaps on the log that differed in light or temperature or chemistry. Since colonizing gaps is critical to their success, I wondered just how each of them managed to find gaps and begin new lives.



Dicranum flagellare with both sporophyte and asexual brood branches

The foliage of *D. flagellare* would never be mistaken for the round shining leaves of *Tetraphis*. Each leaf is long and stiffly pointed, like a tiny pine needle. Its reproductive strategy calls for making sexual spores as well as asexual or clonal propagules. Rather than the lovely gemmae that *Tetraphis* splashes around the log, *D. flagellare* clones itself with little bristle–like tufts at the tip of each shoot. Theoretically, these tufts can break off, releasing individual "brood branches," long thin cylinders of green, about a millimeter long. Each brood branch has the potential to clone a new plant. But potential does not always align with reality. In order to be useful, the brood branch would have to detach from the parent and somehow move to a new gap of bare wood.

Try as I might, I couldn't see how that happened. I thought they might splash like *Tetraphis* gemmae, so I set up experiments to shower them with water. Nothing. Wind? I put sticky traps around the plants to detect any brood branches that might blow from the parent. Nothing. I added a strong fan to help matters along. Still nothing. *D. flagellare* makes clonal propagules but seems incapable of using them. Nonfunctional parts to organisms are not uncommon. Many organisms have vestigial structures that have lost their function, like the human appendix. Perhaps brood branches were similarly useless.

My student, Craig Young, and I spent two summers on hands and knees. Dead logs and their moss communities became our world. Each gap in the mossy cover of the logs was painstakingly described. Its moisture, light, pH, size, position, the trees overhead, and the mosses at the gap edge—all was recorded in our notebooks. Contrary to popular belief, blood sacrifice did not disappear with the dawn of science. The blackflies in May, the mosquitoes in June, and the deerflies in July all benefited by the hours we spent sitting still by logs, mapping out the pieces of the jigsaw puzzle. Craig became adept at grabbing our tormentors out of the air when they were flying away, heavily laden. His notebook was splotched with squashed flies and small spatters of our blood.

Our observations revealed a pattern so clear that I marveled at its constancy. While *Tetraphis* and *D. flagellare* both colonize gaps on dead logs, there is a marked separation between them, a segregation so complete you'd think there were "*Tetraphis* only" signs posted at the gap edges. *Tetraphis* was most common in big gaps, those more than about four square inches. The bigger the gap, the more *Tetraphis*. *D. flagellare* was restricted to small gaps, generally about the size of a quarter. Because gaps occur in many shapes and sizes on the log, apparently the two species could coexist by specializing. With *Tetraphis* in big gaps and *D. flagellare* in small ones, they could avoid competition.

This pattern directly mirrored the gap dynamics of the forest overhead. *Tetraphis* responded to big gaps, as if it had taken lessons from aspen, sending out lots of highly dispersable propagules, quickly cloning itself to fill the space. *D. flagellare* seemed to be the equivalent of yellow birch, surviving by jumping into the smallest of gaps. The carpet mosses played the same role as the climax beech and maples, slow, enduring competitors poised to move in.

But the story of *Tetraphis* and *D. flagellare* is even more complex than the pattern of the trees. We found that *Tetraphis*'s large gaps and *D. flagellare*'s small ones occurred in very different places. Large *Tetraphis* gaps were nearly always on the sides of logs. *D. flagellare* was restricted to the tops of logs with striking regularity. We reasoned that the two gap sizes must have different causes, but what?

Catastrophic windstorms create opportunities for aspen, but it is fungi and the inevitability of gravity that make good *Tetraphis* habitat. In particular, a group of wood-destroying fungi known as the cubical brown rots are responsible for gap formation. These fungi digest wood in a very distinctive way, dissolving the glue between cell walls in a way that causes the wood to decay in blocks, rather than fiber by fiber as do the white rot fungi. On the steep side of a log, the decay-loosened wood needs only gravity, or the dragged hoof of a passing deer, to dislodge the blocks and send them tumbling down. The falling block may rip away a carpet of competitors, or other *Tetraphis* colonies, creating a large gap by a landslide of decayed wood.

But what of *D. flagellare*'s small gaps? Their origin remained a mystery, as did the mechanism of how their reluctant brood branches could ever detach and find their way to a waiting gap. We were missing a crucial piece of the puzzle and so, on hands and knees, we went looking.

Moist logs are prime real estate for slugs. Every morning their slime trails glisten on the mosses, their circuitous tracks like a message written on the log in disappearing ink, a script we tried to decipher with an experiment. We wondered if perhaps slugs were responsible for the movement of *D. flagellare* brood branches. We even imagined the propagules being glued to the wood with slug slime. So on misty mornings Craig and I went slug hunting. Every time we found a slug, we would gently pick it up and touch its belly to a clean glass microscope slide, like a round inky thumb pressed to a fingerprint card. Then we put the surprised slugs right back where we found them and after a moment of playing dead they continued their slow progress across the moss. With the care of detectives fingerprinting a subject, we carefully brought our slug prints back to the lab and under the microscope we checked the slime for the presence of moss propagules. Sure enough, caught in the sticky film were fragments of green. Perhaps we were on to something.

Slugs seemed to have the ability to pick up bits of moss, but could they carry it far enough to move the brood branches into the gaps? In order to gauge their potential as moss dispersers, we created a little raceway for them, a steeplechase course for mollusks. The course was a long glass plate, a smooth surface over which they could ooze with ease. We placed the freshly caught slugs at one end of the glass on a bed of *D. flagellare*, bristling with brood branches. The idea was to trace their path across the glass and measure the distances slugs carried brood branches. Craig comes from Kentucky, land of the thoroughbreds and Churchill Downs. Racing gets in your blood, I guess, and we placed bets on our favorites in the upcoming slug race and were humming "Camptown Races" as we set up the experiment. Doo-dah, doo-dah. The only problem was that the slugs were content to stay right there on the moss. They roamed a little, touched antennae, and then backed away and lay there like tiny brown walruses basking on the beach, oblivious to our expectations. Clearly, we needed something to excite them, to entice them out to glide over the glass. What is it that motivates slugs? I am an inveterate reader of garden catalogs and remembered reading that you could lure slugs out of lettuce beds at night by leaving shallow pans of beer as traps. So, using an inducement as old as civilization, we offered a refreshing beverage at the end of the race course. It worked. Antennae stretched toward the malty aroma, our subjects abandoned their sluggish behavior and headed across the glass to their reward, leaving their trails behind them.

The race was slow enough that we could go have lunch between the starting gun and the finish. As it turns out, the slugs did carry *D. flagellare* brood branches in their slime. But nearly all were dropped within only a few centimeters of the moss beds. None rode their slugs as far as the beer. Disappointed, we returned the slugs to the woods, concluding that their role in moving mosses was probably a minor one. The transport of brood branches continued to elude us.

A few days later, on a day so hot and humid we wished we had packed along some of that slug lure, we sat swatting flies by a log and eating lunch. Craig's peanut butter and jelly sandwich sat atop the log, a drip of strawberry jam running down the side. Chipmunks are bold around a field station, and are habituated to peanut butter. They practically knock on the door of the live traps, asking to be let in for a peanut butter snack, in compensation for the annoyance of being measured by a student. Tail held high, with ears alert, one came running down the log, straight for the sandwich. We looked at each other and grinned as the light bulb went on.

The next day, our *D. flagellare* steeplechase was set up again, this time in a long track, with a bed of *D. flagellare* and a volunteer chipmunk at one end and several meters of sticky white paper stretched before him. When we opened the cage door, it shot out like a bullet, ran over the moss and down the race course into another cage at the end. When we lifted it out for a close look, squirming and twisting, we found bits of green clinging to the fur of its belly and to its moist pink feet. And all along the sticky paper, for meter after meter were footprints of scattered brood branches. Eureka! Here was our distributor of brood branches, not water or wind or slugs, but a chipmunk. Its footsteps broke off the bristly brood branches, and their tiny leaves caught like burdocks on the silky fur, to be scattered along behind it. We thanked our chipmunk with great appreciation and released it back to the woods with a peanut.

Perhaps you've noticed that chipmunks, in their busy-ness rarely run on the ground. Instead, you see them following the twisted paths formed by rocks, by stumps and wood, like the "don't touch the ground" games we used to play as kids. They use logs as highways through the forest.

For days, we sat quietly watching chipmunks travel along our *D. flagellare*-covered logs. Each was traversed many times a day as the chipmunks moved between feeding places and the safety of the burrow. They run with a start and a stop, sporadically putting on the brakes to do a bright-eyed check for predators. We noticed that when they came to a halt little bits of moss were kicked up from the surface, like gravel spun out by a hard-braking car. It seems that the chipmunks in their workaday lives were making the small gaps we found in the moss turf, like potholes in a roadway. And with each traverse they regularly delivered a sprinkle of *D. flagellare* propagules from their toes. Here was the missing puzzle piece. So this was why *D. flagellare* was found only on top of logs. Only where chipmunks run back and forth making opportunities for a small moss to live. How amazing to live in such a world where order arises from the seeming coincidence of the smallest things.

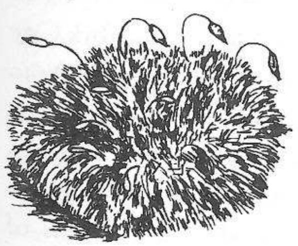
In time, the wind-thrown trees become mossy logs and the aftermath of the storm is a tapestry of mosses on a log, mirroring the same dynamics that shaped the forest around it. Aspen seeds flying in the wind of a tree-throwing gale create a new forest. *Tetraphis* spores spread green over a landslide gap on the side of a log. Yellow birch quietly takes its place in a single tree gap, while *D. flagellare* fills small patches on a log top. There is a home for everything, the puzzle pieces slip into place, each part essential to the whole. The same cycle of disturbance and regeneration, the same story of resilience, is played out at a minute scale, a tale of the interwoven fates of mosses, fungi, and the footfalls of chipmunks.

City Mosses

If you're a city dweller, you don't have to go on vacation to see mosses. Sure, they're much more abundant on a mountaintop or in the falls of your favorite trout stream, but they also live alongside us every day. The city mosses have much in common with their urban human counterparts; they are diverse, adaptable, stress-tolerant, resistant to pollution, and thrive on crowded conditions. They are also well traveled.

A city offers mosses a multitude of habitats which may otherwise be quite uncommon in nature. Some moss species are far more abundant in the human-made environment than they are in the wild. *Grimmia* doesn't discriminate between a granite crag in the White Mountains and a granite obelisk on Boston Common. Limestone cliffs are not abundant in nature, but there's one on every Chicago street corner and mosses perch contentedly on its pillars and cornices. Statues provide all kinds of water-holding niches where mosses abound. Next time you walk through the park, look in the folds of the flowing coat of whatever general sits mounted on a pedestal, or in the wavy marble locks of Justice's hair outside the courthouse. Mosses bathe at the edges of our fountains and trace the letters on our gravestones.

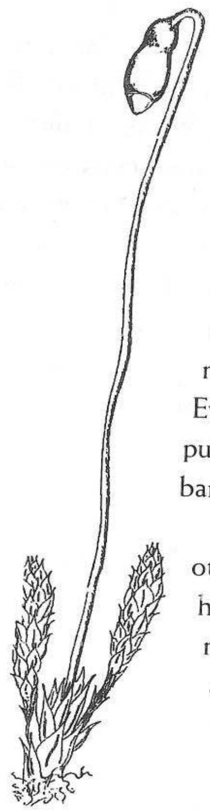
Ecologists Doug Larson, Jeremy Lundholm, and colleagues have speculated that the stress-tolerant, weedy species that cohabit our urban spaces may have been with us since our earliest days as a species. In their urban cliff hypothesis, they note a striking number of parallels between the flora and fauna of natural cliff ecosystems and the vertical walls of cities. Many weeds, mice, pigeons, house sparrows, cockroaches, and others are all endemic to cliff and talus-slope ecosystems, so perhaps it is no surprise that they



Cushion of Grimmia pulvinata

willingly share our cities. The same can be said for urban mosses, many of which are typical of rock outcrops, whether natural or human-made. We tend to devalue the flora of cities as a depauperate collection of stragglers, arising *de novo* with the relatively recent development of cities. In fact, the urban cliff hypothesis suggests that the association between humans and these species may be ancient, dating from our pre-Neanderthal days when we both took refuge in cave and cliff dwellings. In creating cities, we have incorporated design elements of the cliff habitat and our companions have followed.

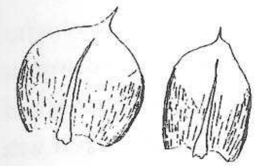
Admittedly, city mosses are not the soft feathery mats of forest mosses. The harsh conditions of urban life limit them to small cushions and dense turfs as tough as the places they inhabit. The arid conditions of pavements and window ledges cause mosses to dry out quickly. To defend against drying, the moss shoots pack closely together, so that limited moisture may be shared among shoots and held as long as possible. *Ceratodon purpureus* makes such dense colonies that when dry they resemble small bricks; when wet, green velvet. You'll find *Ceratodon* most commonly in gravelly spots, like at the edge of a parking lot or on a rooftop. I've even seen it growing on the rusted metal of old Chevys and abandoned railroad cars. Every year it produces a dense crop of unmistakable purplish sporophytes to send its spores off to the next bare patch.



Shoot and sporophyte of Bryum argenteum

The most ubiquitous of mosses, urban or otherwise, is *Bryum argenteum*, the Silvery Bryum. I have never traveled without encountering *Bryum* on my journey. It was on the tarmac in New York City and on the tiled roof outside my window in Quito the next morning. *Bryum* spores are a constant component of aerial plankton, the cloud of spores and pollen which circulates all around the globe.

You've probably walked over millions of *Bryum* without ever realizing it, for it is the



Leaves of Bryum argenteum

quintessential moss of sidewalk cracks. After a rain, or a hosing down by a sanitation worker, water lingers in the tiny canyon of a fissure in the pavement. Mingling with the nutrients provided by the flotsam of pedestrians, the crack becomes ideal for Silvery Bryum. It takes its name from the burnished silver color of the dry plants. Each tiny round leaf, less than a millimeter long, is fringed with silky white hairs, visible with a magnifying glass. The shiny hairs reflect away the sun and protect the plant from drying. Under the right conditions, the pearly plants will put up a host of sporophytes to cast their young into the aerial plankton, so that a New York *Bryum* could easily end up in Hong Kong. However, the much more common route for dispersal is by footsteps. *Bryum* shoots are fragile at their tips and in fact are designed to break off. The broken tips, scuffed along by a pedestrian, will take hold in another sidewalk, spreading Silvery Bryum all over the city.

The native habitat of *B. argenteum* is quite specialized and finds many equivalents in an urban setting. It has doubtless become far more abundant with the rise of cities than it was in our agrarian past. For example, the natural habitat of *Bryum* includes seabird rookeries where it colonizes the accumulated guano. Its urban counterpart is a pigeon-stained windowsill where it will form silvery cushions among the droppings. Similarly, *B. argenteum* is associated with prairie dogs in the Midwest and lemmings in the Arctic, where it spreads out like a welcome mat at the entrance to their burrows. The animals urinate by their doorways to mark their territory, and *B. argenteum* thrives where nitrogen is abundant. The base of a city fire hydrant is equally inviting.

Lawns are another good place to look for mosses—if you have a chemical-free lawn, that is. Down at the base of the grass plants are often threads of *Brachythecium*, *Eurhynchium*, or any number of other species, trailing among the grasses.

One of the pleasures of university life is fielding questions from the community about biology. Sometimes people send in plants to be identified or ask about the use of a certain plant. But I'm saddened that many requests we get concern how to kill something. A soil ecology colleague tells the story of a panicked phone call from a woman who had followed the directions in a pamphlet he'd written to start a compost pile in her backyard. Several weeks had elapsed and when she checked the pile of leaves and salad scraps, she was horrified to find that it was full of bugs and worms. She wanted to know how to kill them.

I once had a phone call from an urban homeowner asking for information on how to kill the mosses in his lawn. He was quite convinced that the mosses were killing his carefully tended lawn and wanted revenge. I asked a few questions and learned that the grass was on the north side of the house in the deep shade of maples. What my caller was observing was that his grass was dwindling, and the mosses which had always been there were now taking advantage of the open space. Mosses cannot kill grasses. They simply haven't the ability to outcompete them. Mosses appear in a lawn when conditions for moss growth are better than conditions for grass growth. Too much shade or water, too low a pH, soil compaction—any of these things can discourage grasses and let the mosses appear. Killing the mosses would not help the ailing grass in any way. Better to increase the sunlight, or better yet, pull out the remaining grass and let nature build you a first-rate moss garden.

The abundance of mosses in a city owes much to the local rainfall. Seattle and Portland support the most prolific urban moss floras I know. It's not just the trees and buildings—in the long rainy winters moss will grow on just about anything. I used to walk past a fraternity house at Oregon State University where a tree was festooned with shoes, high in the branches. From time to time, a shoelace would rot through and a sneaker would plummet to the sidewalk, completely engulfed in moss.

Oregonians seem to have a love-hate relationship with their mosses. On the one hand, there's a certain civic pride among folks who label themselves mossbacks and cheer for teams with aquatic mascots—Beavers and Ducks. On the other hand, moss eradication is big business. Hardware stores stock shelves of chemicals with names like Moss-Out, Moss-B-Gone, and X-Moss. An ad campaign on Portland billboards read: "Small, Green, Fuzzy? Kill It!" These chemicals eventually end up in the streams and in the food chain of threatened salmon. And the mosses always come back. Roofing professionals have led homeowners

to believe that mosses lead to degradation of the shingles and eventually to leaks. For an annual fee, they will gladly remove them. Allegedly, the moss rhizoids penetrate tiny cracks in the shingles and accelerate their deterioration. However, there is no scientific evidence to support or refute this claim. It seems unlikely that microscopic rhizoids could pose a serious threat to a well-built roof. One technical representative for a shingle company acknowledges that he's never seen any damage by mosses. Why not just let them be?

In such a utopian climate for mosses, living roofs seem an ideal alternative to endless extermination. A mossy roof can actually protect shingles from the cracking and curling caused by intense exposure to the sun. Moss adds a cooling layer in the summer and, when the rains come, slows stormwater runoff. And besides, a mossy roof is a thing of beauty. Golden cushions of *Dicranoweisia* and thick mats of *Racomitrium* are much more appealing than a barren expanse of asphalt shingles. And yet we invest lots of time and money in removing them. There seems to be an unspoken agreement in a trim suburban neighborhood that a mossy roof represents a hint of moral decay as well as decomposing shingles. The ethics seem inverted. A mossy roof has come to mean that the homeowner is somehow negligent in his/her responsibilities for maintenance. Shouldn't the moral high ground belong to the folks who've found a way of living with natural processes rather than battling them? I think we need a new aesthetic that honors a mossy roof as a status symbol of how responsibly the homeowner behaves in maintaining the ecosystem. The greener the better. Neighbors would look askance at the owner of a roof scraped bare of friendly moss.

Some city folks try to get rid of mosses, and some invite them in. The most remarkable assemblage of urban mosses I've ever seen inhabits a loft in Manhattan. I usually hike or paddle a canoe to see my favorite mosses, but this time I took a subway and eventually an elevator to the fifth floor high above the streets of New York City, to the home of Jackie Brookner. Jackie is small and quiet, but she has a gleam that makes her stand out in the crowd, like a richly colored pebble on a gravel beach. I went to see her because that summer we were both working on boulders.

My boulder is Adirondack anorthocite, rolled twelve thousand years ago to the shores of Whoosh Pond by a glacier. Her boulder began as an aluminum armature with a skin of fiberglass cloth stretched over its contours. She mixed sand and gravel into cement and with her hands formed ridges and valleys over the surface. She then pressed soil into the still-wet surface. My boulder is lit by sunflecks through a canopy of maples and moistened by an overnight rain and the mists from the stream where brook trout lie in the shadows. Her boulder is illuminated by a bank of growlights suspended from the high ceiling of the loft and watered by a spray system on a timer. It sits in a blue plastic wading pool where goldfish hide beneath the lily pads. My boulder is named #11N. Her boulder is named Prima. It's short for Prima Lingua, the First Tongue.

Jackie is an environmental artist. Her loft is full of ideas made visible: chairs shaped from earth, nests of roots and wire, and a collection of feet, sharecroppers' feet, molded from the same native clay that lay beneath their cotton. Prima Lingua: the first tongue speaks in the first language, the sound of water flowing over rock. Prima's looming presence—she stands six feet tall—also speaks of environmental processes, the cycling of water and nutrients, and the interconnectedness of the animate and inanimate worlds. Jackie's creation is more than "rock" and water, it is a living boulder covered with mosses. The prepared surface was first inoculated by the moss spores which flew in her open window above the streets of Manhattan. *Bryum argenteum* and *Ceratodon purpureus* were among her first colonists. Mosses and rocks were meant to be together, no matter their origins. On walks and travels, Jackie also picked up bits of moss and invited them home to live with Prima. A thriving community began to form when the right conditions were created.

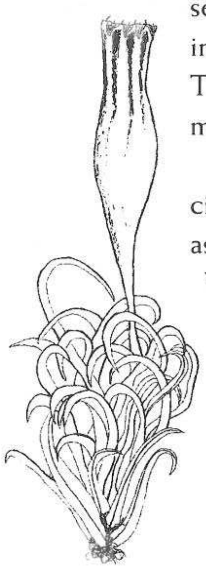
Prima is also about ecological restoration. Its beauty is as much functional as visual. The living sculpture is actively purifying the water which flows over it. Mosses have an exceptional capacity for removing toxins from water, binding them to cell walls. Jackie's artwork is being explored for use in wastewater treatment and protection of urban streams.

Together, we pore over Prima with magnifying glasses, looking at the species patterns and the mites and springtails which move among the leaves. Jackie's art materials are protonema and sporophytes and she knows them well. A small microscope sits on the same table with sketches and inks. Drawings of archegonia are taped above her work table. The sad truth is that many scientists believe they have the sole method for understanding the workings of the natural world. Artists don't seem to share that illusion of exclusive truth. In midwifing the birth of a moss community, Jackie has discovered more about moss establishment on rock than any scientist I know. We stay up half the night talking, with Prima murmuring agreement in the background.

Amidst the traffic and the smokestacks, city dwellers confront the health impacts of air pollution every day. When you draw a breath of air, it is pulled deep and then deeper into your lungs. Down tiny branching pathways, closer and closer to the bloodstream which is waiting for the oxygen it carries. In the alveoli, your breath is but a single cell away from your blood. The cells are glistening and wet, so that the oxygen may dissolve and pass over. Through this thin watery film, deep in the lungs, our bodies become continuous with the atmosphere. For better and for worse. The urban epidemic of asthma is symptomatic of a wider air-quality problem. The health of mosses in a neighborhood also reflects the level of air quality. Mosses and lichens are both very sensitive to air pollution. Street trees which once were greened over by moss are now bare. Check out the trees in your neighborhood. Their presence or absence has meaning. They are the canaries in the mine.

Mosses are much more susceptible to air pollution damage than are higher plants. Of particular concern is the sulfur dioxide which spews from power plants. It is a by-product of combustion of high-sulfur fossil fuels. The leaves of grasses, shrubs, and trees are many layers thick and are coated with a waxy layer, the cuticle. Mosses have no such protection. Their leaves are only a single cell thick, so, like the delicate tissue of your lung, they are in direct contact with the atmosphere. This is advantageous in clean air, but disastrous in areas polluted with sulfur dioxide. A moss leaf has much in common with the alveolus, it works only when it is wet. The water film allows the beneficial gases of photosynthesis, oxygen and carbon dioxide, to be exchanged. However, when sulfur dioxide meets that water film it turns to sulfuric acid. Nitrous oxide from car exhausts turns to nitric acid, and also bathes the leaf in acid. Without the protection of a cuticle, leaf tissue dies and becomes bleached and pale. Eventually, most mosses are killed by such severe conditions, leaving polluted urban centers virtually without mosses. Mosses began disappearing from cities soon after industrialization began and continue to decline wherever air pollution is serious. As many as thirty species which once flourished in cities have all but vanished, as air pollution increased.

The sensitivity of mosses to air pollution makes them useful as biological monitors of contamination. Different moss species are tolerant of varying levels of pollution in highly predictable ways. The type of mosses present on a tree can be used as a measurement of air quality. For example, the presence of *Ulota crispa* in dime-sized domes on a tree indicates that sulfur dioxide levels are less than 0.004 ppm, since it is highly sensitive to pollution. Urban bryologists have observed that the moss flora changes in concentric zones, radiating outward from the city center. Mosses are often absent at the center, but several tolerant species inhabit the next zone, with increasing numbers of species at the margins of the city. The good news is that when air quality improves, the mosses return.

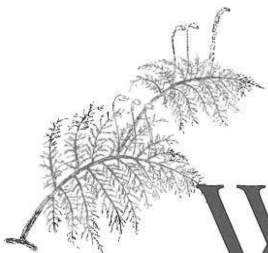


Shoot of Ulota crispa

Some people, myself included, could never live in a city. I go to the city whenever I must and leave as soon as I can. Rural folks are more like *Thuidium delicatulum*. We need a lot of room and shady moisture to flourish, choosing to live along quiet brooks rather than busy streets. Our pace of life is slow and we are much less tolerant of stress. In a city, that lifestyle would be a liability. On the streets of New York City the *Ceratodon* style is much in demand, fast paced, always changing, and making the best of the crowds. The urban landscape is not the native habitat for mosses or for humans and yet both,

adaptable and stress tolerant, have made a home there among the urban cliffs. Next time the bus is late, take those waiting minutes to look around for signs of life. Mosses on the trees are a good sign, their absence a concern. And everywhere beneath your feet is *Bryum argenteum*. Amidst the noise and the fumes and the elbowing crowds, there is some small reassurance in the moss between the cracks.

The Web of Reciprocity: Indigenous Uses of Moss



With the first scent of burning sage, the ripples on the surface of my mind become still and it is as if I am looking deep into clear sunlit water. Murmured prayer surrounds me with wisps of smoke and I can hear each word inside me. My uncle Big Bear smudges us in the old way, calling upon the sage to carry his thoughts to the Creator. The smoke of our sacred plants is thought made visible and his thoughts are a blessing breathed in.

Big Bear's voice is low; he's tired from a day driving into the city where he's been negotiating to obtain an old school building, abandoned in the remote foothills of the Sierra. I admire the way he walks in both worlds, that of government red tape and the traditional ways. His vision is to start a new kind of school for kids in the area. His school would teach the fundamentals. How to read a river in order to catch a fish, how to gather food plants, how to live in a way that is respectful of those gifts. He values a modern education and is proud of his grandsons' straight A's. But, in his work with troubled families he sees every day the costs of not learning about respectful relationship.

In indigenous ways of knowing, it is understood that each living being has a particular role to play. Every being is endowed with certain gifts, its own intelligence, its own spirit, its own story. Our stories tell us that the Creator gave these to us, as original instructions. The foundation of education is to discover that gift within us and learn to use it well.

These gifts are also responsibilities, a way of caring for each other. Wood Thrush received the gift of song; it's his responsibility to say the evening prayer. Maple received the gift of sweet sap and the coupled responsibility to share that gift in feeding the people at a hungry time

of year. This is the web of reciprocity that the elders speak of, that which connects us all. I find no discord between this story of creation and my scientific training. This reciprocity is what I see all the time, in studies of ecological communities. Sage has its duties, to draw up water to its leaves for the rabbits, to shelter the baby quail. Part of its responsibility is also to the people. Sage helps us clear our minds of ill thoughts, and carry our good thoughts upward. The roles of mosses are to clothe the rocks, purify the water, and soften the nests of birds. That much is clear. I'm wondering though, what is the gift they share with the people?

If each plant has a particular role and is interconnected with the lives of humans, how do we come to know what that role is? How do we use the plant in accordance with its gifts? The legacy of traditional ecological knowledge, the intellectual twin to science, has been handed down in the oral tradition for countless generations. It passes from grandmother to granddaughter gathering together in the meadow, from uncle to nephew fishing on the riverbank, and next year to the students in Big Bear's school. But, where did it first come from? How did they know which plant to use in childbirth, which plant to conceal the scent of a hunter? Like scientific information, traditional knowledge arises from careful systematic observation of nature, from the results of innumerable lived experiments. Traditional knowledge is rooted in intimacy with a local landscape where the land itself is the teacher. Plant knowledge comes from watching what the animals eat, how Bear harvests lilies and how Squirrel taps maple trees. Plant knowledge also comes from the plants themselves. To the attentive observer, plants reveal their gifts.

The sanitized suburban life has succeeded in separating us from the plants that sustain us. Their roles are camouflaged under layers of marketing and technology. You can't hear the rustle of corn leaves in a box of Froot Loops. Most people have lost the ability to read the role of a medicine plant from the landscape and read instead the "directions for use" on a tamper-proof bottle of Echinacea. Who would recognize those purple blossoms in this disguise? We don't even know their names anymore. The average person knows the name of less than a dozen plants, and this includes such categories as "Christmas Tree." Losing their names is a step in losing respect. Knowing their names is the first step in regaining our connection.

I was so lucky. I grew up knowing plants, wandering the fields and staining my fingers red with tiny wild strawberries. My baskets were pretty crude, but I loved gathering the willow shoots and soaking them in the creek. My mother taught me the names of plants, and my father which trees made the best firewood. When I went away to college to study botany, the focus shifted. I learned all about plant physiology and anatomy, habitat distributions, and cell biology. We carefully studied plant interactions with insects, with fungi, and with wildlife. But I don't think a word was ever said about people. Especially not Native people, even though our college sits on the ancestral homelands of the Onondaga, the center of the great Iroquois Confederacy. Humans were carefully excluded from the story, either by accident or by design, I'm not sure. I got the impression that the stature of science would somehow be lessened if we included human relationships. So when Jeannie asked me to be a partner in guiding plant walks at Onondaga Nation, I was at first reluctant. I admitted with regret that all I could offer were names and explanations of ecology. I found that Jeannie valued the scientific way of knowing that I could bring to our class, but of course, I ended up learning much more than I taught.

I have been blessed with good teachers. I am grateful for the guidance of my friend and teacher, Jeannie Shenandoah, a traditional Onondaga herbalist and midwife. There is solidity about her, she moves as if she is aware of the ground beneath her feet. We grew to share a wonderful partnership in our teaching. I'd contribute whatever I knew about the biology of the plants we found, and she would share her knowledge of traditional uses. Walking beside her, clipping twigs of crampbark for childbirth, poplar buds for salves, I began to understand the woods in a different way. I had studied with fascination the intricate connections between plants and the rest of the ecosystem. But the web of interconnection had never before included me, except as an observer, outside looking in. Then from Jeannie I learned to treat my daughter's cough with syrup from the black cherry on my hilltop, and lower a fever with boneset collected from the edge of my pond. As I gathered greens for dinner I regained my childhood relationship with the woods, one of participation, of reciprocity, and thanksgiving. It's just about impossible to feel academic detachment from the land with a bellyful of wild leeks, fragrant, hot, and buttered.

I have been wrapped up in the lives of mosses for lots of years, but I understand that our encounters had been at arm's length. We met on an intellectual plane. They teach me about their lives, but our lives have not been joined. To really know them, I need to know what role was given them when the world was beginning. What did the Creator whisper to them about their gift in caring for people? I asked Jeannie about how her people had used mosses and she didn't know. They weren't used as a medicine or a food. I know that mosses must be a part of this web of reciprocal relationship, but generations removed from the immediate connection, how are we to know? Jeannie showed me that the plants still remember, even when the people have forgotten.

In traditional ways of knowing, one way of learning a plant's particular gift is to be sensitive to its comings and goings. Consistent with the indigenous worldview that recognizes each plant as a being with its own will, it is understood that plants come when and where they are needed. They find their way to the place where they can fulfill their roles. One spring Jeannie told me about a new plant that had appeared along the old stone wall in her hedgerow. Among the buttercups and mallows was a big clump of blue vervain. She'd never seen it there before. I offered up some explanation about how the wet spring had changed the soil conditions and made way for it. I remember how she raised a skeptical eyebrow, but respectfully did not correct me. That summer, her daughter-in-law was diagnosed with liver disease. She came to Jeannie for help. Vervain is an excellent tonic for the liver and it was waiting in the hedgerow. Over and over again, plants come when they are needed. Is there something in this pattern that can tell us anything about how mosses were used? They occur everywhere, as part of the everyday landscape, so small that they often escape our notice. In the language of plant signs, perhaps this speaks of their role in human households, a small and unobtrusive role. It's the small everyday items we miss the most when they are gone.

I asked Big Bear and other elders what they could tell me of moss use and found nothing. There are too many generations and too much government-sponsored assimilation between the elders today and those who used the mosses. So much has been lost through disuse. So like any good academic I went to the library. I pored over the archived field notes of anthropologists to forage for old connections to mosses, reading old ethnographies to try and glean a hint of what the old ones would say if I could only ask. I hoped these pages would be like the sage smoke, their thoughts made visible.

I take great pleasure in gathering plants, filling my basket with roots and leaves. Usually I go with a specific plant in mind, when it's time for elderberries or the bergamot is heavy with oils. But it's the wandering itself that has such appeal, the unexpected discoveries while looking for something else. I get the same feeling in the library. It's so very much like picking berries—the peaceful field of books, the concentrated attention of the search, and the knowledge that hidden somewhere in the thicket is something worth finding.

I sifted through dictionaries of native languages, looking to see if there were indigenous words recorded for moss. I assumed that if moss was part of the everyday vocabulary, then it was also part of everyday use. In obscure proceedings of various academic societies, I found not one word, but many. Words for moss, for tree moss, berry moss, rock moss, water moss, and alder moss. The English dictionary on my desk has only one, reducing the 22,000 species to a single type.

While mosses live in every habitat, and are named by the people, I'm finding scarcely a trace of them in the transcribed notes from anthropologists. Maybe they played so small a role that their presence was scarcely worth reporting. Or maybe the reporters didn't know enough to ask. For example, I'm finding accounts of building homes, from longhouses to wigwams, replete with construction details on the way that planks were hewn and bark shingles applied. There is hardly a mention that mosses were used to chink the cracks between the logs. That's not very noteworthy until the winter wind comes rushing in. An icy wind at the back of your neck does tend to grab your attention.

The insulating nature of packed moss was also good for keeping winter cold away from fingers and toes. In browsing through source after source, I find that northern people traditionally lined their winter boots and mittens with soft mosses for an extra layer of insulation. When the renowned "Ice Man," a 5,200-year-old body from a melting Tyrolean glacier, was recovered, his boots were found to be packed with mosses, including *Neckera complanata*. The moss actually provided an important clue as to his origins, since *Neckera* was known to occur only in lowland valleys, some sixty miles to the south. In the boreal forest, where feather mosses are a blanket beneath the spruces, their warm cushioning was also put to good use in bedding and pillows. Linnaeus, the "father of modern plant taxonomy," reports sleeping on a bedroll of portable *Polytrichum* moss, as he traveled among the indigenous Sammi peoples of Lapland. A pillow made of *Hypnum* mosses was said to impart special dreams to the sleeper. In fact, the genus name *Hypnum* refers to this trancelike effect.

I can glean that mosses were woven as decoration into baskets, used as lamp wicks and for scrubbing dishes. I'm pleased to have discovered these small notes that show that people were not oblivious of mosses, that they did play a role in daily life. But I'm also disappointed. There is nothing here that speaks of a special gift from the Creator, a unique role that could be fulfilled by no other plant. After all, dry grass can also insulate boots and a layer of pine needles can make a soft bed, too. I was hoping to find a use that reflects the essence of mossness. I was hoping to find that the people of that distant time knew mosses the way I do.

The library brought me a little further, but intuition told me that the story found there was incomplete. Every way of knowing has its own strengths and weaknesses. Taking a breather, hidden behind the accumulated stacks of books, I remembered going with Jeannie to look for plants just as soon as the snow melted and green shoots started to poke up through the winter's matted leaves. One of the first plants we found in bloom was coltsfoot, growing along the gravelly bank of Onondaga Creek. A botanist might explain this preference for March streambanks by its physiologic requirements, or perhaps its intolerance of competition. This is quite probably true. However, in the Onondaga understanding, coltsfoot grows here because it is near to its use; the medicine lies close to the source of the illness. After a long winter, just after the ice goes out, the running water is irresistible to kids. They wade and splash and race sticks in the current, soaking themselves, oblivious to the deep chill until they get home and wake up coughing in the night. Coltsfoot tea is good for just that kind of cough, the kind that comes with wet feet in small children. Another tenet of indigenous plant knowledge is that we can learn a plant's use by where it occurs. For example, it's well known that a medicinal plant frequently occurs in the vicinity of the source of the illness. There's nothing in Jeannies' telling that negates the scientific explanation. It expands the question beyond how coltsfoot lives beside the creek, to the question of why, crossing over a boundary where plant physiology cannot follow.

The plant's purpose can be read through its place. I remember this when I'm tromping through the woods and mistakenly grab a vine of poison ivy to haul myself up a steep bank. I look immediately for its companion. Remarkable in its fidelity, jewelweed is growing in the same moist soil as the poison ivy. I crush the succulent stem between my palms with a satisfying crunch and a rush of juice, and wipe the antidote all over my hands. It detoxifies the poison ivy and prevents the rash from ever developing.

So, if plants show us their uses by where they live, what is the message from mosses? I think of where they live, in bogs, along streambanks, and in the spray of the waterfalls where salmon jump. And if this weren't sign enough, they reveal their gifts every time it rains. Mosses have a natural affinity for water. Watch a moss, dry and crisp, swell with water after a thunderstorm. It's teaching its role, in language more direct and graceful than anything I've found in the library.

Perhaps the limited information on mosses in nineteenth-century anthropology is rooted in the fact that most of the observers of indigenous communities were upper-crust gentlemen. They focussed their studies on what they could see. And what they could see was conditioned by the world they came from. Their notebooks bulged with records of the pursuits of men; hunting, fishing, and making tools. When moss once appeared in a weapon, as wadding behind a harpoon tip, it was described in considerable detail. Then, just at the point when I'm ready to give up the search, I find it. A single entry. You can almost

see the blush in the brevity of the statement: "Moss was in widespread use for diapers and sanitary napkins."

Imagine the complex relationships that lie behind that one entry, reduced to a single sentence. The most important uses of mosses, roles that reflect their best gifts, were everyday tools in the hands of women. Somehow I'm not surprised that the gentlemen ethnographers did not delve into the details of baby care, particularly the unglamorous but inescapable issue of diapers. And yet what could be more fundamental to the survival of a family than the well-being of babies? In this time of disposable diapers and antiseptic baby wipes, it's hard to envision infant care without this technology. If I try to imagine carrying an infant on my back all day without benefit of diapers, I don't like the image that comes to mind. I know with certainty that our grandmothers' grandmothers would have figured out an ingenious solution. In this most fundamental aspect of family life, mosses showed their great utility. To say nothing of humility. Babies were packed in their cradleboards in a comfy nest of dried moss. We know that *Sphagnum* moss can absorb twenty to forty times its weight in water. This rivals the performance of Pampers, making it the first disposable diaper. A pouch filled with mosses was probably as vital to those mothers as is the ubiquitous diaper bag today. The plentiful air spaces in dried *Sphagnum* would wick the urine away from the baby's skin, just as it wicks up moisture in a bog. The acid astringency and mildly antiseptic properties even prevented diaper rash. Like the coltsfoot, the spongy mosses placed themselves near at hand, right at the edge of the shallow pools where mothers knelt to wash their babies. They came where they were needed. As a mother at the beginning of a new millennium, I feel a certain regret that my babies never felt the touch of soft moss against their skin, forging a bond with the world that Pampers can never provide.

A woman's life was also intertwined with mosses during her menstrual period, known as her "moontime" in many traditional cultures. Dry mosses were widely used as sanitary napkins. Again, the ethnographic information is sketchy here, as males were not privy to the activities of women in menstrual seclusion huts. I imagine the huts as gathering places for the women in synchronous moontime, which occurs in communities subject to night skies uninterrupted by artificial light. The conventional wisdom of anthropologists is that menstruating women were isolated from daily life because they were unclean. But this interpretation grew from the cultural assumptions of the anthropologists and not from indigenous women themselves, who tell a different story. Yurok women describe a time of meditation and speak of special mountain pools where only moontime women were permitted to bathe. Iroquois women tell that any prohibitions on women's activities in their moontime arose because women were at the height of their spiritual powers at this time, and the powerful flow of energy could disrupt the balance of energy around them. In some tribal people, menstrual seclusion was a time of spiritual purification and training, akin to the sweat-lodge training of men. Tucked among the objects in their huts must have been baskets of mosses, selected with great care for their purpose. It seems an inescapable conclusion that women were skilled observers of different moss species, knowing their texture and creating an intimate taxonomy long before Linnaeus. The good missionary ladies must have grimaced in horror at this practice, but I think something was lost in the transition to boiled white rags.

I find another ethnography, this one written by a woman, Erna Gunther. It is full of observations of the work of women, particularly food preparation. Mosses themselves were not used for food. I've tasted them and one bitter gritty taste will dispel any thought of a meal of mosses. But while they were not eaten directly, they were an important part of food preparation among the tribes of the rainy Pacific Northwest where mosses are especially abundant. The two staple foods in the watershed of the Columbia River are salmon and camas root, both of which are revered for their gifts of sustaining the people and both of which are connected to mosses.

Salmon harvesting is generally an activity that requires the contribution of the entire family. Fishing itself is the province of the men and the women prepare the fish for drying over an alderwood fire. The dried smoked salmon will feed the tribe throughout the year and the process must be done carefully in order to assure the quality and the safety of the food. Prior to drying, the slimy coating on the newly caught fish must be wiped away. This removes potential toxins and

keeps the fish from shriveling up when it is dried. In early days, salmon wiping was done with mosses. Ethnographies of the Chinook-speaking peoples describe how women would store large quantities of dry moss in boxes and baskets, to have an ample supply on hand when the salmon were running.

Mosses play a supporting role in another staple food of the Northwest, camas. Camas (*Camassia quamash*) is a member of the lily family and produces a spray of royal blue flowers in the spring. The wet meadows where it occurs were carefully tended by the tribes, including the Nez Perce, the Calapooya, and the Umatilla. Careful tending by burning, weeding, and digging produced large camas prairies. Lewis and Clark reported expanses of blooms so huge that from a distance they mistook the camas swales for shimmering blue lakes. The expedition had survived a difficult crossing of the Bitterroot Mountains and was near starvation. The Nez Perce fed them on their winter stores of camas and saved their lives.

The underground bulb is starchy and crisp, tasting somewhat like a raw potato. It is usually not eaten fresh, but painstakingly prepared by a method that yields a thick paste with the sweetness of molasses. The camas was prepared by creation of a pit oven for baking and steaming. The earthen pit was lined with hot rocks and layers of camas bulbs were placed in the pit. A mat of wet moss was then laid over the camas, building up a stack of alternating layers of moss and camas. The entire oven was topped with ferns and a fire built over the top, which burned all night long. The wet mosses provided a source of steam, which permeated the camas bulbs and baked them to a deep brown color. When the oven was opened and cooled, the steamed camas was shaped into loaves or bricks for storage. Camas was consumed all year round and traded widely throughout the west, packaged in a wrapping of moss and ferns.

Camas remains an honored ceremonial food among the western tribes, even today. At Onondaga in upstate New York, the year is marked by ceremonies of thanksgiving to the plants, as they appear each in their turn, first the maples, then the strawberries, the beans, and the corn. October at Big Bears in California brings a feast to acknowledge the acorns. As far as I know, there is no special ceremony for mosses.

Maybe it's more fitting to honor these small everyday plants in small everyday ways. Cradling our babies, holding our blood, stanching a wound, keeping out the cold—isn't this the way we find our place, by participation in the life of the world?

The people gather together to give thanks that the plants, the grand and the humble, have once again fulfilled their caregiving responsibilities to the people. Tobacco will be burned in their honor. In my culture, tobacco is a bringer of knowledge. I think it's also important that we honor the different paths that lead to knowledge, the teachers in the oral tradition, the teachers in the written tradition, and the teachers among the plants. It's the time we should also turn our thoughts to our own responsibilities. In the web of reciprocity, what is our special gift, our responsibility that we offer to the plants in return?

Our ancient teachers tell us that the role of human beings is respect and stewardship. Our responsibility is to care for the plants and all the land in a way that honors life. We are taught that using a plant shows respect for its nature, and we use it in a way that allows it to continue bringing its gifts. The role of our sacred sage is to make thoughts visible to the Creator. We can learn from this teacher and live in such a way that our thoughts of respect and gratitude are also made visible to the world.

The Red Sneaker

As I dance alone in a sunlit bog, the ground beneath my feet rolls in slow waves. For a long seasick moment my foot hangs in midair, waiting for a solid place to stand. Every step sets off a new undulation, like walking on a waterbed. I reach out to steady myself, grabbing a branch of tamarack, but I've stood too long in one place and the cold water rises around my ankle. The bog sucks at my foot and I drag it out with a slow sucking sound, my leg coated to midcalf in black muck. I'm glad I left my boots back at the top of the esker. An old red sneaker of mine lies somewhere in the depths, lost on another research trip several years ago. Now I go barefoot. Apart from its proclivity for stealing footwear, a quaking bog is a lovely place to spend an August afternoon.

The ring of trees at the perimeter walls off the bog from the rest of the forest. The circle of *Sphagnum* glows green like a firefly against the wall of dark spruce. Here, the seen and the unseen worlds our elders speak of coexist in close proximity, the sunlit surface of the bog and the dark depths of the pond. There is more here than meets the eye.

The lands of my ancestors are dotted with kettle hole bogs among the forests of the Great Lakes. The Anishinabe people conduct their ceremonies using the Water Drum, a drum so sacred that it is not to be viewed by the public. Deerhide stretched across a bowl of wood filled with sacred water, the Water Drum "signifies the heartbeat of the water, of the universe, of creation and of the people." The wooden bowl gives honor to the plants, the deerhide honors the animals, and the water within the life of Mother Earth. The drum is bound with a hoop that represents the circle in which all things move; birth, growth, and death, the circle of the seasons, the circle of our years.

There is no ecosystem on earth where mosses achieve greater prominence than in a *Sphagnum* bog. There is more living carbon in *Sphagnum* moss than in any other single genus on the planet. In terrestrial