

## *The Advantages of Being Small: Life in the Boundary Layer*



**T**he wailing toddler attached to the end of my arm earns me a disapproving look from a sour-faced lady. My niece is inconsolable, because I made her hold my hand when we crossed the street. She is in full voice now, yelling, "I am not too little, I want to be big!" If she only knew how quickly her wish would come true. Back in the car, after she has whined through the ignominy of being buckled into her car seat, I try to have a reasonable talk with her, reminding her of the advantages of being small. She can fit in the secret fort under the lilac bush, and hide from her brother. What about stories in grandma's lap? But, she's not buying it. She falls asleep on the way home, clutching her new kite, a stubborn pout still on her face.

I brought a moss-covered rock to her pre-school for a science show and tell. I asked the kids at pre-school what a moss was. They skipped right over the question of animal, vegetable, or mineral and got directly to the most salient feature; mosses are small. Kids recognize that right away. This most obvious attribute has tremendous consequences for the way mosses inhabit the world.

Mosses are small because they lack any support system to hold them upright. Large mosses occur mostly in lakes and streams, where the water can support their weight. Trees stand tall and rigid because of their vascular tissue, the network of xylem, thick-walled tubular cells that conduct water within the plant like wooden plumbing. Mosses are the most primitive of plants and lack any such vascular tissue. Their slender stems couldn't support their weight if they were any taller. This same lack of xylem means that they can't conduct water from the soil to leaves at the top of the shoot. A plant more than a few centimeters high can't keep itself hydrated.

However, being small doesn't mean being unsuccessful. Mosses are successful by any biological measure—they inhabit nearly every ecosystem on earth and number as many as 22,000 species. Like my niece finding small places to hide, mosses can live in a great diversity of small microcommunities where being large would be a disadvantage. Between the cracks of the sidewalk, on the branches of an oak, on the back of a beetle, or on the ledge of a cliff, mosses can fill in the empty spaces left between the big plants. Beautifully adapted for life in miniature, mosses take full advantage of being small, and grow beyond their sphere at their peril.

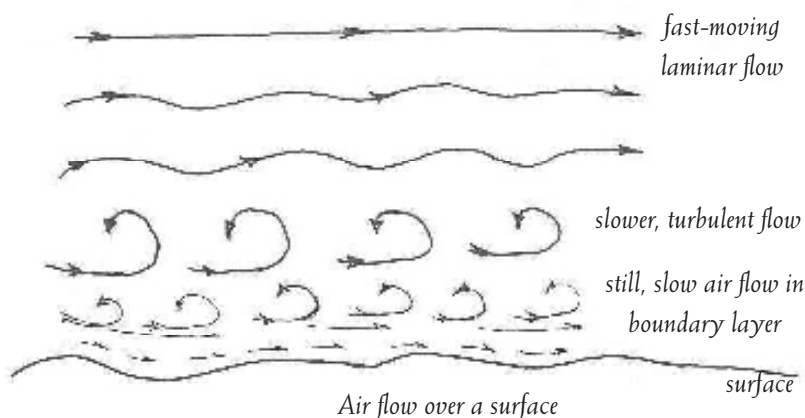
With extensive root systems and shading canopies, trees are the undisputed dominants of the forest. Their competitive superiority and heavy leaf fall are no match for mosses. One consequence of being small is that competing for sunlight is simply not possible—the trees will always win. So mosses are usually limited to life in the shade, and they flourish there. The type of chlorophyll in their leaves differs from their sun-loving counterparts, and is fine-tuned to absorb the wavelengths of light that filter through the forest canopy.

Mosses are prolific under the moist shaded canopy of evergreens, often creating a dense carpet of green. But in deciduous forests, autumn makes the forest floor virtually uninhabitable by mosses, smothering them under a dark wet blanket of falling leaves. Mosses find a refuge from the drifting leaves on logs and stumps which rise above the forest floor like buttes above the plain. Mosses succeed by inhabiting places that trees cannot, hard, impermeable substrates such as rocks and cliff faces and bark of trees. But with elegant adaptation, mosses don't suffer from this restriction; rather, they are the undisputed masters of their chosen environment.

Mosses inhabit surfaces: the surfaces of rocks, the bark of trees, the surface of a log, that small space where earth and atmosphere first make contact. This meeting ground between air and land is known as the boundary layer. Lying cheek to cheek with rocks and logs, mosses are intimate with the contours and textures of their substrate. Far from being a liability, the size of mosses allows them to take advantage of the unique microenvironment created within the boundary layer.

What is this interface between atmosphere and earth? Every surface, be it as small as a leaf or as large as a hill, possesses a boundary layer. We've all experienced it in very simple ways. When you lie on the ground on a sunny summer afternoon to look up and watch the clouds go by, you place yourself in the boundary layer of the Earth's surface. When you are flat on the ground, the wind speed is reduced; you can scarcely feel the breeze that would ruffle your hair if you were standing up. It's warm down there as well; the sun-warmed ground radiates heat back at you, and the lack of breeze at the surface lets the heat linger. The climate right next to the ground is different from the one six feet above. The effect that we feel lying on the ground is repeated over every surface, large and small.

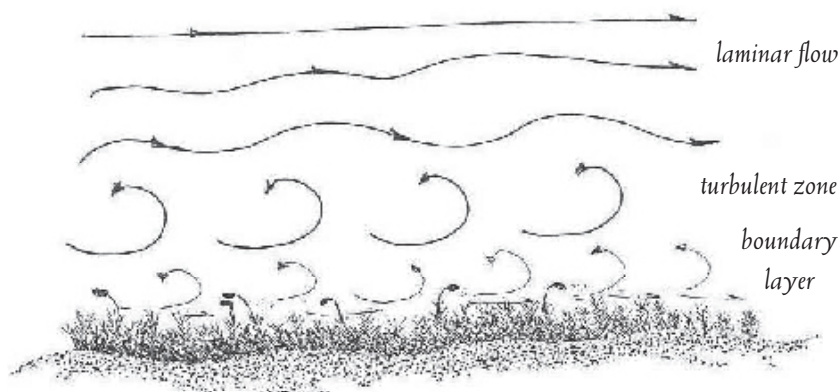
Air seems insubstantial, but it interacts in interesting ways with the things it touches, much as moving water interacts with the contours of the riverbed. As moving air passes over a surface like a rock, the surface changes the behavior of the air. Without obstacles, the air would tend to move smoothly in a linear path called *laminar flow*. If we could see it, it would look like water flowing freely in a smooth deep river. But as the air encounters a surface, friction tugs at the moving air and slows it down. You see this in the flow of water; when a river meets a rocky bottom or logs fallen in its path, the water slows. As the laminar flow is disrupted by the drag of the surface, the air stream becomes separated into layers of different speed. There is swiftly moving air aloft, flowing in a smooth sheet. Beneath it lies a zone of turbulence, where the air swirls and eddies as it encounters obstacles. Down toward the surface,



the air becomes progressively slower and slower until, immediately adjacent to the surface, the air is perfectly still, captured by the friction with the surface itself. It is this layer of still air that you experience while lying on the ground.

At a larger scale, I encounter these layers of air every spring. On the first mild day in April, our beautiful kites that have been hanging draped with cobwebs on the porch all winter rustle in the breeze and remind us of blue sky. So, we take them out to play in the boundary layer. In our sheltered valley, the breezes are seldom strong enough to immediately catch the big dragon kites that the kids and I love. So we run crazily back and forth over the back pasture, dodging cow pies and trying to generate enough wind to carry the kite upward. Close to the surface of the earth, the winds are too slow to support the kites' weight. They are trapped, beyond the reach of the breeze. Only when our mad dashes loft one of the kites up to escape the layer of still air does it pull and dance on the string. Its wild pitches and threatened crashes show that it has ascended into the turbulent zone. And then at last, the kite's string pulls taut and the red and yellow dragon sails into the freely moving air above. Kites were made for the airy zone of laminar flow; mosses were made for the boundary layer.

Our pasture is littered with rocks left by the glacier, and I stop to sit on one and spool out the kite string, listening to meadowlarks. The rock is warm from the sun and softened by mosses. I can imagine the pattern of air, flowing smoothly around it until it encounters the surface, where the mosses live. The sun's warmth gets trapped in the tiny layer of



*Pattern of air flow over a moss carpet*

still air. Since the air is nearly motionless, it acts as an insulating layer, much like the dead space in a storm window, which forms a barrier to heat exchange. The spring breeze around me is chilly, but the air right at the surface of the rock is much warmer. Even on a day when the temperature is below freezing, the mosses on a sunlit rock may be bathed in liquid water. By being small, mosses can live in that boundary layer, like a floating greenhouse hovering just above the rock surface.

The boundary layer traps not only heat, but water vapor, as well. Moisture evaporating from the surface of a damp log is captured in the boundary layer, creating a humid zone in which the mosses flourish. Mosses can grow only when they are moist. As soon as they dry out, photosynthesis must cease, and growth is halted. The right conditions for growth can be infrequent, and so mosses grow very slowly. Living within the confines of the boundary layer prolongs the window of opportunity for growth, by keeping the wind from stealing the moisture. Being small enough to live within the boundary layer allows the mosses to experience a warm, moist habitat unknown by the larger plants.

The boundary layer can also hold gases other than water vapor. The chemical composition of the atmosphere in the slim boundary layer of a log differs considerably from that of the surrounding forest. The decaying log is inhabited by a myriad of microorganisms. Fungi and bacteria are constantly at work degrading the log, with an outcome as sure as that of a wrecking ball. The continual work of the decomposers slowly turns the solid log to crumbling humus and releases vapors rich in carbon dioxide, which is also trapped in the boundary layer. The ambient atmosphere has a carbon dioxide concentration of approximately 380 parts per million. But the boundary layer above a log may contain up to ten times that amount. Carbon dioxide is the raw material of photosynthesis, and is readily absorbed into the moist leaves of the mosses. Thus, the boundary layer can provide not only a favorable microclimate for moss growth, but also an enhanced supply of carbon dioxide, the raw material for photosynthesis. Why live anywhere else?

Being small enough to live in the boundary layer is a distinct advantage. Mosses have found the microhabitats where their size becomes an asset. The growth of a moss would be sharply curtailed if the shoots grew too tall and into the drying air of the turbulent

zone. We might predict therefore that all mosses are uniformly small, corresponding to the limits imposed by the boundary layer. However, mosses exhibit a tremendous range in height, equivalent to the height disparity between a blueberry bush and a redwood. They range from tiny crusts only a millimeter high to lush wefts that can be up to ten centimeters tall. These differences in stature can usually be traced to differences in the depth of the boundary layer in the particular habitat. The boundary layer on a rock face exposed to wind and full sun is quite thin. Hence, the mosses of such arid places must be very small in order to stay within the protective boundary layer. In contrast, mosses on a rock in a moist forest can grow much taller and still remain within a favorable microclimate, because the boundary layer of the rock is under the umbrella of the boundary layer of the forest itself. The trees slow the wind and their shade reduces evaporation, buffering the area against the drying atmosphere. In a humid rainforest, the mosses can be lush and tall. The larger the boundary layer, the larger the moss can be.

Mosses can also control the depth of their own boundary layers by changes in their shape. Any feature of a surface that increases friction with moving air can slow the air and create a thicker boundary layer. A roughened surface slows the passage of air more effectively than a smooth one. Imagine being caught in a fierce prairie blizzard with strong winds blasting sheets of snow against your face. To escape the force of the winds, you lie down, taking refuge in the shelter of the earth's boundary layer. Given a choice, would you be warmer lying in the open or in a field of tall grass? The projection of the tall grass into the moving air stream slows the air and makes a larger boundary layer, helping to conserve your body heat. Mosses utilize this same principle to enlarge the boundary layers above them. The surface textures of a moss itself can create resistance to airflow. The greater the resistance, the deeper the boundary layer. Like a tall grassy field in miniature, moss shoots exhibit adaptations that slow air movement. Many moss species have long narrow leaves held upright to slow the airflow around them. Moreover, the leaves of mosses in dry sites often possess dense hairs, long reflective leaf tips, or minuscule spines. These extensions from the leaf surface also slow the moving air and reduce evaporation of essential moisture by creating a thicker boundary layer.

In arid zones, mosses often rely on dew for their daily ration of water. The interplay of the atmosphere and the rock surface creates the conditions for dew formation. At night, when the sun's heat dissipates, the temperature differential between the rock surface (which has retained some warmth) and the air may provide a site for condensation of water. A thin film of dew is created right at the air-rock interface, where it can be readily absorbed by the mosses. Only a very small being can take advantage of such a thin and evanescent supply of moisture in the desert, living on dew.

The safe and balmy realm of the boundary layer provides a secure refuge for mosses. But the very same nurturing environment that sustains growth to maturity poses a problem for the next generation. Like my niece, mosses eventually need to escape from protection by their elders and find their own places. Mosses reproduce by the formation of spores, tiny powdery propagules that require wind to carry them far afield. Most spores can't germinate in the leafy carpet of their own parents, so getting away is imperative. Air currents in the still air of the boundary layer are not sufficient to disperse them. So, to catch a breeze and help them leave the home territory, mosses elevate their spores on long setae, stalks that poke up above the boundary layer. The rapidly maturing sporophytes are thrust up through the boundary layer and into the turbulent zone like a kite on the wind. Here vortices of air swirl around the capsules, pulling out the spores and carrying them off to new habitats. Like the young of every species they escape the restrictions of their elders and seek out the freedom of the wide-open spaces.

The length of the seta or stalk is strongly correlated with the depth of the boundary layer. The seta of a forest moss must be quite tall to escape the boundary layer and catch the light breeze that moves over the forest floor. In contrast, mosses of open sites where the boundary layer is thin typically have short setae.

Mosses take possession of spaces from which other plants are excluded by their size. Their ways of being are a celebration of smallness. They succeed by matching the unique properties of their form to the physical laws of interaction between air and earth. In being small, their limitation is their strength. Try telling that to my niece.