Book Review

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Gathering Moss: A Natural and Cultural History of Mosses
by Robin Wall Kimmerer 2003. Oregon State University Press. Corvallis, Oregon, USA. 168 pages. Winner of the John Burroughs Medal Award for Natural History Writing. ISBN: 0-87071-499-6 (softbound, in English)

A while ago, a mutual colleague recommended an enchanting, 2003 book to us, Gathering *Moss. A Natural and Cultural History of Mosses* by Robin Wall Kimmerer. As I read it, I envisioned the landscapes the author, a Native American scholar from the Potawatomi people, was describing.

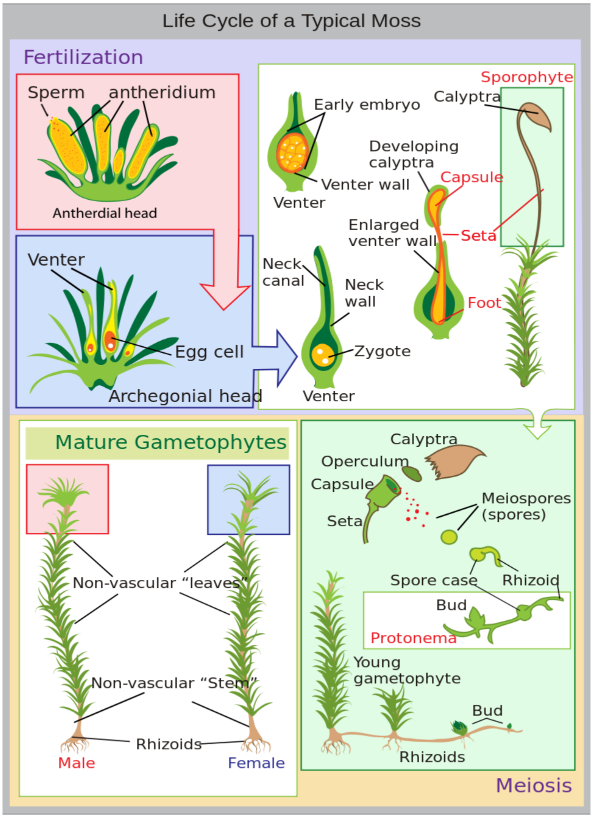

Figure 1. Life history of a moss. Attribution: LadyofHats. Web source: https://commons.wikimedia.org/wiki/File:Lifecycle_moss_svg_diagram.svg

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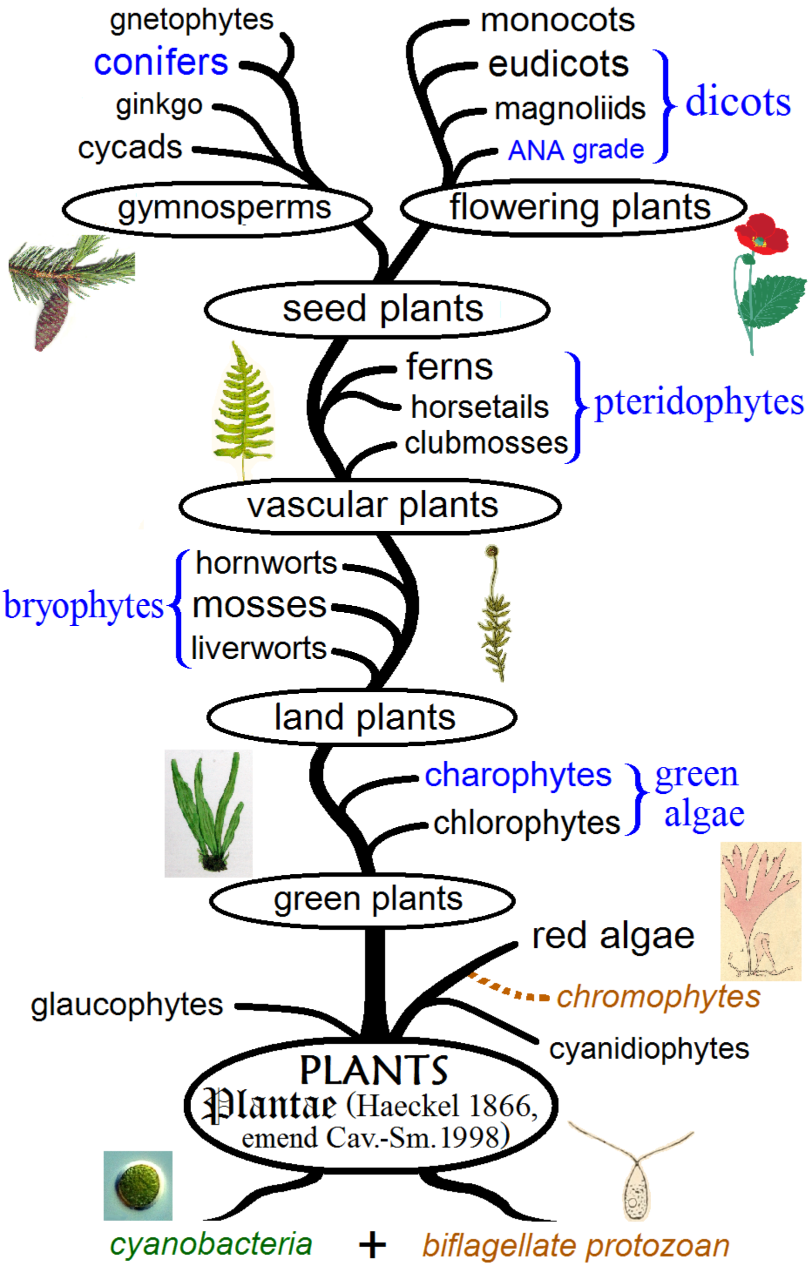

Figure 2. A simplified family tree of plants. Attribution: Maulucioni. Web source: https://upload.wikimedia.org/wikipedia/commons/3/36/Plant_phylogeny.png

In its 19 essays and a *Preface*, Kimmerer intertwines vast biological knowledge about mosses, with the author's reflections on her life and her personal philosophy about the natural world. In the *Preface*, Kimmerer states there are many ways of knowing, such as through the mind, body, "heart" (or emotions), and spiritually. The first three remind us of Bloom's taxonomy of knowledge: cognitive, kinesthetic, and affective. I suspect that Kimmerer's overt perspectives are becoming more common among some scientists, many of which have openly rejected positivism, the notion that science can answer all questions. Kimmerer's broad scientific interest is botany or, as she refers to it, plant science.

For decades, one of the author's objects of scientific inquiry has been mosses, a group of generally small, often overlooked plants, consisting of approximately 12,000 described species (circa 20,000 if the liverworts and hornworts are included), distributed worldwide and known from the Carboniferous, some 300 million years ago and perhaps earlier. Bryophytes, the larger taxonomically informal group to which mosses belong, do not have vascular tissues, such as xylem and phloem. Also, they lack seeds, cones, or flowers (Figures 1 - 2). Although in more recent botanical classifications, mosses are considered a group on its own, colloquially they are still often lumped with the superficial look-alike's, liverworts and hornworts (the prefix "wort" is an Old English word, meaning plant) under the term, "bryophyte".

In *Standing Rocks*, she takes readers on a gentle stroll through a path on Cranberry Lake Biological Station, located in the northwestern portion of the Adirondack Mountains in the state of New York (USA), approximately 80 km from Canada where most of her studies of mosses have taken place. As I was listening to the reading, filled with vivid descriptions, I could picture the views, listen to the sounds of the birds, feel the changes in temperature, and experience the sensory inputs from her writing. Importantly, I could so easily see the isolated rocks populated by different species of mosses, pioneers along with lichens in ecological succession, as physical islands amidst a forested sea (Figure 3). I asked myself the same questions she must have asked decades long before: what determines the distribution of mosses in different rocks? There is a sense of irony in using some of the so-called "simplest" plants to try to garner understanding of some of the most complex biological problems. As I have experienced many times, one is in a reverie or trance when one is in the field asking more questions than one can ever hope to answer.

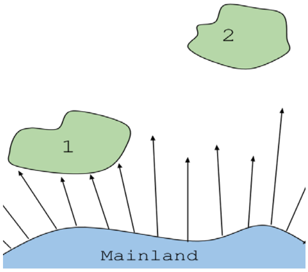

Figure 3. Basics of island biogeography theory. The number of species on an isolated region, such as Kimmerer's boulders is affected by the size of the island and the distance from a source of the organisms, or mainland. Author: Hdelucalowell15. Web source: https://commons.wikimedia.org/wiki/File:Insular_Biogeography_(Distance).png

The Advantages of Being Small: Life in the Boundary Layer discusses the advantages of being small. Being small has important correlates, including lack of support structures and the presence of different species in a relatively small volume. Mosses tend to thrive in shady places but, in the fall, they tend to be in trouble under a forest floor filled with leaves. Mosses do very well in the so-called boundary layer (Figure 4), where it is less windy, warmer, moister, and there is a bit more carbon dioxide owing to the action of decomposers nearby. Mosses vary in size, from 1 mm tall in wind-beaten bare rock to 10 cm tall in moist forest or grasslands. Drier habitats tend to be associated with mosses that bear dead extensions creating a greater boundary layer. In those arid places, mosses depend on dew as a source of water. Mosses reproduce sexually through spores produced in a diploid structure, called sporophyte, that is elevated well above the boundary layer.

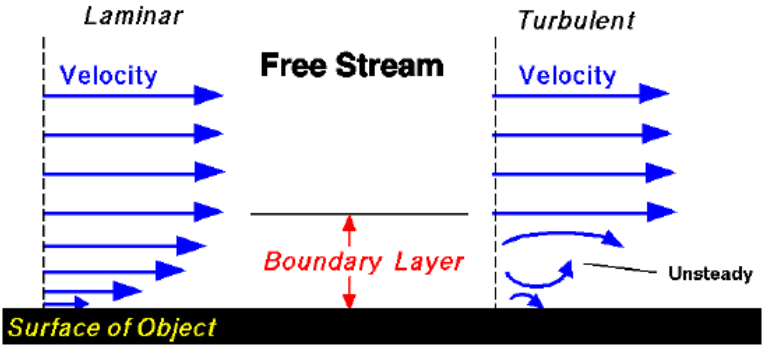

Figure 4. Boundary layer refers to the volume of a fluid that moves close to the surface of an object, such as a moss. The movement can be laminar or turbulent. Image from NASA Glenn Research Center. Web source: https://www.grc.nasa.gov/WWW/K-12/VirtualAero/BottleRocket/airplane/boundlay.html

Figure 5. A moss, with orange-yellow sporophytes located well above the green and leafy gametophytes. Web source: https://commons.wikimedia.org/wiki/File:RedMoss.jpg Author: Transferred from en.wikipedia to Commons by Von.grzanka using CommonsHelper. The original uploader was Vaelta at English Wikipedia.

In the essay, *Back to the Pond*, the author describes a walk on a path to collect mosses between a house and a pond using a multisensorial, yet accessible language at times reminiscent of Rachel Carson's writings. Like frogs, mosses are amphibious, needing water to live or, at a minimum, to reproduce. Just like the Zuni story of life on Earth, life began in the sea, with algae, according to Kimmerer. The most ancestral land plants are the bryophytes, including mosses. But how to reproduce on land if one is used to amphibious life? The reproductive structures of mosses still depend on water. Other differences between algae and mosses include the presence of rhizoids, small leaves, and ovules and sperm produced inside a protected larger structure (Figure 1). The scarce water forms an aqueous film that bridges the mosses' ovules and sperm. Water is tough medium to swim through but the male structures, the antheridia, produces a surfactant that makes water less viscous, carrying sperm like surfers on a wave. In other species of moss, the sperm depends on water droplets for movement. Special cells connect the moss to a developing diploid zygote, the first cell of the diploid sporophyte. Therein, the spores are formed and are eventually dispersed. Upon germination, the spores form the protonema, a haploid structure not too different from the looks of some algae.

Sexual Asymmetry and the Satellite Sisters discusses how the author's personal life sometimes mimics the life and evolution of some mosses, such as the species of *Dicranum*. Numerous species can coexist by having different niches, or occupations, within the forest. Some species have skewed sex ratios in which the males are minuscule and uncommon, living amidst larger groups of females. If the germinated spores have not yet differentiated into males and females, sometimes the existing females produce chemicals that force the undifferentiated spores into becoming dwarf males.

An Affinity for Water discusses the many ways in which mosses depend and secure water. Mosses depend on water for survival and reproduction. A moss without water is a desiccated, shriveled plant. Also, water is essential for photosynthesis (Figure 6).

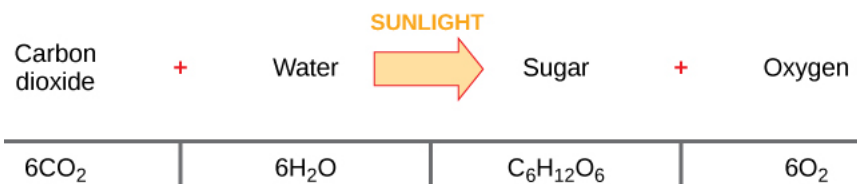

Figure 6. Equation for photosynthesis. Author: CNX OpenStax. Web source. https://upload.wikimedia.org/wikipedia/commons/a/a3/Figure_08_01_04.jpg

Like fishes, water is essential for the sperm cells to move. Ancestral plants, such as bryophytes and pteridophytes (ferns and their allies), as well as cycads (gymnosperms) have sperm! The densely packed leaves of mosses, which are one cell thick, as well as specialized structures on their leaves, assist in water retention. Inexorably, water evaporates, and mosses desiccate until the next rainy season. However, before desiccation, repair enzymes are manufactured and stored in the cell membrane, and they stand ready to repair the cells as quickly as 20 minutes into a rainy season. Epiphytic moss clumps can be considered as sponges temporarily trapping water; the excess dripping down the trunk to the host tree roots.

Binding up the Wounds: Mosses in Ecological Succession describes how mosses occupy small spaces in cracks in rocks, thereafter, seedlings of larger plants begin taking hold, continuing the ecological succession. Mosses, the rugs of nature, provide a safe and stable site for germination of the seeds and other plants. While for Kimmerer, the carpet store served as inspiration for the moss forest, for me (JASB), hardware stores and their personnel are the go-to places. Vegetation helps absorb water and build soil, the beginning of succession. Some mosses occupy specialized habitats, such as abandoned, or orphan, mines, rich in ores and tailings, seeping out of the mine. The tailings have a microbial community including bacteria, algae, and fungi.

In the Forest of the Waterbear, Kimmerer describes in detail the moss microforest. If we could be miniaturized, we could see many little animals, or animalcules as Leewenhoek called them, including tardigrades (Figures 7 - 8), rotifers, springtails, nematodes, mites, etc. The moss forest itself is a miniature version of the bigger thing, with all the interactions, such as predation, commensalism, mutualism, etc. of the actors and actresses in the drama of life.

Figure 7. Examples of invertebrates that live in the moss forest. Left panel, tardigrade. Source: Schokraie E, Warnken U, Hotz-Wagenblatt A, Grohme MA, Hengherr S, et al. (2012) Comparative proteome analysis of Milnesium tardigradum in early embryonic state versus adults in active and anhydrobiotic state. *PLoS ONE* 7(9): e45682. doi:10.1371/journal.pone.0045682. Right panel, rotifer. Web source: https://commons.wikimedia.org/wiki/File:Bdelloid_Rotifer_(cropped).jpg . Author: Bob Blaylock (talk). Authors: Schokraie E, Warnken U, Hotz-Wagenblatt A, Grohme MA, Hengherr S, et al. (2012).

Figure 8. A forest of mosses. Author: Ernst Haeckel's *Kunstformen der Natur*, 1904 Web source: https://en.wikipedia.org/wiki/Moss#/media/File:Haeckel_Muscinae.jpg . Identity of the mosses can be found here: http://caliban.mpiz-koeln.mpg.de/haeckel/kunstformen/high/Tafel_072_schema_300.html

Kickapoo takes us on a canoe ride in southwestern Wisconsin, looking for rare lichens and mosses. This is a great example of how new projects come into the minds of scientists. In this case, what causes the horizontal bands of mosses in the Kickapoo river? Humboldt must have asked a similar question when he contemplated the horizontal bands of vegetation in Mt. Chimborazo, Ecuador, or what Connell saw in the distribution of barnacles in the rocky intertidal of Scotland, or what Payne asked in the distribution of organisms in the rocky intertidal of the US state of Washington. Briefly, *Conocephalum* mosses do not tolerate prolonged flooding, hence found in the upper layers of the cliff. In contrast, *Fissidens* are outcompeted by *Conocephalum* and tolerates flooding. Thus, *Fissidens* can be found in the lower strata. In between those two horizontal bands of mosses, there are many other species of mosses. The intermediate disturbance hypothesis states that biological diversity is maximized when the frequency of disturbance is neither too frequent nor too rare (Figure 9).

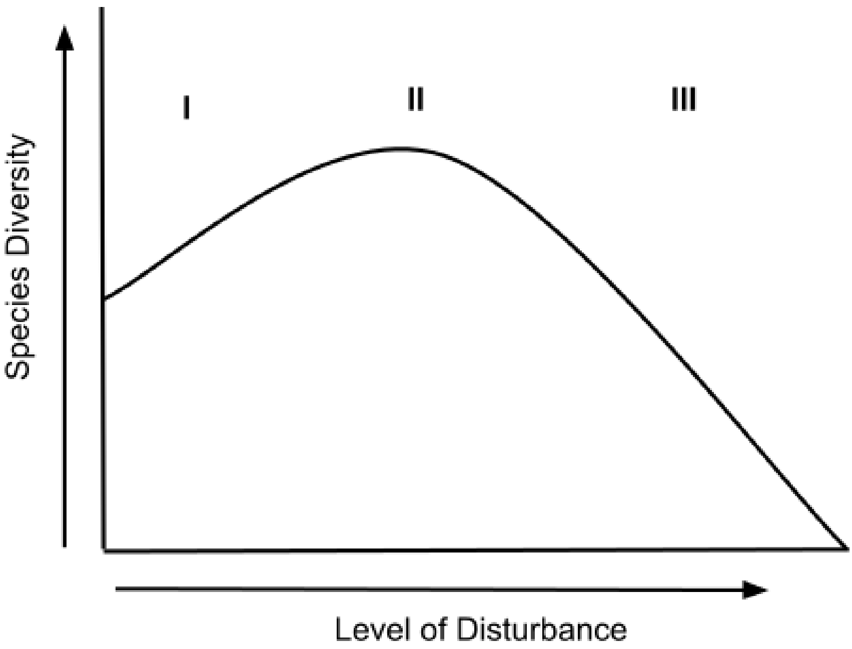

Figure 9. Intermediate Disturbance Hypothesis as related to biodiversity. At low or high levels of disturbance, a reduced number of species tend to dominate. At intermediate levels of disturbance, species biodiversity is the greatest. Web source: https://upload.wikimedia.org/wikipedia/commons/3/37/Intermediate_Disturbance_Hypothesis_Graph.svg . Author: Sciencerelatedusername.

Choices… choices, choices, details the variety of reproductive strategies of mosses, from asexual cellular reproduction (e.g., gemma, plural gemmae; one or more cells that can separate from the rest of the organism and initiate a new organism, as in a plant cutting) to sexual cellular reproduction. In the game of survival and reproduction, sexual cellular reproduction increases genetic variability. However, sexual cellular reproduction disrupts coadapted gene complexes and it is energetically costly. The amount of energy an organism devotes to sexual reproduction is known as the "reproductive effort" and this effort tends to vary depending on the environmental conditions and genetics of the organism. For instance, in patches of *Tetraphi*s mosses, low density tends to be associated with asexual reproduction; patches of high density tend to favor sexual cellular reproduction.

Besides the undeniable influence of genetics and of the environment on how something looks, or phenotype, events whose causality is difficult to pin down, or chance events, are also important. *A Landscape of Chance* introduces us to such events at the level of the populations and ecological communities (Figure 10). Communities have a structure made from the species that live in a place and their interactions. More than visualizing communities as immovable pieces of a landscape, I prefer seeing the components of communities as loosely interlocking pieces that change over time, like the moving staircases and wall decorations in Hogwarts of *Harry Potter* fame. For instance, catastrophes, such as storms, fires, landslides, etc. can change the landscape and trigger a change in the organisms that begin living in the altered place. This is known as ecological succession. Although most of us know of succession from studies on larger plants, the phenomenon has been documented within the forest of mosses. What factors are important in the ecological succession within the forest of mosses? Kimmerer and collaborators have discovered that small mammals, such as chipmunks haphazardly help distribute portions of mosses, called brood branches, to other places. In contrast, slugs, which were experimentally induced to cooperate using beer, are not as important in dispersing mosses.

City Mosses possess the interesting hypothesis that city mosses can thrive there just like some mosses do on cliffs and other environmentally stressful rocky outcrops throughout the world. Yet, just as humans are part of nature, these mosses thrive in the arid city by clumping, thus desiccating as little as possible. Yet, in rainy cities, such as Seattle, Washington, or Portland, Oregon, mosses find many safe havens, by living on shingled roofs amidst other humans who want to harvest mosses for money. Some cities have a particularly high air pollution problem and mosses, having one-cell thick leaves, are particularly susceptible to airborne sulfur compounds resulting from the burning of fossil fuels. Thus, some species of moss are air quality indicators. In some cities, structures filled with mosses, help diminish the air pollution problem.

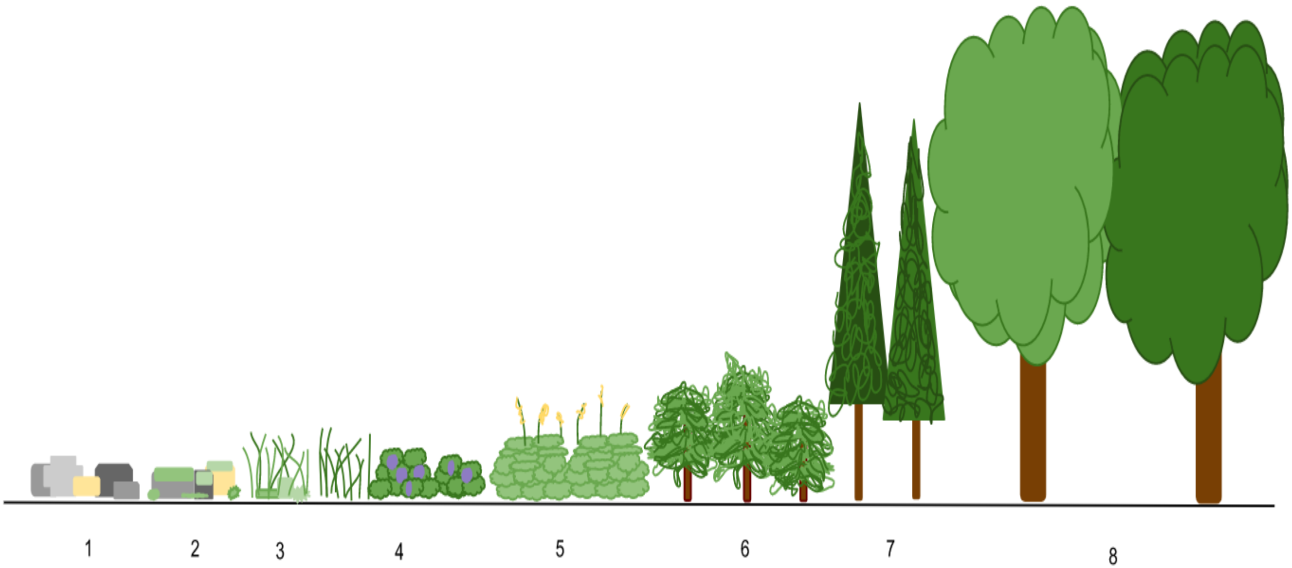

Figure 10. Ecological succession leading to a temperate forest. "(1) After a volcano or glacial retreat, bare rocks are left. (2) Lichens and mosses grow on the rocks, then the rocks are slowly broken down as plants grow over them and a soil layer is formed from dead plant material. (3) Grass starts to grow with the lichen. (4) Taller grasses and perennials thrive. These species are replaced by new vegetation in the following succession, which happens gradually: (5) low shrubs, high shrubs, (6) shrub-trees, (7) short trees such as pines, and (8) high trees. The area eventually becomes covered in forest and remains that way" until the area is hit again by a disturbance. https://upload.wikimedia.org/wikipedia/commons/d/d3/Primary_Succession.svg

Being a book written by a Native American scholar, I was not surprised to read a chapter on the ethnobotany of mosses. *The Web of Reciprocity: Indigenous Uses of Moss* discusses the philosophical perspective on nature by Kimmerer. These views reminded us of the movie, *Bless Me, Última*, and of scholars who are interested in a Native American perspective of nature and their interactions between other organisms. Besides material to fill cracks in, Native Americans have used mosses for pillows, decoration, scrubs, diapers and sanitary napkins, cooking, and many others.

Imagine a pond and imagine it in cross section. *The Red Sneaker* takes readers on such an imaginary trip. The first time I stepped on a bog in Maine (USA), I felt as I on a trampoline, one with occasional holes. For me, seeing classmates going down all the way to their waist was not fun. One variety of bog is the *Spagnum* bog. A *Spagnum* plant is mostly composed of dead cells with holes. Those holes allow water to fill in the cells making the rest of the pond less watery. Additionally, the bog has very little oxygen, thus reducing the rate of decomposition. The watery mess is nutrient-limited, particularly for nitrogen. Not surprisingly, some of the other plants that live on a bog, carnivorous plants (Figure 11) can survive by supplementing their "diet" trapping arthropods, whose exoskeleton is rich in chitin, a nitrogenous polysaccharide. The water in the bog is acidic and that further limits microbial activity and plant life. *Sphagnum* has many uses, including heating, ethanol production, or as ornamental in gardens, as in the chapter entitled, *The Owner* (next page). If any one of us should lose a colorful sneaker, centuries later someone else may recover it in pretty good shape.

Figure 11. Left panel. A Sphagnum bog. Attribution: Bob Jenkins / Sphagnum Bog, Ponsonby Fell / CC BY-SA 2.0 Web source: https://commons.wikimedia.org/wiki/File:Sphagnum_Bog,_Ponsonby_Fell_-_geograph.org.uk_-_105601.jpg . Right panel. Sundew, *Drosera capensis* L. (Droseraceae), a plant that tends to occur in bogs. From an Exhibition of Carnivorous plants in the Botanical Gardens of Charles University, 10. - 19.06.2016 Prague, Czech Republic. Author: Karelj. Web source: https://upload.wikimedia.org/wikipedia/commons/8/8a/Drosera_capensis_Exhibition_of_Carnivorous_Plants_Prague_2016_1.jpg

Portrait of Splachnum describes some factors that determine the distribution of mosses. Some mosses are habitat generalists. On the other extreme, *Splachnum* mosses, whose sporophyte looks like a flower, tend to thrive on feces of different species of mammals. How? Poop releases chemicals that attract flies containing the spores of different species of *Splachnum.* The flies lay eggs in the same island of feces that will be used by the mosses to grow.

To us, *The Owner* was the most mysterious chapter. Here, someone evidently well-to-do, wants to have a garden decorated with mosses, beginning with bare rocks. Although simply getting rocks already colonized by mosses is easier (Figure 12), growing mosses *de novo* on a bare substrate is difficult as they grow slowly.

Figure 12. Moss-covered rocks. Attribution: Attribution: Helen Wilkinson. Web source: https://upload.wikimedia.org/wikipedia/commons/e/ed/Moss_covered_rocks_-_geograph.org.uk_-_506693.jpg

The Forest Gives Thanks to the Mosses poetically describes the interconnectedness of all the living components of an ecosystem, such as ferns, trees, smaller and larger animals, etc. Those components also include the tiny ecosystems hiding in plain sight in layers of mosses, intertwined by fungi that live in an interdependent relationship with plants. Mosses trap rain and, through the layers of pectin in their cell walls, absorb additional H_2O helping retain water and slowly releasing it to the rest of the components of the ecosystem, including the roots. By using markers, one can follow the path of key elements, such as phosphorous (Figure 13), through the ecosystem. It is easy to imagine how deforestation or the replacement of old growth forest by rapidly growing trees contributes to erosion as it is not the same to have old trees, along with everything growing on it than a monoculture of forest trees. In other words, for nature, not all trees are created equal, as not all are planks of wood or pulp for paper. An insightful remark was the idea that in the US state of Oregon, a strip of uncut trees stands – by law - between roads and clear-cut forest, to protect the public's view. Or could it be to deceive us making us believe that there is an expansive forest next to the road?

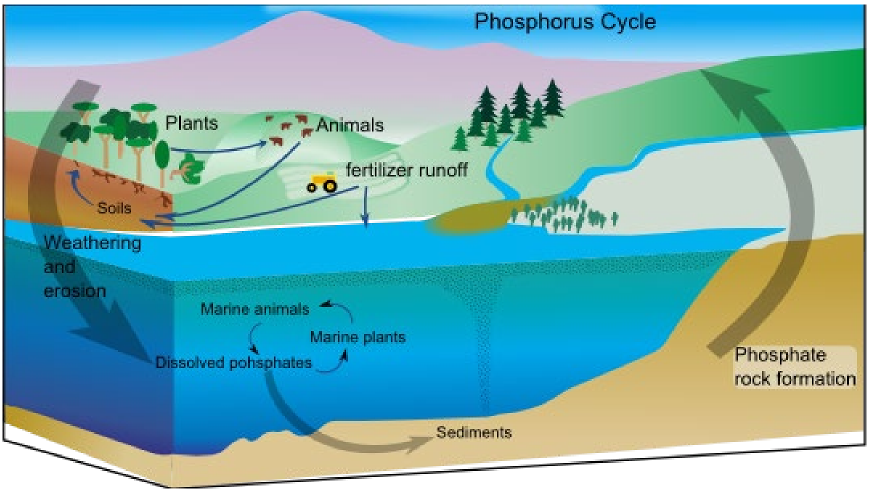

Figure 13. Cycle of phosphorous. Web source: https://commons.wikimedia.org/wiki/File:Phosphorus_cycle.png Author: Bonniemf Incorporates work by NASA Earth Science Enterprise

The Bystander evoked in me memories of temporarily losing my bearings amidst forests. Of some surprise to us was the existence of a vigorous industry of moss pickers, particularly in the Pacific Northwest. With the ravaging of the mosses come the destruction of ecosystems whose communities thrive on intricate interactions between its components. Sometimes, we naively overlook the plant-animal interactions at the level of the mosses, but there are organisms that feed on bryophytes and a community of scholars who study those interactions.

Straw into Gold describes the not always easy boat trip to The Cranberry Lake Biological Station (https://www.esf.edu/clbs/) across Cranberry Lake, a nearly 11 km sojourn in upstate New York. Happy memories of yesteryears with the author's family follow. One of those was the finding of *Schistostega* *pennata*, a moss whose phase most commonly seen is the haploid protonema and that has adapted to living in penumbra, such as in caves, where other plants cannot grow. Its cells contents reflect light and the whole mat glows yellowish-green (Figure 14). During the short time of the year when light is more abundant, the diploid phase, or sporophyte, grows. I have learned to enjoy precious moments while they last.

Figure 14. *Schistostega pennata* in Mount Ontake, Gero, Gifu Prefecture, Japan. Web source:https://upload.wikimedia.org/wikipedia/commons/4/43/Schistostega_pennata_s7.jpg . Author: Alpsdake.

Most welcomed sections, *Suggestions for Further Reading* and an *Index* that works, conclude this book. If you are into natural history books that inspire a sense of completeness, this book is for you. Want to learn about mosses? *Gathering Moss. A Natural and Cultural History of Mosses* by Robin Wall Kimmerer will get your appetite ready to learn a lot more (Figure 15).

Figure 15. Sample of mosses. Author: A. Schanlou. Web source. https://www.nps.gov/romo/learn/nature/mosses_liverworts.htm