CHAPTER 7-1
GARDENING: HORTICULTURAL USES

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CHAPTER 7-1 GARDENING: HORTICULTURAL USES

Figure 1. ***Sphagnum*** species such as this ***S. russowii*** are commonly used in horticulture as bedding material. Photo by Michael Lüth.

Horticultural Uses

I was surprised that in my search for moss uses in horticulture I stumbled on a patent for culturing "moss seedlings" (Hiraoka 1995). The patent was to culture mosses that could henceforth be transplanted and grown in a nursery. Hiraoka presented this as a means of reducing the necessity of collecting wild mosses and creating undesirable forest conditions due to drying soils and erosion. This consideration should serve as a warning for all who desire to use bryophytes for any commercial purpose, and even on a small personal scale, collection can produce local damage.

"People have probably used organic materials as an aid for plant culture since the eve of human history, but documentation is scarce" (Raviv *et al*. 1986). Use of organic materials, including mosses, may not have started that early, but if monkeys can discover the advantage of mosses for getting water to drink, why not? At the beginning of the 18th Century, we find reference to using peat moss as an amendment for clay soils, whereas animal dung was used for sandy soils (Raviv *et al*. 1986). Since then, the need to keep plants alive during transfer made bryophytes a desirable medium because of their ability to retain moisture.

It is surprising how difficult it is today to find literature on the use of bryophytes in plant cultivation, despite the widespread sale of peat mosses for gardening, potting, air layering, and other uses. Rather, the use of mosses, especially peat moss, seems to be assumed and publications concentrate on finding substitutions for it (*e.g.* Tripepi *et al*. 1996) or creating the right mix of moss and amendments (*e.g.* Chong & Lumis 2000; Shujun *et al*. 2004).

Horticulture is the largest market for moss products in Asia (Tan 2003), and probably in most North American countries (Muir *et al*. 2006). In horticulture, mosses find a niche unparalleled in any other living bryophyte industry (Nelson & Carpenter 1965; Tan 2003). In some parts of

the world, they are routinely mined (Clarke 2008). Bryophytes, especially peat mosses (Figure 1), have played a major role in horticulture for centuries (Perin 1962; Arzeni 1963; Adderley 1964, 1965). Although their use as part of the landscape in gardens has traditionally been mostly an Asian practice, they have commonly been used as soil additives and bedding for greenhouse crops, potted ornamental plants, and seedling beds (Cox & Westing 1963; Sjors 1980). They are stuffed into wire frames to make totem poles to support climbing plants (at the Mossers Lee Plant), topiary (Figure 2), moss-filled wreaths, or baskets (Thomason 1994), or for covering the soil in floral arrangements. One company advertises a birch bark pedestal topped by a moss globe.

Figure 2. A swan topiary exhibited in a pedestrian area of Minneapolis, Minnesota, USA. Photo courtesy of David Long.

Overuse of mosses is concerning in several countries. Thus, some horticulturists seek substitutes. The use of rice hulls may provide a more renewable alternative to ***Sphagnum*** (Figure 1) peat for horticulture usage (Sambo *et al*. 2008). Peat has more total pore space and a lower air-filled pore space compared to rice hulls, coinciding with a higher water-holding capacity and the highest water content at container capacity. Nevertheless, peat had a lower available water content than the rice hulls, while releasing its water more slowly.

Shipping and Protecting

Sphagnum (Figure 1) is almost indispensable for shipping live plants, keeping them moist, yet free from mold. In countries where peat is abundant, the damp peat is burned to produce a smoke screen against frost, hence protecting the plants (Thieret 1954). This is one of its uses in Asian countries as well (Tan 2003).

Soil Conditioning

The Shuswap Indians of North America use ***Aulacomnium*** (Figure 3) and ***Dicranum*** (Figure 4) mixed with dirt to make plants healthier (Palmer 1975). As a soil conditioner, coarse-textured mosses increase water storage capacity; fine-textured mosses provide air spaces (Ishikawa 1974; Bernier 1992; Bernier *et al*. 1995). Although supporting experiments seem to be lacking, we assume that mosses improve the nutrient condition of outdoor soils by holding nutrients, especially from dust and rainfall, then releasing them slowly over a much longer period than normal nutrient residency near the soil surface (Stewart 1977; Rieley *et al.* 1979; Scafone unpubl. data).

Figure 3. ***Aulacomnium palustre***. Species of ***Dicranum*** used by the Shuswap Indians of North America to condition the soil for plant growth. Photo by Michael Lüth, with permission.

Figure 4. ***Dicranum scoparium***. Species of ***Dicranum*** used by the Shuswap Indians of North America to condition the soil for plant growth. Photo by Janice Glime.

Their ability to sequester nutrients varies with species and type of nutrient. For most taxa, they do not compete for soil nutrients like phosphorus, but can accumulate from rainfall the potassium, magnesium, and calcium (Timmer 1970). When the mosses later dehydrate, their membranes are damaged, making them leaky. When they rehydrate, nutrients can be dissolved and washed into the soil. It takes a few hours to a day to repair the damaged membranes, giving the roots beneath a chance to retrieve the nutrients that are slowly being washed down from the dusty, leaky mosses. This is dependent also on the force of the rain, with light rains more likely to remain on the mosses long enough for them to absorb the nutrients. This seems to be especially important for potassium, the most soluble and most easily leached nutrient. (See Nutrient chapter in Volume 1 for details.)

Peat, in particular, offers a number of properties important to the growth of plants. To be suitable for most root growth, the peat needs to have about equal proportions of air and water retention. The Peat Research Institute determined that the inclusion of shrubs and cotton grass

from the field site could make the peat inconsistent and alter the water-holding capacity and aeration needed for good plant growth. Therefore, they recommended that the proportion of subshrub residues not exceed 3% wet weight, that the proportion of cotton grass and sedge residues not exceed 6%, and that the proportion of ***Sphagnum*** (Figure 1) residues be at least 90% (Puustjarvi 1982).

In remote places, including national parks, remote villages, and other places where sewage systems are not in place, peat may be mixed with human waste to form compost (Wikipedia 2017). The extra aeration provided by the spaces among the peat plants helps the process of breaking down the sewage. Nevertheless, human pathogens can be a problem, with the greatest of these being *Ascaris* eggs (a nematode parasite; Figure 5-Figure 6) (Hill 2013). A long time or high temperatures are needed to destroy these pathogens. Berger (2011) claims that the compost should be free of live pathogens after at least two weeks at 55ºC or one week at 60ºC.

Figure 5. ***Ascaris*** larva hatched on microscope slide, a genus of parasitic worms of concern in human feces. Photo by SuSanA Secretariat, through Creative Commons.

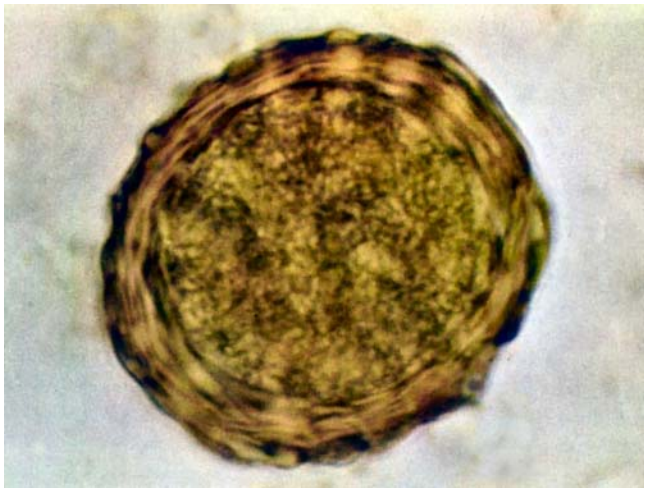

Figure 6. ***Ascaris lumbricoides*** fertilized egg. Presence of these in human feces is of concern when the feces are mixed with peat as a plant growth medium. Photo by Graham Colm, through Creative Commons

In England, the Wye College, University of London, and Southern Water have cooperated to develop a compost that takes advantage of sewage, mixed with peat mosses, providing a valuable soil conditioner and slow-release fertilizer that can be used for container-grown plants (Lopez-Real *et al.* 1989).

One use for the nasty-smelling fish offal takes advantage of the absorptive properties of ***Sphagnum*** (Figure 1) to create a superior compost (Martin & Chintalapati 1990), a real boon for getting rid of fish waste. And, when mixed with fish processing wastes, peat mosses are superior to sawdust and wood shavings in conserving nitrogen, but are a bit more expensive (Liao *et al*. 1995).

Martin (1992) considered that it should be an easy and inexpensive process to use fish by-products (fish offal) with ***Sphagnum*** (Figure 1) peat as a substrate to grow microorganisms for submerged fermentation. Martin conducted experiments on growing fungi and yeast as potential sources of microbial biomass protein for feeding animals. These products, which the fish were willing to include in their diet, served successfully as proteinaceous food for feeding farmed fish.

One of the microorganisms tested was the acid-tolerant fungus ***Scytalidium acidophilum*** (Figure 7) (Martin & Chintalapati 1989). Martin and Chintalapati found that the culture did not produce any better concentration of the fungus dry weight than when they used a diluted ***Sphagnum*** (Figure 1) peat hydrolysate as the substrate source. Martin and Chintalapati (1990) considered that the higher production of nutrients such as nitrogen in the fish offal mixed with peat made this a "promising" source of protein produced by ***Scytalidium acidophilum***.

Figure 7. ***Scytalidium*** sp. ***Scytalidium acidophilum*** is a promising source of protein when grown in fish offal with peat. Photo by Gerardo Garcia-Aguirre, Virginia Vanzinni-Zago, Hugo Quiroz-Mercado, through Creative Commons.

Johnson *et al*. (1992) similarly worked with people from the Wisconsin Sea Grant Inst to find a suitable use for fish by-products to provide a useful compost. They found that the wide range of values for the C:N ratios and other properties related mostly to the initial C:N ratio and the time the mix of peat and fish by-products had been allowed to cure. The ***Sphagnum*** (Figure 1) peat fish by-product composts, especially those with higher C:N ratios, compared well with commercial fertilized mixes.

As with human waste, destruction of pathogens is important for the fish waste, but Liao and coworkers (Liao 1997; Liao *et al*. 1997) found that the rise in temperature during composting, plus the ammonia and volatile fatty acids produced, were sufficient to destroy the pathogens. Addition of fir (*Abies*) or alder (*Alnus*) chips (Figure 8) caused the compost to stabilize sooner.

Figure 8. Wood chips like those used to stabilize the fish offal/***Sphagnum*** compost and destroy pathogens. Photo through Creative Commons.

The addition of ***Sphagnum fuscum*** (Figure 9) peat to hog manure reduced the volatile loss of ammonia, a primary source of nitrogen, by 75%, mainly due to lowered *p*H, making it a more suitable fertilizer (Al-Kanani *et al*. 1992a). It offers the added advantage of preventing release of offensive odors caused by 1,2-ethanediamine, methyl hydrazine, N-methyl methanamine, 3-methyl 2-butanamine, ethanethioic acid, and methanethiol (Al-Kanani *et al*. 1992b).

Figure 9. ***Sphagnum fuscum*** combined with hog manure makes a suitable fertilizer high in nitrogen. Photo by Michael Lüth, with permission.

Rao and Burns (1990) found yet another way of providing nitrogen in the culture of oil-seed rape. They provide **Cyanobacteria** (nitrogen fixers; Figure 10) and bryophytes in the growing medium. Bryophytes are well known for their ability to harbor **Cyanobacteria**.

Miller (1981) found that bryophytes can even increase the buffering capacity of the soil, surprisingly even against the abrupt changes resulting from fertilizer. And as a mulch, the slow decomposition of peat mosses makes them much more long-lasting than leaf litter and compost.

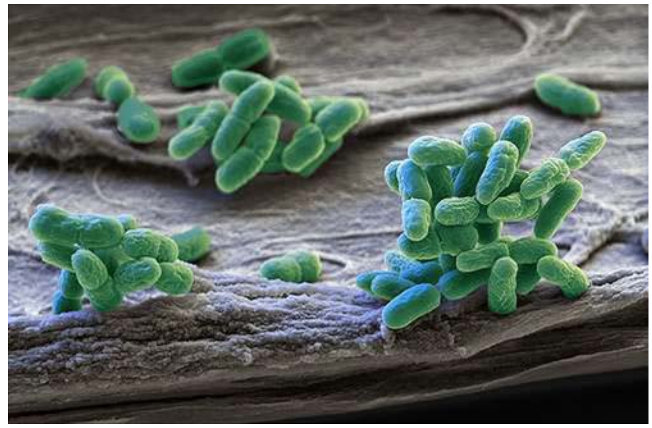

Figure 10. SEM image of ***Synechocystis*** (***Cyanobacteria***) on substrate. Photo from BASF, through Creative Commons.

Mosses such as ***Sphagnum*** (Figure 1) retain moisture and prevent weed growth, while at the same time discouraging damping-off fungi (Miller & Miller 1979).

Culturing

Some mosses, for example the epiphytic ***Octoblepharum albidum*** (Figure 11), are especially suitable for growing hard-to-grow epiphytic ferns (Arzeni 1963). In the Philippines, ***Leucophanes octoblepharioides*** (see Figure 12) and other members of the family are used by gardeners and plant growers instead of peat moss in potting new plants (Ben C. Tan, pers. comm.). ***Leucobryum*** (Figure 13) is a suitable medium for inducing good root sprouts on orchid cuttings, sold at U.S. $0.50 per kilo (in 1963), increased to US $1 in 1986 (Tan 2003). The most popular moss medium for growing orchids, most of which are likewise epiphytes, is ***Sphagnum*** (Figure 1), but mosses like ***Homalothecium arenarium*** (Figure 14), ***Hypnum imponens*** (Figure 15-Figure 16), ***Leucobryum*** spp. (Figure 13), ***Rhytidiopsis robusta*** (Figure 17), and ***Thuidium delicatulum*** (Figure 18) are also useful (Perin 1962; Adderley 1964, 1965). Chen and Chang (2000a, b) had almost 100% survival success when growing the orchid *Oncidium* (Figure 19) from callus explants on ***Sphagnum*** peat. Whereas most of their culture media produced abnormal shoots, both embryo-and shoot-bud-derived regenerants developed into healthy plantlets when potted in ***Sphagnum*** and acclimatized in the greenhouse.

Figure 11. ***Octoblepharum albidum***, a moss suitable for growing hard-to-grow epiphytic ferns. Photo by Niels Klazenga, with permission.

Figure 12. ***Leucophanes*** sp. ***Leucophanes octoblepharioides*** is used instead of peat moss in the Philippines for planting new plants. Photo by Niels Klazenga, with permission.

Figure 13. This epiphytic species of ***Leucobryum*** demonstrates its suitability for supporting root growth by hosting an epiphytic fern. Photo by Janice Glime.

Figure 14. ***Homalothecium aureum*** may be used as a substitute for peat in potting young plants. Photo by Jan-Peter Frahm, with permission.

Figure 15. ***Hypnum imponens*** growing in a sheet on a log. Photo by Janice Glime.

Figure 16. ***Hypnum imponens***, a moss that may be used as a substitute for peat in potting young plants. Photo by Janice Glime.

Figure 17. ***Rhytidiopsis robusta***, a moss that may be used as a substitute for peat in potting young plants. Photo by Blanka Shaw, with permission.

Figure 18. ***Thuidium delicatulum***, a moss that may be used as a substitute for peat in potting young plants. Photo by Janice Glime.

Figure 19. New ***Oncidium*** hybrid pseudobulb that must form a mycorrhizal connection. Photo by Consuelo Tugnoli, through Creative Commons.

But one consideration is that orchids are **mycorrhizal** (see Figure 20). That means they require an appropriate fungal partner in order to successfully form plants from seeds or cuttings. Kreier (2003) reasoned that a fungus that was mycorrhizal to bryophytes might be a good place to find a proper associate for the orchids. Several members of the liverwort family **Aneuraceae** (Figure 21) are mycorrhizal in association with the fungal genus ***Tulasnella*** (Figure 21-Figure 22). Kreier reasoned that if the orchids have the same mycorrhizal fungi, then it should be possible to use those liverwort associations to inoculate the orchids with mycorrhizae from the liverworts. Oberwinkler *et al*. (2017) reported ***Tulasnella*** species are worldwide and likewise are associated with orchids on a global scale. The possibilities look good.

Figure 20. Mycorrhizal root tips of an ***Amanita*** mushroom, partnering with a tree. Photo by Ellen Larsson, R. Henrik Nilsson, Erik Kristiansson, Martin Ryberg, and Karl-Henrik Larsson, through Creative Commons.

Figure 21. ***Cryptothallus*** (white; in **Aneuraceae**) and ***Pinus pinaster*-*Tulasnella*** ectomycorrhizae. Photo courtesy of Martin Bidartondo.

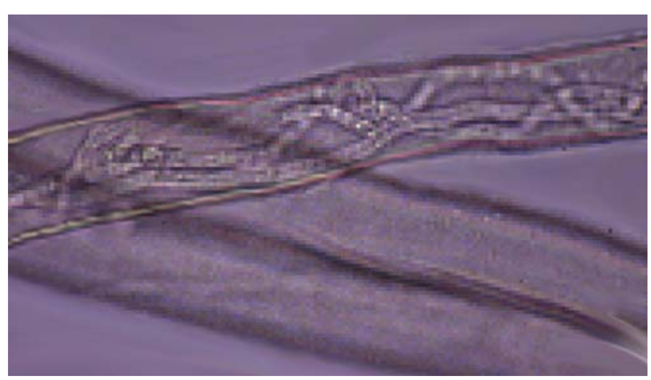

Figure 22. ***Cryptothallus*** rhizoids colonized by ***Tulasnella*** hyphae in a microcosm. Photo courtesy of Martin Bidartondo.

Air Layering

Horticulturists may have learned some lessons from nature. Mosses in nature provide suitable media for air layering of plants like the heath shrub *Calluna* (Figure 23) (Scandrett & Gimingham 1991; MacDonald *et al*. 1995) and even some tropical trees. MacDonald and coworkers (1995) demonstrated that layering was actually associated with the absence or low abundance of the mosses ***Hypnum cupressiforme*** (Figure 24) and ***H. jutlandicum*** (Figure 25) and *Cladonia* lichens (*e.g.* Figure 26). On the other hand, there seems to be a weak connection with layering in ***Sphagnum*** spp. (Figure 1), ***Leucobryum glaucum*** (Figure 27), and pleurocarpous mosses other than ***Hypnum***.

Figure 23. *Calluna vulgaris*, a species that undergoes air layering in mosses in nature. Photo by Willow, through Creative Commons.

Figure 24. ***Hypnum cupressiforme***, a moss that is negatively associated with air layering of *Calluna* in nature. Photo by Michael Lüth, with permission.

Figure 25. ***Hypnum jutlandicum***, a moss that is negatively associated with air layering of *Calluna* in nature. Photo by Janice Glime.

Figure 26. ***Cladonia fimbriata***, a moss that is negatively associated with air layering of *Calluna* in nature. Photo by Paul Cannon, through Creative Commons.

Figure 27. ***Leucobryum glaucum***, a moss that can contribute to air layering of *Calluna*. Photo by Janice Glime.

Despite these somewhat weak connections for ***Calluna*** (Figure 23), mosses, especially ***Sphagnum*** (Figure 1), are used almost exclusively for air layering as a means of propagation of plants. The moss is wrapped (Figure 28) around the area where roots (Figure 29) are to be encouraged, often held in place with cloth mesh, wire, or dark plastic (Figure 30). The moss provides a continuous supply of moisture and encourages the development of adventitious roots while discouraging fungi. Once the roots have formed, the stem can be cut below that point and the explant grown into a new individual (Figure 31). Pant (1989) reports similar use for grafting fruit trees.

Figure 28. Wrapping the tree with ***Sphagnum*** for air layering to make a bonsai. Photo from Bonsai Eejit, through Creative Commons.

Figure 29. Removal of part of the air layer, exposing roots and new branches of a bonsai. Photo from Bonsai Eejit, through Creative Commons.

Figure 30. Bonsai showing air layering with ***Sphagnum***. Photo from Bonsai Eejit, through Creative Commons.

Figure 31. Air layer of oak using moss to make bonsai. Photo from Bonsai Eejit, through Creative Commons.

In addition to its ability to promote root sprouts in orchid cuttings, ***Sphagnum*** (Figure 1) is suitable for air layering of a number of kinds of plants, including trees for bonsai (Tan 2003). The moisture and antimicrobial properties are beneficial in the development of new shoots and roots.

It appears that preparing a tree for bonsai often involves air layering with mosses (Morrow 2001; Hasegawa 2002; Relf 2009). In their book on bonsai, Yoshimura and Halford (1957) provide instructions for making a bonsai. Mosses, usually ***Sphagnum*** (Figure 1), are wrapped around the stem, including a location with young buds, and covered with a material like plastic to retain the moisture. If the plastic is transparent, you can see when the new roots and branches have formed. The lower part of the old stem is then cut off and the layering removed. The bonsai is ready for planting.

Figure 33. Potted *Fuchsias*, a genus whose growth is encouraged by potting with mosses in the mix. Photo by pxhere, through Creative Commons.

Pot Culture

Mosses can also encourage growth of potted plants. Pant (1989) reports that *Begonia* (Figure 32) and *Fuchsia* (Figure 33) bud and flower more profusely in pots where mosses are used to separate the humus-rich top soil from the bottom soil. Members of the Ericaceae, in particular, benefit from the acid of peat mosses. But in Japan, ***Hypnum plumaeforme*** (Figure 34), ***Leucobryum bowringii*** (Figure 35), ***L. neilgherrense***, and occasionally ***L. scabrum*** (Figure 36) fragments are used, mixed with sand or soil, to cultivate *Rhododendron* (Figure 37) shrubs (Ando 1957). Could it be that these mosses also acidify the soil?

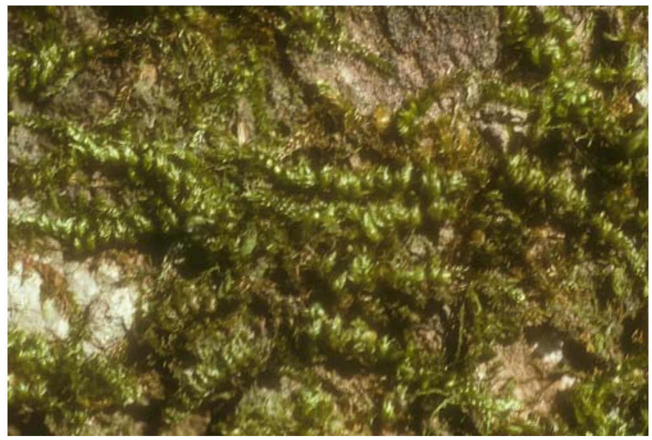

Figure 34. ***Hypnum plumaeforme***, a species used in Japan with sand or soil to cultivate *Rhododendron* shrubs. Photo by Janice Glime.

Figure 32. Potted begonias, a genus whose growth is encouraged by potting with mosses in the mix. Photo by Pixabay, through Creative Commons.

Figure 35. ***Leucobryum bowringii***, a species used in Japan with sand or soil to cultivate *Rhododendron* shrubs. Photo through Creative Commons.

Figure 36. ***Leucobryum scabrum***, a species used in Japan with sand or soil to cultivate *Rhododendron* shrubs. Photo Taiwan Encyclopedia of Life, through Creative Commons.

Figure 37. *Rhododendron*, a genus that benefits from having mosses in the potting mix. Photo by Pete Bobb, through Creative Commons.

The forestry industry likewise finds peat invaluable for culturing young seedlings (see also Reforestation below). Heiskanen and Rikala (2000) found ***Sphagnum*** (Figure 1) peat to be superior to fine sand or peat with perlite, the latter resulting in more weakened seedlings as a consequence of the lower water retention of the medium. However, peat is not always readily available. Israeli researchers found that composted cattle manure mixed with grape marc were good substitutes for peat in that country where peat must be imported; the substitutes were likewise effective at suppressing plant pathogens (Chen *et al*. 1992).

In other cases, the pots themselves (Figure 38) are made of mosses. These are good for starting seedlings and can be planted without removing the plants. Roots will eventually penetrate the pot and grow into the soil.

Figure 38. 3-Inch Jiffy pot of peat moss fibers from Second Sun Garden Supply. Photo from Second Sun Garden Supply, modified by Janice Glime.

Potting Medium

In parts of Asia, horticultural mosses include ***Vesicularia*** (Figure 39), ***Bazzania*** (Figure 40), ***Heteroscyphus*** (Figure 41), and ***Pallavicinia*** (Figure 42) (Tan 2003). Orchid growers in particular use ***Leucobryum*** (Figure 35-Figure 36, Figure 43) and ***Sphagnum*** (Figure 1, Figure 44), especially for their ability to store large amounts of water in their **hyaline cells** (Figure 43-Figure 44).

Figure 39. ***Vesicularia vesicularis*** var. ***vesicularis***. The genus ***Vesicularia*** is among the horticultural mosses in Japan. Photo by Michael Lüth, with permission.

Figure 40. ***Bazzania trilobata***, a leafy liverwort. The genus ***Bazzania*** is among the horticultural bryophytes used in Japan. Photo by Ondřej Zicha (Discover Life), through Creative Commons.

Figure 41. ***Heteroscyphus fissistipus***, a leafy liverwort. The genus ***Heteroscyphus*** is among the horticultural bryophytes used in Japan. Photo by David Francis, through Creative Commons.

Figure 42. ***Pallavicinia lyellii***, a thallose liverwort. The genus ***Pallavicinia*** is among the horticultural bryophytes used in Japan. Photo by Des Callaghan, with permission.

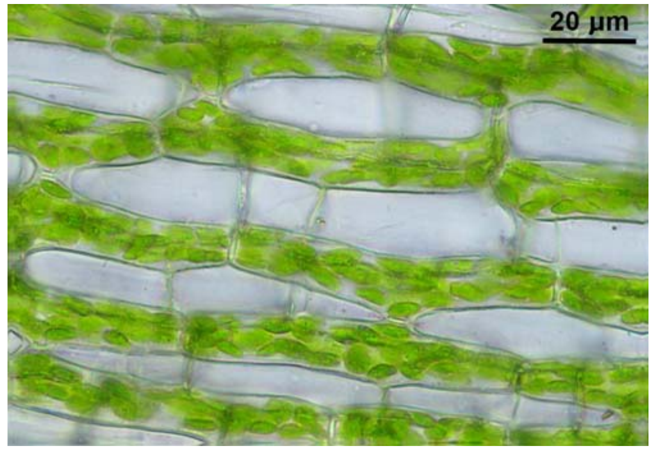

Figure 43. ***Leucobryum glaucum*** leaf cells showing alternating hyaline and photosynthetic cells. Photo by Ralf Wagner <www.drralf-waner.de>, with permission.

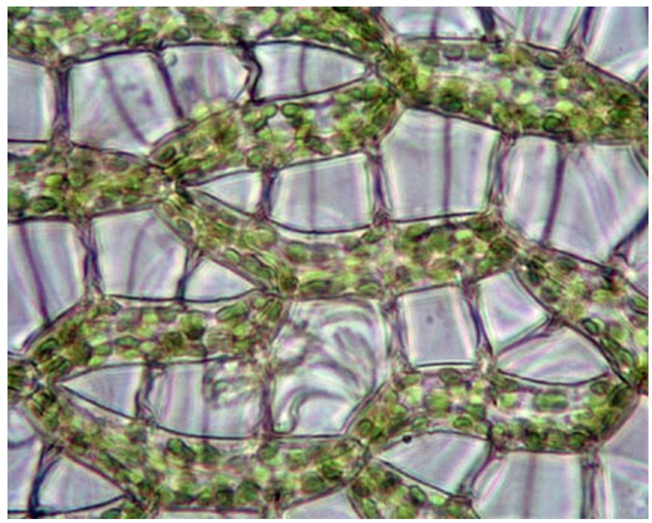

Figure 44. ***Sphagnum palustre*** photosynthetic (green) and hyaline cells. Note that the hyaline cells are not short cells, but are elongate cells with bars across them. Photo by Malcolm Storey through Creative Commons.

Sphagnum (Figure 1) and ***Leucobryum*** (Figure 35-Figure 36) seem to be particularly preferred as a potting medium for orchids (Tan 2003). Tan reported the use of ***Leucobryum*** as a substitute for peat moss to grow orchid cuttings in Asia. The mosses, especially ***Sphagnum***, were good as a potting medium for a variety of seeds.

But in North America, diversity of mosses as a potting medium seems to be absent. I searched with Google for "potting medium moss" and stopped after the 20th hit. All 20 of the mosses were named as peat moss or ***Sphagnum*** (Figure 1).

Dangers of Peat Culturing

There are drawbacks to using mosses in culturing of some plants. We have seen that ***Sphagnum*** (Figure 1) can be dangerous because of its cohabiting fungus that causes **sporotrichosis** (Chapter 1 of this volume). In containers of conifer seedlings, they can choke young seedlings, compete for nutrients, and repel water (Haglund *et al*. 1981). But they can also pose serious dangers. But causing fires? As Michael Richardson shared with Bryonet on 20 June 2013,

peat, including shrubs and other debris along with the mosses, is good potting material, but it can be flammable under the wrong circumstances. The oxygen available in the pot can permit decay to occur, causing heat that is amplified if the pot is in the sun. An article in the *Northumberland News* reported a house fire in June 2013 that was attributed to a pot with peat mosses on a second floor balcony. The deputy chief of the fire department said that the dry peat can easily ignite and can, after being in direct sunlight long enough, ignite by itself. This was not his first experience with flower beds on fire. His advice is to use non-combustible flower pots (not plastic), such as concrete or metal.

Covering Pot Soil

Sheet mosses are frequently used to cover the soil in pots housing flowering plants (Nelson & Carpenter 1965). This is especially true when they are sold by florists. Species of ***Leucobryum*** (not a sheet moss; Figure 35-Figure 36) can be used for this purpose, providing a pale green color contrast to the green of most tracheophyte leaves. In some cases, the strong anti-microbial properties of bryophytes might reduce invasions of bacteria and fungi.

Mat-forming mosses are typically sold as sheet mosses (Figure 45) (Peck *et al*. 2001). These are pleurocarpous mosses that grow horizontally, often on logs. Collectors strip the logs, and sometimes low branches, of their mats. In the eastern USA, one of the mosses used is ***Thuidium*** (Figure 46).

Figure 45. A package of sheet moss being sold in a gardening shop in Ohio, USA. Photo by Janice Glime.

Figure 46. ***Thuidium*** sheet moss, sold at a gardening shop in Ohio, USA. Photo by Janice Glime.

Culturing Mushrooms and Other Fungi

Sphagnum (Figure 1) peat is the substrate of choice as casing medium for cultivating the common grocery store mushroom, *Agaricus bisporus* (Figure 47) (Eicker & van Greuning 1989; Reddy & Patrick 1990; Jarial *et al*. 2005). (Casing is the process in which a non-nutritious layer, in this case peat, is applied over the colonized substrate so that the mycelium has access to more moisture, thereby increasing the size and number of growths.) Sungrow had a multi-million-dollar contract from Campbell (of Campbell soup fame) to improve mushroom culturing using a ***Sphagnum*** mix (Vitt, pers. comm.; Miller 1981). However, in places such as South Africa, where there is no peat, substitutes are necessary. The need for peat substitutes led Eicker and van Greuning (1989) to test other substrata and compare, but peat still gave the highest yields compared to eight other materials, with only weathered, spent compost offering similar results. Other types of mushrooms are grown in peat as well, such as *Pleurotus ostreatus* (Figure 48) (Manu-Tawiah & Martin 1986).

Figure 47. *Agaricus bisporus*, a species commonly grown in ***Sphagnum***. Photo by I. G. Safonov, through Creative Commons.

Figure 48. ***Pleurotus ostreatus*** on a mossy tree trunk. This species can be cultivated in peat. Photo from Charl de Mille-Isles.

In an attempt to make further improvements in mushroom success, Beyer (1997) sought ways to reduce the effect of accumulated substances on late mushroom crops. Surprisingly, he found that the addition of ***Hypnum*** (Figure 15-Figure 16, Figure 24-Figure 25) peat to the compost improved later break yield, but the addition of ***Sphagnum*** (Figure 1) did not. One of the concerns is that the peat becomes infested with nematodes (Figure 49) and may carry *Pseudomonas tolaasii* (see Figure 50), the cause of bacterial blotch, both of which cause serious diseases to the mushrooms (Nikandrow *et al*. 1982).

Figure 49. Soil nematode, a common pest in ***Sphagnum*** that may carry the bacterium ***Pseudomonas tolaasii***. Photo by Christina Menta, through Creative Commons.

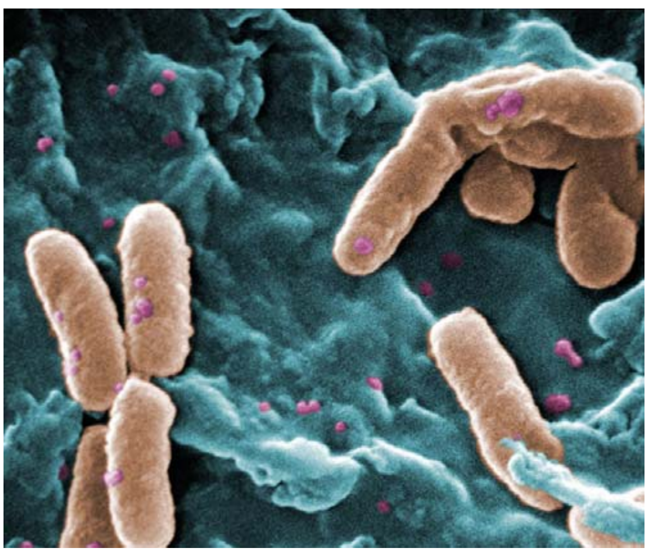

Figure 50. *Pseudomonas*, a bacterium carried by soil nematodes. Photo by Janice Carr, through public domain.

Martin and Bailey (1983) succeeded in using peat as a fermentation medium in which acclimated fungi could be grown. They were more successful with the common mushroom *Agaricus campestris* (Figure 51) than with the morel *Morchella esculenta* (Figure 52) (Martin 1982). Martin and Bailey considered that growth inhibitors might be present in peat. Using sulfuric acid hydrolysates with autoclaved peat released a liquid that, when supplemented with nutrients, would enhance growth and crude protein content of these two edible fungi. Nutrient-supplemented peat hydrolysates enhance growth and crude protein content of fungal biomass.

Figure 51. ***Agaricus campestris***, a species that grows well in a peat fermentation medium. Photo by Andreas Kunze, through Creative Commons.

Figure 52. *Morchella esculenta*, the common morel, can be cultured in a bed of peat. Photo by Janice Glime.

A mixture of ***Sphagnum*** (Figure 1) with fish offal promises to be a suitable substrate for culturing the acid-tolerant fungus *Scytalidium acidophilum* (see Figure 7), which is considered to be a promising source of microbial protein (Martin & Chintalapati 1990). However, not all fungal cultures seem to benefit from peat mixtures. In one commercial operation, the yield of mushrooms improved when the peat was omitted from the cultivation medium (Smith 1983).

Reforestation

The genus ***Tulasnella*** (Figure 21-Figure 22) is a mycorrhizal partner with several members of the thallose liverwort family **Aneuraceae** (Figure 21). If this fungus is likewise a partner with trees, then it should be possible to use those liverworts to help the trees to become established (Kreier 2003). In fact, ***Cryptothallus*** (Figure 21), a member of the **Aneuraceae**, shares its fungal partner with at least some members of the birch (*Betula*; Figure 53) and pine (*Pinus*; Figure 54) genera. Kreier found that both liverworts ***Riccardia palmata*** (Figure 55) and ***R. latifrons*** (Figure 56) grew on rotten wood and were well infected by

mycorrhizal fungi. Kreier also figured it would be relatively easy to disperse these liverworts on the forest floor, and that they would spread easily, preparing the soil with mycorrhizae that could partner with the trees. At that time, the fungi had been grown in culture but not the field. However, the discovery of rhizoidal bridges in tropical ***Aneura*** (**Aneuraceae;** Figure 57) provided a hopeful twist. In 2017, Oberwinkler *et al*. noted that ***Tulasnella*** species are worldwide in distribution and that they may occur in many forest ecosystems in association with wood. And we have already noted that they form mycorrhizal associations with orchids.

Figure 53. *Betula pendula*. Some members of the genus *Betula* share their fungal partner with the thallose liverwort ***Cryptothallus***. Photo by Percita, through Creative Commons.

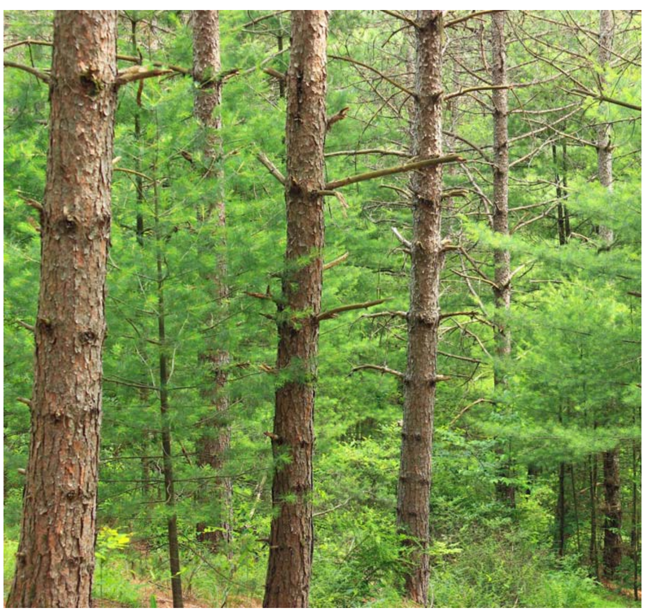

Figure 54. *Pinus strobus*. Some members of the genus *Pinus* share their fungal partner with the thallose liverwort ***Cryptothallus***. Photo through Creative Commons.

Figure 55. ***Riccardia palmata***, a species that grows on rotten wood and is infected by mycorrhizal fungi. Photo by Bernd Haynold, through Creative Commons.

Figure 56. ***Riccardia latifrons***, a species that grows on rotten wood and is infected by mycorrhizal fungi. Photo by Bernd Haynold, through Creative Commons.

Figure 57. ***Aneura pinguis***, a species that might be associated with ***Tulasnella*** on wood. Photo by Li Zhang, with permission.

Container Gardens

Mosses are commonly used in container gardens with **bonsai** (dwarfed ornamental tree; Figure 58) and **bonkei** (tray landscape; Figure 59), where they help to stabilize the soil and retain moisture for the shallow roots.

Figure 58. Bonsai at Dawes Arboretum, Ohio, USA, showing dwarfed tree and mosses at base. Photo by Janice Glime.

Figure 59. Outdoor bonkei in a Japanese private garden. *Selaginella*, a relative of club mosses and not a true moss, is used to represent a tree, with mosses growing on the rocks that form the basin for a small "lake." Photo by Janice Glime.

Designers select the species of mosses to serve particular functions in the container landscapes. Large, upright mosses such as ***Atrichum*** (Figure 60), ***Climacium*** (Figure 61), ***Dicranum*** (Figure 4), ***Polytrichum*** (Figure 62), and ***Rhodobryum*** (Figure 63) simulate forests. ***Bryum argenteum*** (Figure 64) has a silvery, compact look that can simulate grasslands, and ***Leucobryum*** (Figure 27) usually has the role of a mountain. For snow-capped mountains, ***Racomitrium canescens*** (Figure 65) provides a frosted look. ***Physcomitrium*** (Figure 66-Figure 67), often a volunteer in greenhouse flower pots, is so miniature as to appear like a moss, or maybe a grass, in a landscape of ***Leucobryum*** mountains. ***Barbula unguiculata*** (Figure 68), ***Funaria hygrometrica*** (Figure 69), and ***Weissia controversa*** (Figure 70) can contribute to needs of intermediate size. In Mexico, some mosses are even used for fake bonsai: ***Campylopus*** (Figure 71), ***Dendropogonella rufescens***, ***Hypnum*** (Figure 15-Figure 16, Figure 24-Figure 25, Figure 34), and ***Thuidium*** (Figure 18) (C. Delgadillo, pers. comm.). In the Pacific Northwest of North America, ***Leptobryum pyriforme*** (Figure 72), known as Kyoto moss, is sold for bonsai trays (J. Christy, pers. comm.). I would expect ***Climacium*** and ***Polytrichum*** to serve well as trees in miniature landscapes as well.

Figure 60. ***Atrichum angustatum***, in a genus used to simulate forests in tray gardens. Photo by Keith Bowman, with permission.

Figure 61. ***Climacium dendroides***, simulating trees in a dish garden. Photo by Keith Bowman, with permission.

Figure 62. ***Polytrichum juniperinum***, in a genus used to simulate forests in tray gardens. Photo by Janice Glime.

Figure 65. ***Racomitrium canescens***, a moss that is used to simulate snow on mountains. Photo by Michael Lüth, with permission.

Figure 63. ***Rhodobryum roseum***, in a genus used to simulate forests in tray gardens. Photo by Michael Lüth, with permission.

Figure 66. ***Physcomitrium pyriforme*** in a dish garden. Photo by Michael Lüth, with permission.

Figure 64. ***Bryum argenteum***, a species used to simulate grasslands or mountains in tray gardens. Photo by Tushar Wankhede, with permission.

Figure 67. ***Physcomitrium pyriforme*** with capsules, a common volunteer in flower pots. Photo by Janice Glime.

Figure 68. ***Barbula unguiculata***, a moss of intermediate size to fill in as grass or other intermediate needs. Photo by Michael Lüth, with permission.

Figure 69. ***Funaria hygrometrica***, a moss of intermediate size to fill in as grass or other intermediate needs. Photo by Michael Lüth, with permission.

Figure 70. ***Weissia controversa***, a moss of intermediate size to fill in as grass or other intermediate needs. Photo by Michael Lüth, with permission.

Figure 71. ***Campylopus introflexus***; the genus ***Campylopus*** is used in Mexico for fake bonsai. Photo by Michael Lüth, with permission.

Figure 72. ***Leptobryum pyriforme***, a species that is used in the Pacific Northwest, USA, in bonsai trays. Photo by Michael Lüth, with permission.

Bonkei

Miniature tray landscapes [bonkei or **saikei** (art of creating tray landscapes that combine miniature living trees with soil, rocks, water, and related vegetation); Figure 73-Figure 76] in Japan use mosses to provide appropriate texture and color with little danger of damage due to drying (Kawamoto 1980; Oishi 1981). Such trays can delight the bed-ridden. Gerritson (1928) arranged sixteen species of mosses in various stages of maturity to provide a changing landscape for a hospitalized friend: "Each day the mosses had changed appearance; so each day added a new joy. The nurses came from time to time to see and admire. Other patients shared its freshness and beauty. Visitors, too were invited to see the charm of a 'platter of mosses.'"

Figure 73. Bonkei with its miniature landscape containing mosses to simulate mountains. Photo courtesy of Hironori Deguchi.

Figure 74. Bonkei with mosses simulating trees with a rocky crag. Photo courtesy of Hironori Deguchi.

Figure 75. Bonkei simulating a volcano and surrounding mountains and forests. Photo courtesy of Hironori Deguchi.

Figure 76. *Selaginella* (a club moss relative) and moss bonsai, Kyushu, Japan. Photo by Janice Glime.

For making these miniature landscapes, Schenk (1997) recommends the usual potting mix of humus, including peat moss, ground-up tree bark, or rotted sawdust. He cautions that sand, vermiculite, or perlite can be used, but that they must be kept moist because they tend to have larger spaces and dry quickly near the surface, leaving the moss with no source of moisture.

Even in this seemingly harmless occupation, one must use caution against allergens. Tray gardens and other forms of bonsai and dish gardens may use ***Sphagnum*** (Figure 1) peat as a medium or even as the plants of interest (Figure 77). This moss is well known for its ability to harbor the fungus that causes sporotrichosis (Dong *et al*. 1995).

Figure 77. ***Sphagnum*** moss pot in Japan, a potential source of allergens. Photo courtesy of Hironori Deguchi.

Dish Gardens

Dish gardens (Figure 78) are a scaled down version of bonkei. The size may not be scaled down, but they typically do not represent a landscape and may have only one bryophyte species (Figure 78), sometimes as ground cover for flowering plants like spring bulbs (Figure 79).

Figure 78. Dish garden of moss. Photo courtesy of J. Paul Moore.

Figure 79. Dish garden for spring bulbs in cafe in Helsingborg, Sweden. Photo courtesy of Irene Bisang.

Figure 80. A cross between a bonsai arrangement and a dish garden. Photo courtesy of Lars Hedenas and Irene Bisang.

Annie Martin, a prize-winning gardener and landscaper (Figure 81), runs classes for both adults and children in which she teaches them how to make dish gardens and terraria (Figure 82-Figure 83).

Figure 81. The award-winning creator (Annie Martin) of dish gardens, terrariums, and moss gardens is shown here framed by her own artistic bryophyte creation. Photo courtesy of Annie Martin.

Figure 82. Children creating their first dish garden, under the tutelage of Annie Martin, MountainMoss. Photo courtesy of Annie Martin.

Figure 83. The proud owner of a new dish garden that she created. Photo courtesy of Annie Martin.

Similar to the dish gardens, moss rocks (Figure 84-Figure 85) have become popular in some places. These typically have a species of moss growing in a depression or on the surface of a rock.

Figure 84. ***Dicranodontium denudatum*** stone pots in shop in Hakone, Japan. These are a variation on the dish garden, but the mosses are grown on the surface or in a depression of a natural rock and typically have only one moss species. Photo courtesy of Hironori Deguchi.

Figure 85. Moss-Rocks-logo at Moss and Stone Gardens, Pennsylvania, USA, showing a more formal American version. Photo with permission from David Smith.

Bonsai

The term **bonsai** (Figure 86) refers to a dwarfed ornamental tree or shrub grown in a pot and prevented from reaching its normal size. Inoue (1972) pointed out that moss bonsai and moss bonkei (tray landscapes) are popular in Japan by both amateurs and professional horticulturists. But even bonsai trees are potted in wide pots and the soil is typically covered with mosses (Figure 86-Figure 89).

Figure 86. Bonsai at Dawes Arboretum, Ohio, USA, showing the dwarfed tree and mosses at its base. Photo by Janice Glime.

Figure 87. This bonsai arrangement incorporates features of bonkei with rocks and mosses giving it the look of a miniature forest. Photo by Janice Glime.

Figure 88. Bonsai at Dawes Arboretum, Ohio, USA. This bonsai uses a deciduous tree, and bryophytes can warn its owner to water it before the leaves begin to drop or become crispy. Photo by Janice Glime.

Figure 89. Bonsai using the fern ***Osmunda lancea***. Courtesy of Hironori Deguchi.

The mosses can contribute to the success of the bonsai. When the mosses appear dry, you can be sure your bonsai needs water (Figure 90-Figure 91). However, mosses are not always the friends of the bonsai. The continuous moisture of the mosses can inhibit root growth and promote sudden fungal attacks. The experts advise removing the mosses each autumn to reduce fungal damage (Bland 1971).

Figure 90. Bonsai in Dawes Arboretum, Ohio, USA. Mosses on the roots are a good indicator when the soil is becoming dry and the tree needs water. Photo by Janice Glime.

Figure 91. Bonsai on wood, increasing the need for bryophytes to maintain root moisture and warn when it is time to water it. Photo courtesy of Annie Martin, MountainMoss.

In India, bonsai is included in horticultural texts. Dhanda (1984) suggests that the bonsai may be finished off with a layer of moss on top (Figure 92). Yoshimura and Halford (1957) likewise consider the mosses growing around the bonsai to be important. The mosses provide several advantages. They add aesthetic appeal, creating a more natural looking landscape. And they make watering easier, permitting a raised base on the tree while catching the water and protecting the furniture.

Figure 92. Bonsai at Dawes Arboretum, Ohio, USA, illustrating mosses covering the pot and signalling when the tree roots need more water. Photo by Janice Glime.

In Malaysia, bonsai makers typically use the acrocarpous mosses ***Bryum*** (Figure 93) and ***Philonotis*** (Figure 94), and sometimes the pleurocarpous mosses ***Isopterygium/Pseudotaxiphyllum*** (Figure 95) and ***Vesicularia*** (Figure 39) and the thallose liverwort ***Riccia*** (Figure 96) (Tan 2003). In Singapore, the moss ***Ochrobryum kurzianum*** is imported from Thailand for ornamental use in bonsai arrangements. In Japan, ***Leucobryum*** (Figure 27) is common in bonsai landscape design.

Figure 93. ***Bryum capillare*** with capsules, in a genus used in bonsai in Malaysia. Photo by Michael Lüth with permission.

Figure 94. ***Philonotis fontana***, in a genus used in bonsai in Malaysia. Photo by Michael Lüth, with permission.

Figure 95. ***Pseudotaxiphyllum elegans***, in a genus used in bonsai in Malaysia. Photo by J. C. Schou, with permission.

Figure 96. ***Riccia sorocarpa***, in a genus used in bonsai in Malaysia. Photo by <www.aphotofauna.com>, with permission.

Hanging Baskets

Mosses are often used in the construction of hanging baskets for flowers (Smith 1996). In California, USA, meter-long "strips" 8-10 cm wide are used to make hundreds of baskets per week!

In Asia, species of ***Sphagnum*** (Figure 1) are used to line hanging baskets (Tan 2003). Its ability to hold water and its antimicrobial activity make this a good substrate for the roots of flowering plants.

A wire frame is used to give the basket support, with mosses wound among the wires or laid within to provide the structure. Not only do they make an attractive, natural-looking basket, but they reduce the need for frequent watering (Lohr & Pearson-Mims 2001). Species of ***Hypnum*** (Figure 15-Figure 16, Figure 24-Figure 25, Figure 34) and ***Sphagnum*** (Figure 1) are commonly used for this purpose.

The long, stiff stems of ***Polytrichum*** (Figure 62) permitted the early Romans to weave it into baskets (Bland 1971), but these most likely did not have a horticultural purpose.

Terraria

The **terrarium**, a drier plant version of the aquarium, is often arranged like an enclosed garden (Figure 97), a miniature garden like the container gardens. Because of its small size, bryophytes are often used to give the look of mountains (Figure 98); dry brooks made of pebbles ramble between clumps of various hues of green. But bryophytes are not easy to grow in such conditions. If the container is fully open (Figure 98, Figure 99), mosses soon dry out and become crispy. If it is sealed (Figure 97, Figure 100-Figure 103), as many terraria are, fungi can easily grow. The best choice is to leave the top partially open to permit air circulation.

Figure 97. Closed terrarium from MountainMoss, showing miniature garden. Photo courtesy of Annie Martin.

Figure 98. Open terrarium from MountainMoss. Note the mound of ***Leucobryum*** which is sometimes used to simulate mountains. Photo courtesy of Annie Martin.

Figure 99. Open terrarium with moss. Photo courtesy of J. Paul Moore, with permission.

Figure 100. In some covered terraria, small holes with plugs, similar to the green ones seen here, can be opened and even kept open to maintain at least some air movement and reduce condensation. Photo courtesy of Annie Martin of MountainMoss.

Figure 101. Tiered terrarium from MountainMoss. Photo courtesy of Annie Martin.

Figure 102. Terrarium with lid. Note the tiny figure that turns the tall mosses into "trees." Photo by Erin, through Creative Commons.

Figure 103. Tall moss terrarium that not only permits taller plants like ferns, but also provides more air space, reducing fungal takeover. Photo by Ken Gergle, through David Spain.

It seems appropriate to cite the first terrarium, known as the **Wardian case** (Figure 104), invented by Nathaniel Bagshaw Ward (1791-1868) (Hershey 1996). He had fallen in love with plants on a trip to Jamaica and despite ultimately pursuing a profession as a physician, he pursued plants through his attempts at gardening. But, sadly, his attempts at a moss and fern garden failed, due severe air pollution in the outskirts of London. It was this failure that led him to invent the Wardian case, or terrarium. He had placed a "chrysalis" (actually a moth pupa) in a bottle and observed it daily. Then, to his surprise, a "seedling" fern and a grass appeared. He considered the conditions and noted the need for "a moist atmosphere free from soot or other extraneous particles; light; heat; moisture; periods of rest; and change of air." He moved the bottle to the outside of a northern window and there the plants thrived for four years with no additional attention!

Figure 104. Wardian Case, similar to the first terrarium by Nathaniel Bagshaw Ward. Image through public domain.

Choice of mosses depends in part on how moist you intend to keep it and in part on the effect you want to achieve. ***Polytrichum*** (Figure 62) can survive in a somewhat dry terrarium but will easily be covered with mold when it is too damp. Likewise, ***Leucobryum*** (Figure 27) likes it airy with good circulation. ***Ceratodon purpureus*** (Figure 105) is sometimes successful, again requiring at least some air circulation. Schenk (1997) states, "I must tell the whole truth by identifying the great enemy of terrarium gardening with native woodlanders, for there is one: mold." He admonishes that most terraria have a short life due to this problem. My own experience certainly agrees.

Figure 105. ***Ceratodon purpureus***, a species used in bonsai in Malaysia. Photo by Michael Lüth, with permission.

Funaria hygrometrica (Figure 69) can be encouraged in more moist conditions, but it still needs circulation. With a little luck it will even produce capsules. We successfully maintained ***F. hygrometrica*** in an uncovered aquarium in our university greenhouse. These lasted for several years, but we avoided getting tap water on them and only used misting from distilled water or tap water that had been allowed to sit to allow the chlorine to escape.

Schenk (1997) suggests that a container the size of an aquarium (Figure 106) is best, smaller ones being more subject to mold. Air space is of the essence, and it needs to circulate. He considers a potting mix to be suitable, whereas it does not tend to work well in open-air gardens. On the other hand, if the bryophytes have their own deep brown portions (Figure 107), no substrate is necessary. Charcoal may be added to the substrate to absorb excessive acidity and gases produced by decay. Little water is needed as it will recycle (Figure 108) within the nearly sealed container. Adding flowering plants can add color (Figure 109). Mosses that are collected wet generally do not need additional water and may even need to be dried by leaving the terrarium open wide for a day or two. Slightly dry mosses can be moistened with 30-35 ml (2-3 tablespoons) of water; totally dry ones may require up to 70 ml (1/4 cup) (Schenk 1997).

Figure 106. Kitchen terrarium in an aquarium. Photo by Janice Glime.

Figure 107. ***Campylopus flexuosus*** with brown base, needing no substrate. Photo by Michael Lüth, with permission.

Figure 108. Condensation on wall of kitchen terrarium, endangering a mold outbreak. Photo by Janice Glime.

Figure 109. Mix of a variety of plants with color (red-leafed *Begonias*, pale *Tillandsias*) and rocks in kitchen terrarium built in an aquarium. Photo by Janice Glime.

Maintenance for the first few days after planting is essential to avoid an immediate mold attack. Schenk (1997) advises that if a heavy dew (Figure 108, Figure 110) appears on the walls of the container, open it and dry the walls. This should be repeated daily until morning brings only a light condensation on the upper half of the walls of the container. When you discover, probably in a few weeks, that there is no longer any morning dew, it is time to add water, but not much.

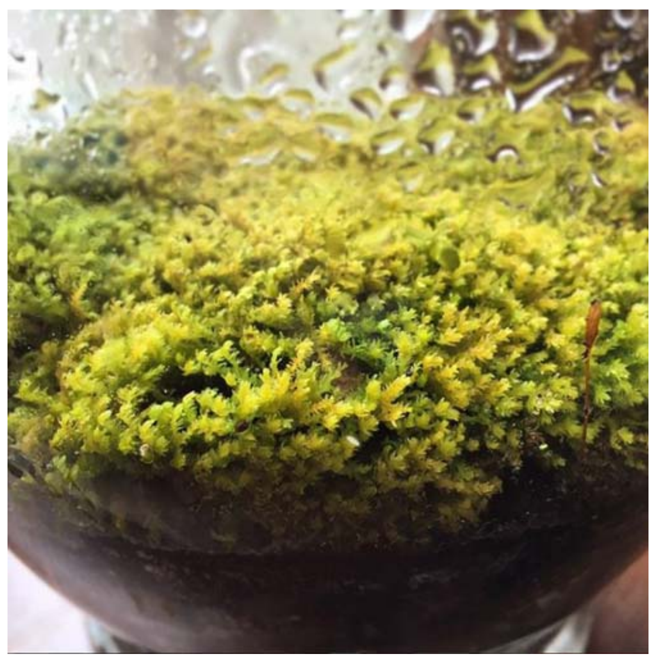

Figure 110. Terrarium with moss, showing severe condensation that must be removed by drying the walls or keeping the container open until it is gone. Photo by J. Paul Moore, with permission.

After all this care, Schenk (1997) warns that the terrarium will most likely last only three weeks! (I have had better success than that with larger aquaria.) That can be extended by providing fluorescent lights to avoid the etiolated growth so noticeable in low light. Nevertheless, a mold garden is most likely to ensue within this short time,

and great care and luck are needed to find the right wetting and drying cycle.

Within those first few weeks, a moss garden terrarium can be full of surprises, with mushrooms appearing, capsules extending, and the somewhat rapid but unnatural elongation of the moss stems in low light.

One of the contributors to the demise of the moss terrarium indoors is the warm temperatures night and day indoors. If there is a cool location for the terrarium, it might survive a longer display, and surely in the refrigerator it would last, but would be of little use, not to mention suffering from lack of light.

One last caution I would insert is that lichens are to be avoided if one wishes to maintain a moss terrarium for any length of time. In the moist conditions of confinement, they will soon spread their fungi broadly and overtake the moss, albeit no longer as lichens, but nevertheless encroaching rapidly upon the surfaces of green. If lichens are to be enjoyed in this terrarium, it must by all means be kept open and the mosses provided with water occasionally as needed, perhaps with dry periods, but not too frequently.

I was relieved to read this moss gardener's treatment of the terrarium. If such an expert as Schenk was able to maintain such a terrarium garden for only three weeks, I felt elated that I, too, had succeeded on occasion to maintain one for so long! In short, if you wish to maintain a terrarium of bryophytes for a lengthy period of time, my best advice to you is Good Luck!

Echoing the comments above, David Wagner (Bryonet 23 June 2013) suggested that the problem with terraria is that they are usually closed containers. He has observed mosses doing well for several years in an open water table where water flowed across the water table. This depends on water that is low in dissolved minerals and may require a filtering system on tap water. One danger in closed terraria, especially small ones, is that the enclosed humidity and lack of air movement encourages the growth of fungi and soon they take over.

Alison Downing (Bryonet 23 June 2013) reported success in growing bryophytes for display by using fish tanks for the mesic species. She attributed the success to using water from a garden pond, citing high levels of chlorine in tap water as a possible source of bryophyte collapse. Nevertheless, these bryophytes in the aquaria also have a limited life.

Ben Tan (Bryonet 23 June 2013) found that bryophytes transplanted to a closed terrarium usually survived from 6-18 months. Even on moss walls, the bryophytes needed complete replacement every two years to maintain aesthetic appeal. This is with no fertilizer, watered with tap water, in a fully air-conditioned room. Even ***Bryum*** (Figure 93) and ***Hyophila*** (Figure 111) last only about one year in a self-contained environment indoors with proper light and high humidity.

Alison Dibble (Bryonet June 2013) reports better success. She grows bryophytes on the windowsill all winter in small bonsai dishes. Others are in clear plastic boxes or a clear glass container with a loose-fitting lid. If the container is open, Dibble soaks the mosses in the sink once a week. In the summer she puts them outside under the overhang of a north-facing boulder and lets nature do the watering, but if there is a dry spell she waters them. Using this method, she has kept one bottle of mosses, including ***Sphagnum*** (Figure 1), for more than three years. And even in a terrarium there is competition. Her ***Saelania glaucescens*** (Figure 112) had been growing well for five years, but ***Mnium*** (Figure 113) began to overtake it.

Figure 111, ***Hyophila involuta***, in a genus that lasts about one year in a terrarium. Photo by Michael Lüth, with permission.

Figure 112. ***Saelania glaucescens***, a moss that has survived a terrarium for five years, but that is being overtaken by ***Mnium***. Photo by Janice Glime.

Figure 113. ***Mnium marginatum*** overgrowing other mosses, a problem it can cause in a terrarium. Photo by Jan-Peter Frahm, with permission.

Appropriate moisture levels are clearly a problem. Yoest (2011) suggests that if mosses and flowering plants or other tracheophytes are to co-exist, one must periodically remove the covering to water the tracheophytes. Keep the cover off for a day or two to allow excess water to escape. When you return the lid, check for condensation and vent the container until you achieve the right balance. In a dish garden or terrarium, proper drainage is needed, so putting pebbles on the bottom can help. Contrary to what most people might expect, the humidity level must be kept low. This condition can often be achieved by using a cover with a small opening at the top.

As an alternative, David Spain (in Yoest 2011) suggests removing the cover in the daytime and covering it at night. He has created a terrarium with a tall cover over a dish, using this routine. The terrarium has the fern ebony spleenwort (*Asplenium platyneuron*; Figure 114) and the mosses ***Dicranum scoparium*** (Figure 4), ***Leucobryum glaucum*** (Figure 27), ***Hypnum imponens*** (Figure 15-Figure 16), and ***Campylopus introflexus*** (Figure 71). (Be careful with the latter – it is an invasive species, so don't just throw it outside when you no longer want it.) Another of Spain's favorites is the moss ***Climacium americanum*** (Figure 115). Spain concludes that "mosses do not make ideal terrarium plants."

Figure 114. ***Asplenium platyneuron***, a fern that survives in a terrarium that is opened daily and closed at night. Photo by F. B. Matos, through Creative Commons.

Figure 115. ***Climacium americanum*** with capsules in moss garden, a species that looks good in a terrarium. Photo by Janice Glime.

I have a large (40-gallon) terrarium with begonias, ferns, *Tillandsia*, and a few mosses (Figure 106). Like Spain and Yoest, when I water it, I leave the cover partially open for a few days until the excess water evaporates. Then I cover it and it will last about six months before it needs to be watered again. I have limited success with the mosses because they seem to produce weak stems and to become infected with fungi. Extra aeration helps to avoid fungi, but then more frequent watering is needed, at least for the tracheophytes.

Bryophytes as Pests

Sadly, bryophytes can even be considered to be pests in gardens and flower pots (*e.g.* Newby *et al.* 2007). Greenhouse managers are often dismayed at having the invasion of ***Marchantia polymorpha*** (Figure 116) in many of their flower pots. But it is their method of watering that distributes this liverwort everywhere. The heavy force of water from a hose propels the gemmae out of their cups and onto bare soil nearby. These liverworts often arrive in the greenhouse initially as free-loading passengers in flower pots of new flowers or ferns, either as plants or as gemmae. And the greenhouse satisfies their growing needs.

Figure 116. ***Marchantia polymorpha*** with gemmae cups. Gemmae are splashed about in greenhouses when plants are watered. Photo by David T. Holyoak, with permission.

Another species known throughout most of North America only in greenhouses is the thallose liverwort ***Lunularia cruciata*** (Figure 117). Like species of ***Marchantia*** (Figure 116), it produces gemma in cups, in this case crescent-shaped cups, and these likewise are easily dispersed by typical greenhouse watering methods.

Figure 117. ***Lunularia cruciata*** with gemmae cups and gemmae that are distributed with rain or watering in a greenhouse. Photo by Des Callaghan, with permission.

Other volunteers that I have observed include ***Bryum*** spp. (Figure 64, Figure 93), ***Leptobryum pyriforme*** (Figure 72), and ***Ceratodon purpureus*** (Figure 105). These are all mosses, with the latter two frequently producing numerous capsules and thus most likely spreading by spores. ***Bryum argenteum*** (Figure 64) has detachable terminal buds that will grow new plants. It is likely that it benefits in the same way as the gemmae of the two liverwort species.

A final caution is appropriate. Some bryophytes are invasive, although much less so than their flowering plant counterparts. Nevertheless, they can disrupt ecosystems, changing the success of seed germination, affecting the invertebrates that live there, and changing the hydrology. In addition to the ones that like to travel among flower pots, the most invasive and widespread of these are ***Campylopus introflexus*** (Figure 71), ***Eurhynchium praelongum*** (Figure 118), ***Lunularia cruciata*** (Figure 117), ***Orthodontium lineare*** (Figure 119), ***Pseudoscleropodium purum*** (Figure 120), and ***Lophocolea semiteres*** (Figure 121) (Essl *et al*. 2013; Mateo *et al*. 2015). Some of these have spread due to their use as packing material, especially for shipping plants in the horticultural industry.

Figure 118. ***Eurhynchium praelongum***, a widespread moss species that often travels in flower pots. Photo by Janice Glime.

Figure 119. ***Orthodontium lineare***, a widespread moss species that often travels in flower pots. Photo by Michael Lüth, with permission.

Figure 120. ***Pseudoscleropodium purum***, a widespread moss species that often travels in flower pots and also is used for packing. Photo by Phil Bendle, with permission.

Figure 121. ***Lophocolea semiteres***, a widespread leafy liverwort species that often travels in flower pots. Photo by David Long, with permission.

Summary

Peat mosses have been widely used in horticulture as soil additives, and for bedding, as well as forming the foundation for topiary, wreaths, and hanging baskets. Their ability to add moisture makes them ideal as a shipping medium for plants.

Peat mosses are used as soil conditioners, providing a holding medium for nutrients, releasing them slowly following drying. They provide good compost, especially when mixed with such waste products as fish offal or sewage. Some peat mosses provide additional fixed nitrogen through their **Cyanobacteria** flora. Their antibiotic properties discourage damping-off fungal growth while maintaining moisture. These same properties make them good for air layering. All of these properties make peat mosses good culture media and potting mixes, but other relatively dense mosses work well also.

Peat mosses have been used in forestry to culture young seedlings and in the food industry to culture mushrooms and morels.

Small mosses work well in container gardens such as bonsai and bonkei, where various species are used to simulate different aspects of miniature landscapes. Terraria are more difficult, with mold being a frequent problem. Aeration is important, as is the choice of mosses.

Some species are pests in greenhouses, sometimes being dispersed as gemmae. The watering techniques make gemmae and other detachable parts airborne.

Acknowledgments

Thank you to Michael Richardson for sending the story on fire in a flower pot to Bryonet.

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CHAPTER 7-2
GARDENING: JAPANESE MOSS GARDENS

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CHAPTER 7-2 GARDENING: JAPANESE MOSS GARDENS

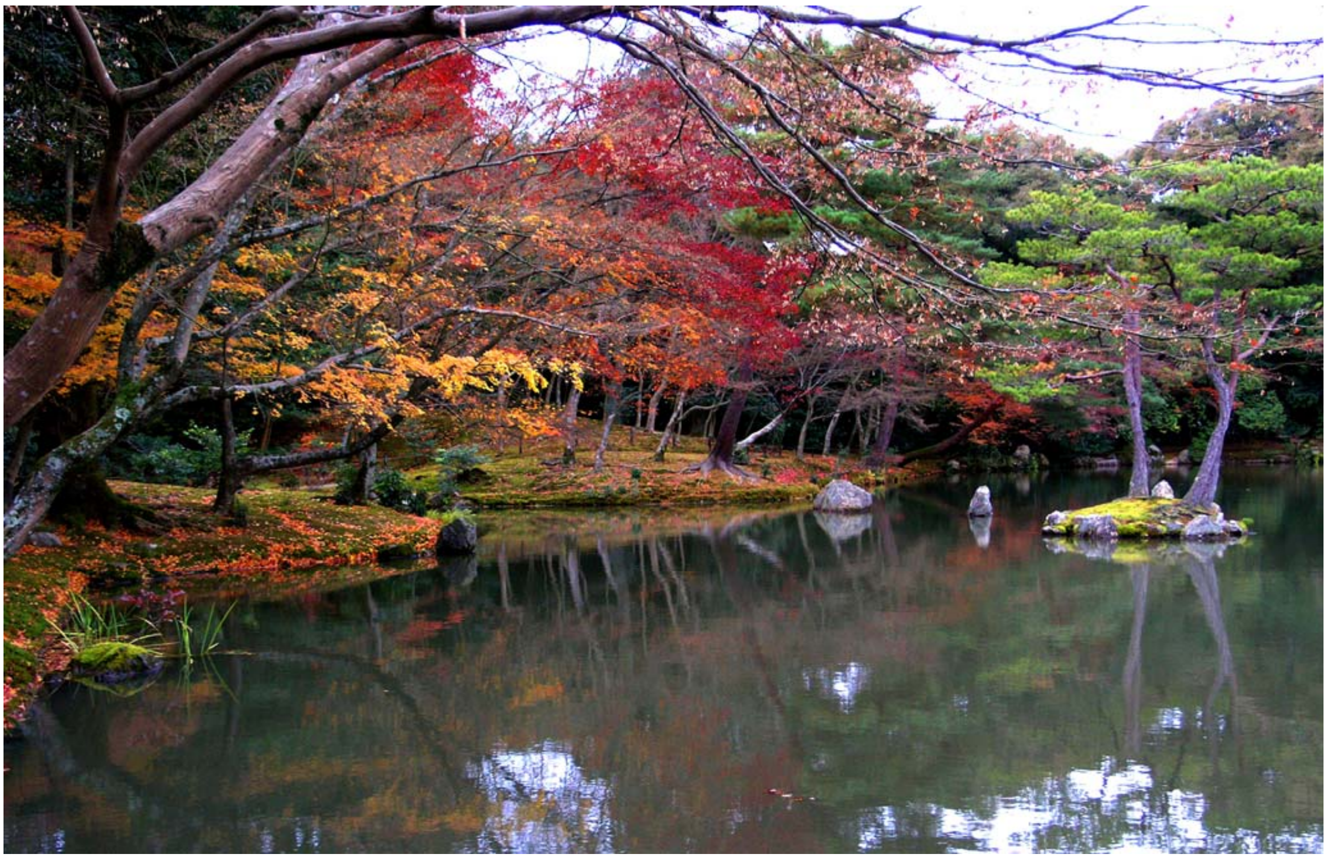

Figure 1. Kyoto Gold Temple moss garden in fall. Photo courtesy of Leng Yang.

Moss Gardens

It is the end of a hectic week and your mind is racing between projects nagging to be finished before another set entreats you. The afternoon hour is late and Friday traffic winds about you in the fury to be somewhere else. Children shout and horns warn of impending danger, or just impatience. You turn the corner and park in the only remaining spot next to the shrouded garden. The Japanese have taught us how to construct a fence that deflects the city's clamor, creating a refuge from the turmoil that bombards our daily lives. But within that fence, in the midst of the city, is a garden – a moss garden. Barely 50 meters on a side, the garden is a far away and peaceful world. Here all seems to melt away as the soft mountains in the distance, created by gentle hills of moss, blend into the quiet fields of green before us. At last we can relax. In such a setting, we can reflect on all that is beautiful and calm.

For the caretaker of this garden, be it large or small, it certainly requires an understanding of mosses in all their ecological and physiological glory. Although the Japanese have been successful for centuries, moss gardening is no small challenge.

Japanese Moss Gardens

Perhaps originating in their present usage during Japan's feudal era (12th-19th centuries), mosses have become a part of Japanese tradition (Schenk 1997). In Japanese, ***koke*** means moss and ***dera*** means temple, hence the name of the moss temple *kokedera* (Figure 1). However, as far back as a thousand years ago the Zen Buddhist monks wrote of the mosses in their temple gardens. Yet the rest of the world is just beginning to understand and copy the tranquility of the moss garden.

Bryophytes have always been greatly appreciated as a precious attribute in Japanese gardens (Figure 1). Some of the Japanese gardens are known from as early as the 7th

century A.D. (Seike *et al*. 1980). The earliest of these were based on the T'ang China gardens, but they soon developed their own character, resembling the Japanese landscape. The theme generally reflects the Japanese religion of Shinto, wherein the world is viewed as "infused with the primeval forces of creation" (Seike *et al*. 1980).

By the fifteenth and sixteenth centuries, the scale of the gardens was smaller, opening the way for miniature plants such as bryophytes to provide the feeling of expanse. Natural features such as ponds and waterfalls were represented by stone and gravel (Figure 2). Unlike gardens throughout most of the world, the Japanese garden is ruled by simplicity. Following this theme of tranquility, the garden must not appear manicured, but rather must maintain a natural look, as in Figure 3. For this reason, as the gardens became the setting for the tea ceremony, they also continued this tradition of a natural look. To avoid the austerity of too much care, the Tea Masters considered the most appropriate caretakers to be old men (Figure 4) and boys who would not be too painstaking in their care to sweep and clean the garden. Having leaves tucked among the rocks or at the bases of trees provides interest (A. L. Sadler in Seike *et al*. 1980).

Figure 2. This moss is interrupted by a sand garden at Ginkakuji, Kyoto, Japan. This sand resembles a river and the rock an island. Photo by Janice Glime.

Figure 3. Ginkakuji Silver Temple Moss Garden with ***Polytrichum*** in Kyoto, Japan. Stones give the sense of boulders, giving the feeling of mountain crags, adding focus and depth. Photo by Janice Glime.

Public gardens often have a gate at the entrance. Even these offer serenity and often have bryophytes growing on the roof of the gate (Figure 5). The gate gives one the impression of shutting out the world of work, noise, and traffic.

Figure 4. Ginkakuji moss gardener using a broom to clean leaves from the moss garden. Photo by Janice Glime.

Figure 5. Kyoto gold temple with mosses growing on the entrance gate. Photo courtesy of Leng Yang.

Courtyard gardens (Figure 6-Figure 7) are small and provide a relaxing view from a window or doorway. Generally only a few plants provide highlights to an arrangement of gravel and rocks. Mosses may be used here to make a green layer on the ground, or may be islands in a bed of gravel (Figure 8) that simulates the sea or a pond (Seike *et al*. 1980). In even larger courtyards and many moss gardens, the pond may be real, with koi swimming about (Figure 9).

Figure 6. Courtyard with moss garden outside window of Kanazawa Historical Pharmacist (merchant) residence in Japan. Photo courtesy of Elin LeClaire.

Figure 7. Courtyard garden at Tofukuji Reiunin, Japan. Photo from Wikimedia Commons.

Figure 8. Zuihō-in garden, the Garden of the Blissful Mountain, in Kyoto, Japan. Rocks and raked sand in wave formation simulate the ocean, with mosses to simulate islands. Photo from Wikimedia Commons.

Figure 9. Shrine and pond with koi in Kyoto, Japan. Photo by Janice Glime.

Sand is used in many of the gardens. It is always well kept, often raked with the ridges of raking forming various designs (Figure 10-Figure 12). Some of these simulate a lake with islands and mountains (Figure 10). In other cases, the mosses surround a gravel bed shaped to resemble a lake (Figure 11). The mosses are not arranged in rectangular plots so common to western gardens, but rather typically follow a circular theme. Species of ***Polytrichum*** (Figure 12) are often used for these islands to break up the bright appearance of the sand (Saito 1980).

Figure 10. Tofukuji Garden bordered with mosses. The raked sand and moss islands give the illusion of a lake with mountains. Photo from Wikimedia Commons.

Figure 11. Rosan-ji garden, Kyoto, Japan, showing gravel with islands of mosses. Photo from Wikimedia Commons.

Figure 12. Toufuku-ji hojyo, a sand garden surrounded with ***Polytrichum***. Photo from Wikimedia Commons.

A path of stones may meander (Figure 13) through the gravel or across the moss bed and is often not straight or even direct. Even the straight paths give a sense of meander by mixing large and small stones (Figure 14) or making sure 4 corners never meet (Seike *et al*. 1980). Small stone or wooden bridges (Figure 15) may cross the gravel bed in somewhat larger courtyards, and generally a stone or iron lamp such as the one seen in Figure 16-Figure 17 provides the soft light of a candle or merely a point of interest. Other common objects in the moss and temple gardens are a small pagoda, often made of stone (Figure

18) or a basin for washing one's hands (Figure 19-Figure 20). A small garden, such as most courtyard gardens, will typically have a single plant or one of the above objects as its point of focus.

Figure 13. Stone path in moss garden. Photo by Szabolcs Arany, through Creative Commons.

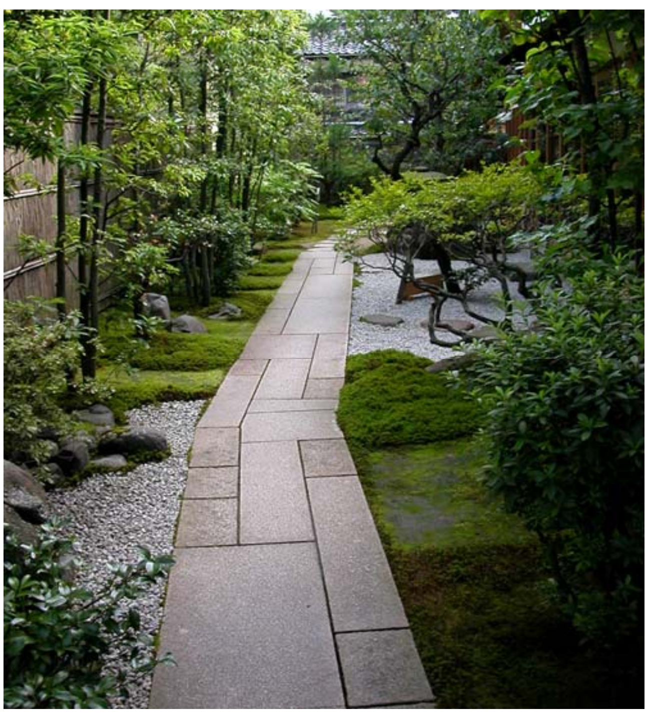

Figure 14. Kanazawa, Japan – Nagamachi samurai district, house garden walk, demonstrating a straight path with multiple sizes of stones, giving a sense of meandering. Photo courtesy of Elin LeClaire.

Figure 15. A rock bridge retains a natural look in this moss garden and pond at Ginkakuji, Kyoto, Japan. Photo by Janice Glime.

Figure 16. Shrine and pond with stone lamp (foreground), Kyoto, Japan. Photo by Janice Glime.

Figure 17. Nagoya Private Moss Garden with stone lantern as a point of focus. Photo by Janice Glime.

Figure 18. Kanazawa Kenroku-en Garden in Japan showing stone pagoda. Photo by Elin LeClaire.

Figure 19. Kanazawa, Japan – Nagamachi samurai district, house garden with small basin for washing hands. Photo courtesy of Elin LeClaire.

Figure 20. Kenroku-en garden stone water basin in a moss garden in Japan. Note the natural appearance of the basin. It is likely that the leaf was added as a touch of nature and to add a spot of color. Photo from Wikimedia Commons.

Among the larger gardens, one may see, instead of mosses mimicking the mountains, that shrubs mimic the mosses (Figure 21). In these gardens, the shrubs are cut into rounded forms that look like moss-covered rocks, cascading down a hillside, and sometimes with a small stream or waterfall in their midst. Waterfalls are common in the larger gardens, but occasionally even in very small ones (Figure 22-Figure 24).

Figure 21. Saihouji-kokedera. In this moss garden, the shrubs are cut to look like moss cushions. Photo from Wikimedia Commons.

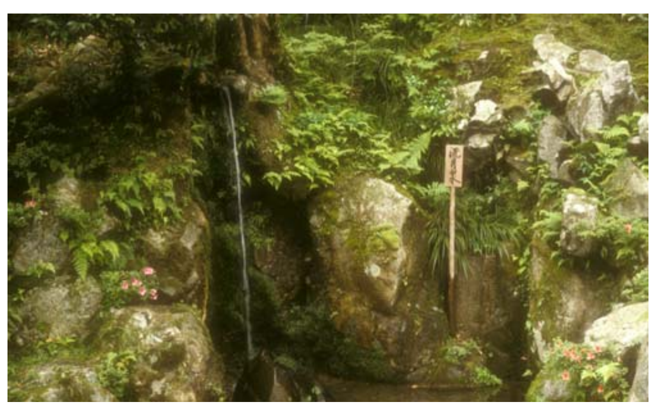

Figure 22. This small waterfall in Ginkakuji moss garden in Japan retains the natural look using rocks and ferns with the mosses. Photo by Janice Glime.

Figure 23. Nanzen-in – Nanzenji, Kyoto, Japan, showing a natural waterfall in a mossy part of this garden. Photo from Wikimedia Commons.

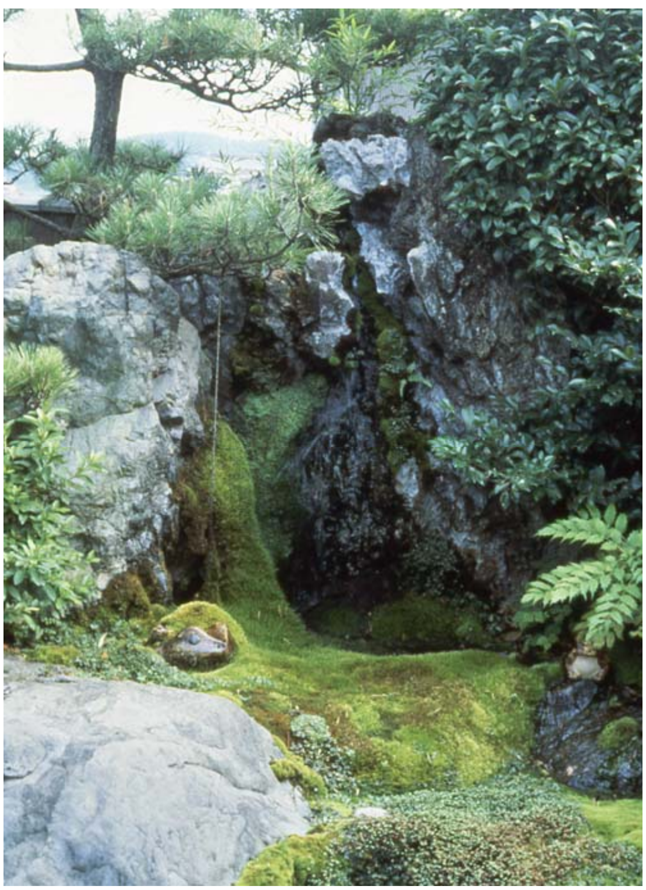

Figure 24. Even this tiny restaurant garden in Nagoya, Japan has a waterfall. This is a restful view outside your window while you eat. Photo by Janice Glime.

Many attractive moss gardens are seen in Kyoto, the ancient capital city of Japan, where the surrounding mountains ensure constant humidity, and prolonged summer rainy seasons favor growth and survival of the mosses. Perhaps the most popular Kokedera, or Moss Temple, is the Koinzan Saihoji Temple (Figure 21) located at the foot of Mt. Koinzan in the west of Kyoto City. There are 92 different species there, each with its own required environmental conditions (Figure 25).

Figure 25. Hill and pond garden in Koinzan Saihoji Temple garden in Kyoto, Japan, with ***Polytrichum*** in the foreground and several other bryophyte species. Photo by Janice Glime.

Types of Japanese Moss Gardens

Generally there are three types of Japanese moss gardens: the flat garden (Figure 26) "for contemplation and meditation," the Tea Ceremony garden (Figure 27-Figure 28) that must convey the feeling of simplicity and seclusion, and both the oldest and most widely appreciated – the hill and pond garden (Figure 29-Figure 31). A roofed courtyard or indoor garden may provide a tea table and cushions for a tea ceremony. The hill and pond gardens resemble the natural landscapes of Japan in simplified form (Avery 1966). They may have bridges, often not straight (Figure 32), forcing the visitor to walk slowly and enjoy the garden. The use of rocks to portray mountains or add a focus point (Figure 33), ponds as oceans or lakes (Figure 25), and bryophytes as the foliage are the essence of traditional Japanese gardens where flowers, *per se*, are of lesser importance; a green garden, unlike ephemeral flowers, symbolizes long life and offers a place for relaxation and contemplation. In sharp contrast to the myriad of colors and shapes in a traditional American or European garden, the moss garden allures with its subtle shades of green, accented here and there with a rock or group of rocks (Figure 34), a bamboo fountain (Figure 35), a lamp (Figure 36), or an occasional small flowering shrub (Figure 37).

Figure 26. Ryoanji Temple garden in Kyoto, Japan, representing the flat garden. Photo by Janice Glime.

Figure 29. Kanazawa Kenroku-en Garden in Japan, an example of a hill and pond garden. Note the lamp that adds a point of focus. Photo courtesy of Elin LeClaire.

Figure 27. Japanese Tea Garden in San Francisco, CA, USA. Photo by Redhairedflip, through Creative Commons.

Figure 30. Kyoto Nijo Castle, Shogun's palace garden, illustrating the hill and pond garden with mosses and stones. Photo by Elin LeClaire.

Figure 28. The same Japanese Tea Garden, San Francisco, CA, USA, as in Figure 27, but with the azaleas in full bloom. Photo by Caroline Culler, through Creative Commons.

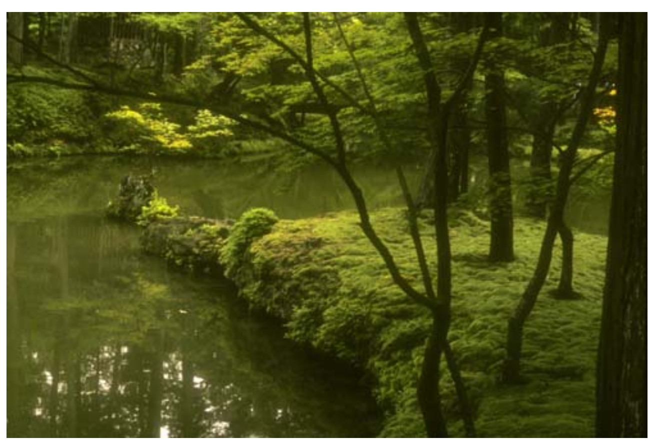

Figure 31. Kokedera Pond in Kyoto, Japan, an example of a hill and pond garden. Photo by Janice Glime.

Figure 32. Kanazawa Kenroku-en Garden in Japan, showing a meandering bridge that forces the visitor to slow down. Photo courtesy of Elin LeClaire.

Figure 33. Boulders add interest to this moss garden at the Saihoji Kokedera in Kyoto, Japan. Photo by Janice Glime.

Figure 34. Kyoto Nijo Castle garden with rocks, Shogun's residence. Photo by Elin LeClaire.

Figure 35. Bamboo fountain in moss garden, a point of interest and focus. Photo by Jeff Kramer, through Creative Commons.

Figure 36. Kanazawa - Nagamachi samurai district, house garden with lamp. Stone lamps are common in Japanese gardens. Photo by courtesy of Elin LeClaire.

Figure 37. Kokedera moss garden in Kyoto, Japan, with ***Leucobryum*** and two flowering shrubs as highlights and points of focus. Photo by Janice Glime.

Imagine yourself sitting alone in a Japanese spa perched near the top of a mountainside overlooking a green valley untouched by habitation. On every side of the valley are mountains and boulders – as far as you can see. All is peaceful and you are able to relax your eyes and your body. Thousands of Japanese seek just such retreats every year to take them away from the stresses of daily life. Among the most ancient uses of mosses that has persisted into modern life is the design of moss gardens to create that same feeling of distance, lack of commercial clutter, and tranquility of spirit. By using rocks and tiny plants such as mosses, the Japanese create in miniature those scenes that they crave in nature. Even in the space of a few feet in a dooryard or window garden in a city, they often create such an illusion of distant mountains, dry stream beds, and green forests (Figure 38). The Japanese Zen scholars have philosophical ideas about landscapes, and about simplicity and repose, which they try to express in their traditional gardens (Fletcher 1991). While the space in the gardens is usually small, they may try to create an atmosphere of being deep within the mountains and provide a feeling of tranquility. Japanese gardening is not a mere imitation of nature; perhaps "borrowed scenery" is a more appropriate description (Avery 1966) for the attempt to alleviate the drabness of city life. Contemporary Zen scholars contend that many such gardens represent the best in abstract art (Avery 1966).

Figure 38. This tiny moss garden with a waterfall can be seen through a guest window in a restaurant in Nagoya, Japan. ***Platyhypnidium riparioides*** is in the water and ***Philonotis falcata*** is at the edge. Photo by Janice Glime.

Even bowls (Figure 39) and other objects in the gardens are likely to be covered in mosses, softening the lines and giving a quiet, cool appearance.

Figure 39. This moss-bearing basin is in a city park in Nagoya, Japan. Photo by Janice Glime.

Dangers to Gardens

These ancient gardens suffer new dangers in our modern society. Kyoto is the city of moss gardens (Figure 40-Figure 56), especially temple gardens. But even restaurants and private residences share in the serenity with their own small gardens. Aside from the effects of trampling from the ever-increasing population of visitors, the fumes of cars and busses have taken their toll. The pollution from these visitor vehicles has forced the closing of Saihoji in Kyoto to the casual visitor, requiring reservations in advance and forcing visitors to park at the bottom of the hill and walk up to avoid further damage from air pollution.

Figure 40. This moss garden in Kyoto, Japan, has a single species to emphasize its tranquility. Photo by Janice Glime.

Figure 41. This pond in the moss garden at the Saihoji Kokedera (moss temple) in Kyoto, Japan, gives a natural look and one of distance. Photo by Janice Glime.

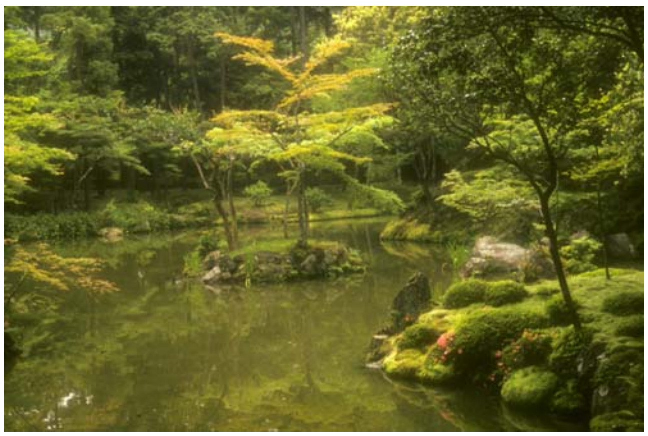

Figure 42. This pond with a small island and surrounded with mosses at the Saihoji Kokedera in Kyoto, Japan, gives the illusion of a lake. Photo by Janice Glime.

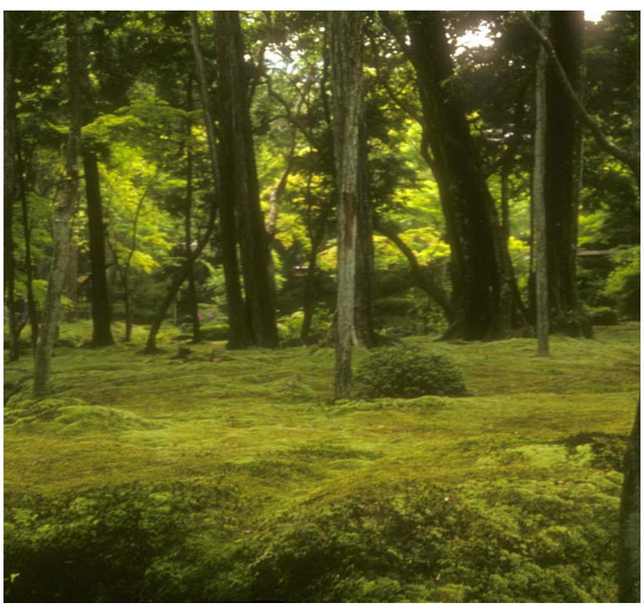

Figure 43. Several mosses provide subtle color differences in this moss garden at Saihoji Kokedera in Kyoto, Japan. Photo by Janice Glime.

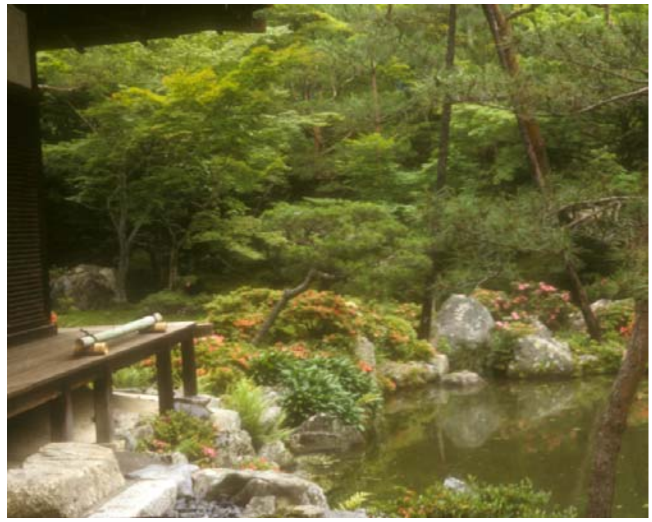

Figure 44. This Ginkakuji Temple (Silver Temple) overlooks moss gardens in Kyoto, Japan. Photo by Janice Glime.

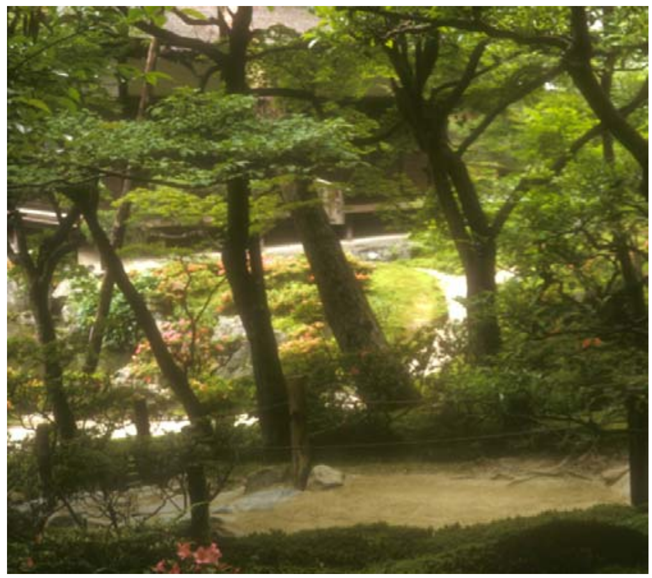

Figure 45. A small river provides a natural setting in this moss garden at Ginkakuji in Kyoto, Japan. Photo by Janice Glime.

Figure 46. Here sand forms a volcano (mid right) and mosses miniaturize the landscape at the Ginkakuji shrine in Kyoto, Japan. Photo by Janice Glime.

Figure 47. This path through the moss garden at Ginkakuji Temple in Kyoto, Japan, retains a natural appearance. Photo by Janice Glime.

Figure 48. This moss garden at Ginkakuji Temple in Kyoto, Japan, has depth provided by the pond. Photo by Janice Glime.

Figure 49. Sand is used for dry stream beds and unused paths in moss gardens such as this one at Ginkakuji Temple in Kyoto, Japan. Photo by Janice Glime.

Figure 50. This moss garden at Ginkakuji (Silver Temple) garden in Kyoto, Japan, maintains a natural look. Photo by Janice Glime.

Educational Gardens

One unusual feature at the Ginkakuji (Silver Temple) garden in Kyoto is that it attempts to teach the public about the mosses. In Japan, each species has a Japanese name, and like birds and flowering plants, mosses are known by these names. However, the bryologists know both the scientific names and Japanese names of the mosses. The displays of mosses provide an explanation of their utility to the gardens, showing the most important species (Figure 51, Figure 52). The "interrupter" mosses are "undesirable" mosses that must be weeded out (Figure 53). Among these are non-weedy things, but nevertheless undesirable ones, often for aesthetic reasons. To our surprise, this included ***Andreaea*** (Figure 54) because of its nearly black (and undesirable) color. Heinjo During, with the help of his students, attempted to interpret the Japanese names into their proper Latin ones, giving us a list of important temple garden species (Figure 55).

Figure 51. This educational display is labelled VIP mosses. Each is labelled with its Japanese name. These VIP mosses are among the most important ones in the moss garden at the Ginkakuji Temple in Kyoto. Photo courtesy of Onno Muller.

Figure 52. These mosses, also on educational display at the Ginkakuji Temple, are normal inhabitants of the Ginkakuji garden. Photo courtesy of Onno Muller.

Figure 53. This educational display is labelled "the Interrupter Mosses." These are weedy mosses that must be pulled from the gardens to permit the others to survive. Apparently they "interrupt" the tranquility. Photo courtesy of Onno Muller.

Figure 54. ***Andreaea rupestris rupestris***. ***Andreaea rupestris*** var. ***fauriei*** is among the mosses considered undesirable in the Ginkakuji (Silver Temple) garden in Kyoto because of its black color. Photo by Des Callaghan, with permission.

【銀閣寺の大切な苔】	**Very Important Mosses**
オオスギゴケ、	*Polytrichum formosum*
コスギゴケ、	*Pogonatum inflexum*
スギゴケ、	*Polytrichum juniperinum*
ウマスギゴケ、	*Polytrichum commune*
ミヤマスギゴケ	*Polytrichastrum alpinum*
ホウライスギゴケ	*Pogonatum cirratum*
ビロードゴケ	??
アラハシラガゴケ	*Leucobryum bowringii*
チャボスギゴケ、	*Pogonatum otaruense*
イトラッキョウゴケ、	*Anoectangium thomsonii*
ヤマゴケ、	*Oreas martiana*
カモジゴケ、	*Dicranum scoparium*
イワダレゴケ、	*Hylocomium splendens*
コキンシゴケ、	??
ネジクチゴケ、	*Barbula unguiculata*
ホソバシラガゴケ、	??
ヒノキゴケ、	*Rhizogonium dozyanum*
ヒロハヒノキゴケ、	*Pyrrhobryum spiniforme* var. *budakense*
イノウエネジクチゴケ、	??
コツクシサワゴケ、	*Philonotis thwaitesii*
アラハシラガゴケ、	*Leucobryum bowringii*
オオホウオウゴケ、	??
ハマキゴケ、	??
キャラハラッコゴケ。	*Taxiphyllum taxirameum*?
【ちょっと邪魔な苔】	**The inhabitants of Ginkaku-ji**
ヒロハツヤゴケ、	*Entodon challengeri*
タチハイゴケ、	*Pleurozium schreberi*
ハイゴケ、	*Hypnum plumaeforme*
タニゴケ、	??
コツボゴケ、	*Plagiomnium acutum*
コバノチョウチンゴケ、	*Trachycystis microphylla*
ハネヒツジゴケ、	*Brachythecium plumosum*
オオサナダゴケ、	*Plagiothecium neckeroideum*
サナダゴケ、	??
ススキゴケ、	*Dicranella heteromalla*
エダツヤゴケ、	*Entodon flavescens*
ミズシダゴケ。	??
【とても邪魔な苔】	**Moss the Interrupter**
ゼニゴケ、	*Marchantia polymorpha*
ヒメジャゴケ、	*Conocephalum japonicum*
ジャゴケ、	*Conocephalum conicum*
ホソバミズゼニゴケ、	*Pellia endiviifolia*
アズマゼニゴケ、	*Wiesnerella denudata*
ミズゼニゴケ、	*Pellia epiphylla*
コバノエゾシノブゴケ、	*Thuidium recognitum* var. *delicatulum*
アオシノブゴケ、	*Thuidium pristocalyx*
トヤマシノブゴケ、	*Thuidium kanedae*
タカネカモジゴケ、	*Dicranum viride* var. *hakkodense*
クロゴケ、	*Andreaea rupestris* var. *fauriei*
センニチゴケ。??	

Figure 55. Japanese moss names and Latin names for those in the educational collection in Kyoto. From Heinjo During.

Figure 56. This moss is growing on the tile of a temple garden roof in Kyoto, Japan. Photo by Janice Glime.

Variations

We must not forget that the Japanese are also creative. While they appreciate the calm of a garden, they do not restrict themselves to the purity of the three garden types mentioned above. The following images illustrate some of that diversity (Figure 57-Figure 63).

Figure 57. Tōfuku-ji, Kyoto, Japan. This formal pattern looks like a mix of western and Japanese design. Photo from Wikimedia Commons.

Figure 58. Here the meandering path takes on a different form in the Rhododendron garden with mosses playing a minor role. Photo by Monty Monsees, through Creative Commons.

Figure 59. Ankokuji garden in Hiroshima, Japan, giving a natural appearance but with rocks providing the major feature. Photo from Wikimedia Commons.

Figure 60. Kanazawa Kenroku-en Garden showing the famous koto-fret stone lantern. The bamboo fence is also a common feature in Japanese gardens. Photo courtesy of Elin LeClaire.

Figure 61. Courtyard garden of a former geisha house in Kanazawa, Ishikawa, Japan – straw protects trees from snow. But even that protection is artistic, natural, and restful. Photo from Wikimedia Commons.

Figure 62. Ginkakuji Moss Garden pool in Kyoto, Japan, with coins, a practice that may have originated in western countries. Photo by Janice Glime.

Figure 63. The mosses in this Japanese garden near Columbus, Ohio, USA, do not quite reach the restful landscape achieved in most of the Japanese gardens. This may be partly due to the lack of a rainy season and the land-bound location. Photo by Janice Glime.

Charcoal Gardens

Nancy Church provided me with images of the charcoal gardens (Figure 64-Figure 66) in which moss gardeners used charcoal, providing highlights. The small black pieces with lines are charcoal, a feature that Nancy considered to be beautiful and amazing.

Figure 64. Japanese charcoal and moss garden. Photo by Amy Laudenslager through Nancy Church.

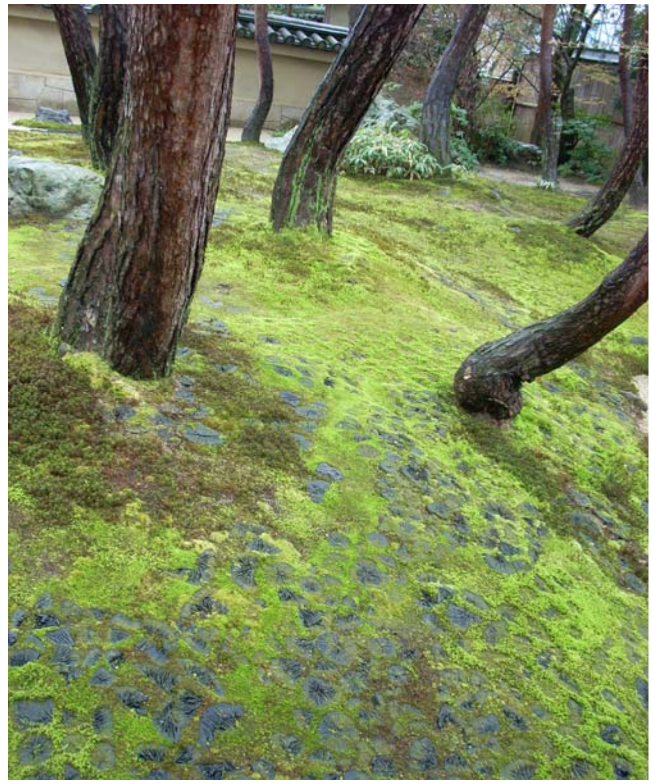

Figure 65. Japanese charcoal and moss garden. Photo by Amy Laudenslager, through Nancy Church.

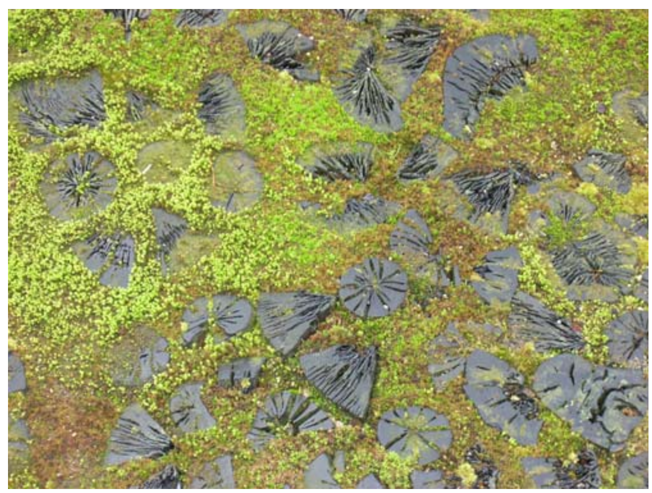

Figure 66. Japanese charcoal and moss gardens. Photo by Amy Laudenslager, through Nancy Church.

Dominant Species

Although many species are used, a few dominate the gardens, especially the private gardens. One of the most common is ***Polytrichum*** (Figure 67-Figure 71). This is most likely because it does well in the conditions of the garden and is easier to transplant than most (personal experience). ***Leucobryum*** (Figure 72-Figure 74) is used frequently, despite its narrower requirements (it seems to be a problem to cultivate in the USA according to my friends and my own experience). Perhaps the Japanese species are easier to grow than ours. But its endearing quality is its beautiful, pale cushions. It creates a restful landscape.

Figure 67. Ginkakuji Moss Garden, Kyoto, with a carpet of ***Polytrichum***. Photo by Janice Glime.

Figure 68. Kanazawa Kenroku-en Garden in Japan with lawn of ***Polytrichum***. Photo courtesy of Elin LeClaire.

Figure 69. Kanazawa Kenroku-en Garden with **Polytrichaceae**. Photo courtesy of Elin LeClaire.

Figure 70. Kanazawa Kenroku-en Garden in Japan, with a ***Polytrichum*** lawn and stone lantern. Photo courtesy of Elin LeClaire.

Figure 71. ***Polytrichum commune*** in a small garden at the entrance to the Japanese Cake Shop in Hiroshima, Japan. Photo courtesy of Hironori Deguchi.

Figure 72. ***Leucobryum*** spills down a slope in a moss garden at the Saihoji Kokedera (moss temple) in Kyoto, Japan. Photo by Janice Glime.

Figure 73. ***Leucobryum juniperoideum*** at moss temple in Kyoto, Japan. Photo courtesy of Zen Iwatsuki.

Figure 74. ***Leucobryum*** in a temple garden in Japan. Photo by Janice Glime.

At a plantation preparing for the sale of bryophytes for gardens, the thallose liverwort ***Riccia*** (Figure 75) was cultured. It has the advantage of being able to withstand dry conditions for long periods, then wake up during the rainy season. But I must admit to finding none of it in the gardens I saw. It does not give the restful look of the two mosses mentioned above.

Figure 75. Nagoya bryophyte plantation with ***Riccia***, a thallose liverwort that is able to dry up and then rejuvenate during the rainy season. Photo by Janice Glime.

Summary

Moss gardens are known for their serenity, emphasizing simple shades of green with only occasional color from shrubs or other flowers. Mosses are used to miniaturize the landscape, giving the feeling of distance. They have been a part of Japanese tradition since the feudal era.

There are three basic types of Japanese moss gardens: flat gardens, Tea Ceremony gardens, and pool and mountain gardens. In addition, sand gardens are often combined with moss gardens, often simulating lakes or streams. A number of variants exist, including the charcoal garden.

Even private homes, restaurants, and other shopkeepers maintain small moss gardens, especially where they can be viewed from within the building. The greatest number of moss gardens is in the city of Kyoto. The primary mosses used are species of ***Polytrichum*** and ***Leucobryum***, but some gardens have nearly 100 species.

Acknowledgments

Heinjo During kindly sent me the pictures and gained the permission for me to use the educational pictures taken by his student, Onno Muller, illustrating the educational displays at the gardens at Ginkakuji, Kyoto, Japan. He and his students translated the Japanese names into the Latin names.

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CHAPTER 7-3
GARDENING: PRIVATE MOSS GARDENS

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CHAPTER 7-3
GARDENING: PRIVATE MOSS GARDENS

Figure 1. This is a large private moss garden in Nagoya, Japan, using boulders to add interest. Photo by Janice Glime.

Private Gardens

Private gardens are gaining popularity in the USA (Dunn 2008; Martin 2008; Cullina 2009). You know moss gardens are coming of age when an article appears in the *New York Times* (see Tortorella 2014). Garden journals give advice on establishment and care of moss gardens. But what works in one part of the world may not work in another, and that is true within countries as well. Watering instructions and species choice must be in tune with local climate, light, available bryophytes, and competing species.

In Japan, even tiny spaces a meter wide by three meters long are used for a garden. It may be a vegetable garden, but often it is a moss garden with a few tracheophyte highlights (Figure 1). Such private gardens give their owners a sense of space and tranquility (Figure 2). Mosses are particularly enjoyed because they miniaturize the landscape and give a feeling of looking into the distance (Figure 3-Figure 9). Cushions of ***Leucobryum*** (Figure 10) can resemble distant mountains. ***Polytrichum*** (Figure 11) can simulate a forest. ***Hypnum imponens*** (Figure 12), a common "sheet moss" sold for decorative purposes, is used to "fill nooks and crannies" (Cullina 2008). Small mosses in the foreground provide the open fields. Pebbles become boulders.

Figure 2. This peaceful scene is a private moss garden in Kyoto, Japan. Photo by Janice Glime.

Figure 3. This lamp adds interest in a private moss garden at a home near Nagoya, Japan. Photo by Janice Glime.

Figure 4. These rocks form a path through ***Polytrichum*** in a private moss garden in Nagoya, Japan. Picture by Janice Glime.

Figure 5. Fukushima-san sweeping his private moss garden in Nagoya, Japan. Photo by Janice Glime.

Figure 6. This path leads through ***Polytrichum*** in a private garden in Nagoya, Japan. Photo by Janice Glime.

Figure 7. ***Entodon*** and ***Polytrichum*** grow in a private moss garden in Nagoya, Japan. Typically, the ***Polytrichum*** will outgrow the pleurocarpous mosses such as ***Entodon***. Photo by Janice Glime.

Figure 8. This portion of a private moss garden in Nagoya, Japan, has texture created by different species of mosses. Photo by Janice Glime.

Figure 9. This private moss garden in Nagoya, Japan, has a dry "stream" and bridge. Photo by Janice Glime.

Figure 10. ***Leucobryum glaucum*** growing naturally around a tree at Coopers Rock, West Virginia, USA. Species of ***Leucobryum*** are used to simulate mountains in moss gardens. Photo by Janice Glime.

Figure 11. ***Polytrichum piliferum*** showing white leaf tips. Species of ***Polytrichum*** are used to simulate mountains in moss gardens. Photo by David Holyoak, with permission.

Figure 12. ***Hypnum imponens***, a common species in private gardens, available as sheet moss. Photo by Janice Glime.

Smith *et al.* (2010) summarized the role of residential gardens in preserving biodiversity in urban areas. But bryophytes are typically neglected in such studies. In their studies of 61 domestic gardens in Sheffield, UK, they found 67 bryophyte taxa and 77 lichen taxa. The individual gardens supported growth of 3 to 24 bryophyte species each, with a mean richness of 11.3 species. Of these, 14 species occurred in lawns. About one quarter of the species occurred in only one garden. Only 10% of the species occurred in more than half the gardens. The richness of species correlated with garden area (correlated with substrate richness) and altitude. Species present in 20 or more of the 61 gardens were ***Amblystegium serpens*** (Figure 13; 31 spp), ***Barbula convoluta*** (Figure 14; 30 spp), ***Barbula unguiculata*** (Figure 63; 22), ***Brachythecium rutabulum*** (Figure 15; 55 spp), ***Bryum argenteum*** (Figure 16; 21 spp), ***Ceratodon purpureus*** (Figure 45-Figure 46; 42 spp), ***Didymodon insulanus*** (Figure 17; 27 spp), ***Funaria hygrometrica*** (Figure 18; 23 spp), ***Kindbergia praelonga*** (Figure 19; 56 spp), ***Ptychostomum capillare*** (Figure 20; 37 spp), ***Rhynchostegium confertum*** (Figure 21; 32 spp), ***Rhytidiadelphus squarrosus*** (Figure 22; 23 spp), and ***Tortula muralis*** (Figure 23; 35 spp).

Figure 13. ***Amblystegium serpens***, a species that occurred in more than 50% of the gardens studied in Sheffield, UK. Photo by Michael Lüth, with permission.

Figure 14. ***Barbula convoluta***, a species that occurred in more than 30% of the gardens studied in Sheffield, UK. Photo by Ivanov, with permission.

Figure 15. ***Brachythecium rutabulum*** capsule, a species that occurred in more than 50% of the gardens studied in Sheffield, UK. Photo by Wesley, with permission from BBS webmaster.

Figure 16. ***Bryum argenteum***, a species that occurred in more than 30% of the gardens studied in Sheffield, UK. Photo by Michael Lüth, with permission.

Figure 17. ***Didymodon insulanus***, a species that occurred in more than 30% of the gardens studied in Sheffield, UK. Photo by David T. Holyoak, with permission.

Figure 18. ***Funaria hygrometrica***, a species that occurred in more than 30% of the gardens studied in Sheffield, UK. Photo by Michael Lüth, with permission.

Figure 19. ***Kindbergia praelonga***, a species that occurred in more than 50% of the gardens studied in Sheffield, UK. Photo by Michael Lüth, with permission.

Figure 20. ***Ptychostomum capillare*** with capsules, a species that occurred in more than 50% of the gardens studied in Sheffield, UK. Photo by through Creative Commons.

Figure 21. ***Rhynchostegium confertum*** with capsules, a species that occurred in more than 50% of the gardens studied in Sheffield, UK. Photo by Michael Lüth, with permission.

Figure 22. ***Rhytidiadelphus squarrosus***, a species that occurred in more than 30% of the gardens studied in Sheffield, UK. This species often occurs in lawns in Europe. Photo by Michael Lüth, with permission.

Figure 23. ***Tortula muralis*** and water drops in Dunblane Scotland, a species that occurred in more than 50% of the gardens studied in Sheffield, UK. Photo courtesy of Peggy Edwards.

Making Your Garden

Private moss gardens are common in Japan (Pullar 1966/1967; Inoue 1980), but elsewhere they are rare. In Chatsworth, Great Britain, there is a moss and lichen garden of 33 moss and 4 liverwort species, including such common taxa as ***Dicranella heteromalla*** (Figure 24-Figure 25), ***Dicranum scoparium*** (Figure 26), ***Hylocomium splendens*** (Figure 27), ***Neckera crispa*** (Figure 28), ***Plagiomnium undulatum*** (Figure 29), ***Polytrichum commune*** (Figure 30), ***P. piliferum*** (Figure 31-Figure 32), ***Rhizomnium punctatum*** (Figure 33-Figure 34), and ***Thamnobryum alopecurum*** (Figure 35) (Ando 1972). And where else but at the home of a poet – we find cushions of ***Polytrichum commune*** adorning the gardens of Poet Laureate W. Wordsworth.

Figure 24. ***Dicranella heteromalla*** on soil bank, a common species in this habitat. Photo by Janice Glime.

Figure 25. ***Dicranella heteromalla*** with capsules, showing the hair-like leaves. Photo by Michael Lüth, with permission.

Figure 26. ***Dicranum scoparium***, a common species that is used in moss gardens in Europe and the USA. Photo by Janice Glime.

Figure 27. ***Hylocomium splendens***, a common northern moss used in European and American moss gardens. Photo by Michael Lüth, with permission.

Figure 28. ***Neckera crispa***, a common species in Europe, where it is used in moss gardens. Photo by Michael Lüth, with permission.

Figure 29. ***Plagiomnium undulatum***, a common species in Europe, where it is used in moss gardens. Photo by Michael Lüth, with permission.

Figure 30. ***Polytrichum commune***, a common species that is used in moss gardens in Europe and the USA. Photo by David Holyoak, with permission.

Figure 31. ***Polytrichum piliferum*** antheridial splash cups. These add color to moss gardens in the spring. Photo by Janice Glime.

Figure 32. ***Polytrichum piliferum*** with calyptrae, demonstrating colorful calyptrae in late summer. Photo through GNU Free Documentation License.

Figure 33. ***Rhizomnium punctatum*** exhibiting its typical growth form on a rock wall; compare to the soil form in Figure 34. Photo by Michael Lüth, with permission.

Figure 34. ***Rhizomnium punctatum*** exhibiting its growth form on soil. This species is common and often used in moss gardens in Europe. Photo by Michael Lüth, with permission.

Figure 35. ***Thamnobryum alopecurum*** with capsules, a common species that is used in moss gardens in Europe. Photo by Michael Lüth, with permission.

In the Netherlands, a Japanese garden at the estate of Clingendael has become a moss garden. It sports several locally rare species [the leafy liverworts ***Odontoschisma denudatum*** (Figure 36) and ***Plagiochila asplenioides*** (Figure 37)] among its 57 taxa. Schoenmakers (1985) speculates that several of the species that are restricted to paths are the inadvertent contributions of visitors.

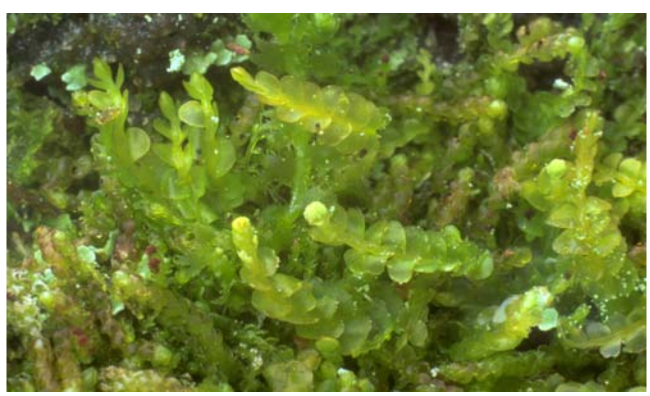

Figure 36. ***Odontoschisma denudatum***, one of 57 taxa in a moss garden in The Netherlands. Photo by Jan-Peter Frahm, with permission.

Figure 37. ***Plagiochila asplenioides***, one of 57 taxa in a moss garden in The Netherlands. Photo by Michael Lüth, with permission.

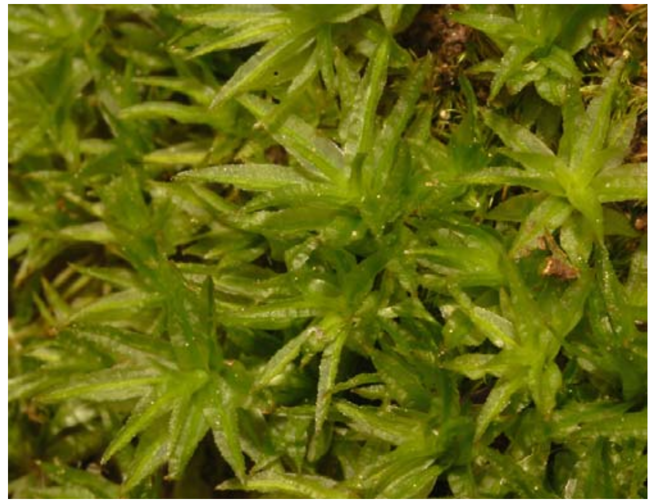

Figure 38. ***Atrichum altecristatum***, a rapid invader of newly opened forest edges and a suitable moss garden species. Photo courtesy of Eric Schneider.

Mossery

In the 19th Century, a number of British and Americans joined the fad of moss collecting (Wikipedia 2017). This interest led to the establishment of mosseries in a number of both British and American gardens. Mosseries are typically made with slatted wood, with a flat roof. They are open to the north, permitting the entrance of light while maintaining shade. Moss samples were installed in the cracks between the wooden slats. Regular moistening of the entire structure helped to maintain growth.

Garden Variety

In the United States, mosses are being used as a means of exploring new garden themes (Massie 1996). A number of web sites give instructions for planting moss gardens, often supplying pictures of very small ones to the large ones of Japan. Even in the highly settled New Jersey, one anthropologist maintains an entire acre of moss (Whiteside 1987). And the prestigious journal *Horticulture* sports one article titled "Even a rolling stone could get some moss here" (Atkinson 1990).

In spite of the presence of moss gardens in the United States at least as early as the 1930's (at Cutting Estate, Great River, Long Island, N.Y.; Grout 1931), few suppliers provide a selection of mosses. Atkinson (1990) complained that when inquiring of the editor of a horticulture magazine where one could obtain mosses for gardens he was referred to Carolina Biological Supply! Nevertheless, more recently a quick search on the web revealed several sources for ***Atrichum*** (Figure 38), ***Callicladium*** (Figure 39), ***Dicranum scoparium*** (Figure 26), ***Campylopus*** (Figure 40), ***Hypnum imponens*** (Figure 12), ***Thuidium delicatulum*** (Figure 41), ***Leucobryum*** (Figure 10), ***Climacium dendroides*** (Figure 42), ***Dicranella heteromalla*** (Figure 24-Figure 25), and ***Plagiomnium cuspidatum*** (Figure 43). One site sold sheet moss that had been cleaned, spread on a backing, glued down, and dyed green! No, thank you! Another source offers a complete garden, including 400 sq feet of moss, for $US 399.99.

Figure 39. ***Callicladium haldanianum***, a shade-loving moss available for purchase for moss gardens in the USA. Photo by Janice Glime.

Figure 40. ***Campylopus pilifer***; the genus ***Campylopus*** can be purchased in the USA for use in moss gardens. Photo by Michael Lüth, with permission.

Figure 41. ***Thuidium delicatulum***, a moss that does well in American moss gardens. Photo by Janice Glime.

Figure 42. ***Climacium dendroides***, a moss often used in American moss gardens. Photo by Janice Glime.

Figure 43. ***Plagiomnium cuspidatum***, a common species in American moss gardens, often as a volunteer. Photo by Janice Glime.

Seasons

To maintain variations in color through the growing season, one needs to pay attention to the phenological changes among the mosses, just as in planting a flower garden. This can provide highlights in different places as the garden changes through the growing season.

Mosses have life cycles that change their appearance. Spring is a typical season for the production of antheridial splash cups. In some species these are reddish (Figure 31); in others, especially splash platforms, they are green, but look like green flowers (Figure 44). Others have colorful setae (Figure 45, Figure 47) and capsules (Figure 46-Figure 48), and these can appear throughout the summer and autumn, depending on the species.

Figure 44. ***Rhizomnium punctatum*** males showing splash platforms that look like green flowers. Photo by Michael Lüth, with permission.

Figure 45. ***Ceratodon purpureus*** showing red-tipped setae in early spring. Photo by Hermann Schachner, through Creative Commons.

Figure 46. ***Ceratodon purpureus***, showing red capsules in early summer. Photo by Michael Lüth, with permission.

Figure 47. Moss with ice on capsules, showing colorful setae even in early winter. Photo by J. Paul Moore, with permission.

Figure 48. ***Pottia lanceolata*** with contrasting capsule color. Photo by Michael Lüth, with permission.

Water Gardens

Many bryophytes like a damp habitat (Figure 49). And some of these habitats are very poor in nutrients. Hence, the bryophytes are naturals for water gardens (Figure 50-Figure 51) (Freiland 2017).

Among the many aquatic species, one of the best for a garden is ***Philonotis fontana*** (Figure 52). It has a fresh, pale green color and tolerates partial submersion or soggy ground.

Figure 49. Water garden and moss where a pipe has been repurposed for creating a garden. Photo from pxhere, through Creative Commons.

Figure 50. Water garden with mosses and waterfall. Photo by David Spain, with permission.

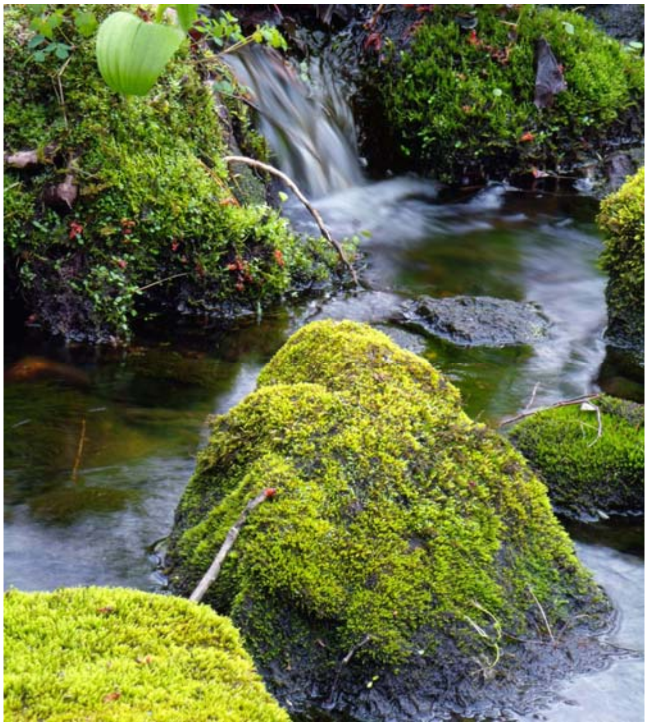

Figure 51. Water garden with mosses on rocks. Photo from pxhere, through Creative Commons.

Figure 52. ***Philonotis fontana*** with capsules, a suitable moss for water gardens. Photo by Michael Lüth, with permission.

Bog Garden

Gardeners such as Case (1994) have found ***Sphagnum*** (Figure 53) bog gardens to be a viable alternative in the Great Lakes area, avoiding high maintenance problems of woodland species unsuited for residential living. These require special conditions devoid of limestone rock and chlorine.

The RaisingRarities website <http://raisingrarities.com/bog-garden/> provides instructions for preparing a bog garden. The pond is excavated and a pond liner is used to cover the shape (Figure 54). It can have a pool attached, as in the diagram, but will require a shallow section for the bog (Figure 55). The lining at the lip of the bog area keeps sand from entering the deeper pool and should go up the bog side of the stones and under them (Figure 56). The bog shelf should be filled 2.5-5 cm deep with pure silica sand. Plant ***Sphagnum*** (Figure 53) on the bog shelf and fill the entire shelf with it. Pitcher plants and sundews can be added for interest, planted among the ***Sphagnum***. Collect rainwater and use it to keep the pond and bog at a constant level.

Figure 53. Colorful ***Sphagnum*** that could be used in a bog garden. Photo by Janice Glime.

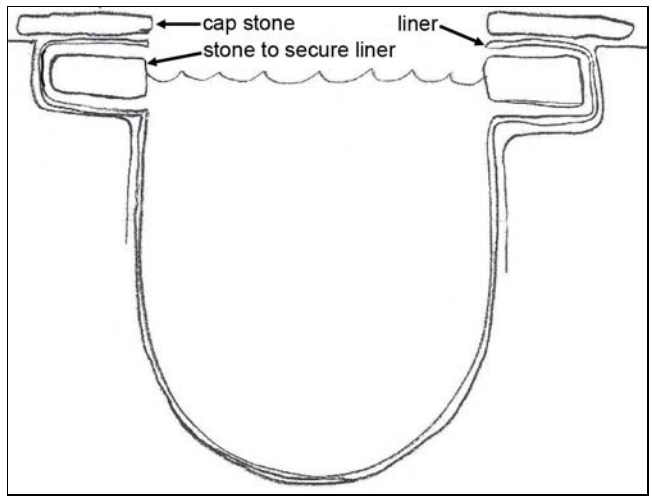

Figure 54. Bog basin and liner in cross section. Redrawn from RaisingRarities.

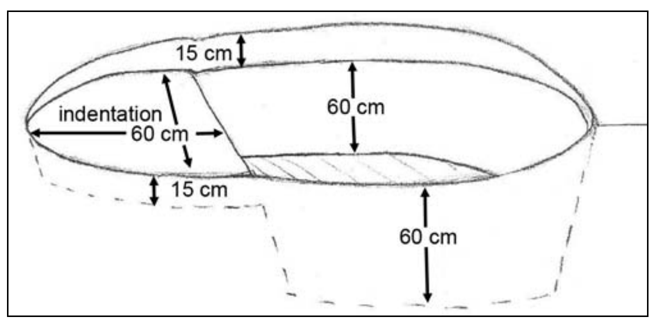

Figure 55. Bog basin and liner showing important dimensions. Redrawn from RaisingRarities.

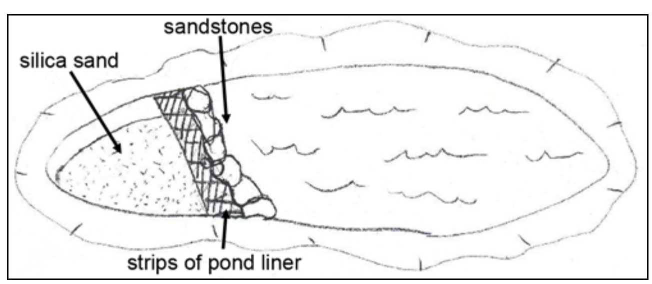

Figure 56. Bog basin shape showing retaining rocks. ***Sphagnum*** will be located on top of the sand. Redrawn from RaisingRarities.

My Personal Garden

For my own moss garden, I managed to rescue ***Marchantia polymorpha*** (Figure 57; with gemmae cups) that was being overtaken by lawn grass on the university campus. It started as a small clump, but one day only a few weeks later I found tiny grey-green specks all over my bare soil (I was just starting the garden). On closer inspection, I found these to be germinating gemmae – the liverwort had spread all over the bare surface and was invading my dying ***Leucobryum*** (Figure 10) cushion as well. By the second year, I had several forests of archegoniophores (Figure 58), but it seems I didn't get any males.

Figure 57. My moss garden initially had a small patch of ***Marchantia polymorpha***, about 10 cm in diameter. Within a month, it spread by gemmae, extending about a half meter in each direction. Photo by Michael Lüth, with permission.

Figure 58. The second year these ***Marchantia*** plants produced archegoniophores in abundance. After a few years, I had to remove some of the ***Marchantia*** to provide space for mosses. Photo by Janice Glime.

Added to that were ***Fissidens*** (Figure 59), ***Brachythecium*** (Figure 60), ***Climacium dendroides*** (Figure 42), ***Dicranum scoparium*** (Figure 26)), ***Leucobryum glaucum*** (Figure 10), ***Plagiomnium cuspidatum*** (Figure 43), ***Polytrichum juniperinum*** (Figure 61), ***Rhytidiadelphus triquetris*** (Figure 62), ***Barbula*** (Figure 63), ***Thuidium delicatulum*** (Figure 41), and ***Ceratodon purpureus*** (Figure 45-Figure 46) that I was able to collect locally, mostly in places where they were doomed to be overgrown or destroyed by traffic. Of these, ***Fissidens***, ***Plagiomnium cuspidatum***, and ***Thuidium delicatulum*** (Figure 41) were the most successful.

Figure 59. ***Fissidens taxifolius*** with capsules; some species of ***Fissidens*** grow easily in moss gardens in North America. Photo by Keith Bowman, with permission.

Figure 60. ***Brachythecium salebrosum***, a species that can occur in large mats usable for moss gardens. Photo by Michael Lüth, with permission.

Figure 61. ***Polytrichum juniperinum*** with capsules in moss garden in Michigan, USA. Photo by Janice Glime.

Figure 62. ***Rhytidiadelphus triquetrus***, a species that often grows well in moss gardens in North America. Photo by Janice Glime.

Figure 63. ***Barbula unguiculata***, a hardy species that adds a contrasting color in the moss garden, preferring a sunny site. Photo by Michael Lüth, with permission.

The ***Leucobryum glaucum*** (Figure 10) was a gift from a friend, and it fared well the first year. It looked bad when winter ended and stains of tannic acid from leaf litter discolored it. It survived, but not well, so the next year I made sure it was not covered with litter for the winter, but it did not make it. I replaced it with a really nice hummock of ***L. glaucum***. This time I put it on a bed of pine needles, a substrate it often has in nature. But it wasn't long before the chipmunks decided that made a nice entrance to their tunnel.

Some night-active animal also tore up all the ***Dicranum scoparium*** (Figure 26) and ***Thuidium delicatulum*** (Figure 41) the first night, and once dismembered from their normal growth habit, both failed to thrive. However, later introductions have survived winter and both have produced new growth, so there is hope. Some rodent decided that the ***Thuidium*** patch was the best place to enter its underground passage, but I seem to have thwarted that hole by stepping on it and filling it in. Alas, now there is a hole in the ***Polytrichum*** patch.

Most of the ***Polytrichum juniperinum*** (Figure 61) is doing fine (Figure 64). It is only the large patch that didn't have good structural integrity that looks like a fallen forest. But even there a few die-hards are putting up new shoots.

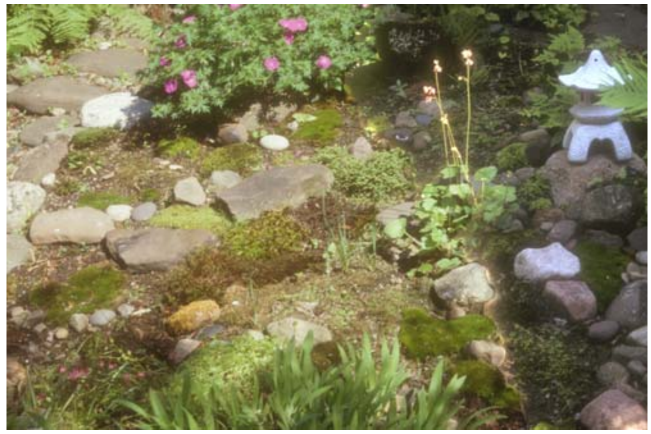

Figure 64. My personal moss garden, when it was about three years old, in Houghton, Michigan, USA. Photo by Janice Glime.

The real winners [***Marchantia*** (Figure 57-Figure 58) aside] are ***Fissidens*** (Figure 59) and ***Plagiomnium cuspidatum*** (Figure 43), with the latter looking a luscious bright green. To my surprise, the ***Rhytidiadelphus triquetrus*** (Figure 62) did well, whereas ***Hylocomium splendens*** (Figure 27) didn't like its transplant at all. One patch of ***Climacium dendroides*** (Figure 42) had mostly brown plants with a few new green shoots arising, but the second patch eventually sprang to life, producing a solid cushion of plants of a most vital green. The old, weedy ***Ceratodon purpureus*** (Figure 45) seems not to like my gardens much and disappears rather rapidly.

A new patch of the liverwort ***Conocephalum conicum*** (Figure 65) seems to be doing well. It, and ***Fissidens*** (Figure 59), also fared well in my indoor garden. That is, they fared well until the birds ate the ***Conocephalum***. I found it with triangular cuts around the edge. Each day it grew smaller until it disappeared. The ***Fissidens*** diminished and ultimately disappeared after the box turtle died. Apparently the turtle had been an effective dispersal agent for both species because they kept appearing in new places until after the turtle died.

Figure 65. ***Conocephalum conicum***, a rock and soil dweller that adds interesting texture to a moss garden. Photo by Robert Klips, with permission.

I attribute my success, after several failures, to the installation of a sprinkling system. It comes on about 4 am for 20 minutes each night. (We usually don't get much rain in spring or summer.) That makes it hydrated and ready to

take advantage of the cool morning sun. It seems to have made all the difference.

I have learned that leaf litter apparently creates more problems than just deprivation of light during the growing season. The tannic acid seems detrimental to several species, because even when I remove the litter the day the snow retreats from its surface, the mosses that were covered with it seem to have suffered. When I removed most of the leaves before winter, the mosses seemed to fare much better.

Mountain Moss Enterprises

The Mountain Moss Enterprises is located near Revard, North Carolina, USA, and is owned by Annie Martin. Known as Mossin' Annie, this entrepreneur has dedicated her life to rescuing bryophytes that are in the path of destruction due to construction or other human activities. These mosses she either plants in one of her many projects, both public and private, or in her own garden where she cares for them until they meet their destiny in a moss garden somewhere.

One of the frequent sources of her bryophytes is from overgrown blacktop. This seemingly unlikely habitat can be a good source for large patches of bryophytes that come in large sheets. Others come from roofs where the owners are convinced they are harmful.

Martin lives in an area of the Appalachians that receives 150-200 cm rainfall per year (Tortorella 2014). Nevertheless, she waters her moss gardens three times each day. She claims that with 3-4 minutes of supplemental water per day the mosses will grow year-round in "nearly any temperature." (I can't imagine that watering when they are under snow is helpful. It would most likely create ice that could actually dry them out more.)

Mosses can dry out or freeze, and easily survive, green up when once again getting wet, but during that dry period they don't look nice. This ability to dry makes them easy to ship, so the distance to a moss supplier is not a real problem. But obtaining mosses from elsewhere does present ecological problems. In addition to the raping of the landscape by some moss collectors, it introduces non-native species.

Martin makes a variety of designs in her gardens, sometimes using differences in colors of leaves to create designs (Figure 66). In other cases, she may use colorful lichens (Figure 67) or furniture to create highlights (Figure 68).

Figure 66. Moss garden at Mountain Moss Enterprises, Pisgah Forest, North Carolina, USA, August 2009. Photo by Annie Martin.

Figure 67. MountainMoss Enterprises moss arrangement with red cap lichens, ***Cladonia*** sp. Photo courtesy of Annie Martin.

Figure 68. Mossin' Annie garden in snow, showing the green of the mosses, even in winter. Photo courtesy of Annie Martin.

Annie Martin (pers. comm. 31 January 2010) received a grant to explore the cultivation of mosses as a cash crop to replace declining tobacco farms. This study involved a partnership of NC Cooperative Extension, Rural Advancement foundation International-USA, and the NC Tobacco Trust Fund Commission which provided the funding. Martin was able to explore various propagation techniques.

Martin points out that moss cultivation requires far less time, labor, and equipment for both maintenance and harvesting compared to tobacco farming. Start-up money is likewise far less for establishing mosses. Maintenance costs are limited to labor and watering, requiring no chemicals, no fertilizers, no pesticides, and no herbicides. This eliminates the pollution of groundwater that is typical of agriculture. On the other hand, the mosses in the Southeast can be harvested any time of year, with their productivity measured in square feet.

Moss and Stone Gardens

David Spain is the owner of Moss and Stone Gardens in Raleigh, North Carolina, USA (Tortorella 2014). Spain presented moss gardening on the Martha Stewart Show, reporting that "she was a big moss fanatic." Spain recounts his early attempts to grow mosses, bemoaning the lack of teachers or sources appropriate for the area. One of these early attempts, following online advice, was to make a mix of mosses in a blender with buttermilk. This slurry was

painted onto rocks or soil. Instead of a moss garden, he got a mold garden. His garden designs tend to mimic nature (Figure 96-Figure 98).

Figure 69. ***Thuidium delicatulum*** in Moss and Stone Garden, showing a fern highlight and a small stream with a stone bridge. Photo from Moss and Stone Garden, with permission from David Spain.

Dale Sievert's Garden

Dale Sievert is a landscape gardener in Wisconsin. He became enamored with mosses and now his property is adorned with 60 species of bryophytes. Some of these species arrived by themselves. Among the more common ones in the garden are ***Bryum caespiticium*** (a widespread species; Figure 70), ***Thuidium delicatulum*** (a species that spreads rapidly; Figure 71), ***Rhodobryum ontariense*** (an interesting species that resembles miniature palm trees; Figure 72), ***Plagiomnium cuspidatum*** (a species that commonly volunteers; Figure 73), ***Leucobryum glaucum*** (a cushion moss that prefers acidic soil; Figure 75), and ***Anomodon rostratus*** (a very common species locally and in his garden; Figure 87).

Figure 70. ***Bryum caespiticium*** forming intriguing hummocks among the rocks. Photo courtesy of Dale Sievert.

Figure 71. ***Thuidium delicatulum***, a moss that spreads easily and usually survives well in the Sievert and other gardens. Photo courtesy of Dale Sievert.

Figure 72. ***Rhodobryum ontariense***, a moss shaped like a palm tree that adds interest to any garden. Photo courtesy of Dale Sievert.

Figure 73. ***Plagiomnium cuspidatum*** in snow. This is a common volunteer in Dale Sievert's garden and in mine, where it doesn't mind being buried in snow. Photo courtesy of Dale Sievert.

Sometimes Sievert lets the mosses determine their own successional pathway. As is typical, pleurocarpous mosses often overrun the acrocarpous mosses (Figure 74). But acrocarpous mosses can invade tight acrocarpous moss cushions as well, as is a common event in which ***Polytrichum*** invades a ***Leucobryum*** cushion (Figure 75). A series of pictures demonstrates some of the changes through time, 2011-2015 (Figure 76-Figure 78).

Figure 74. Nature has her own ideas about what belongs where. Here ***Atrichum*** is being invaded by pleurocarpous mosses. Photo courtesy of Dale Sievert.

Figure 75. ***Leucobryum glaucum*** with invading ***Polytrichum***. Photo courtesy of Dale Sievert.

Figure 76. Moss and cat statues in 2011 showing well-established but still thin mat of mosses. Photo courtesy of Dale Sievert.

Figure 77. Moss and cat statues in 2013 showing thick mat and capsules. Photo courtesy of Dale Sievert.

Figure 78. Moss and cat statues in 2015. The original moss has been replaced with ***Thuidium delicatulum*** dominating the scene. Photo courtesy of Dale Sievert.

Sievert has a number of special features to highlight the various areas of his garden. A bamboo fountain pours into a small pool surrounded by mosses (Figure 79). A bird bath is adorned by colorful rocks and moss-covered rocks (Figure 80). As in many gardens, including my own, a Japanese lantern adds interest (Figure 81). Small to large boulders can add diversity to the scene and may add their own beauty (Figure 82-Figure 83). Stumps provide flat platforms for miniature gardens (Figure 84-Figure 85) or depressions that have their own interest and are great bryophyte substrates (Figure 86). Statuary peers at the visitors or poses playfully among mosses (Figure 85-Figure 86). Ferns provide changes in texture (Figure 87). Pools can attract frogs (Figure 88).

Figure 79. Bamboo fountain in mossy garden, creating a refreshing pool that raises the humidity for the nearby mosses. Photo courtesy of Dale Sievert.

Figure 82. Rocks and a bit of wood enhance this scene with mostly ***Anomodon rostratus***, a common mss in Dale Sievert's garden. Photo courtesy of Dale Sievert.

Figure 80. Birdbath garden in Dale Sievert's moss garden. Photo courtesy of Dale Sievert.

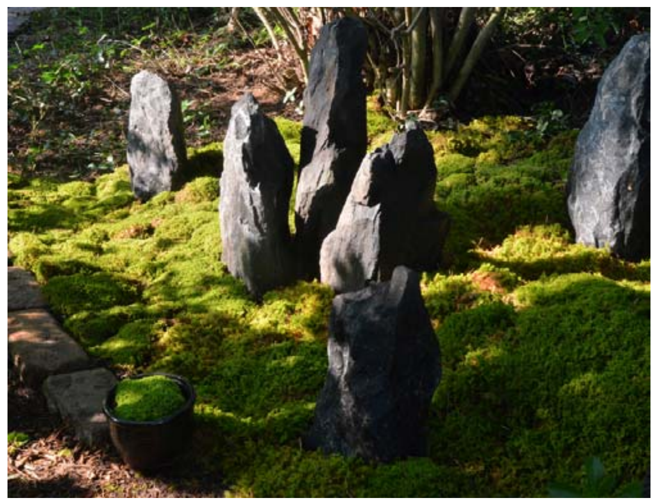

Figure 83. ***Thuidium delicatulum*** and rocks in Dale Sievert's moss garden. Photo courtesy of Dale Sievert.

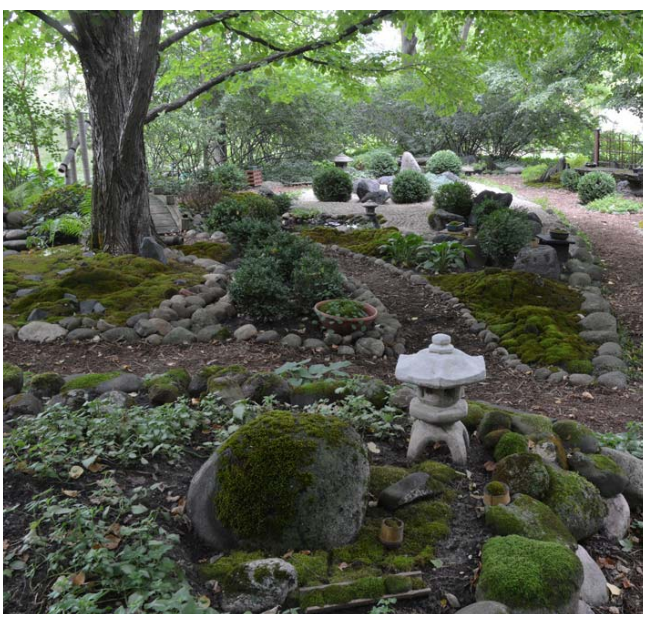

Figure 81. Dale Sievert's moss garden, adorned by a Japanese lamp. Photo courtesy of Dale Sievert.

Figure 84. Here a miniature garden grows on a stump in Dale Sievert's moss garden. Photo courtesy of Dale Sievert.

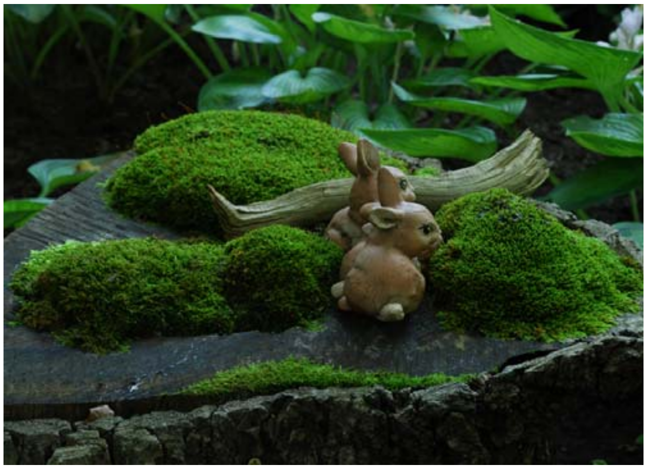

Figure 85. Statuary can add interest or even bring a laugh. Here ***Anomodon rostratus*** grows with bunnies on a stump. Photo courtesy of Dale Sievert.

Figure 86. Raccoon statues in tree stump bring a smile in the moss garden. Photo courtesy of Dale Sievert.

Figure 87. Even a fern can provide a highlight, seen here hovering over ***Anomodon rostratus***. Photo courtesy of Dale Sievert.

Figure 88. Pools can provide habitat and a welcome drink for wildlife. Here the Green Frog ***Rana clamitans*** sits on a mossy rock. Photo courtesy of Dale Sievert.

Fungi (Figure 89-Figure 90) are willing participants in Dale Sievert's garden. The mosses help to keep the soil moist longer, permitting the fungal threads to thrive. In the right conditions, the fruiting bodies emerge, adding color to the garden.

Figure 89. The pore fungus *Boletus* sp. and moss. Photo courtesy of Dale Sievert.

Figure 90. ***Coprinus*** with the moss ***Anomodon rostratus***. Photo courtesy of Dale Sievert.

Dale has been fortunate to have some of his mosses exhibit prolific "fruiting." The setae and capsules often add brilliant colors to the landscape.

Figure 91. ***Ceratodon purpureus*** with numerous red setae. Later red capsules will develop. Photo courtesy of Dale Sievert.

Figure 92. ***Amblystegium varium*** with capsules, a colorful addition in a rock garden. Photo courtesy of Dale Sievert.

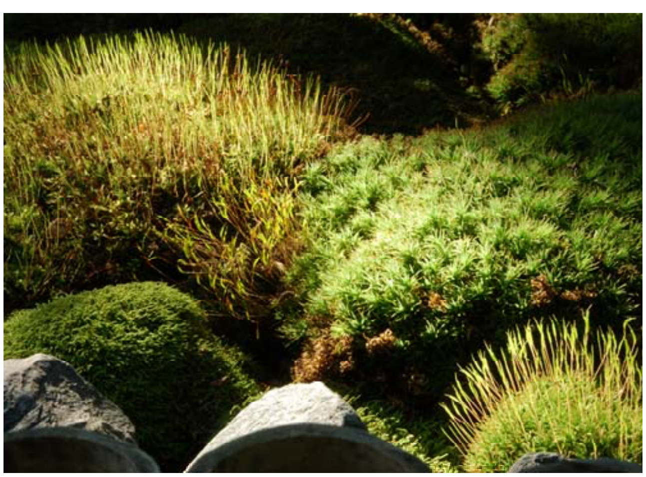

Figure 93. This patch of mixed mosses will soon have capsules to change the color scheme. Photo courtesy of Dale Sievert.

Figure 94. ***Plagiomnium cuspidatum*** with capsules, adding a fresh shade of green to the scene. Photo courtesy of Dale Sievert.

The beauty of a Japanese garden captures the admiration of many moss gardeners. And Dale Sievert's garden has its own Japanese garden section. It is complete with a small pond, bridge, and Japanese lantern (Figure 95).

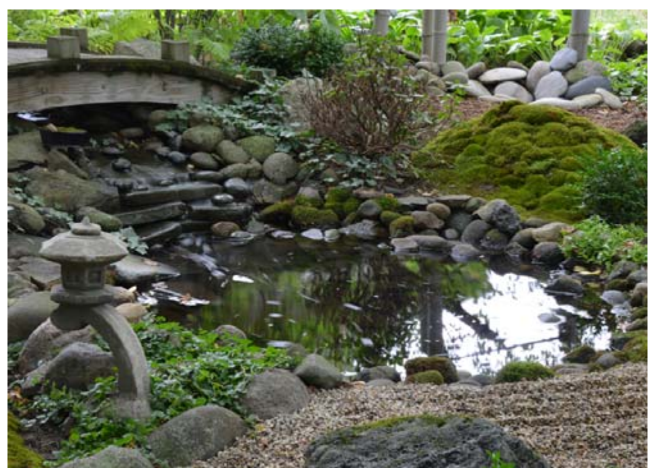

Figure 95. In the Japanese garden portion, a pool, moss, rocks, and raked sand give the feel of a Japanese garden. Photo courtesy of Dale Sievert.

New Methods in Moss Gardening

Rick Smith (2009) has written one of the North American guides to moss gardening, *New Methods in Moss Gardening*. Smith provides his personal experiences around the world where he has created moss gardens or been a consultant. He provides instructions for growing twelve of the most common mosses, accompanied by pictures (Figure 96-Figure 98).

Figure 96. Moss garden designed by Rick Smith. Photo courtesy of Rick Smith.

Figure 97. Moss garden designed by Rick Smith at Illinois Central College. Note the ***Polytrichum*** in the foreground. Photo by Rick Smith, with permission.

Figure 98. Moss garden designed by Rick Smith. Photo courtesy of Rick Smith.

Indoor Moss Garden

As my aging body prevents me from maintaining my outdoor moss garden, I am now attempting an indoor moss garden. So far, I am able to do the required bending, but at least once planted it is essentially maintenance-free – no weeds! I was pleased to have a supplier who rescues the bryophytes she sells by removing them from roofs or construction sites where they are slated for destruction, then cultivates them. Several other suppliers state that they grow their own mosses. I avoid the "grab bags" after trying one and concluding they were ravaged from the forest.

My previous attempts at introducing mosses inside were unsuccessful, with the town's water quality being incompatible despite a filter on the garden room watering system. I was successful with ***Conocephalum*** *cf.* ***salebrosum***. And it also appeared that my turtle was successful in dispersing it.

My new adventure in the indoor moss garden is still quite young, but I do have some success stories. My first introduction was again ***Conocephalum*** *cf.* ***salebrosum*** (Figure 99-Figure 104), and it has been highly successful. The ***Conocephalum*** *cf.* ***salebrosum*** is doing especially well at the base of the waterfall and the stream margins (Figure 99-Figure 101). My ***Marchantia polymorpha*** got dried out, but it is trying to come back, perhaps from gemmae.

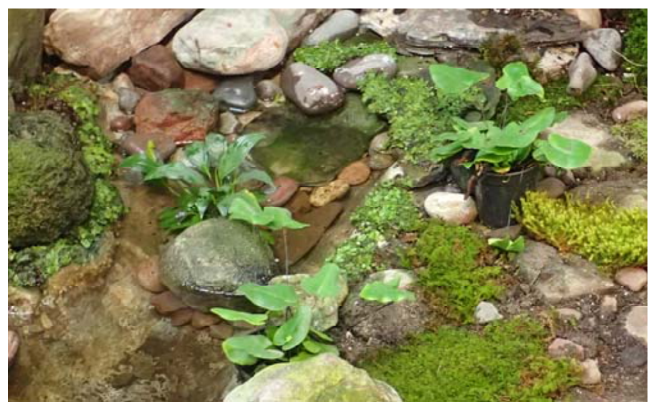

Figure 99. Newly planted ***Conocephalum salebrosum*** along stream, with some bare fake rock at edge. on 16 December 2022. Photo by Janice Glime.

Figure 100. ***Conocephalum salebrosum*** growing successfully at the very moist base of the waterfall on 19 February 2023. The green rock and its surrounding liverworts can be seen at the middle left of Figure 99 from two months earlier. Photo by Janice Glime.

Figure 101. ***Conocephalum salebrosum*** growing on wet soil beside the stream in the garden room, 16 December 2022. Photo by Janice Glime.

Figure 102. ***Conocephalum salebrosum*** invading soil on the rock, extending by fragments from the clump above in Figure 101, two months after being planted. Photo by Janice Glime.

Figure 103. ***Conocephalum salebrosum*** colonizing a ledge in the garden room waterfall. Photo by Janice Glime.

Figure 104. ***Conocephalum salebrosum*** showing the bright green of new branches on the thallus after two months in the garden room. Photo by Janice Glime.

My next adventure was a small patch of ***Thuidium delicatulum*** (Figure 105). To my surprise, this was also quite successful (Figure 106). Both of these bryophytes have produced new branches and have a wonderful, fresh color.

Figure 105. ***Thuidium delicatulum*** in garden room on 19 Feb 2023. Photo by Janice Glime.

Figure 106. ***Thuidium delicatulum*** in garden room on 19 Feb 2023; it was planted ~25 November 2022. Photo by Janice Glime.

Two other bryophytes seem to be doing very well – ***Rhytidiadelphus squarrosus*** and ***Rhytidiadelphus triquetris***. I wasn't surprised at the latter because it had also been successful in my outdoor garden. ***Leucobryum glaucum*** is surviving, appears healthy, but so far no expansion. Of course it is winter here, so the room is cool, but not freezing. It gets watered at least 3 times a week and has a small, two-meter high waterfall to maintain moisture.

Figure 107. ***Rhytidiadelphus squarrosus*** in garden room 19 Feb 2023 after nearly three months. Photo by Janice Glime.

Figure 108. ***Rhytidiadelphus triquetrus*** in garden room 19 Feb 2023 after nearly three months there. Photo by Janice Glime.

Figure 109. ***Leucobryum glaucum*** in garden room 19 Feb 2023 after ~3 months. The color is darker than normal and many apical pieces are scattered loose on it. Photo by Janice Glime.

Sun-loving mosses usually die within the same growing season. Likewise, xerophytes don't do well in the high level of moisture.

After 45 years, there are at last volunteers in the garden. These are mostly on pumice that I put there just for that purpose. The mosses are thin and I don't recognize them, but they are healthy.

Figure 110. Volunteer moss on pumice beside the garden room waterfall – after more than 40 years of opportunity! Photo by Janice Glime.

Harvesting Ban

In 2006, a moratorium was declared on moss harvesting in the national forests around Asheville, North Carolina, USA (Tortorella 2014). This ban was based on a study of the moss trade. Local collectors would sell sheet moss for as little as $.50 per pound to members of the floral trade. But stripping a log of all its moss requires 20 years for a new crop, despite all the local rainfall. Gary Kauffman, an ecologist and researcher on the study, determined that if a third of the moss was left on the log, the mosses would grow back in ten years. One of the dangers of collecting the mosses is what fishermen call "bycatch." Unintended species come along with the desired ones, and some of these are rare and endangered. Including these bycatch species, studies indicate that more than 70 species are harvested in the Appalachian moss industry.

Because of these conservation concerns, it is best to do as Annie Martin has done – rescue mosses and liverworts that are scheduled for destruction. In many of these locations, the moss "invaders" are hardy species and ones likely to survive in a garden.

Summary

Private moss gardens tend to serve the same purpose as the larger moss gardens. Rocks, pebble paths, lamps, and other items add interest, and the limited color gives them a peaceful appeal. Outside of Japan, fewer moss gardens exist, in part because the climate is often not suitable. Another difference seems to be the love of color in other parts of the world.

Mosseries are an older form of growing mosses. The moss gardens themselves have a wide variety, using artistic designs, Japanese styles, natural styles, and mixed with flowering plants. They vary by season, changing colors when producing reproductive structures and between wet and dry states. Water gardens require different species, but running water can add sound to the landscape. Bog gardens can be used to grow insectivorous plants and other bog plants.

Worldwide, mosses such as ***Polytrichum*** and ***Leucobryum*** seem to be popular choices for these gardens. Species like ***Thuidium delicatulum***, ***Fissidens*** sp., and ***Plagiomnium cuspidatum*** spread easily and may overtake acrocarpous mosses nearby. ***Plagiomnium cuspidatum*** can often arrive by itself.

Conocephalum salebrosum, ***Thuidium delicatulum***, ***Rhytidiadelphus triquetrus***, and ***R. squarrosus*** do well in indoor gardens.

Harvesting mosses should only be done on your own property or other private property where you have permission. The best way to get plants is to rescue them where they are scheduled for destruction.

Acknowledgments

I appreciate the email discussions with Nancy Church, Annie Martin, Rick Smith, and David Spain. Most recently, I spent an afternoon discussing mosses and moss gardening with Dale Sievert, leading me to include additional topics in an attempt to answer his questions.

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CHAPTER 7-4
GARDENING: MOSS GARDEN DEVELOPMENT AND MAINTENANCE

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CHAPTER 7-4 GARDENING: MOSS GARDEN DEVELOPMENT AND MAINTENANCE

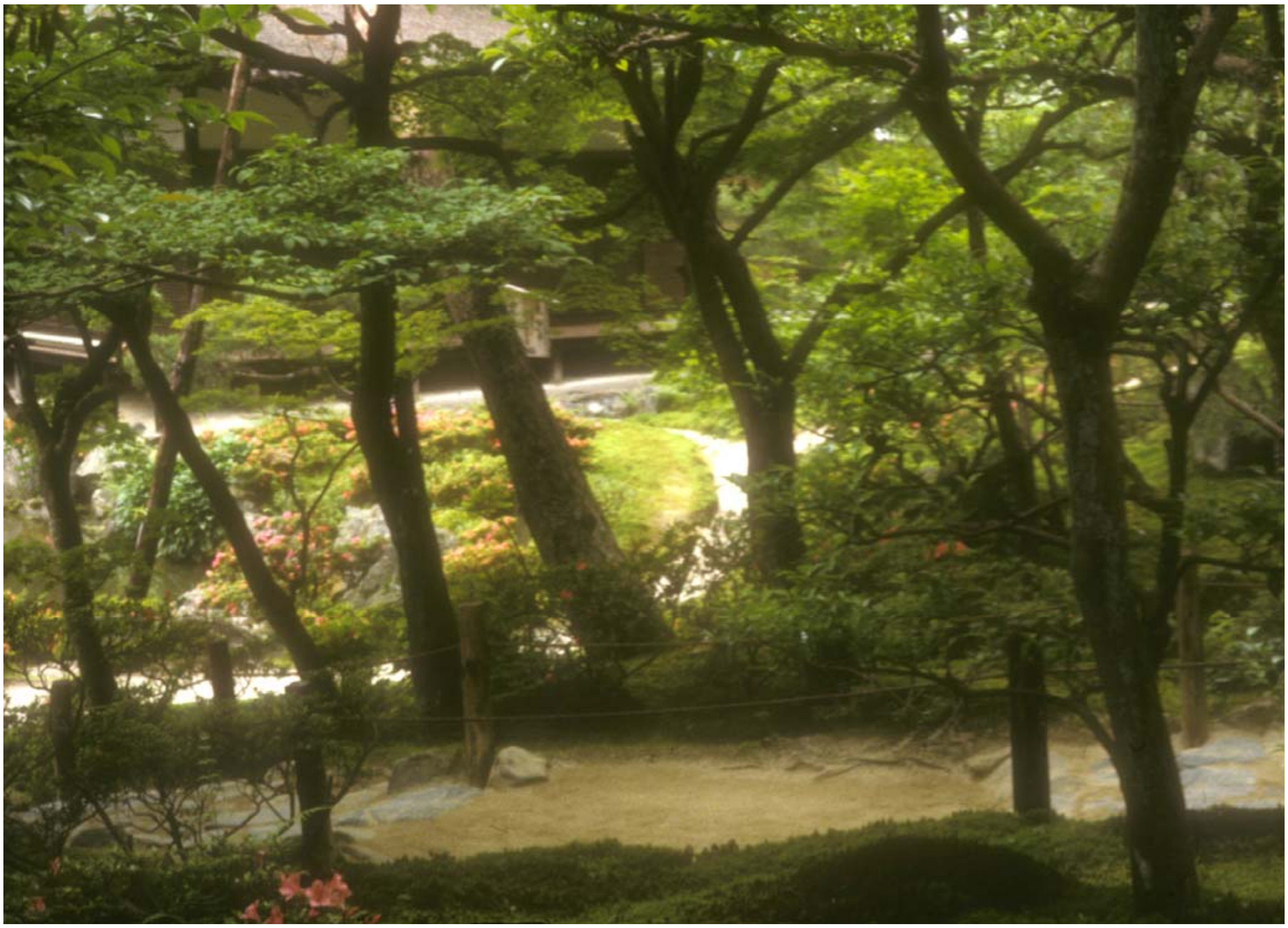

Figure 1. This moss garden in Kyoto, Japan, takes advantage of a stream to add to its peaceful nature. Photo by Janice Glime.

Choice of Bryophytes

Careful selection of bryophytes will greatly increase the chances for success. These plants often have niches that are not provided by the typical garden spot, so care should be taken to select species with habitat requirements similar to that available in the garden.

When you collect different species of mosses and then plant them together, the needs of the different species may differ. There are many species and it's often difficult to discern differences without using a hand lens or consulting a bryologist. If requirements differ, the one most suited can more easily overgrow the other. I suggest that you learn to distinguish the acrocarpous from pleurocarpous species and keep these two separated. The horizontal growth form of pleurocarpous species easily overtakes the upright acrocarpous species.

Most acrocarpous mosses do not like constant moisture whereas most pleurocarpous ones do. One way to deal with this is to maintain a regular watering schedule and allow the mosses that are flourishing to take over the ones that are not. Dead or dying mosses of one species can make a welcoming surface for other mosses to invade or provide suitable substrate for spores to germinate. You can speed up the process by fragmenting some of the flourishing mosses directly on top of the ones that are failing.

In some cases large areas might be transplanted with a moss that is not appropriate for the new conditions and all of the new transplants die. If the area continues to be watered as if the moss is still alive, after several months the spores of another species might germinate on top of the decaying moss and a more appropriate species will develop.

This bed of dead moss retains moisture, controls erosion, and reduces weed invasion. It permits spores of other mosses to have places to land and establish without blowing away. Developing a moss area will eventually lead to some of the species performing better than others and the faster-growing species will subsequently dominate the area.

Spain (2012a) advises that you can "let mother nature decide what species to introduce by clearing the area down to bare earth and then begin watering just as though there was moss already present… If you build it, they will come!"

One might learn from the mosses that are often considered weeds. Charlie Campbell (Bryonet 17 April 2014) found that his parents' lawn in northern England had ***Rhytidiadelphus squarrosus*** (Figure 2) as a co-dominant with the grass. ***Atrichum undulatum*** (Figure 3) and ***Plagiomnium undulatum*** (Figure 4) also occurred in small patches. In Berkshire, his flats were surrounded by grasslands and were on dry, sandy, open lawn. On the shady side of the flats the ***Rhytidiadelphus squarrosus*** grew, but on the sunny areas two different communities developed. On the west-facing slope the community was rich in bryophytes, including ***Riccia glauca*** (Figure 5), ***Sphaerocarpos*** sp. (Figure 6), ***Didymodon vinealis*** (Figure 7), and others. On the east-facing side, an abundant ***Polytrichum juniperinum*** (Figure 8) cover developed. After several days of rain, ***Lophocolea bidentata*** (Figure 9) became extremely frequent on both sunny sites.

Figure 2. ***Rhytidiadelphus squarrosus***, a common moss in lawns in parts of Europe. Photo by Michael Lüth, with permission.

Figure 3. ***Atrichum undulatum***, a moss that sometimes invades lawns. Photo by Janice Glime.

Figure 4. ***Plagiomnium undulatum*** with ice, a moss that sometimes invades lawns in Europe. Photo by Tim Waters through Creative Commons.

Figure 5. ***Riccia glauca***, a thallose liverwort that survives on west-facing slopes. Photo by Bernd Haynold, through Creative Commons.

Figure 6. ***Sphaerocarpos*** sp., a liverwort that survives on west-facing slopes. Photo by David T. Holyoak, with permission.

Figure 7. The moss ***Didymodon vinealis*** is often found on rooftops, concrete, and rock walls. Photo by Michael Lüth, with permission.

Figure 8. ***Polytrichum juniperinum***, a moss that does well on west-facing slopes. Photo by Jan-Peter Frahm, with permission.

Figure 9. ***Lophocolea bidentata***, a moss that seems to suddenly appear in sunny spots after a rainfall. Photo by Michael Lüth, with permission.

Few published studies have taken an experimental approach to moss gardening, although I'm sure many gardeners have used trial and error to determine the best bryophytes for their gardens. Radu *et al.* (2016), however, were interested in bryophytes for a variety of applications and set out to determine the most suitable species. They used six species of mosses in hydroponic experiments: ***Syntrichia ruralis*** (Figure 10), ***Homalothecium sericeum*** (Figure 11), ***Ceratodon purpureus*** (Figure 12), ***Grimmia pulvinata*** (Figure 13), ***Racomitrium aciculare*** (Figure 14), and ***Bryum capillare*** (Figure 15). These species were tested at different light intensities and water dosing regimes. The researchers concluded that ***Grimmia pulvinata*** and ***Ceratodon purpureus*** adapted the best to the controlled environment. They thus considered them to be suitable for use in landscape design. But lab conditions are not field conditions, and constant conditions are quite different from constantly varying conditions. The chapter on Phenology in Volume 1 can suggest a few.

Figure 10. ***Syntrichia ruralis***, a species tolerant of bright sun and desiccation. Photo by Janice Glime.

Figure 11. ***Homalothecium sericeum***, a common species in Europe. Photo by Janice Glime.

Figure 12. ***Ceratodon purpureus***, a widespread and sun-tolerant species that adapts well to a controlled environment. Photo by Janice Glime.

Figure 13. ***Grimmia pulvinata*** on wall, a moss that is widespread and common on walls and rock. It also grows well in controlled environments. Photo from Botany Department Website, UBC, Canada, with permission.

Figure 14. ***Racomitrium aciculare***, a rock-dwelling moss. Photo by Michael Lüth, with permission.

Figure 15. ***Bryum capillare***, a common moss with a wide distribution. Photo by Des Callaghan, with permission.

Thallose Liverworts

One seldom thinks of liverworts in the context of a "moss" garden, but several thallose liverworts are suitable for "moss" gardens. These can be pressed into soft soil so that they have good contact with the substrate (Fletcher 1991). Among the known successful ones are ***Marchantia polymorpha*** (Figure 16) and ***Lunularia cruciata*** (Figure 17) on garden paths and damp soil, ***Conocephalum conicum*** (moist soil; Figure 18), and ***Riccia sorocarpa*** (Figure 19) and ***Riccia glauca*** (Figure 5) in damp fields and garden beds (but small and easily overgrown).

Figure 16. ***Marchantia polymorpha*** with its umbrella-like **archegoniophores**, a species that spreads easily on disturbed soil. Photo by Janice Glime.

Figure 17. ***Lunularia cruciata***, a species that is common in greenhouses in the USA, but can be grown in moss gardens. Photo by Des Callaghan, with permission.

Figure 18. ***Conocephalum conicum***, a thallose liverwort that multiplies rapidly and can be dispersed by turtles and other fauna. Photo by Janice Glime.

Figure 19. ***Riccia sorocarpa***, a common thallose liverwort. Photo by Michael Lüth, with permission.

Sphagnum – peat mosses

Most ***Sphagnum*** (Figure 20) taxa require a wet, acidic habitat, and most have a somewhat narrow range for both of these. Their habitat should be mimicked, and that means that they need to be supplied water from below (Fletcher 1991). This can be accomplished by placing them in flower pots in a shallow tray of standing water. ***Sphagnum*** is well constructed to soak up and transport the water externally through all the capillary spaces surrounding its stem. The proper *p*H can be maintained by growing the plants on their own peat. Tap water can easily kill them. If it has many minerals in it, they will accumulate on the surface and eventually kill them. Calcium is particularly lethal to ***Sphagnum***. To solve this dilemma, distilled water or rainwater is the best watering medium. No fertilizer is needed, and in fact should be avoided.

Figure 20. ***Sphagnum fuscum***, a species that lives on tops of hummocks. Photo by Michael Lüth, with permission.

Sphagnum comes in a wide range of colors (Figure 21), and a bouquet of colors and hues can be arranged in the same garden by using some care in choices of species. Some of these may be maintained by placing them at greater distance from the water source, such as ***Sphagnum fuscum*** (Figure 20) (Fletcher 1991).

Figure 21. ***Sphagnum magellanicum*** and other species of ***Sphagnum*** showing some of the range of colors that occur together naturally. Photo by Janice Glime.

Although many ***Sphagnum*** (Figure 20) species are sun-loving, too much can fry them. Fletcher (1991) reports losing many of his plants during a hot summer when he forgot to move the plants into the shade. The problem is that sun will quickly dry out the plants, and most of the taxa are not drought tolerant. Furthermore, most lack protection against bright sun that can destroy the chlorophyll.

Birds can be a problem in a moss garden. The conditions that favor growth of ***Sphagnum*** (Figure 20-Figure 21) also favor the presence of a number of invertebrates. Hungry birds, especially early in spring, can be quite disruptive as they rummage for dinner. And nesting can be an even bigger problem, especially if your garden provides lots of mosses in a city area where few other mosses exist. In my indoor garden, mosses and zebra finches simply cannot co-exist. The birds win every time, carrying off every bit of moss for nesting material. Fletcher (1991) suggests covering the mosses with netting to minimize the disturbance. Wire netting must be avoided because it is likely to release zinc or other metal that is toxic to the bryophytes.

Fletcher (1991) suggests ***Sphagnum quinquefarium*** (Figure 22) for well-drained slopes in wet woods. ***Sphagnum cuspidatum*** (Figure 23) does well in pools, where it looks like a wet kitten. Fletcher has even kept it in a jam jar for a year. On a bed of peat, ***Sphagnum compactum*** (Figure 24) can tolerate drying, prefers shade, and does not like being water-logged.

Figure 22. ***Sphagnum quinquefarium***, a moss of well-drained slopes in forests. Photo by Michael Lüth, with permission.

Figure 23. ***Sphagnum cuspidatum***, an emergent species for pools. Photo by Jan-Peter Frahm, with permission.

Figure 24. ***Sphagnum compactum***, a species that grows on wet sand or rocks in shaded areas where it tolerates drying. Photo by Michael Lüth, with permission.

Polytrichum – hairy cap mosses

The most common of the mosses in Japanese gardens (Figure 1) of all kinds is the common hairy cap moss, ***Polytrichum*** (Figure 25). This group of mosses is common in both temple gardens and private gardens. ***Polytrichum*** is difficult to transplant because the clump easily becomes disturbed in the process. For that reason, smaller, young clumps work best. But don't despair if those larger clumps collapse and turn brown. I have learned to trust the resilience of moss stems, and ***Polytrichum*** stems are a good example to support this trust. I transplanted one year after they had collapsed from their original orientation. They looked pretty bad when they went into the garden, and they didn't improve much. The next spring I was nearly ready to remove them, but didn't get the energy to do it. Then small green tips began to appear. Most of the sprawling clump still looks rather sad. They might have come back, but a chipmunk decided to occupy that part of the garden, building an entrance to its underground runway, Nevertheless, life is there, and perhaps with time the clump will fill in through stems.

Figure 25. ***Polytrichum commune*** var ***commune***, a common species used in moss gardens. Photo by David Holyoak, with permission.

Members of the genus ***Polytrichum*** can resist disturbance by the broom or bamboo rake used to remove fallen leaves and other debris (Ando 1987), and they are unusual among mosses for their resistance to drought and ability to withstand direct sunlight as well as shade (Steere 1968). ***Polytrichum juniperinum*** (Figure 8) and ***P. piliferum*** (Figure 26-Figure 27) do well if the clump integrity is maintained, again making small, young clumps easier to transplant.

Figure 26. ***Polytrichum piliferum*** males, adding a bit of color to moss gardens in spring. Photo from Proyecto Musgo, through Creative Commons.

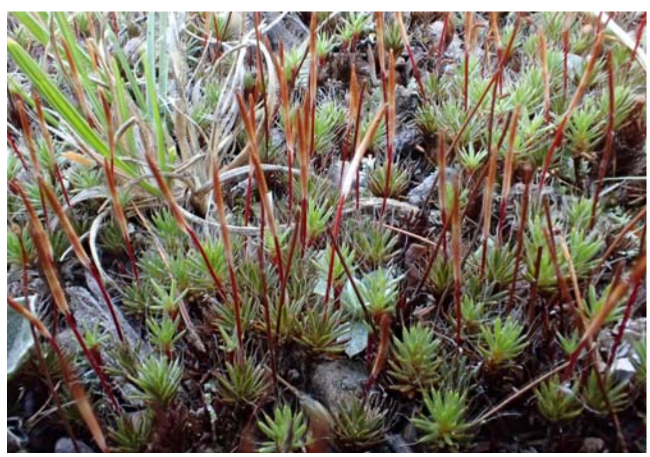

Figure 27. ***Polytrichum piliferum*** with young sporophytes. Photo by Janice Glime.

As with ***Sphagnum*** (Figure 22-Figure 24), lime in some tap water can form crusts on the leaves (Fletcher 1991). One reason for this is that water for ***Sphagnum*** in nature must generally come from above. Although many mosses have good capillary action to move water externally, ***Polytrichum*** (Figure 25-Figure 27) species have large, waxy leaves that tend to repel water and do not move it well externally. Although they have one of the best developed internal conducting systems, they still take in most, if not all, of their water through the tip of the plant. Thus, water must be supplied from above and needs to be almost completely free from minerals. Even so, dust splashing from the soil can easily reach the leaves and contribute to their mineral accumulation.

Fletcher (1991) contends that the most easily grown mosses are those that have strong rhizoids, because they are least damaged by lime. For the remaining majority, one can use peat as a substrate, but that is often too moist. Another alternative is to use a sand substrate or in some cases organic soil free of lime, and water only with distilled water. Rain water is also a good choice, but may be contaminated with lime in areas with alkaline soil or limestone rocks. Nevertheless, as Fletcher points out, the impact of rainfall helps to wash off the minerals. A good spraying system is essential in areas where rainfall is infrequent. Fletcher advises to wash the mosses off with a spray of rainwater when they have accumulated minerals on their leaves.

Fletcher has succeeded in keeping ***Polytrichum*** (Figure 8) alive for 20 years, but he finds it necessary to transplant them every 1-2 years onto fresh peat. Once done, this permits old, dying shoots to produce new sprouts that emerge from the peat. On the other hand, I have had a bed of ***Polytrichum juniperinum*** (Figure 8) for seven years without disturbing it, and it is still doing well. It looks awful in the spring, but it recovers.

Polytrichum commune (Figure 25) and ***P. strictum*** (Figure 28) grow mostly in bogs and fens. ***Polytrichum strictum*** is aided in its quest for water by a white tomentum on the lower part of the stem.

Figure 28. ***Polytrichum strictum*** with capsules, a bog/fen species that is suitable for moss gardens. Photo by Michael Lüth, with permission.

Atrichum

Atrichum (Figure 3) is a relative in the same family as ***Polytrichum*** (Figure 25-Figure 27). But its needs are somewhat different. Whereas ***Polytrichum*** has stiff, waxy leaves with lamellae across most of the surface, ***Atrichum*** has thin leaves (Figure 29) with lamellae only in the middle over the more narrow costa (Figure 30). This genus does best on soil, not peat (Fletcher 1991). Some species can be an invasive moss along paths (Figure 31) and can easily regrow from fragments. These provide a nice yellowish green.

Figure 29. ***Atrichum altecristatum*** leaf portion showing lamellae over costa down center. Photo by Bob Klips, with permission.

Figure 30. ***Atrichum altecristatum*** showing lamellae over costa in leaf cross section. Photo by Bob Klips, with permission.

Figure 31. ***Atrichum altecristatum*** along a path in the forest in Houghton, Michigan, USA. Photo by Janice Glime.

When ***Atrichum*** dries, the leaves curl (Figure 32) and often turn brown (Figure 33). In this form it is not very attractive. It will look nice in a well-watered or humid garden.

Figure 32. ***Atrichum altecristatum*** drying and curling. Photo courtesy of Eric Schneider.

Figure 33. ***Atrichum angustatum*** with dry, brown leaves and capsules. Photo by Janice Glime.

Leucobryum

Leucobryum glaucum (Figure 34) was a favorite moss of many of my students. A common moss, it is easily recognizable by its whitish color and pincushion appearance. Its whiteness is emphasized in its name, with *bryum* meaning moss, *leuco* meaning white, and *glaucum* meaning whitish like wax. It goes by the common names of cushion, pincushion, or white moss. It likes acid soil, frequently occurring in conifer forests. Although it typically occurs in the shade, it can tolerate sun exposures. And the genus is common on many continents.

Leucobryum (Figure 34) is an **acrocarpous** moss, or upright type, producing stalks and capsules at the tips of the upright stems. Its mound form (Figure 34) makes a striking element in garden designs and borders, providing both a break in the topography and a striking contrast in color. This color contrast is due to hyaline cells that mask the green color of the leaves. As the moss dries, the hyaline cells lose water, the optics change, and the moss appears whiter.

Figure 34. ***Leucobryum glaucum*** at tree base, a common species in moss gardens. Photo by Janice Glime.

The texture of ***Leucobryum*** (Figure 34) cushions is somewhat coarse, due to the leaves that are more than one cell thick and relatively large. Cushion size can become quite large (Figure 35), and these will be very compact.

Figure 35. ***Leucobryum glaucum*** demonstrating the large cushions in an undisturbed forest In Copper Harbor, Michigan, USA. Photo by Janice Glime.

Annie Martin (Mountain Moss Newsletter winter 2010) relayed her experience relocating ***Leucobryum glaucum*** (Figure 34) from a gravel road where it was growing in full sun. It was dehydrated and white. She placed it among other ***Leucobryum*** plants in her garden and watered it three different times that evening. By morning it looked as fresh and alive as the established ***Leucobryum*** plants.

I have attempted cultivating ***Leucobryum glaucum*** (Figure 34) several times with only short-lived success. This moss seems especially susceptible to destruction by the leachates of leaf litter, even if the litter is cleared as soon as the snow melts.

Another habit of this plant might lead to dismay if one isn't familiar with its behavior. When it is reproducing

asexually, the leaves at the tip break off, providing a white covering of fragments on the colony (Martin 2010). This gives it a "cruddy" appearance for a while, but the plants are fine – just reproducing and dispersing. You can sweep these off with a soft brush to improve the appearance and at the same time disperse your ***Leucobryum*** (Figure 34) to additional locations in your garden.

If your ***Leucobryum glaucum*** (Figure 34) turns black, you do have a problem. This indicates that it is being kept too wet (Martin 2010). Perhaps this explains its sickly look in my garden when it emerged from the snow in spring. The slow melt in spring may have kept it too wet too long with little light and no opportunity to get dry. This discoloration can also be caused by fungal attack – an event further promoted by moisture. Martin advises to let the moss dry out for a while to see if it will recover.

On the other side of the coin, ***Leucobryum*** (Figure 34) has some remarkable recovery techniques. If it gets turned upside down, it will begin growing from the exposed side (Martin 2010), sometimes making a ball!

Martin (2010) finds this moss to be easy to pick up. The pincushion sits on the soil surface and grows on its own dead base (Figure 36). There is usually no soil attached. I have been advised to plant it on a bed of pine needles, but my one attempt at that was undone by a chipmunk that chose it for making the entrance to a burrow. It seems to like sandy soil and to avoid rich soil. As always, Martin warns us not to take bryophytes from parks or forests and to ask permission before collecting on private land.

Figure 36. ***Leucobryum glaucum*** showing dead lower parts that sit on the soil surface. Photo courtesy of Diane Lucas.

Leucobryum bowringii (Figure 37), ***L. juniperoideum*** (Figure 38) grow in mounds or cushions, creating a gentle, rolling landscape resembling miniature hills (like Figure 36). ***Leucobryum*** (Figure 39) is abundant and highly praised for its huge whitish cushions that provide beautiful contrast.

Figure 37. ***Leucobryum bowringii***, a species used in Japanese moss gardens. Photo through Creative Commons.

Figure 38. ***Leucobryum juniperoideum***, a species used in Japanese moss gardens. Photo by Jan-Peter Frahm, with permission.

Figure 39. ***Leucobryum*** "spills" down the hill in a moss garden in Kyoto, Japan. Photo by Janice Glime.

Dicranum

Dicranum is an acrocarpous genus that prefers shade. The most widespread and common species, ***Dicranum scoparium*** (Figure 40), forms cushions. The leaves curve and typically they all curve in one direction (Figure 41), creating the temptation to pet it. It provides a dark green contrast to ***Leucobryum*** (Figure 34) species and is found in

many parts of the world, permitting its use in the moss gardens of Japan.

Figure 40. ***Dicranum scoparium*** on forest floor, a common moss of forests that adds a dark green to the garden. Photo by Janice Glime.

Figure 41. ***Dicranum scoparium*** showing leaves curved in one direction. Photo by Janice Glime.

Mniaceae

Mniaceae can be similarly propagated, preferring damp, shaded places. ***Plagiomnium cuspidatum*** (Figure 42) has been quite successful in my garden and thrived as an invader among the shrubs around the campus library. Several members of **Mniaceae** are known and used for their big, lush leaves (Figure 42).

Figure 42. ***Plagiomnium cuspidatum*** is easily grown if it can be transplanted without disturbing its connections to the soil and each other. Photo by Michael Lüth, with permission.

I have found this species as a well-developed moss among my flagstones on a path, where it was totally a volunteer.

Thuidium delicatulum

Thuidium delicatulum (Figure 43) is one of the fast-growing mosses (Martin 2010) and can take over a moss garden (Dale Sievert, pers. Comm. 13 October 2017). Despite the disturbances by chipmunks, I have found it to be persistent in my garden, showing up in new locations.

Figure 43. ***Thuidium delicatulum*** when it is wet and fresh. Photo by Jan-Peter Frahm, with permission.

Martin (2010) finds this moss to be a strong grower in winter in North Carolina – in her words, growing "by leaps and bounds during the winter months." She found that it quickly spread over mosses like ***Leucobryum*** (Figure 34) and ***Dicranum*** (Figure 40), invading and sometimes covering these mounds.

Thuidium is papillose (Figure 44), crunchy when dry (Figure 45), but soft when wet (Figure 43). It looks like a miniature fern and is often known as "fern moss." It will grow in open areas among grasses, but its need for some shade makes it a more likely candidate for shady portions of a garden.

Figure 44. ***Thuidium delicatulum*** branch showing the projecting papillae on the leaves. Photo by Bob Klips, with permission.

Figure 45. ***Thuidium delicatulum*** dry (and crunchy). Photo by Janice Glime.

Pseudoscleropodium purum

Pseudoscleropodium purum (Figure 46) is a large, pleurocarpous moss that tends to grow on acidic soil. It seems to like acidic grasslands, roadsides, and maintained lawns. It has attractive branches that look rope-like due to the concave leaves that end in a sudden, short, narrow tip. Like ***Thuidium*** (Figure 43), it is a rapidly growing species (Martin 2010). But be careful – it is also an invasive species, sometimes getting introduced when it is used as a packing material.

Figure 46. ***Pseudoscleropodium purum***, a common moss in Europe, but invasive in parts of the USA. Photo by Janice Glime.

Rhodobryum

Rhodobryum (Figure 47) is a special genus that has very attractive individual plants. The leaves are crowded at the tips of the stems, making these look like a colony of miniature palm trees. The genus can grow in deep shade and seems to like it somewhat damp. Hilty (2017) describes its habitats in Illinois as moist ground in woodlands, wooded hillsides, ground at the base of trees in woods, swampy woodlands, shaded clay banks of ravines, moist decaying logs, limestone rocks along streams, moist limestone cliffs, shaded limestone ledges, limestone blocks in woods, thin soil over sandstone rocks in wooded areas, shaded ground in hanging fens, and sandy clay banks along creeks. Although it is a relatively uncommon moss, this presents a wide range of habitats where you can grow them.

Figure 47. ***Rhodobryum ontariense***, an attractive moss for gardens. It prefers alkaline habitats but also grows over sandstone rocks. Photo by Janice Glime.

The ***Fissidens*** (Figure 48) in my moss garden has spread to other gardens in my yard. It can be aggressive, as seen in Figure 49 where it is overgrowing ***Marchantia polymorpha***.

Fissidens

Fissidens (Figure 48) is not often mentioned as a genus for moss gardens. However, my experience with it is that it is an excellent choice. It holds up well and stays green when it is dry. But the best news is that it grows well when propagated and spreads by itself, perhaps with the help of the chipmunks.

Figure 48. ***Fissidens adianthoides*** is a moss easily cultivated by transplant or fragments. Photo by Michael Lüth, with permission.

Figure 49. ***Fissidens*** in my moss garden in Houghton, Michigan, USA, on 15 April 2010 soon after snow melt. Here it is taking over ***Marchantia polymorpha***. Photo by Janice Glime.

Others

In the shade in Japan, common species include ***Pyrrhobryum dozyanum*** (Figure 50), and ***Trachycystis microphylla*** (Figure 51). Like ***Leucobryum***, these latter taxa grow in mounds or cushions, creating a gentle, rolling landscape resembling miniature hills. ***Hypnum*** (Figure 52) and ***Racomitrium*** (Figure 53) are common in drier places and ***Fissidens*** (Figure 48) and ***Atrichum*** (Figure 3) in wet places (Steere 1968). Both ***Hypnum plumaeforme*** (Figure 54) and ***Racomitrium canescens*** (Figure 53) are able to grow without deep shade, but require frequent watering and weeding (Ueta & Deguchi 1980). In his webpage, Svenson (2000) recommended ***Racomitrium canescens*** as a moss for both sun and shade. It is quite drought tolerant, and it can form large, thick mats that have a broad tolerance, even to trampling. Other mosses suitable for gardens include ***Eurhynchium praelongum*** (Figure 55), ***Rhynchostegium confertum*** (Figure 56), ***Brachythecium rutabulum*** (Figure 57), and ***Rhytidiadelphus squarrosus*** (Figure 2) (Fletcher 1991).

Figure 50. ***Pyrrhobryum dozyanum***, a large moss that does well in shady sites in Japanese gardens. Photo by Janice Glime.

Figure 51. ***Trachycystis microphylla*** with capsules, a moss that does well in shady sites in Japanese gardens. Photo from Digital Museum, Hiroshima University, with permission.

Figure 52. ***Hypnum imponens***, a widespread species suitable for moss gardens. Photo by Janice Glime.

Figure 53. ***Racomitrium canescens***, a moss suitable for a sunny garden that might get dry frequently. Photo by Michael Lüth, with permission.

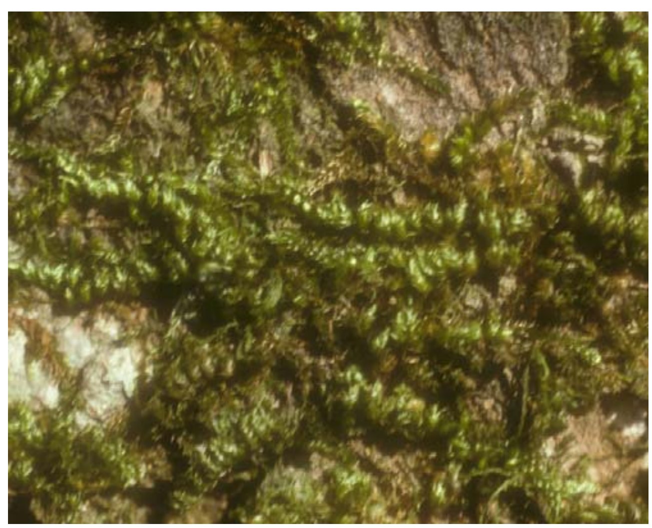

Figure 54. ***Hypnum plumaeforme***, an epiphyte in Japan. When planted in moss gardens, it requires frequent watering and weeding. Photo by Janice Glime.

Figure 55. ***Eurhynchium praelongum***, a beautiful plumose moss suitable for gardens. Photo by Blanka Shaw, with permission.

Figure 56. ***Rhynchostegium confertum*** with capsules, a species suitable for moss gardens. Photo by Michael Lüth, with permission.

Figure 57. ***Brachythecium rutabulum*** with capsules, a common moss that will grow in gardens. Photo by Michael Lüth, with permission.

Some mosses are especially adept at being transplanted and seem to survive despite drought or rainy season. Among these, I have been most successful with the medium-sized species of ***Fissidens*** such as ***F. adianthoides*** (Figure 48). It helps considerably if the shape of the original colony can be maintained, preventing exposure of longer stems by maintaining the shorter outer members of the cushion. This is especially true for cushion-formers like ***Leucobryum*** (Figure 39) and ***Dicranum*** (Figure 40). If this is not possible, pushing a rock against the exposed broken parts of the cushion helps to maintain the moisture there.

Hylocomium splendens (Figure 58) and ***Pleurozium schreberi*** (Figure 59) likewise do not transplant well. I have to wonder if a symbiotic fungus is involved. I was surprised that ***Rhytidiadelphus triquetris*** (Figure 60), a species in the same family as ***Pleurozium*** and ***Hylocomium***, does well. ***Thuidium delicatulum*** (Figure 43-Figure 45) is somewhat successful, but mine was disturbed badly by a chipmunk that seemed to think that was the best place to enter its burrow. Followed by a very dry summer, ***T. delicatulum*** did not seem to be doing well. Nevertheless, it now occupies spots shaded by flowering plants and rocks, having dispersed there without my help.

Figure 58. ***Hylocomium splendens***, a species that does not transplant well. Michael Lüth, with permission.

Figure 59. ***Pleurozium schreberi***, a species that does not transplant well. Photo by Sture Hermansson, with online permission.

Figure 60. ***Rhytidiadelphus triquetrus***, a species that transplants well. Photo by Janice Glime.

Moss gardening is a growing industry, even in the United States and other parts of the world outside Japan. However, not all plants touted as mosses are truly mosses. Spanish moss (***Tillandsia usneoides***; Figure 61), a bromeliad, hence a flowering plant, is included among the types available from at least one moss seller. Rock mosses (*Selaginella*; Figure 62) and club mosses (Figure 63) (both Lycopodiaceae) are both cryptogamic tracheophytes, not bryophytes. Sheet moss, ***Sphagnum*** (Figure 20-Figure 24), and "bun" moss (growing in clumps) are other types listed and are true mosses. Sheet mosses include such mosses as ***Hypnum*** (Figure 52) and ***Thuidium*** (Figure 43-Figure 45) (Nelson & Carpenter 1965).

Figure 61. ***Tillandsia usneoides***, Spanish moss, but not a real moss. Photo by George Shepherd, through Creative Commons.

Figure 62. ***Selaginella rupestris***, a rock moss that resembles a moss when it lacks the strobili shown here. Photo by Nancy Leonard, with permission.

Figure 63. ***Lycopodium annotinum***, a club moss, but not a true moss. Photo by Janice Glime.

Annie Martin has ***Climacium americanum*** in her moss garden (Figure 64). This attractive moss looks like miniature trees. It is especially interesting when it produces capsules because it looks like a miniature Christmas tree with candles (Figure 66). This same moss grows in abundance along the path to the Frank Lloyd Wright house, Falling Waters, Pennsylvania, USA (Figure 65).

Figure 64. ***Climacium americanum*** in MountainMoss Enterprises garden. Photo by Annie Martin <www.mountainmoss.com>, with permission.

Figure 65. ***Climacium americanum*** bordering the path at Falling Waters, Pennsylvania, USA. Photo by Janice Glime.

Figure 66. ***Climacium americanum*** with capsules in moss garden. Photo by Janice Glime.

Sources

Few sellers are available for purchasing live mosses. And even where these sources are available, the mosses are usually expensive. Even when people have the sources and the money for purchase, gathering one's own is always a temptation. There are advantages to the latter – it shows the gatherer how and where the moss grows in nature and makes it easier to create the right microclimate for it.

BUT good stewardship is of paramount importance. And good stewardship precludes removing mosses from nature, whether it is a national forest or private land. Annie Martin, in response to criticism from Bryonetters, explained her method of developing moss mats for sale. She obtains her mosses in two ways – rescuing those that are about to be destroyed by development or because they are presumed to be a nuisance (roofs, parking lots, cracks in the sidewalk) or by obtaining permission from owners on private land. Judicious harvesting on private land can permit the mosses to grow back. On her own property, she cultivates these for sale. Martin expressed dismay that she could not get a permit to remove mosses in an area to be logged. Logging permits are permitted, but saving mosses beforehand is prohibited! They can't even be rescued to prevent destruction by trucks fighting fires. On the other hand, Martin has had good experience with private owners and business owners who give her permission to remove mosses. People in the area know her and call her before destroying unwanted mosses.

It also helps to know the relative growth rates of mosses. Annie Martin suggests that log mosses tend to fall in the faster growing category. I can add ***Plagiomnium cuspidatum*** (Figure 42), ***Fissidens adianthoides*** (Figure 48), and ***Marchantia polymorpha*** (Figure 16) as species that spread quickly.

Lawns

One typical push lawn mower running for one hour equals 43 new automobiles running for the same time (Martin 2010)! Go green with moss!

David Benner developed a moss lawn so he would never have to mow again (Dunn 2008). He hasn't watered or mowed his lawn since the Kennedy Administration, and it's doing just fine, reports Jancee Dundee (2008) in her "In the Garden" column. Benner, a retired professor of horticulture, is a long-time moss lawn advocate. He is delighted that this approach is gaining momentum. But to visitors of his mossy lawn, he forbids high heels. (I wonder if it isn't more dangerous for the wearer than it is for the moss!)

Tim Currier, owner of Sticks and Stones Farm, Newtown, CT, USA, had been selling mosses for gardening for ten years, but in 2007 his sales increased by 30% (Dunn 2008). Celeste Kennedy, owner of Rolling Hill Farm in Green Bay, VA, USA, reports a 40% increase in the same time frame. Both homeowners and businesses have contributed to this rise in sales.

Dunn (2008) touts the advantages of mosses, including erosion prevention, density that repels weeds, no need for fertilizer, lack of herbivory by deer, and tolerates at least some trampling (*e.g.* Figure 67). It thrives in poor soil and only requires shade and occasional water.

Figure 67. Moss lawn near Minisink Lake, Bushkill, PA, USA. Photo by Janice Glime.

The American Society of Landscape Architects predicted that native drought-resistant plants such as mosses would be a trendy change in 2008, providing a sustainable substitute for grass in lawns (Dunn 2008). Nancy Somerville, the executive vice president, states that the organization is seeing more creative plantings, with moss being "a great one." It satisfies needs for both better environmentalism and concerns about water. The EPA estimates that nearly one third of residential water use is for landscaping, a condition our diminishing water supply cannot sustain. The condition will only get worse with global warming, although in some areas more rain will fall.

Christine Cook, owner of Mossaics in Easton, CT, USA, contends that a moss lawn needs only one percent or less of the amount of water needed to maintain a suburban grass lawn (Dunn 2008). Benner's philosophy (Dunn 2008) is even better – he doesn't water; "things have to tough it out."

In 1962, when Benner first began his moss lawn, the only book he could find on the subject was written in Japanese (Dunn 2008). But he knew that moss thrives in acidic soil, whereas some people spread lime on a grassy lawn to eliminate moss. Therefore, he covered his lawn with a mix of sulfur powder and aluminum sulfate to acidify it. Three months later he removed the dead leaves, exposing the soil. Winter was the wait and see period, but in the spring mosses began to sprout everywhere. "It was like magic" he remembers. He didn't even have to plant – he just waited for spores to blow in. He now has 25 different kinds, and he didn't plant any of them! He has found fern moss (***Thuidium*** sp.; Figure 43-Figure 45), hair cap moss (***Polytrichum***; Figure 8, Figure 25-Figure 28), rock cap moss (***Dicranum***; Figure 40), and cushion moss (***Leucobryum***; Figure 34, Figure 37-Figure 39) to be the easiest to grow. These four taxa are now sold by his son, Al Benner, through Moss Acres, a commercial establishment in the Poconos of Pennsylvania, USA. This business has actually increased about 30% each year, with such customers as the New York Times' headquarters for its atrium garden.

Benner senior claims that "some sort of magical invigorating energy goes through you when you stand on a thick patch of wet moss" (Dunn 2008).

It seems that moss enthusiasts are lurking everywhere. T. J. Turgeon, an executive vice president of a private bank for wealthy people, began his moss growing in 2004 (Dunn 2008). He says, "I'm having an absolute blast with it. I'm great at a dinner party, because I can talk about moss and no one's ever heard it before. People at work think I'm out of my mind. I don't know if other people do this, but wherever I go, I take moss."

Sallie Baldwin is a graphic designer from Greenwich, CT, USA, who has been turning her front yard into a moss lawn for 18 years (Dunn 2008). She sometimes amuses her neighbors by swapping a bit of "weedy" grass in her lawn for the "weedy" moss in theirs.

Special Use Species

You may choose to place some of your bryophytes in special locations that are more restrictive. These could include boulders, rock or concrete walls, or even paths. Some mosses are suitable for transplanting to these special situations.

If it is not too dry, ***Marchantia polymorpha*** (Figure 16) does well on disturbed soil. My ***Marchantia polymorpha*** (Figure 16) sported a bevy of children in a 25-cm circle around the parent plants, products of gemmae (Figure 68) splashed by the rain or the sprinkler system, and the parents had only been in the garden about three weeks! These young thalli were not only on the bare ground, but had become established on the cushions of ***Leucobryum*** (Figure 34) within reach. The following year the original clump was a forest of **archegoniophores** (structure where female gametes and ultimately capsules are produced; Figure 16).

My ***Marchantia polymorpha*** (Figure 16) sported a bevy of children in a 25-cm circle around the parent plants, products of gemmae splashed by the rain or the sprinkler system, and the parents had only been in the garden about three weeks! These young thalli were not only on the bare ground, but had become established on the cushions of ***Leucobryum*** (Figure 34) within reach.

Figure 68. ***Marchantia polymorpha*** gemmae cups with gemmae. Photo by Dick Haaksma, with permission.

Lawn Species

For substitute lawns and gardens, ***Eurhynchium praelongum*** (Figure 55), ***Calliergonella cuspidata*** (Figure 69), and ***Polytrichum juniperinum*** (Figure 8) serve well, although I doubt the North American populations of ***C. cuspidata*** would do so well in most terrestrial areas. In Europe this moss is found on dry hillsides, but in North America it behaves as an aquatic, at least anywhere I have seen it.

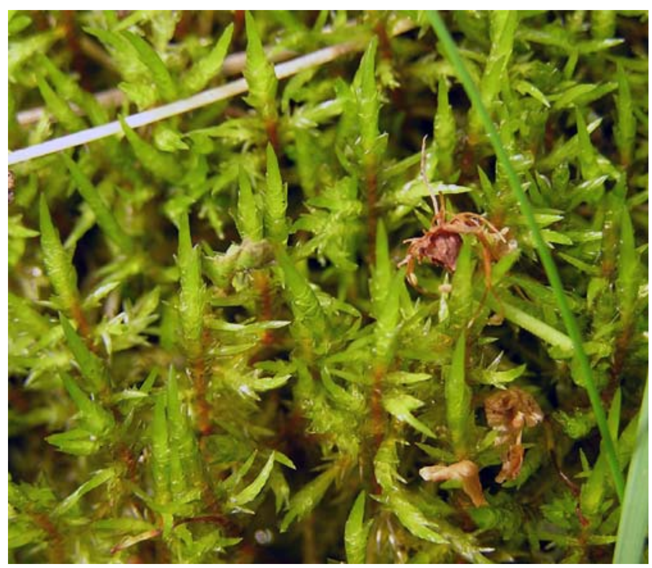

Figure 69. ***Calliergonella cuspidata***, a species that does well in lawns and gardens in Europe, but not in North America. Photo by Michael Becker through creative Commons.

One of the most common lawn mosses is the pleurocarpous species ***Brachythecium rutabulum*** (Figure 57) (Fletcher 1991). It is among the largest of the ***Brachythecium*** species, has the typical plicate leaves, and can be distinguished from the others by its papillose seta (Figure 70-Figure 71). Its ability to grow in more sunny areas makes it also a good candidate for gardens as well as paths. It has invaded between the stones of the path along the side of my house. The moss ***Eurhynchium***

praelongum (Figure 55) will grow in similar areas, but is a smaller plant.

Figure 70. ***Brachythecium rutabulum*** showing setae that support the capsules. Photo by David Holyoak, with permission.

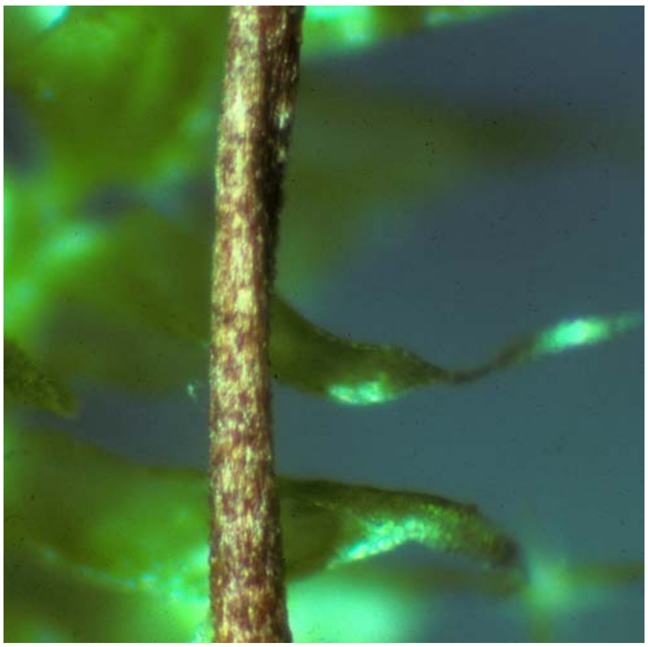

Figure 71. ***Brachythecium rutabulum*** papillose seta. The papillae are best seen along the lower sides of the seta in this picture. Photo by Janice Glime.

Another lawn species in Europe is ***Rhytidiadelphus squarrosus*** (Figure 2). Well manicured and fertilized lawns are deprived of this species, but grassy meadows mowed by livestock may have it abundantly (Fletcher 1991).

Since mosses barely penetrate the soil with their rhizoids, only shallow soil of 1-2 cm is needed. Texture determines ability to attach but also determines moisture retention. Thus species that typically grow on sand are not likely to do well on humus or clay. Fletcher (1991) suggests bringing back a small plastic bag of soil that can be placed on top of a peat substrate. He contends that the soil type is more important for small moss plants than for large ones. Large plants most likely provide their own substrate after a few years of growth (Figure 72).

Figure 72. ***Campylopus flexuosus*** showing senesced lower parts of plants upon which the active parts are able to grow. Photo by Michael Lüth, with permission.

Sun Species

Bryum argenteum (Figure 73) and ***Ceratodon purpureus*** (Figure 12) are good sun species. ***Bryum argenteum*** changes little in appearance between wet and dry. It reproduces largely by fragmentation of the tips and typically does well in locations where there is a fair amount of foot traffic.

Figure 73. ***Bryum argenteum***, a common lawn species that propagates from fragments from the tips. Photo by Michael Lüth, with permission.

Ceratodon purpureus (Figure 12; Figure 74-Figure 84) is the moss my students nicknamed "tricky moss." It can take on many forms, depending on its microclimatic conditions. In spring, it is usually well hydrated and bright green (Figure 74-Figure 75). In summer, and often in autumn, it is usually dry and becomes crispy, brittle, and dark green or brownish (Figure 80-Figure 82). Its carpets can be somewhat loose (Figure 75) or quite tight (Figure 77). It is an early invader of roofs, areas on the ground receiving roof runoff, rock ledges, road sides, parking lots, and sparsely vegetated fields. In even grows in Antarctic pools (Figure 84). Nevertheless, it often does not respond well to transplantation.

Figure 74. ***Ceratodon purpureus*** in its fresh, green form. Photo by Michael Lüth, with permission.

Figure 75. ***Ceratodon purpureus*** with an uncommon loose form. Photo by Michael Lüth, with permission.

Figure 76. ***Ceratodon purpureus***, with lush, green color after a wet summer and autumn. Setae are formed for next spring's capsules. Photo by Janice Glime.

Figure 77. ***Ceratodon purpureus*** with red setae and young capsules. Photo by Annie Martin <www.mountainmoss.com>, with permission.

Figure 78. ***Ceratodon purpureus*** in moss garden at Mountain Moss Enterprises, showing spring growth and mature capsules. Photo by Annie Martin <www.mountainmoss.com>, with permission.

Figure 79. ***Ceratodon purpureus*** showing dry portion (upper left) and moist portion. Photo by Janice Glime.

Figure 80. ***Ceratodon purpureus*** showing dry plants in autumn. Photo by Janice Glime.

Figure 81. ***Ceratodon purpureus*** dry with immature capsules. Photo by Bob Klips, with permission.

Figure 82. ***Ceratodon purpureus*** in brown state after a dry summer. Photo by Janice Glime.

Figure 83. ***Ceratodon purpureus*** with mature capsules and dry leaves. Photo by Michael Lüth, with permission.

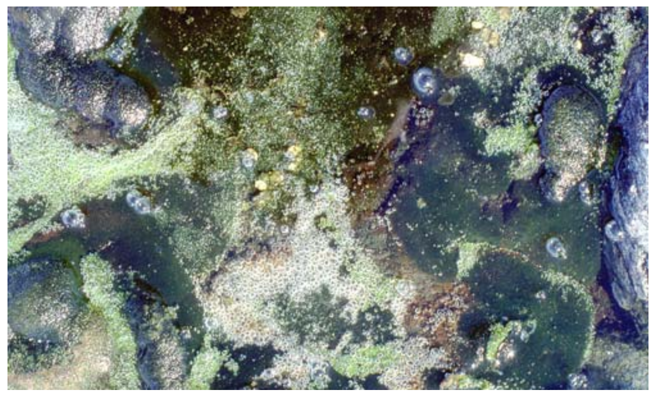

Figure 84. ***Ceratodon purpureus*** submersed with air bubbles at Casey Station, Antarctica. Photo courtesy of Rod Seppelt.

Wall Species

The common European moss ***Tortula muralis*** (Figure 85) easily establishes itself on cement, bricks, or other walls (Fletcher 1991). Although it may be found on soil, this is not its best habitat. For rooftops (the clay tile kind), concrete, and rock walls, Svenson (2000) recommends ***Tortula muralis*** and ***Didymodon vinealis*** (Figure 7).

Figure 85. The moss ***Tortula muralis*** is often found on rooftops, concrete, and rock walls; *muralis* means "of the wall." Photo by Michael Lüth, with permission.

Path Species

The most famous of the species growing on paths is ***Bryum argenteum*** (Figure 73), silver moss. It is easily dispersed by its deciduous tips whenever something walks across it. Hence, it is common in cemeteries and other soil areas with light foot traffic.

In addition to the ubiquitous silver moss, ***Barbula*** [***B. unguiculata*** (Figure 86), ***B. convoluta*** (Figure 87), ***B. cylindrica*** (Figure 88), and ***B. fallax*** (Figure 89) is common, especially between bricks or stones (Figure 90) (Fletcher 1991). Species of ***Barbula*** add a fresh green color to the garden (Figure 91).

Figure 86. ***Barbula unguiculata***, a common species between bricks and stones. Photo by Michael Lüth, with permission.

Figure 87. ***Barbula convoluta***, a common species between bricks and stones. Photo by Janice Glime.

Figure 88. ***Barbula cylindrica***, a common species between bricks and stones. Photo by Des Callaghan, with permission.

Figure 89. ***Barbula fallax***, a common species between bricks and stones. Photo by Kristian Peters, with permission.

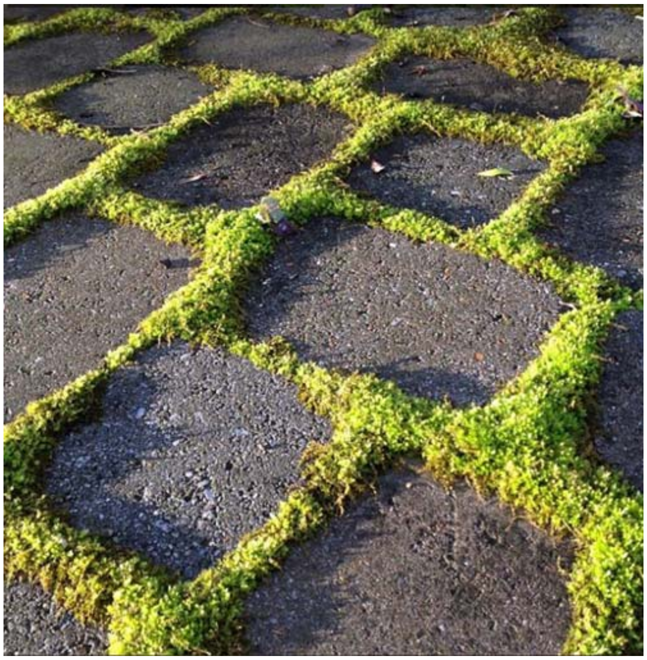

Figure 90. Mosses in pavement. Photo by J. Paul Moore, with permission.

Figure 91. ***Barbula unguiculata*** in the center, flanked by ***Conocephalum conicum*** at the top right, and ***Polytrichum juniperinum*** below it. Photo by Janice Glime.

Based on invasion of a newly cut ski trail, I would recommend ***Atrichum altecristatum*** (Figure 92). This moss invaded quickly about 10 years ago and is still present today. The plants provide a yellow-green color when fresh. However, when they dry out they are not nice to look out. If a watering system is present, they will benefit.

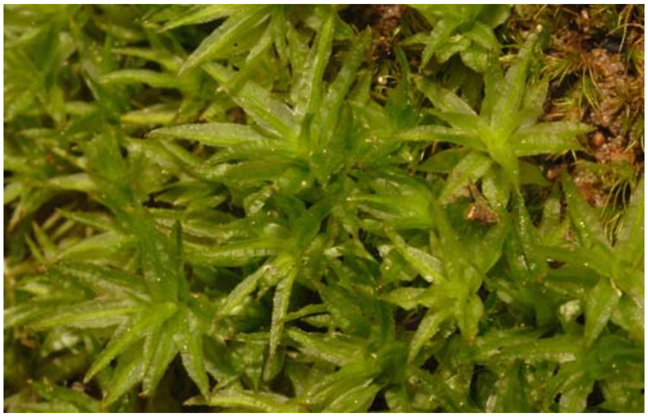

Figure 92. ***Atrichum altecristatum*** drying, a species tolerant of living on paths. Photo courtesy of Eric Schneider.

Annie Martin includes ***Ceratodon purpureus*** (Figure 93-Figure 94) among her plantings between stones of paths. If you are willing to wait, this species will probably arrive by itself.

Figure 93. Stone path planting, showing Annie Martin pushing mosses, including ***Ceratodon purpureus***, into cracks between the stones. Photo courtesy of Annie Martin <www.mountainmoss.com>.

Figure 94. ***Ceratodon purpureus*** with capsules in stone path in March 2017. These were planted here in December 2016. Photo courtesy of Annie Martin <www.mountainmoss.com>.

I was surprised to find ***Hedwigia ciliata*** (Figure 95) covering paths in our local cemetery (Figure 96). The paths were covered in gravel and could be identified by the yellow-green color of the wet moss. The moss all but disappeared from a distance when it dried and became whitened. I would not ordinarily think of this as a path moss, but it was certainly doing well in parts of the cemetery.

Figure 95. ***Hedwigia ciliata*** drying, a moss that grows on pebbles and rocks. Photo by Janice Glime.

Figure 96. ***Hedwigia ciliata*** wet, on pebbles, in the Houghton cemetery path. Photo by Janice Glime.

Erosion Control

The use of mosses to control erosion has probably been known for many centuries. Shana Gross (Bryonet 23 January 2009) reported her experiments on establishing moss growths for this purpose. She examined effects of fragment size, substrate, fragment location along the shoot, watering methods, hormone application, and nutrient application on ***Bryum argenteum*** (Figure 73), ***Ceratodon purpureus*** (Figure 12; Figure 74-Figure 84), and ***Polytrichum juniperinum*** (Figure 8). The responses depended on the species. She strongly supports the use of mosses for erosion control, but this adventure is not without its problems. The mosses grew well in the greenhouse, but responded poorly in the field. Fragments planted in the field required some means to affix them until

they became established. Transplanting clumps from field populations was more successful, but that is not feasible for larger areas. She suggested using methodology from cryptogamic crusts (see Belnap 1993), where inoculum of the species improved colonization over letting nature do the propagating.

Shaw (1986) developed experimental propagation methods. He was successful in propagation when he dried the gametophytes (leafy plants), ground them into a fine powder, and sowed them on native soil. His purpose was to develop a laboratory protocol for evolutionary studies, but it could be applied to getting starter biomass for stopping erosion. He found that the plants presented normal morphology.

Cultivation

Fletcher (1991) has found that mosses can be grown in a variety of containers, including Perspex sandwich boxes, Tupperware, plastic ice cream boxes, glass jars, and aquaria. However, bryophytes kept in this way typically do not survive for more than a few months. He replaced this method with a seed tray, covered with a sheet of glass or sheet of acrylic plastic. These must be kept in cool, open air and shaded. But even this improved method does not work as one might hope; bryophytes fare well for only a few weeks to months. Fletcher even tried peat beds or other means to maintain moisture, but this made matters worse. Clearly there was a need for a better method.

Johannes Enroth related to Bryonet (5 March 2010) his experience growing ***Racomitrium canescens*** (Figure 53) experimentally in a cemetery. The study group took advantage of the fragmentation growth capabilities of mosses and cut the shoots into small pieces (see also Figure 97). They spread these on sand and kept them moist until they became established. "The moss grew fast and formed a dense, beautiful cover that changed color along with changing air moisture" (Figure 105). This moss is a good suggestion for sunny areas.

Figure 97. ***Climacium americanum*** clipping to propagate. Photo by J. Paul Moore, with permission.

In Australia, Alison Downing (Bryonet 23 January 2009) and her coworkers experimented with calcareous and acid soils to look for the success of dormant propagules. They collected soil in the field and carried it back to the lab in cotton bags to prevent mold in the humidity of plastic bags. They collected only the top 10 mm of soil, avoiding the collection of plants. In the lab, they sieved the soil in a clean environment. The sand foundation was steam-sterilized to avoid contamination from the sand. Dry heat is not effective for the resistant bryophytes unless it is at extremely high temperatures. Using the sterilized sand, they filled a 10-cm-diameter plastic horticultural pot to about 1 cm below the top. The collected soil was placed in a 5 mm layer on top of the sand. The soil propagules were cultured in a greenhouse, watered carefully with demineralized water, and the pots covered with sheets of glass to prevent contamination. The pots were checked daily and kept moist by misting with demineralized water when needed. After 8 weeks the calcareous and arid soils exhibited 100% bryophyte cover. The propagules in the non-calcareous soil required a few more weeks. Even rare species can show up using this method.

Annie Martin (Bryonet 6 August 2010) prepares the ground to prevent the invasion of rooted plants. She has used five different substrates (Figure 98-Figure 99) in her gardens, including 0.3 cm synthetic felt, 0.6 cm felt with adhesive plastic backing (used for installing carpets), basic landscape fabric (paper thin), black landscape fabric 0.5 cm thick (perforated and similar to felt; Figure 98), and coco fiber mat (to control erosion; Figure 98-Figure 99). For ***Bryum*** (Figure 73), ***Ceratodon*** (Figure 12; Figure 74-Figure 84), and ***Hedwigia*** (Figure 95), she uses asphalt shingles for a substrate.

Figure 98. Mats for planting mosses. The black layer is a synthetic felt with adhesive plastic backing. Photo by Annie Martin <www.mountainmoss.com>, with permission.

Figure 99. Close view of coco fiber mat and black felt for planting mosses. Photo by Annie Martin <www.mountainmoss.com>, with permission.

These substrates are not eco-friendly or natural. When installing a moss garden for her clients, Martin (Bryonet 6 August 2010) plants the mosses directly on the ground. In the nursery, the felt substrates help in retaining moisture and make it easier to lift the mosses into flats or boxes for shipping.

As Annie Martin (Bryonet 8 March 2012) gained experience, experimenting with various substrates, she developed a preference for Geo-Tex fabric as the primary substrate for field production. This retains moisture and provides a weed barrier. Martin (Bryonet 8 March 2012) plants large areas by transplanting hand-sized colonies and spreading fragments in between (Figure 100). Watering for the next few weeks is critical, but make it gentle.

Figure 100. Planting of bryophytes on mat of coco fibers. Annie Martin disperses fragments between the clumps. Photo by Annie Martin <www.mountainmoss.com>, with permission.

Katherine Frego (pers. comm. to Nancy Church 6 April 2010) reported on her success in growing ***Pleurozium schreberi*** (Figure 59), ***Dicranum polysetum*** (Figure 101), ***D. scoparium*** (Figure 40), ***Ptilium crista-castrensis*** (Figure 102), and ***Ptilidium ciliare*** (Figure 103). She found she could collect them at any time. She then dried them in the shade and chopped them with scissors. These fragments were stored in paper bags for months. When she was ready to culture them, she put them on a humus-y soil and covered them with a hairnet to keep them in place. She sprayed them thoroughly to wet them and they sprouted new shoots very soon afterwards. Fragments about 1 cm long formed new shoots directly. Smaller shoots formed protonemata first, and these were more fragile and vulnerable.

Figure 101. ***Dicranum polysetum*** with capsules, a moss successfully grown from dry fragments. Photo by Janice Glime.

Figure 102. ***Ptilium crista-castrensis***, a moss successfully grown from dry fragments. Photo by Janice Glime.

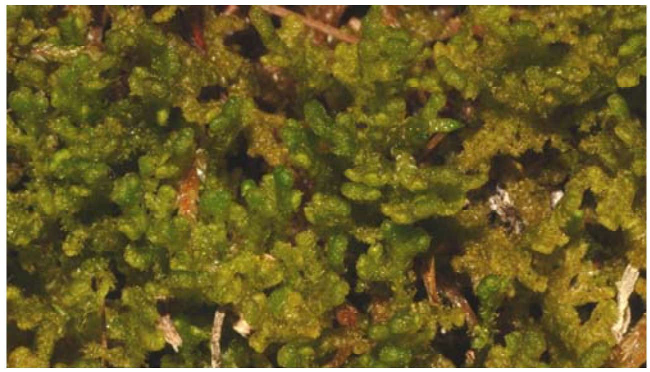

Figure 103. ***Ptilidium ciliare***, a moss successfully grown from dry fragments. Photo courtesy of Eric Schneider.

Johannes Enroth (Bryonet 6 August 2010) became the curator of a stone and moss garden in the courtyard of the Ministry of Education in downtown Helsinki, Finland. The original garden, planted by Timo Koponen in the 1980's, had only three species: ***Racomitrium canescens*** (Figure 104-Figure 105), ***Plagiomnium cuspidatum*** (Figure 42), and ***Climacium dendroides*** (Figure 106). In 2007, the number of species had expanded to 15, dominated by ***Encalypta streptocarpa*** (Figure 107). The latter forms a pure mat of several square meters on the sand in the middle of the yard.

Figure 104. ***Racomitrium canescens*** exhibiting dry appearance. The tips look frosted and add interesting contrast to other shades of green in the garden. Photo by Michael Lüth, with permission.

Figure 105. ***Racomitrium canescens*** in its wet appearance. The pale green color adds a fresh look. Photo by Michael Lüth, with permission.

Figure 106. ***Climacium dendroides***, an attractive moss for moss gardens. Photo by Janice Glime.

Figure 107. ***Encalypta streptocarpa*** with capsules, a species that arrived in a Finnish moss garden by itself. Photo by Michael Lüth, with permission.

I have experimented in my own garden, using various substrates and cultivation methods. One of my early attempts was to use burlap (Figure 108-Figure 109), placing it on top of visqueen plastic to prevent seeds in the soil from germinating and penetrating into the moss carpet (Figure 109). It also meant that seeds germinating on top would be unable to drive their roots into soil. Netting over the mosses helped to hold them in place when chipmunks and squirrels ran over them (Figure 110). But apparently the soil helps in the retention of moisture because these mosses dried out more quickly than those directly on soil.

Figure 108. ***Bryum*** sp. on burlap. Photo by Janice Glime.

Figure 109. ***Ceratodon purpureus*** and ***Bryum*** sp. on burlap. Photo by Janice Glime.

Figure 110. ***Ceratodon purpureus*** and ***Bryum*** sp. with partial netting on burlap. Photo by Janice Glime.

Next I tried cutting the bryophytes into fragments (Figure 111) and spreading them on brown felt (Figure

112-Figure 113). This met with similar problems. The felt dried quickly, became stiff, and the moss fragments likewise dried out.

Figure 111. Fragments of bryophytes on cutting board, ready to plant. Photo by Janice Glime.

Figure 112. Fragments that have been scattered on wet brown felt. Photo by Janice Glime.

Figure 113. Planting fragments of ***Polytrichum juniperinum*** on felt, underlain with visqueen. Photo by Janice Glime.

To understand the best way to keep bryophytes, we must understand how they normally grow. Rather than being the moisture-loving plants portrayed in most popular literature, they actually prefer places with good air circulation and only a small percentage of species grow in the damp, enclosed places most people think of. Rather, many taxa grow on dry rocks, sand, or in open sun. Some prefer acid rocks and some prefer limestone. Most cannot grow where leaf litter will cover them in the fall and remain there for the winter. Some do well in pine forests where they can grow over or between the needle litter.

Johannes Enroth, Bryonet 9 March 2010, recalls covering a surface with ***Racomitrium canescens*** (Figure 104-Figure 105) shoot fragments. Within a matter of months, the moss formed a "nice mat." Two ***Polytrichum*** (Figure 8, Figure 25-Figure 28) species from spores and individual shoots planted in the soil were not very successful. Growth was slow and the planted shoots often died. ***Plagiomnium*** sp. (Figure 42) was more successful.

Nancy Church (pers. comm. 27 July 2010), formerly from Moss Acres, told me that they used a product called Terra Blend70/30 with Ultra Grow. The 70/30 ratio refers to the wood fiber/paper fiber content. The Moss Acre folks believe the "Ultra Grow," the ingredients of which are kept a close secret of the manufacturer, is part of what makes this so effective with mosses. Keith Bowman, one of Dr. Kimmerer's graduate students, worked with Moss Acres on experiments with the Ultra Grow cellulose, and Church was curious to see if the fertilizer helped the vascular plants (weeds) or the moss more. It has certainly helped the moss in all of the "amateur" experiments they've done at Moss Acres.

Sandrine Hogue-Hugron (Bryonet 31 May 2011) experimented with growing bryophytes to restore sand pits. Although there was colonization on the bare sand, colonization was optimal when the sand was mixed with peat. Peat is also a good substrate for making a bog garden. Industrial peat is a good choice because it is usually free of propagules. The peat can be further sterilized by heating to 60ºC for an hour and a half.

Winter Culture

Martin (2010) finds that winter is a good time to harvest and plant mosses in western North Carolina, USA. But if you live in the Keweenaw Peninsula of Michigan, USA, the mosses are under a meter or more of snow. In Japan, the best time to plant is just before the rainy season, reducing the need for frequent watering. Martin reports that her mosses emerge from short snowfall events looking green, whereas when mine emerge after 4-5 months of snow burial, they often look brown, becoming green when new growth appears.

Freezing doesn't harm the mosses (Figure 114), with some photosynthesizing at temperatures below 0ºC (Liu *et al*. 2001). Snow insulates them, and I am guessing that some photosynthesis is able to occur in the light filtering through shallow snow in spring and fall. Martin (2010) has been successful in planting mosses on frozen ground, but the moss itself should be thawed first. She warns that on warmer days when the temperatures are above freezing, the garden should be watered, especially during the first few weeks after planting. (And don't forget to empty the hose so it won't freeze and burst.)

Figure 114. ***Hylocomium splendens*** in snow. Photo by Michael Lüth, with permission.

When there is no snow cover, winter is a season of growth, along with spring and autumn when the air is cool. Bryophytes tend to be dormant in the heat of summer, especially if they are dry.

Moss Plantations

When visiting a commercial moss plantation in Japan near Nagoya, I found the ground planted in several species of ***Polytrichum*** (Figure 8, Figure 25-Figure 28) and its relatives ***Pogonatum*** (Figure 115) and ***Atrichum*** (Figure 3, Figure 92). The landscape was dotted with small pine and fig trees, providing light shade for the mosses beneath (Figure 116). Other growers cover the mosses with straw or bamboo screens to provide shade. The proprietor proceeded to show me, with hand motions and occasional translations by N. Takaki (for whom ***Takakia*** is named), how the mosses were dried, then pulverized between the hands, and sown like grass seed in wooden flats. These flats were kept well watered in full shade until the mosses were well established. Then they were transplanted outside under the shade of the pines and figs until they formed a carpet (Figure 116).

Figure 115. ***Pogonatum japonicum***, a moss in a genus used in moss gardens in Japan. Photo from Digital Museum, Hiroshima University, with permission.

Figure 116. This plantation in Nagoya, Japan, uses pine trees to provide shade for growing mosses. Photo by Janice Glime.

When they were harvested for a buyer, they were removed in squares about 20x20 cm and stacked to dry (Figure 117). Their new owner would then plant them, checkerboard fashion, in a dooryard garden or along a small backyard path, trampling them into the ground and once again breaking off small fragments of moss. A small board can be used to press and spread the mosses instead of trampling, but pressing them into the ground is important. It is the ability of mosses to regenerate from fragments that makes this process work so well. The fragments and new growth eventually fill in the empty squares of the checkerboard, providing a continuous carpet for the moss garden, although Schenk (1997) advises us that it can take 2-3 years for a ***Polytrichum*** (Figure 8, Figure 25-Figure 28) carpet to fill the gap. Mosses such as ***Brachythecium*** (Figure 57), with their horizontal growth form, may fill the gap within a year.

Figure 117. Stacks of ***Polytrichum*** are ready for delivery to a private garden near Nagoya, Japan. Photo by Janice Glime.

This ancient art of planting mosses by pulverizing them has been adopted by the American Horticulturist Society. In their Fact Sheet for Moss Gardening, they recommend grinding dried moss and spreading it as powder, cautioning the gardener never to buy moss from a grower unless you are certain that the moss has been propagated by the seller and not taken from the wild – good conservation advice.

Experimental studies support this pulverizing method as well. Miles and Longton (1990) found that fragmentation was superior to spores in the development of upright shoots in such common garden mosses as ***Atrichum***

undulatum (Figure 3) and ***Bryum argenteum*** (Figure 73). In fact, Shaw (1986) contends that whether in an industrial setting or in the laboratory, starting cultures from spores is impractical for many species. He found, using the pulverizing method, that within a month, new gametophores were evident in most species, and within three months regenerated plants filled his pots. He had the best results when the plants were misted for six seconds every thirty minutes. Svenson (2000), on his moss gardening website, recommended filling in the bare spots between patches of moss by using the pulverizing method. This can be done by putting pieces of moss in a blender with a small quantity of water for two minutes, then spreading them between the transplanted mosses.

A mixture of 50% coarse sand, 30% vermiculite, and 20% peat provides a good substrate, and the optimum growth temperature for temperate zone mosses is believed to be around 10^{o}C (Iwatsuki 1979). In the laboratory, Petri plates with layers of filter paper saturated in tap water have been successfully used to regenerate ***Atrichum undulatum*** (Figure 3) leaf fragments (Gemmell 1953); in nature, the soil will do just fine if kept moist. [Note that not all tap water is created equal; it may kill some species and be worse in some areas.]

My students at Michigan Technological University successfully grew protonemata from fragments of five North American taxa in genera commonly used in moss gardens [***Atrichum oerstedianum*** (Figure 118), ***Dicranum scoparium*** (Figure 40), ***Fissidens adianthoides*** (Figure 48), ***Leucobryum glaucum*** (Figure 34), ***Plagiomnium affine*** (Figure 119)] in a dish garden, using this method and a modified version with a strip of cheesecloth over the fragments to retain moisture (Plante *et al.* unpublished data 1993; pers. obs.). Protonemata developed in 2-3 weeks. Fragments placed on sand alone failed to produce any growth during the experiment. In addition to the fragments, whole plants were planted, and at least a few plants of ***Atrichum oerstedianum***, ***Fissidens adianthoides***, and ***Plagiomnium affine*** produced new branches, although the original branches became brown and wilted. Subdued light (900 lux for 8 hr d^{-1}) and moderate temperatures (ca. 20^{o}C) seemed more favorable than a higher light intensity and temperatures of 38^{o}C.

Figure 118. ***Atrichum oerstedianum***, a species that can be grown from fragments. Photo by Karen Renzaglia, with permission.

Figure 119. ***Plagiomnium affine***, a species that can be grown from fragments. Photo by Janice Glime.

It is during the critical early establishment stage that moisture is very important, and the Japanese often time their planting to coincide with the rainy season so that the mosses get natural watering daily. Yet, the entire first year and often the second require careful attention to water requirements. As discussed in the chapter on "Water Relations: Rehydration and Repair," frequent wetting and drying is quite detrimental to a moss because each time it is dried and rewet it must repair damaged membranes, often requiring a full day before there is any net energy gain. Transplanting brings with it its own share of damage and adjustment that makes the mosses less tolerant of natural stresses.

It is interesting that Schenk (1997), with his long-time experience as a moss gardener, reports that few mosses will grow successfully from fragments. He touts ***Leucobryum*** (Figure 34; Figure 120-Figure 121), ***Racomitrium*** (Figure 53), and ***Dicranoweisia*** (Figure 122) with this ability, but finds others to be reticent to yield to the gardener's wishes. Nevertheless, as he acknowledges, all mosses share this ability to regenerate from fragments, and I have observed in nature young shoots of ***Scapania undulata*** (Figure 123) (Glime 1970) and ***Atrichum*** (Figure 3, Figure 92) (Glime 1982) developing from leaf fragments to which they were still attached. ***Fissidens*** (Figure 48) species are especially adept at this, and I soon found new colonies all over my garden room, presumably transported about as fragments by my box turtle – they had never produced any capsules. In the lab, Plante *et al*. (unpub. data 1993) were successful with both whole plants and fragments of ***Fissidens***.

Figure 120. ***Leucobryum glaucum*** apical rhizoids, ready to grow if they get broken off. Photo courtesy of Sean Edwards.

Figure 121. ***Leucobryum*** sp. showing protonemata growing from leaf fragments. Photo courtesy of Andi Cairns.

Figure 122. ***Dicranoweisia crispula***, a moss that is easily grown from fragments. Photo by Michael Lüth, with permission.

Figure 123. ***Scapania undulata***, a leafy liverwort species that regenerates from leaf fragments. Photo by David T. Holyoak, with permission.

One of the most luxurious growths of moss I have seen outside of nature was on a discarded piece of carpet that was able to soak up and maintain moisture over long periods of time (see, for example, Figure 124). This is reminiscent of the technique of using cheesecloth on flats to grow mosses that are to be draped over rocks or uneven landscapes. The cheesecloth method takes advantage of fragments, although spores can be used as well (McDowell 1968). Partially dried moss fragments must be spread over cheesecloth that overlies a sand-peat moss or sawdust mix in a flat. The *p*H can be lowered by soaking the mix in a solution of 1 part skim milk or prepared powdered milk to 7 parts water (McDowell 1972). These are covered with a second piece of cheesecloth and kept moist by misting.

Figure 124. This rug has a luxurious growth of ***Ceratodon purpureus***. Photo by Michael Lüth, with permission.

When the plants are well established (about 4 ½ months), it is easy to transplant them by lifting the soil/cheesecloth layer. The cheesecloth can be cut to shape as needed. Some gardeners have been successful in growing rock-dwelling taxa this way as well. The cheesecloth can easily be draped over rocks. The mosses grow through the cheesecloth, and eventually the cloth will rot away. If the white color of the cheesecloth is bothersome, coffee (soak in 3 teaspoons instant coffee per cup boiling water for 10 minutes) can be used to stain the cloth (McDowell 1972). Crum (1973) has found that ***Brachythecium salebrosum*** (Figure 125) and ***Plagiomnium cuspidatum*** (Figure 42) are relatively easy to grow in this way, emphasizing that regeneration works better than transplantation.

Figure 125. ***Brachythecium salebrosum*** with capsules, a moss that will develop well on cheesecloth. Photo by Michael Lüth, with permission.

Even when mosses are transplanted or sewn directly on the garden soil, it is often necessary to spread a cover of cheesecloth to prevent damage from birds that would destroy the tender plants before they could gain sufficient establishment. If the moss is to be transplanted, the cheesecloth serves the double purpose of keeping the moss from breaking apart as it is handled.

Planting on rocks can be a challenge, as the moss may buckle up on the dry substrate, or simply get blown away. One solution to this is to glue them there with a good epoxy such as Araldite, a very strong two component epoxy resin (Paul King, pers. comm.).

Transplanting

For those preferring the transplant method, the best place to gather moss is rich woodland areas (Pullar 1966/1967) and the best time of year to collect is from autumn into the winter months (Iwatsuki 1979), depending on where you live. But mosses should not be gathered without permission of the owner, and on public lands a collecting permit is usually required (and should only be done if the area is scheduled for destruction). Furthermore, bryophytes should not be imported from other countries for one's personal gardens, and when such importation is necessary for an institution, proper permission must be gained from both the country of origin and the one of import.

Mosses can be transported in a variety of ways fitting your own convenience. Annie Martin uses plastic sleds (Figure 126) and plastic flats (Figure 127). Paul More uses cardboard boxes (Figure 128). I have used deeper boxes, putting layers of newspaper between the layers of mosses to separate them. The newspaper can be omitted, but it is easier to separate the mosses later when the layers are distinct. I have also used ice cream buckets on short excursions when I had no transportation (Figure 129).

Figure 126. Sleds of mosses, in this case being transported for planting. Photo by Annie Martin <www.mountainmoss.com>, with permission.

Figure 127. Raleigh Project, loading moss in plastic flats into truck. Photo courtesy of Annie Martin <www.mountainmoss.com>.

Figure 128. Paul Moore planting mosses directly on the ground, using boxes to transport them. Photo courtesy of Paul Moore.

Figure 129. Janice Glime gathering moss for her garden. Photo courtesy of Eileen Dumire.

Although bryophytes lack roots, their rhizoids are often connected to symbiotic fungi (*e.g.* Davey & Currah 2006; Renzaglia *et al.* 2007; Pressel *et al.* 2010). Therefore, they should not simply be plucked from their substrate. It is preferable to bring the top layer of soil with them. This is important for several reasons. It will help to maintain fungal connections and provide an inoculum for new associations to establish; it will help hold cushion growth forms together; and it will retain the suitable nutrient and *p*H conditions of its original substrate, at least initially.

For some species, removal from their forest habitat might mean removal from a necessary host plant. Some bryophytes, in particular ***Cryptothallus mirabilis*** (Figure 130), require a photosynthetic partner to provide carbohydrates. This partnership can be mediated by the mycelial threads of a fungus that is also linked to a shrub or tree that reaches closer to the canopy. Or it might be linked to decaying leaves or logs. This is a recent area of research, so we know little about these partnerships, but they may explain the failure of some transplants.

Figure 130. ***Cryptothallus mirabilis***, a thallose liverwort that requires a fungal partner to obtain carbohydrates. Photo by David Holyoak, with permission.

Pinning the bryophytes to the substrate with wooden toothpicks angled through the mat (Figure 131), a technique I learned from Jon Shaw, helps to maintain contact with the substrate during dry periods, and of course keeps them where you put them. Special moss clips (Figure 132) are available for anchoring the mosses, but toothpicks work and are less conspicuous.

Figure 131. Toothpicks holding transplanted mosses onto a clay bank. Photo courtesy of Annie Martin <www.mountainmoss.com>.

Figure 132. Moss pins from Moss and Stone Garden. Photo with permission from David Spain.

In this regard, Schenk (1997) advises maintaining as much soil depth as possible when gathering the clump of moss, whereas Bland (1971) advises one to remove as much as possible to prevent curling up at the edges (Figure 133), turning the moss upside down and washing away the soil to prevent shrinkage. I recommend the former because it causes the least disruption of rhizoids and one doesn't have to worry about destroying possible mycorrhizal connections, which may be more common than we realize. It does require keeping the moss and soil wet until the soil has blended with the underlying substrate.

Figure 133. ***Bryum*** sp. in moss garden. These mosses were touching tightly together when they were planted, but when they dried they shrank, creating spaces around the edges. Photo by Janice Glime.

Signs of death occur rapidly in transplants, but those clumps that remain green will become stabilized within a few weeks. Once they do, Ando (1971) suggests that regular watering can be discontinued. Seike *et al.* (1980), on the other hand, recommend daily watering.

Maintenance of the integrity of the clump is of utmost importance. If it is necessary to expose the lower part of the stems around the edge of the clump (Figure 134) due to using only part of a clump or other disruption, these lower parts should be protected either by building up soil around them or pressing a rock next to them (Figure 135). If some of the stems are taller than the other stems, they can be cut to avoid having them dry out. For many bryophytes, a new branch will form and continue growing.

Figure 134. ***Bryum*** sp. with exposed edge in the forefront. The moss will dry out here and die back from the edge. Rocks placed against such edges, or other moss clumps, will reduce the drying, but frequent watering after transplanting is important. Photo by Janice Glime.

Figure 135. ***Ceratodon purpureus*** and ***Bryum*** sp. with stones to protect edges. Photo by Janice Glime.

If you are trying to establish a lawn, you might be able to purchase a ready-to-go mat (Figure 136). These can be rolled up much as the sod purchased for grass lawns. With a landscaping mat under them, they are easy to handle (Figure 137) and to cut to fit any area (Figure 138-Figure 140).

Figure 136. Pre-vegetated mat from MountainMoss. Photo courtesy of Annie Martin <www.mountainmoss.com>.

Figure 137. Raleigh Project laying down sheet of moss. Photo courtesy of Annie Martin <www.mountainmoss.com>.

Figure 138. Cutting shape of the moss mat. Photo courtesy of Annie Martin <www.mountainmoss.com>.

Weeding of the imported moss is important so that competition is not planted with the mosses. Leaf, stick, and seed litter should be removed, but caution must be used to prevent disruption of the clump.

Some gardeners recommend making a depression, laying a bed of gravel, then putting the mosses on top, but still within the depression. Exposure of the lower parts of the moss seems to be a prescription for disaster due to excessive drying.

Figure 139. Removing cut portion from the moss sheet. Photo courtesy of Annie Martin <www.mountainmoss.com>.

Figure 140. Moss mat after it has been positioned and cut to allow for planting flowers. Photo courtesy of Annie Martin <www.mountainmoss.com>.

It is to our benefit in gardening that the mosses respond quickly to the stresses of sun, showing bleaching or browning of leaves in only a day (Schenk 1997). This quick forewarning tells us to try a different location, a different moss, or provide more care and maintenance.

Substrate Conditioning

Successful moss gardening requires at least a modicum of knowledge of the ecology of mosses, and a student of their ecology has much to learn from the successful moss gardener. Aside from the expectation that they will require a moist, shaded habitat, most non-bryologists have little understanding of bryophyte requirements. Most mosses seem to prefer a *p*H of about 5.5, attainable by spreading powdered sulfur over the soil (about 1.1 kg per 9 m^2) (Schenk 1997). Alternatives include powdered skimmed milk, aluminum sulfate, or rhododendron fertilizer. A light misting from the sprinkler will help to affix these to the ground. However, Alison Downing reminded us on Bryonet (20 April 2005) to be careful using milk (or any lime) on sandstone because the calcium in milk can completely change the nature of a sandstone habitat. Instead of ***Campylopus*** (Figure 141), ***Lophocolea*** (Figure 9), ***Sclerodontium*** (Figure 142), and other typical sandstone taxa, you will find instead introduced or cosmopolitan taxa such as ***Funaria*** (Figure 143) or ***Bryum*** (Figure 73).

Figure 141. ***Campylopus introflexus***, an invasive species that will be discouraged by milk applied to sandstone due to the calcium. Photo by Michael Lüth, with permission.

Figure 142. ***Sclerodontium pallidum***, a species that will be discouraged by milk applied to sandstone due to the calcium. Photo by Niels Klazenga, with permission.

Figure 143. ***Funaria hygrometrica***, a species tolerant of charcoal and calcium. Photo by Michael Lüth, with permission.

Maintenance

Martin (2016) advises using the three W's in caring for a moss garden: Water, Walk, Weed. Although mosses will survive extended drought, they won't look nice. And when you are first propagating them, whether by spores, fragments, or transplants, they need constant hydration, often requiring watering. Walking on more mature plants helps to spread them through fragmentation (Figure 144). Weeding needs no explanation – the tracheophytes can quickly outgrow them.

Figure 144. Annie Martin demonstrates walking on mosses to help in fragmentation and dispersal. Photo by Annie Martin, with permission <www.mountainmoss.com>.

No Fertilizers?

Fertilizers must be applied to mosses with great caution. An "elixir" of manure seems to be a suitable supplement (Schenk 1997). Svenson's (2000) website suggested steeping cow manure in a burlap or cheesecloth bag in a bucket of water for 3 weeks (outside, I hope!) before applying it. An alternative is using 1 part of skim milk or buttermilk to 7 parts of water and applying twice per day for two weeks in spring to acidify the soil. Most other fertilizers, especially if applied dry, can kill the moss.

David H. Wagner (Bryonet 8 May 1998) told us that the egg albumen mixed with buttermilk would polymerize and act as a protein binder, creating an adhesive. As the mosses grow and become established, the mix becomes a source of nitrogen for them.

Iwatsuki and Kodama (1961) caution that fertilizer should never be used for mosses. Contrasting to the powdered sulfur acidifier recommendation of Schenk (1997), Stubbs (1973) recommends the use of fertilizer based on iron sulfate as a means of killing moss fast. In fact, fertilizer is a commonly suggested means for getting rid of unwanted mosses. On these one-cell-thick leaves, the dry powder soon goes into solution when water becomes available, greatly altering the osmotic relationship between outside and in and introducing the potential of membrane damage. Furthermore, dry fertilizers tend to be hygroscopic and draw water from the delicate and unprotected moss leaves. The effect is much like the desiccation seen among the mosses on Mount Rainier shortly after the eruption of nearby Mt. St. Helen's (Figure 145). However, if applied in liquid form followed by frequent watering, fertilizer can benefit the moss. Lime fertilizers, however, should be avoided due to their alteration of the *p*H. The seeming contradiction to the advice of Schenk is that he suggests applying the acidifiers to the soil and wetting them down **before** the moss is planted there.

Horticultural magazines and texts extol the advantages of a wide variety of human foods as starters for mosses. Gillis (1991) describes making moss beds by mixing a handful of moss, a can of beer, and a half teaspoon of sugar in a blender, then spreading the mix 5 mm thick on the ground. She found that the mosses grew within five weeks. In addition to beer, egg whites, and buttermilk, others have successfully used rice water, carrot water, potato water, and just water as the medium. Ellis (1992) claims that such mixtures, even the water, are particularly helpful in adhering the moss fragments to rocks. My own experience is that these food additions serve best to feed fungi and pillbugs, thus being detrimental to the mosses.

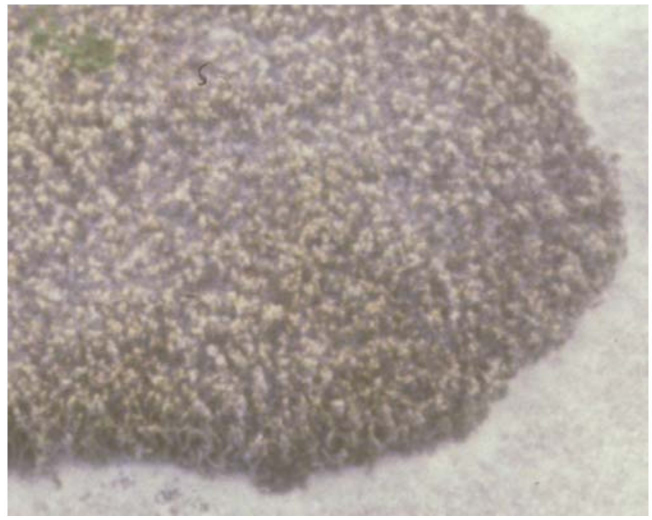

Figure 145. This ***Grimmia*** on Mt. Rainier, Washington, USA, is covered with ash from the eruption of nearby Mt. St. Helen's. The moss is badly desiccated by the ash that is like some fertilizers. Photo by Janice Glime.

Annie Martin (Bryonet 22 June 2013) raised the issue of fertilizing the mosses. First, fertilizers should be applied in very dilute watering additions. Fertilizers on dry mosses can further desiccate them. As in all other issues regarding bryophytes, bryophyte species differ in their responses. Annie Martin (Bryonet 22 June 2013) reported that in her early days of moss gardening experimentation, she watered with Miracle-Gro acid mix. However, when she learned of the dangers of fertilizers she switched to straight tap water only.

One additional problem with applying fertilizers is that flowering plants will benefit more than the mosses, thus introducing a greater weed problem.

Watering

The subject of watering is an interesting one. Some people are adamant that only distilled, demineralized, or rainwater can be used. Others have no problem using tap water (Figure 146). This argument does not surprise me. Tap water can differ greatly between locations. I was amazed to find ***Fontinalis*** (Figure 147) growing happily for years in a tap water aquarium in Japan. But when I tried to grow several species in tap water in New Hampshire, USA, the copper in the water from the pipes turned the plants yellow overnight. After that failure, we used only stream water.

Figure 146. Sprinkling system used by Paul Moore on his moss lawn. Photo courtesy of J. Paul Moore.

Figure 147. ***Fontinalis antipyretica***, an aquatic moss that is sensitive to heat. Photo by Bernd Haynold, through Wikimedia Commons.

City water is much more likely to kill bryophytes than spring water. City water usually has chlorine added and suffers from the solution of metals from water pipes. It also matters if the tap water is the exclusive source of water. Minerals can accumulate on the surface on the bryophytes; intermittent rainfall can remove some of that accumulation. *p*H can make a difference because it is less likely to carry calcium that forms crusts on the mosses. Annie Martin (Bryonet 22 June 2013) has had no problems using tap water (Figure 148) for at least 10 years, but her water is acidic. Martin considers adequate watering to be the most important factor in moss garden success.

For my own garden, I used collected distilled water or rainwater for several years (Figure 149). Other years I used only misting with a sprinkling system that used tap water (Figure 150). However, that tap water went through a filtering system that removed some of the minerals, and spraying it in the air helped to dissipate the chlorine.

Figure 148. Furman-Moss-Watering at Mountain Moss. Photo courtesy of Annie Martin <www.mountainmoss.com>.

Figure 149. Distilled water and collected rainwater are both good sources of water if your tap water is detrimental to your bryophyte garden. Since the garden is outdoors, the bryophytes collect dust and get their nutrients from that dust when they are watered. Photo by Janice Glime.

Figure 150. Sprinkler in my own moss garden. When the water comes on, the sprinkler head rises to about 15 cm and sends water in all direction.

One gardener in Raleigh, NC, USA, has been very successful growing **Mniaceae**, including ***Plagiomnium*** (Figure 42) (reported by Annie Martin, Bryonet 6 August

2010). He, like Martin, uses three layers of felt with plastic underneath and netting on top. Martin believes his success is due to watering six times each day for 4 minutes per watering session. He uses creek water in his misting system. Watering in unplanted areas also resulted in a carpet of thriving ***Plagiomnium*** that arrived by itself.

Annie Martin (Bryonet 6 August 2010) warns that not all mosses have the same nutrient or watering requirements. She finds that ***Bryum*** species (Figure 73) need to dry out sometimes; likewise, ***Dicranum scoparium*** (Figure 40) will not tolerate being wet all the time.

I have never tested it because my own garden is too small to replicate, but I have assumed that watering the mosses on a sunny, hot afternoon is not wise. They can't close guard cells like flowering plants, and they are C_3 plants that respire more than they photosynthesize at higher temperatures, often starting above 20ºC. I have assumed that it is best to let them shut down on hot, sunny afternoons. I do know that ***Fontinalis*** species (Figure 147) cannot sustain vitality if kept in water at 20ºC for more than 3 weeks (Glime 1987), presumably due to the high respiratory ratio. In my own moss garden, I have an automatic sprinkling system that comes on at 6 am, giving the plants sufficient moisture to photosynthesize in the cool hours of the morning. This regime seemed to work well. In hotter locations, an earlier watering time might be preferable.

One dealer recommends daily misting as opposed to intermittent watering to avoid drying or water logging. But one must exercise caution here. Bryophytes that suffer frequent wetting and drying (to the point of damage) will not have sufficient time for repair during the intermittent moist periods. Consider a sprinkling system to keep things moist, preferably on a timer to water at night, permitting the bryophytes to photosynthesize in the cool morning.

I have found that advice I get on moss gardening from another part of the country often does not work for me, and I end up going back to my original methods. Alkaline soils or clay soils will require different watering regimes from those of humus, and ease of transplanting and growing will be much better in humid or rainy climates. For example, I found that mosses stay wet longer for me if I do NOT put them on layers of felt, but can understand that downstate where Rick Smith gardens, limestone soils may serve as a desiccant and dry the mosses more quickly and the felt would protect against that. The felt and plastic do help reduce weed invasion.

Weeding

Mashuri Waite (Bryonet 2 February 2011) expressed his surprise when visiting the Cibodas Botanical Garden in West Java, Indonesia. He found that a species of ***Marchantia*** (Figure 16) was a problem weed in that garden. This was in contrast to his experience in Hawaii. This is yet another example of differences in the success of a species of bryophyte under different growing conditions.

Weeds are also a matter of personal choice. To one person it is a weed; to another it is a cherished plant to be encouraged.

Weeding bryophyte gardens requires different methodology from gardens of flowers and ferns. The surface-growing bryophytes are easily dislodged as the weeds are pulled up. It is best to pull the weeds, especially tracheophytes, as soon as they appear and before they grow large roots. This will create the least disruption. When pulling them, especially if they have penetrated the ground very far, hold the plant to be pulled close to the ground and place the middle and index fingers of the opposite hand so that one is on each side of the base of the stem to hold the bryophyte in place as the rooted plant is pulled. Weeding should be done as often as necessary to keep the garden weed free.

Weeding is not as big a job as it may seem if it is done frequently. Young plants are easy to pull. And usually kneeling or stepping on the bryophytes does not harm the bryophytes and may even help to propagate them.

Herbicides

There actually are a number of publications on the effects of herbicides on bryophytes (*e.g.* Stjernquist 1981; Balcerkiewicz & Rusinska 1987).

Of course mosses are slow growing and soon succumb to the encroachment of tracheophytes, so it is no wonder that herbicide applications can result in luxurious moss carpets. Schenk (1997) has witnessed the ready success of ***Polytrichum*** (Figure 8, Figure 25-Figure 28), ***Pohlia*** (Figure 151), and ***Atrichum*** (Figure 3, Figure 92) following such applications, and Ella Campbell, at a bryological meeting, once commented that the hornworts were ready colonizers following herbicide applications. Likewise, Balcerkiewicz and Rusinska (1987) found that bryophytes expanded on areas treated with herbicides.

Figure 151. ***Pohlia nutans***, a species that seems to benefit from herbicide applications. Photo by Michael Lüth, with permission.

Herbicides such as Paraquat, Simazine (Bond 1976), 2, 4-D, Atrazine (D. H. Wagner, pers. comm.), and Roundup (Schenk 1997) will encourage moss growth by eliminating invading tracheophytes (Bond 1976). Weeding is of course a safer option, but be sure to hold the mosses down as you pull each weed to avoid disrupting the rhizoids too badly.

Ben Tan (Bryonet 15 April 2014) reported that experiments using herbicides and pesticides, conducted by his students, did not result in an easy kill of the mosses except at very high concentrations. He cautioned that if one does eliminate the mosses, aggressive flowering plants (weeds) will readily establish themselves.

But this is not the experience of all researchers. Rowntree *et al.* (2003) found that the herbicide Asulox inhibits moss growth. When they cut plants to a standard length and expose them to Asulox for 24 hours, they found

that all 18 species tested exhibited reduced elongation. The amount varied among species and at different concentrations. The effective concentrations were the same as those effective on fern gametophytes. Rowntree and coworkers suggested that the ability to produce secondary branches might confer tolerance to single exposures of Asulox in some species.

In a different study, Rowntree *et al*. (2005) exposed cultures of ***Bryum rubens*** (Figure 152-Figure 153), ***Campylopus introflexus*** (Figure 141), and ***Polytrichastrum formosum*** (Figure 154) to Asulam in the culture medium. This study used protonemata that were exposed for 24 hours to Asulam, then transferred to herbicide-free media. A second trial maintained the protonemata on the herbicide medium for three weeks. In this case, the 24-hour exposure at concentrations of 0.001 g active ingredient L^{-1} had no effect on growth or development of the mosses. However, all three species experienced reduced growth and developmental anomalies in continuous of exposure at 0.01 g L^{-1}. ***Campylopus introflexus*** was the least sensitive; ***Polytrichastrum formosum*** was the most sensitive, with a 10-fold difference in response.

Figure 152. ***Bryum rubens***, a species for which development is affected by the herbicide Asulam. Photo by Michael Lüth, with permission.

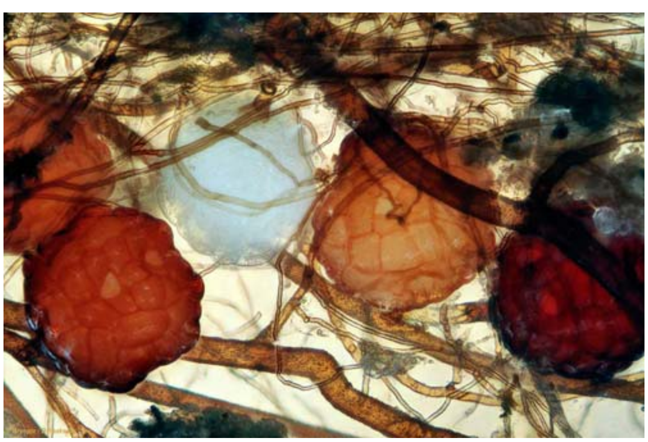

Figure 153. ***Bryum rubens*** tubers that help the plants survive unfavorable conditions and produce new plants. Photo by Dick Haaksma, with permission.

Figure 154. ***Polytrichastrum formosum***, a species for which development is affected by the herbicide Asulam. Photo by Michael Lüth, with permission.

Karunen *et al*. (1976) exposed germinating ***Polytrichum commune*** (Figure 25) spores to S-ethyl dipropylthiocarbamate. Surprisingly, at low concentrations (2 ppm by weight), the herbicide actually stimulated the growth of the young protonemata compared to the controls. They had a higher chloroplast pigment content as well. When the concentration was increased to 100 ppm, however, the development was slowed and there was a 30% reduction of chlorophylls and carotenoids. Nevertheless, the dry weight did not differ significantly from that of the controls. At 200 ppm, the spores either did not germinate, stopped germinating at an early stage, or formed deformed sporelings with few tightly-packed short cells. A number of unusual morphological changes occurred. A concentration of 300 ppm the spores rarely germinated.

Dichlorophen (2, 2′-methylene-bis(4 chlorophenol)) is a commercial product used to eliminate bryophytes (Brown *et al*. 1986). Brown and coworkers experimented with the pleurocarpous moss ***Rhytidiadelphus squarrosus*** (Figure 2) and the thallose liverwort ***Marchantia polymorpha*** (Figure 16). Dichlorophen induces loss of intracellular potassium and magnesium, inhibits photosynthesis, and depending on concentrations either stimulates or depresses CO_2 production in the dark. These symptoms suggest membrane damage. Tissue age affects the sensitivity, but light does not.

Rod Seppelt (Bryonet 17 April 2011) reported that an Australian student had studied the effects of herbicides on mosses. The student concluded that it was the surfactants in some herbicides that provided the damaging factor. But he concluded that bryophyte response to herbicides was complex.

Using 115 plots in a randomized design, Newmaster *et al*. (1999) compared the effects of two silvicultural herbicides (Vision®, Release®) on bryophytes and lichens in a harvested boreal mixed woodland. Concentration gradients of 0.71-6.72 kg active ingredient ha^{-1} caused a decrease in species richness and abundance in both groups. Only a few species of colonizers remained. Bryophytes and lichens could be sorted into herbicide-tolerant colonizers, semi tolerant long-term stayers from dry open forest, and sensitive forest mesophytes.

Bryophyte "Predators"

Bryophytes are not without their share of enemies – playing roles with impacts that few ecologists have begun to imagine. I couldn't keep mosses in my garden room – even when I brought in vast quantities; my finches soon spread them about the room in their efforts to carry them to their nests, but even the dispersed mosses were soon removed by the birds. Newly established protonemata are soon disrupted and destroyed by birds gathering new plants or scratching for grit. In my terrarium, the pillbugs (***Porcellio scaber***; Figure 155) eradicated them from the rocks completely in just a few weeks, and the beautiful carpet I draped on a rock outside was transformed literally overnight into the look of Swiss cheese. Picking up the moss carpet to understand the problem resulted in hundreds of pillbugs falling to the ground! As mentioned earlier, those wanting to use moss they collect are often encouraged to spray a 50% mix of buttermilk and water on the desired surface and then presumably spread a moss carpet over it, but I tried a similar recommendation of raw eggs to little avail. It was that patch of moss that became devoured by pillbugs and I suspect the egg helped make it so.

Figure 155. ***Porcellio*** *cf.* ***scaber*** on ***Marchantia polymorpha***, a common herbivore on bryophytes. Photo by Walter Obermayer, with permission.

To keep your bryophyte garden healthy and green, Mizutani (1975, 1976) and Fukushima (1979a, b, 1980) advise eliminating potential destroyers such as moles (Figure 156), slugs (Figure 157), crickets (Figure 158), and ants (Figure 159). Good luck!

Figure 156. Mole, sometimes a pest in moss gardens. Photo by Michael David Hill, through Creative Commons.

Figure 157. Slug on ***Fissidens*** sp. Photo by Janice Glime.

Figure 158. ***Gryllus rubens***, southeastern field cricket. Crickets can be a pest in moss gardens. Photo by Jeffrey Reed, through Creative Commons.

Figure 159. Ant on moss, sometimes a pest in moss gardens. Photo through Creative Commons.

A second concern may be introducing pests from other locations, especially outside the country. Bryonetters discussed this several years ago, but many of the reports covered what didn't work. Among these, Eva Krab (Bryonet 3 February 2012) reported using 100% CO_2 for 12 hours in a closed chamber, then leaving the cores of moss out at room temperature for 24 hours to allow eggs to hatch, then freezing them at -20ºC. After three rounds of those treatments, she had no success with ***Sphagnum fuscum*** (Figure 20) and only limited success with ***Hylocomium splendens*** (Figure 58).

Other Pests

Rick Smith, on Bryonet 9 February 2011, claimed that "birds have so much time on their hands they relentlessly attack moss gardens and unless the botanic garden has lots of moss then the birds concentrate their damage on the small poor moss garden." My own experience is that chipmunks can be just as destructive. They need only run across the bryophytes and their feet kick them up. And they seem to have a special attraction for ***Thuidium delicatulum*** (Figure 43-Figure 45) as the entrance to their tunnels. Mine never lasted for more than a few days before it had a bare spot and a tunnel entrance in the middle of it! I'm fairly certain that was a chipmunk, but some of those torn up patches may have been the work of birds instead of chipmunks. The fresh patches of mosses seem to attract the most attention. Perhaps it is due to birds looking for food among the fauna. Rick Smith also warned that "other obstacles are rodent damage (vole, squirrel, raccoon) and leaf removal."

Rick Smith has written a small book, *New Methods in Moss Gardening*. In that book he explains using an invisible mat system to reduce the unwanted interaction. He places felt (Figure 162) on the bottom – 2-3 layers, to block the competing vascular plants from emerging and to keep the soil from wicking the water away. On that he grows the mosses with a net on top to keep the birds and rodents from tearing it up. I have not had much success with the felt, but I think the problem is that I start with clumps of moss and Rick starts with tiny pieces that he broadcasts on the felt, then grows them in controlled conditions until they are large enough to put in the garden. I did try that once, but mine dried out too quickly. His method is much like grabbing that discarded carpet that has accumulated bits of soil and a healthy growth of mosses. But for thicker mats where tree seeds can lodge, seeds still germinate and succeed.

Overwatering can have some interesting invertebrate consequences. Too much water encourages earthworms to live closer to the surface, resulting in castings (Spain 2012b). If this is a moss garden with thin mats, the castings are deposited on the moss (Figure 160). When these are numerous, as they can be, they become unsightly. The prevention is to decrease the watering.

Figure 160. Earthworm castings on a moss mat. Photo by Ken Gergle for Moss and Stone Gardens.

Earthworm castings can be removed by letting them dry and removing them with a knife or crumbling them (Spain 2012b). The remaining hard portion can be removed by using a pump sprayer to soften them and gently wash them away. Using a hose or other high-power sprayer should be avoided because it will make the moss and soil wet again, once again encouraging movement of the worms to near the surface.

Netting

The netting is another story. One recommendation is to use a fine net with a mesh of about 0.8 mm such as a bridal veil, a material known as **tulle**, to keep rodents and birds from disrupting the bryophytes. But bridal veil is unsightly. Instead, I started with a fine mesh like one might find on a wedding veil, but instead of the soft cloth of wedding veils, I chose nylon window screening because it was not so conspicuous. That protected the mosses from rodents and birds, but for some of the mosses it kept them from getting wet unless it was a downpour. The water would bead up on top of the screen (Figure 161-Figure 162) and its cohesion kept it from penetrating. Sometimes cohesion and adhesion work to disadvantage!

Figure 161. ***Bryum*** sp. on burlap with wet net in lower half of image. Upper mosses in image have no netting. Photo by Janice Glime.

Figure 163. ***Polytrichum juniperinum*** under netting, showing how they have grown sideways due to the restriction of the netting. Photo by Janice Glime.

Figure 162. Wet netting on ***Polytrichum commune*** that is planted on brown felt, showing the water beading on the net and not penetrating to the moss. Photo by Janice Glime.

Figure 164. ***Polytrichum*** and fragments on felt under nylon window screening. Rocks hold the edges of the screening in place. Photo by Janice Glime.

Polytrichum (Figure 8) had particular problems with the nylon window screening. It often bent over instead of growing through the mesh (Figure 163-Figure 165), and the water beaded up on top of the net. In the morning when dew was on the net, the mosses were invisible. The next growing season some of the narrower young shoots grew through the net, but setae formed the previous autumn were trapped under the net (Figure 166). Finally, all the growing tips were above the netting that spring (Figure 167). But even then, water movement was not normal because of the constricting threads at the point where the moss penetrated the net. And if the mosses grow through the net, the netting can never be removed. Now, seven years later, the net is hidden and the mosses appear to be normal (Figure 168).

Figure 165. ***Polytrichum juniperinum*** under netting after stems became more upright. Photo by Janice Glime.

Figure 166. ***Polytrichum juniperinum*** emergence through netting with sporophytes produced the previous growing season trapped beneath the netting. Photo by Janice Glime.

Figure 167. ***Polytrichum juniperinum*** emergence through netting after several years of growth. Note how it keeps the plants separated, reducing their ability to help each other transport and retain water. Photo by Janice Glime.

Figure 168. ***Polytrichum juniperinum*** in moss garden, November 2017. They are continuing growth above the netting, with netting completely hidden. Photo by Janice Glime.

Rick Smith (Bryonet 30 August 2010) solved the constriction problem by placing the net over moss fragments so that they grew through it while they were still small and thin. Young (small) plants will grow through the bird netting, but so do some young weeds, and they are pretty impossible to pull out by the roots and to get out of the netting.

One solution to this problem is to put bird mist netting over the bryophytes instead. Susan Moyle Studlar (Bryonet 6 February 2012) considers netting to be essential to keep birds out. In her West Virginia, USA, garden, the birds toss the mosses about "with abandon" in search of the invertebrates beneath them. She found that the Berlin Botanic Garden used bird netting to protect the bryophytes from birds (Figure 169).

Figure 169. Moss garden in Berlin Botanic Garden, showing bird netting. Photo courtesy of Susan Moyle Studlar.

I finally solved the problem by ordering bird mist netting. It has a mesh about 5-6 mm and is made of fine black plastic. I hold it in place and help it conform to the uneven surface be pinning it down with bobbi pins. Once it is firmly attached, it is invisible unless you are looking for it or are up close. This type of netting is less conspicuous and doesn't interfere with growth (Figure 170-Figure 171). It must be firmly attached at its edges or the mosses will still be susceptible to disturbance and the netting can come off. Some birds may even try to remove it for nesting material.

Figure 170. ***Leucobryum glaucum*** moss garden with bird netting. Note the clumps that have been broken up – damage done before the netting was applied. Photo by Janice Glime.

Figure 171. ***Leucobryum glaucum*** with bird netting in moss garden. Photo by Janice Glime.

Removing Autumn Leaves

Most of the bryophytes will need partial shade. But in a relatively small space, the best shade is likely to come from one or two deciduous trees. And these dump enough leaves in the fall to bury the bryophytes. The leaves do not decay rapidly enough to expose the bryophytes the next spring, and some seem to suffer from the tannic acids during the winter under the snow. Hence, removal is necessary.

Famous gardens such as Saihoji in Kyoto require constant maintenance to encourage the mosses against the competing tracheophytes. Leaf litter and weeds must be removed lest the mosses be crowded out, but care must be taken to maintain the natural, unmanicured look. Wire or bamboo rakes or soft brooms (Figure 172) are used for such maintenance; brooms should be firm but not harsh to reduce damage to the delicate moss leaves. There is a Japanese saying that only old men and little boys can tend the moss gardens because anyone else would be too careful and the gardens would lose their natural look (Takaki, pers. comm.; Figure 173).

Figure 172. This broom is used for tending a private moss garden in Japan. Photo by Janice Glime.

Figure 173. This "old man" tends moss in Ginkakuji temple garden in Kyoto, Japan. Photo by Janice Glime.

Benner avoids raking leaves by covering the mosses with netting (Dunn 2008). He then collects the leaves and puts them in his compost heap.

Modern technology offers other solutions. One can vacuum the leaves or blow them onto a pile or onto flower gardens where they serve as a mulch (Figure 174). Annie Martin <https://www.youtube.com/watch?v=nh9S1IDfXzE&t=3s> suggests watering the moss garden first when blowing them. The mosses will stay put, but the leaves will still blow. Use an up and down jerky motion to dislodge the leaves.

Figure 174. Blowing leaves off the mosses. Photo by Annie Martin, with permission.

The modern methods of vacuuming the leaves have their limitations. Vacuuming is best done when the leaves are dry, and in some areas there are few dry days at that time of year or in some years. One must be careful not to blow or suck up dry mosses that are not well-connected yet. But then, even raking or brushing the leaves away is best done with dry leaves to protect the bryophytes from being removed.

Overwintering

Generally the predominantly perennial mosses will come through winter just fine. And in most cases, they will look bright green as soon as the snow recedes, being the earliest of the green plants to appear (Figure 175).

Figure 175. ***Dicranella heteromalla*** and ***Atrichum*** sp. demonstrate the fresh condition exhibited by many kinds of mosses that have just been uncovered from winter snow. Photo by Michael Lüth, with permission.

But don't despair if your moss garden comes out from under the snow the next spring looking like soon-to-be fossils. With a few warm (not hot) days and plenty of water, new shoots arise above the pathetic remnants of last year. My ***Leucobryum*** (Figure 34), ***Polytrichum*** (Figure 8, Figure 176), and ***Fissidens*** (Figure 48) did just that. The ***Racomitrium*** (Figure 53) remained brown and dead-looking for a long time, and I was ready to replace it with something more friendly when tiny green tips began to appear. There is nothing like a personal garden to teach you about the trials and tribulations of the bryophytes and their ways of solving these problems. And ***Marchantia polymorpha*** thalli are green and healthy when the snow recedes in the spring. It will be interesting to see how the competition plays out. I think ***Marchantia*** (Figure 16) is going to win.

Figure 176. ***Polytrichum*** sp. in snow. Photo by Annie Martin <www.mountainmoss.com>, with permission.

Arranging the Garden

Give some thought to the arrangement of the mosses and other plants. For the mosses to offer their peaceful appeal, flowering plants must be kept at a minimum. One long-blooming highlight is enough for a garden of $4m^2$, and it should be set off to the side or back to avoid detracting from the mosses (Figure 177). Be sure the plant won't crowd the ground, lie on top of the moss, or prevent light and/or water from reaching the moss. And avoid things that lose lots of leaves, requiring raking. As an alternative, lamps or statues can serve as highlights (Figure 178).

Figure 177. Moss garden with geranium accent. In early spring the irises on the right will bloom and be the accent. Photo by Janice Glime.

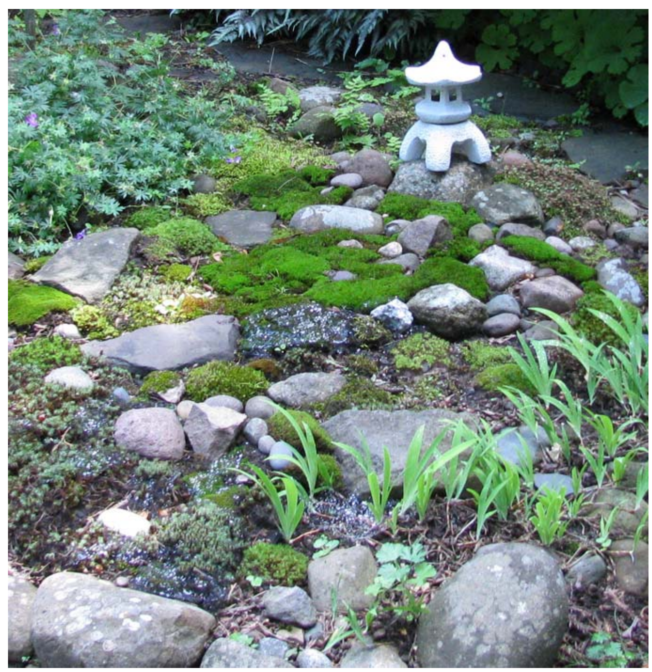

Figure 178. A small painted clay lantern provides a highlight in this garden when the flowers have stopped blooming. Netting over some of the mosses has water beads on the netting. Photo by Janice Glime.

Most mosses will need light shade, especially in the afternoon. A small tree, large shrub, building, or fence can provide this (Figure 179).

Figure 179. A neighbor's garage, a cedar fence, lilac bushes, and a Japanese maple tree provide shade for this moss garden in the morning, with the garage and my house shading it in the afternoon. Photo by Janice Glime.

The benefit of mosses in the garden can extend beyond their aesthetic value to that of enhancing the quality of other garden plants. Schenk (1997) reports that his friend, Gordon Emerson of Ohio, finds that bulbs, tubers, and corms increase more readily under moss cover than when planted in bare ground. Presumably the increased moisture permits them to produce and store more energy.

Environmental Benefits

I have already noted the decrease in water usage need by a moss garden vs a grass lawn. The bryophytes can often provide other solutions to environmental issues, such as collecting and preventing water run-off from storms. They also require no pesticides, herbicides, or fertilizers, therefore avoiding the contamination of the water that filters through them.

Figure 180. ***Fontinalis antipyretica***, an aquatic moss that is sensitive to heat. Photo by Bernd Haynold, through Wikimedia Commons.

Summary

Among the most common "moss" garden plants are thallose liverworts, especially ***Marchantia polymorpha***, peat mosses (***Sphagnum***), ***Polytrichum***, ***Atrichum***, members of the **Mniaceae**, ***Leucobryum*** (but it is somewhat difficult), ***Rhizogonium*** in Asia, ***Rhytidiadelphus triquetris***, ***Eurhynchium*** (*sensu lato*), and ***Bryum argenteum***. *Fissidens* species seem to be particularly easy to grow in temperate North America.

Special habitats may support only a few species, including ***Rhytidiadelphus squarrosus*** and ***Brachythecium rutabulum*** for lawns, ***Bryum argenteum*** and ***Barbula*** for paths, and ***Tortula muralis*** for walls.

Mosses cultivated in containers will need plenty of ventilation. Flats are good starter containers, with the mosses later transplanted to a "plantation" with light shade. Both can be planted by pulverizing the plants and spreading them like grass seed. A sprinkling system may be needed in a climate without a rainy season, and one should take advantage of the rainy season, where it exists, by planting just before it so the young plants or transplanted ones get plenty of water.

When transplanting mosses from the wild, the integrity of the clump or mat must be maintained. Of course one must have permission, and care should be taken not to decimate the population.

The substrate may be amended with a variety of substances to lower the *p*H, but liming and fertilizers are detrimental to bryophyte health. Herbicides may eliminate tracheophyte competition, but hand care by pulling weeds and clearing away litter is most likely a safer choice. Avoid giving the garden a manicured look and use only a light broom or wooden rake to clear away litter. Winter care need be no more than removing deciduous litter.

Once established, the bryophytes will require less water than a lawn or flower garden, require no fertilizers or pesticides, and prevent erosion. They are more environmentally friendly than most kinds of gardens.

Acknowledgments

I must acknowledge many Japanese friends for their tours of Japanese gardens and explanations of the establishment and care. In particular, Zen Iwatsuki and Norio Takaki gave me wonderful tours of both public and private gardens, indoors and out, and explained to me in English what the Japanese gardeners were telling us about the care of the gardens and plantation.

Thank you Ken Kellmann and Steve Soldan for calling our attention to the delightful New York Times article on moss lawns.

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GARDENING: PUBLIC GARDENS

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CHAPTER 7-5
GARDENING: PUBLIC GARDENS

Figure 1. Jassy moss house. This unusual garden transports you into another world. Photo courtesy of Ben Tan.

Botanical Gardens

Botanical gardens often have a bryophyte section, sometimes mimicking a Japanese garden. Some use mosses around indoor or outdoor waterfalls. And some actually label the bryophytes for teaching purposes. As you might guess, Japan is one of the places to see this latter practice.

Bryophyte gardening has been somewhat limited in North America, but there are notable exceptions. Annie Martin rescues bryophytes that are slated for destruction in North Carolina, USA.

Rick Smith teaches moss gardening by offering workshops. As a result of his workshops, Smith was invited to establish a moss garden at the Luthy Botanic Garden in Peoria, Illinois, USA, and a second at the Illinois Central College Arboretum in East Peoria. Both of these gardens have ***Dicranum scoparium*** (a dark green moss forming cushions; Figure 2), ***Polytrichum commune*** (Figure 3), ***Bryoandersonia illecebra*** (Figure 4), ***Leucobryum glaucum*** (Figure 5), ***Hypnum*** spp. (Figure 6), ***Thuidium delicatulum*** (a species that spreads easily; Figure 7), ***Anomodon attenuatus*** (Figure 8), and ***Plagiomnium cuspidatum*** (Figure 9).

Figure 2. ***Dicranum scoparium*** with capsules, a common species in moss gardens, public or private. Photo by Janice Glime.

Figure 3. ***Polytrichum commune***, a moss frequently occurring in moss gardens. Photo by Alan J. Silverside, with permission.

Figure 4. ***Bryoandersonia illecebra***, a moss from the southeastern USA and used by Rick Smith in moss gardens. Photo by Bob Klips, with permission.

Figure 5. ***Leucobryum glaucum***; this genus is used in moss gardens all over the world. Photo by Janice Glime.

Figure 6. ***Hypnum imponens***, a common sheet moss that appears in moss gardens. Photo by Janice Glime.

Figure 7. Fern moss, ***Thuidium delicatulum***, a suitable moss for moss gardens. Photo courtesy of Rick Smith.

Figure 8. ***Anomodon attenuatus*** on trees, a common species in somewhat alkaline areas. Photo by Janice Glime.

Figure 9. ***Plagiomnium cuspidatum***, a frequent volunteer in moss gardens. Photo by Hermann Schachner, through Creative Commons.

Rick Smith (Bryonet) reports that he uses the mat system in both his own private garden and in public gardens. He uses a thin synthetic mat that stores rainwater similar to the storage by a sponge. As the moisture evaporates from the mosses, they draw more water from the underlying mat. He does not water his gardens, but in many climates watering is necessary, especially when the bryophytes are first getting established. He recommends only rainwater if watering is necessary, but occasional watering with other sources such as distilled water usually won't harm the garden if it is interspersed with frequent natural watering.

George Schenk has moss gardens in Seattle, Washington, USA, New Zealand, and the Philippines, all areas that receive considerable annual rainfall. His book on *Moss Gardening* received the 1997 Horticultural Society of America's book of the Year Award. Amazon says of the book "A delightful book that encourages gardeners to pay closer attention to the subtle beauty of miniature landscapes and introduces one of the glories of Japanese gardens into American designs. The author writes entertainingly of mosses on rocks and walls, in containers, and as a lush ground cover, and he presents a gallery of his favorite moss species."

Problems in Public Gardens

Rick Smith (Bryonet 9 February 2010) admonished that the challenge in most public gardens is growing bryophytes in urban areas vs. their natural woodland setting. Traditional moss gardens require a staff to weed the garden of the tracheophyte seedlings.

In public gardens, the gardeners are also the problems. They want to treat the bryophytes like "small vascular plants" that need to be watered and fertilized, but these are just what one must avoid. Care is primarily that of removing unwanted plants and leaf litter.

One additional problem in public gardens is human traffic. Although Annie Martin frequently points out that you should walk on your bryophytes to help in their dispersal, they are not equipped to withstand the parade of an army of people or small children playing tag. This presents the need for paths. These can be presented in a variety of ways, as you will see in the images in this chapter. Sand paths are common, but stone paths can be works of art themselves, with bryophytes filling the spaces between the stones. Wooden steps, including logs, provide niches for additional bryophytes. Care must be taken that there is no smooth wood that might invite algae, hence becoming slippery and a safety hazard.

Moss Gardens of the World

Dale Sievert has visited many gardens, large and small, and has kindly contributed his images for this chapter. This is but a small sampling of moss gardens in the world.

Bloedel Reserve, Washington, USA

The Bloedel Reserve is a 60.7-hectare (150-acre) forest garden on Bainbridge Island in the state of Washington, USA, first opened to the public in 1988. There one can find beautiful mossy landscapes. It includes a Japanese garden with a sand, moss, and rock garden, but many of the bryophyte landscapes in the reserve have a more natural look (Figure 10-Figure 11).

Figure 10. A large moss lawn at Bloedel Reserve, Washington, USA. Photo courtesy of Dale Sievert.

Figure 11. Interesting mossy topography at Bloedel Reserve, Washington, USA. Photo courtesy of Dale Sievert.

Seattle Japanese Garden, Seattle, Washington, USA

The Seattle Japanese Garden occupies 1.4 hectares (3.5 acres) in the Madison Park neighborhood of Seattle. It was designed under the supervision of the Japanese gardener Juki Iida in 1960. It features pools, streams, bridges, lamps, and the beautiful autumn color of Japanese maples, along with bryophytes (Figure 12-Figure 13).

Figure 12. Mosses offset by fall colors of Japanese maples in the Seattle Japanese Garden, Seattle, Washington, USA. Photo courtesy of Dale Sievert.

Figure 13. Moss-covered lantern in Seattle Japanese Garden. Photo courtesy of Dale Sievert.

Portland Japanese Garden, Portland, Oregon, USA

This garden is considered to be the most authentic Japanese garden outside of Japan. It occupies 2.2 hectares (5.5 acres) in the scenic west hills of Portland. The garden was designed by Professor Takuma Tono. One can see crooked paths, waterfalls, arched bridges, moss-covered lanterns, pools with koi, and other features often found in the gardens in Japan. Bryophytes are a prominent feature (Figure 14-Figure 16).

Figure 14. Sand and moss garden at the Portland Japanese Garden, Portland, Oregon, USA. Photo courtesy of Dale Sievert.

Figure 15. Moss lawn at the Portland Japanese Garden, Portland, Oregon, USA. Photo courtesy of Dale Sievert.

Figure 16. Path through the Portland Japanese Garden, Portland, Oregon, USA. Photo courtesy of Dale Sievert.

Anderson Japanese Garden, Rockford, IL, USA

These gardens are considered to be premiere among American Japanese gardens (Figure 17-Figure 19). They were established in 1978 when John Anderson, a Rockford businessman, was inspired by his visit to the Portland Japanese Garden. The design was assisted by Hoichi Kurisu, using the Anderson's swampy backyard. With 12 acres of gardens and koi-filled pools, this setting is often used for both peaceful reprise and weddings.

Figure 17. A blend or rocks, moss, and sand in the Anderson Japanese Garden, Rockford, IL, USA. Photo courtesy of Dale Sievert.

Figure 18. A mixture of round and rectangular steps at the Anderson Japanese Garden, Rockford, IL, USA. Photo courtesy of Dale Sievert.

Figure 19. Water feature with a large, moss-covered rock at the Anderson Japanese Garden, Rockford, IL, USA. Photo courtesy of Dale Sievert.

Golden Gate Park, San Francisco, California, USA

Starting with sand dunes, William Hammond Hall (a park engineer) and master gardener John McLaren created a restful place to escape the bustle of the city. The Golden Gate Park is a large urban park of 411.6 hectares (1,017 acres). In addition to its conservatory of flowers, it presents a Japanese tea garden, an oak forest, a botanical garden that began in 1890, and two Dutch windmills that pump the water to irrigate the garden (Figure 20-Figure 21). More than 8000 varieties of plants occupy the gardens.

Figure 20. Mosses and trees in garden of Golden Gate Park, San Francisco, California, USA. Photo by courtesy of Dale Sievert.

Figure 21. Golden Gate Park, San Francisco, California, USA showing a walking path and a moss lawn. Photo courtesy of Dale Sievert.

Zion National Park, Utah, USA

Zion National Park covers 593 km² (229.1 mi²) and is characterized by rivers in deep canyons, colorful stone cliffs, waterfalls, and fantastic views. Despite the xeric nature of most of the park, one can still find bryophytes there (Figure 22). In 1909, the area was established as a National Monument by President William Henry Taft. But its name of Mukuntuweap National Monument drew criticism because it was difficult to pronounce. In 1918 it was renamed to Zion, the name that had been used by the Mormons who settled there. In 1919 it was established by The United States Congress as a national park.

Figure 22. Moss along walk in Zion National Park, Utah. Photo courtesy of Dale Sievert.

Missouri Botanical Garden, St. Louis, Missouri, USA

The Missouri Botanical Garden was founded in 1859 and is the oldest botanical garden in the USA. The garden is comprised of 32 hectares (79 acres) and includes a Japanese strolling garden (Seiwa-en) of 5.7 hectares (14 acres). Designed by Koichi Kawana, this is the largest Japanese garden in North America (Figure 23).

Figure 23. Moss lawn in the Missouri Botanic Garden, St. Louis, Missouri. Photo courtesy of Dale Sievert.

Rotary Botanical Garden, Janesville, Wisconsin, USA

The Rotary Botanical Garden in Janesville is an 81 hectare (20-acre) reprise. Bryophytes can be seen along some of the paths and in the Japanese garden, and some have managed to establish themselves between the stones of the paths (Figure 24). Of interest to the bryologists is the fern and moss garden.

Figure 24. Path and balls of mosses at the Rotary Botanic Garden, Janesville, Wisconsin, USA. Photo courtesy of Dale Sievert.

Sarah Duke Gardens, Durham, North Carolina, USA

The Sarah Duke Gardens comprise approximately 22 hectares (55 acres) of landscaped and wooded areas at Duke University. There are 5 miles of allées, walks, and pathways throughout the gardens. The official beginning of the gardens was 1934, when Dr. Frederick Moir Hanes, a faculty member at the Duke Medical School, persuaded Sarah P. Duke to provide $20,000 toward planting flowers in a debris-filled ravine. But alas, the gardens were destroyed in 1935 by a flood. Sarah Duke's daughter provided funds to rebuild the gardens above the flooding zone as a memorial to her mother, who died in 1936. In parts of the gardens, the ground is covered by a restful green mat of bryophytes (Figure 25).

Figure 25. Path in moss and shrub garden at Sarah Duke Gardens, Durham, NC, USA. Photo courtesy of Dale Sievert.

Limahuli Gardens, Kauai, Hawaii, USA

The Limahuli Gardens are part of the Limahuli Preserve and occupy 6.9 hectares (17 acres) among the 399 hectares (985 acres) of the preserve. The gardens were built to "honor the connection between nature and humanity." This is in one of the last easily-accessible valleys where native forest, pristine streams, and archaeological complexes remain. The descendants of its original inhabitants are its caretakers. In 1967, after Hawaii became a state, Juliet Rice Wichman, a member of the Hui, was assigned to develop the new park. She immediately began to plan and plant. She bequeathed the gardens to one of her grandsons. Since its beginnings it has been awarded "Best Natural Botanical Garden" from the American Horticultural Society for demonstrating the "best environmental practices of water, soil, and rare plant conservation in an overall garden design" and the Koa Award for dedication to the perpetuation of the Hawaiian culture. Bryophytes contribute to the luscious natural landscape (Figure 26).

Figure 26. Mosses and tropical vegetation in the Limahuli Gardens, Kauai, Hawaii, USA. Photo courtesy of Dale Sievert.

Sikkum, India

In Sikkum, one can find many walls with mounds of mosses growing on the sides and tops. Waterfalls are green with bryophytes. And bryophytes adorn the forest floor and branches (Figure 27-Figure 28).

Figure 27. Moss epiphytes in Sikkum, India. Photo courtesy of Dale Sievert.

Figure 28. Mosses at Sikkum, India. Photo courtesy of Dale Sievert.

Floriade, Venlo, Holland

This garden at Floriade represents modern architecture that utilizes bryophytes in the design (Figure 29).

Figure 29. Moss garden at Floriade, Venlo, Holland. Photo courtesy of Dale Sievert.

Villa d'Este, Tivoli, Italy

The Villa d'Este is near Rome, Italy. It is adorned with numerous fountains, some of which are covered with bryophytes (Figure 30).

Figure 30. Villa d'Este fountain with mosses. Photo courtesy of Dale Sievert.

Herculaneum, Italy

Herculaneum rests in the shadow of Mount Vesuvius. It was an ancient Roman town destroyed in 79 AD by volcanic pyroclastic flows. Only ruins remain of the ancient town, and ruins often provide suitable substrates for bryophytes (Figure 31). But more recent statues may be covered with bryophytes (Figure 32).

Figure 31. Herculaneum, Italy, ruins with mossy surfaces. Photo by Xtreambar, through Creative Commons.

Figure 32. Mossy statuary fountain at Herculaneum, Italy. Photo courtesy of Dale Sievert.

Cibodas Botanical Garden, Java, Indonesia

Gradstein (2006) reported that personnel created a small river and pond to grow ***Plagiomnium*** (Figure 9) in the Cibodas Botanical Garden, Java, Indonesia (Figure 77). The area was sprayed with water, particularly during the dry season. This permitted successful cultivation of ***Marchantia*** (Figure 34), ***Dumortiera*** (Figure 35), ***Trichocolea tomentella*** (Figure 36), and ***Plagiochila tjibodensis***. Other bryophytes that did not require special treatment were ***Hypopterygium*** (Figure 37), ***Pyrrhobryum*** (Figure 38), ***Fissidens*** (Figure 39), ***Thuidium*** (Figure 7), ***Leucobryum*** (Figure 5), and ***Hypnodendron*** (Figure 40). ***Pogonatum*** (Figure 41) grew on sand and ***Rhodobryum*** (Figure 42) grew on a mix of sand and humus. The garden was successful in growing epiphytes on soil covered with bark chips.

Figure 33. Cibodas Botanical Garden, Indonesia, where water sources were added to encourage the success of a moss garden. Photo by Hullie, through Public Domain.

Figure 34. ***Marchantia polymorpha*** with antheridiophores and archegoniophores; ***Marchantia*** may need added water in dry areas until it becomes established. Photo by Robert Klips, with permission.

Figure 35. ***Dumortiera hirsuta***, in a genus that may need added water in dry areas until it becomes established. Photo by Michael Lüth, with permission.

Figure 36. ***Trichocolea tomentella***, a species that may need added water in dry areas until it becomes established. Photo by Michael Lüth, with permission.

Figure 37. ***Hypopterygium didictyon***; ***Hypopterygium*** requires no special treatment when cultivated during a dry season. Photo by Juan Larrain, with permission.

Figure 38. ***Pyrrhobryum spiniforme***, in a genus that requires no special treatment when cultivated during a dry season. Photo by David Long, with permission.

Figure 39. ***Fissidens taxifolius*** (Common Pocket-moss), in a genus that requires no special treatment when cultivated during a dry season. Photo by Barry Stewart, with permission.

Figure 40. ***Hypnodendron comosum***, in a genus that can be grown on sand. Photo by Mezy Moo, through Creative Commons.

Figure 41. ***Pogonatum perichaetiale***, in a genus that can be grown on sand. Photo by Li Zhang, with permission.

Figure 42. ***Rhodobryum giganteum***, in a species from Java that can be grown on mix of sand and humus. Photo by David Long, with permission.

Bryophytes Occurring in Public Gardens

This chapter has only a small sampling of public gardens and parks with mosses, including some that have attempted to mimic the Japanese gardens. Some are natural and others are planted with horticultural varieties, but the non-"moss gardens" included here have bryophytes that have arrived and survived without deliberate human intervention.

Chris Preston (Bryonet 2 February 2022) reported 97 moss species and 14 liverwort species from the Cambridge University Botanic Garden (Figure 43) in the winter/spring season. These were volunteer species, not planted ones. Preston was unable to relocate at least 25 of the species that had been recorded there by past bryologists.

Figure 43. Cambridge Botanic Garden lake, illustrating the variety of habitats that support 97 moss and 14 liverwort species. Photo by C. M. Glee, through Creative Commons.

Morgan *et al*. (2008) reported 52 species of mosses and 15 of liverworts at the 31-hectare Bartlett Arboretum Forest (Figure 44) in Stamford, Connecticut, USA. This multiuse forest provides multiple opportunities for species to arrive on shoes and boots and perhaps even clothing.

Figure 44. Bartlett, Arboretum, Stamford, Connecticut , where 52 moss and 15 liverworts are reported. Photo through Creative Commons.

Eckstein and Burghardt (2008) found 139 bryophyte species in the Old Botanical Garden in Göttingen (Figure 45), Germany. These were comprised of 123 mosses and 16 liverworts, making it one of the richest botanical gardens investigated in Germany and the one with the greatest density of bryophytes. One of these is ***Didymodon umbrosus*** (Figure 46), a rare introduced species. Furthermore, 23 of these species are on the Lower Saxony Red List.

Figure 45. Old Botanical Garden, Universität Göttingen, Germany, home to 123 mosses and 16 liverworts. Photo by Valérie Chansigaud, through Creative Commons.

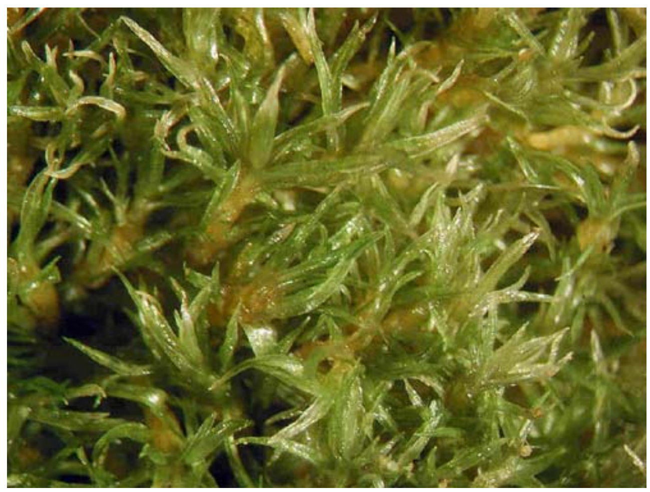

Figure 46. ***Didymodon umbrosus***, an introduced species in the Old Botanical Garden in Göttingen, Germany. Photo by Michael Lüth, with permission.

Odgaard (Bryonet 5 February 2022) has investigated the mosses in the botanical garden of Aarhus, Denmark (Figure 47). In the 1970's, only ***Dicranoweisia cirrata*** (Figure 48) grew there as an epiphyte. In 2022 he reported that the epiphyte flora had expanded considerably, including the new inhabitants ***Orthotrichum affine*** (Figure 49), ***O. diaphanum*** (Figure 50), ***O. lyellii*** (Figure 51-Figure 52), ***O. pulchellum*** (Figure 53), ***Ulota phyllantha*** (Figure 54), ***Syntrichia laevipila*** (Figure 55-Figure 56), ***S. latifolia*** (Figure 57-Figure 59), and ***Zygodon conoideus*** (Figure 60-Figure 62). He attributed this increase in diversity to the improved air quality, especially the reduction of sulfur. Like many researchers, he noted the importance of bryophytes in botanical gardens as a means of monitoring changes in air quality.

Figure 47. Botanical garden of Aarhus, Denmark, where epiphytic bryophytes have increased since the air pollution has decreased. Photo by Andreas Jensen, through Creative Commons.

Figure 48. ***Dicranoweisia cirrata*** with capsules, the only epiphytic species in the botanical garden of Aarhus, Denmark, in the 1970's. Photo by Sharon Pilkington, with permission.

Figure 49. ***Orthotrichum affine*** with capsules, on bark, a species that is a recent arrival in the botanical garden of Aarhus, Denmark and occurs in 5 or more of 14 plots at the Botanic Garden Rombergpark, Germany. Photo by Malcolm Storey, EOL, through Creative Commons.

Figure 50. ***Orthotrichum diaphanum*** with capsules, a species that is a recent arrival in the botanical garden of Aarhus, Denmark. Photo by Hermann Schachner, through Creative Commons.

Figure 51. ***Orthotrichum lyellii***, an epiphytic species that is a recent arrival in the botanical garden of Aarhus, Denmark. Photo by J. C. Schou, with permission.

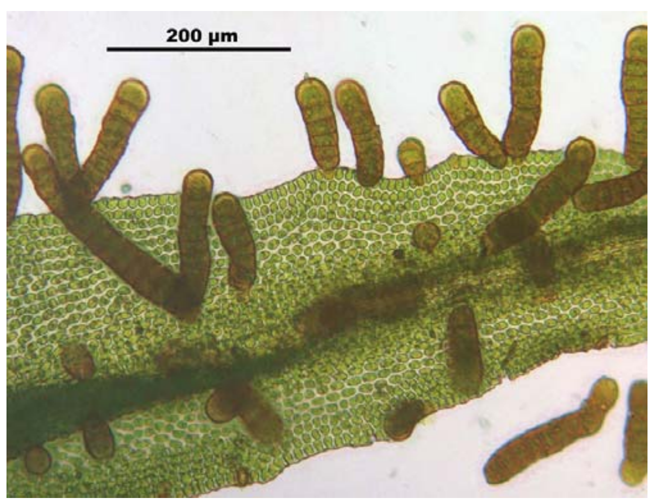

Figure 52. ***Orthotrichum lyellii*** leaf with gemmae, a possible means for its arrival in the botanical garden of Aarhus, Denmark. Photo by Hermann Schachner, through Creative Commons.

Figure 53. ***Orthotrichum pulchellum*** with capsules, an epiphytic species that is a recent arrival in the botanical garden of Aarhus, Denmark. Photo by Biopix, through Creative Commons.

Figure 54. ***Ulota phyllantha*** on a branch, a species that is a recent arrival in the botanical garden of Aarhus, Denmark. Photo by David T. Holyoak, with permission.

Figure 55. ***Syntrichia laevipila*** with gemmae, an epiphytic species that is a recent arrival in the botanical garden of Aarhus, Denmark. Photo by Hugues Tinguy, with permission.

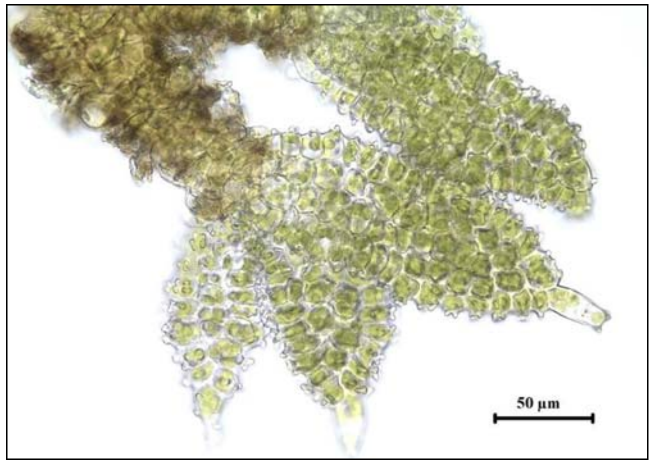

Figure 56. ***Syntrichia laevipila*** gemmae, a possible means for arrival of this species in the botanical garden of Aarhus, Denmark. Photo by Hugues Tinguy, with permission.

Figure 57. ***Syntrichia latifolia*** on tree trunk, an epiphytic species that is a recent arrival in the botanical garden of Aarhus, Denmark. Photo by Sharon Pilkington, with permission.

Figure 58. ***Syntrichia latifolia*** with leaf gemmae, possible propagules to arrive in the botanical garden at Aarhus. Photo by Claire Halpin, with permission.

Figure 59. ***Syntrichia latifolia*** leaf with gemmae, showing how numerous they are. Photo by Claire Halpin, with permission.

Figure 60. ***Zygodon conoideus*** on large branch, an epiphytic species that is a recent arrival in the botanical garden of Aarhus, Denmark. Photo by Sharon Pilkington, with permission.

Figure 61. ***Zygodon conoideus*** with capsules. Photo by Claire Halpin, with permission.

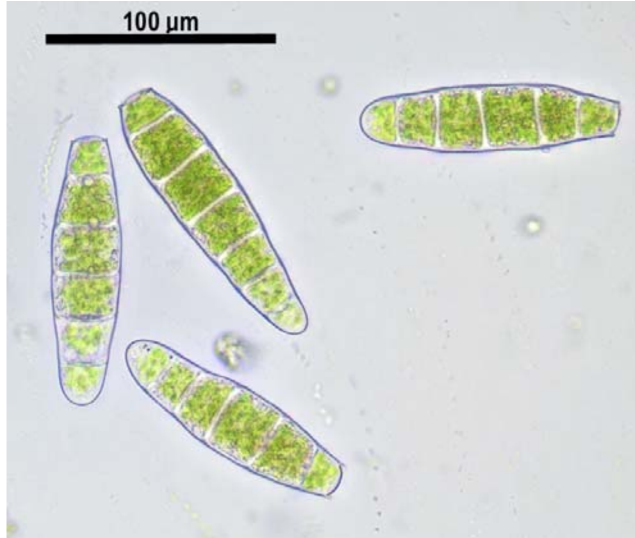

Figure 62. ***Zygodon conoideus*** gemmae, possible dispersal units to reach the botanical garden at Aarhus, Denmark. Photo by Claire Halpin, with permission.

Visnadi (2019) identified 63 species of bryophytes in 158 ha of parkland in the Ibirapuera Park, São Paulo, Brazil (Figure 63). She concluded that city parks serve as refuges for bryophytes, particularly those with heterogeneous forests, streams, and lakes, providing dispersal jumping areas between areas where buildings predominate. Even endemic species have been found there.

Figure 63. Ibirapuera Park, São Paulo, Brazil, showing some of the heterogeneity that supports 63 species of bryophytes. Photo by Sérgio Valle Duarte, through Creative Commons.

Müller (2013) was able to report the first record of epiphytic ***Ulota phyllantha*** (Figure 54) in Brandenburg, eastern Germany, from a population in a botanical garden in Potsdam (Figure 64).

Figure 64. Potsdam botanical garden, Brandenburg, eastern Germany, site of the first record of the epiphyte ***Ulota phyllantha*** (Figure 54) in Brandenburg. Photo by Wolfgang Pehlemann, through Creative Commons.

Common Species in Public Places

Fukarek (2006) notes that the bryophyte survey of the Botanic Garden Rombergpark (Figure 65) in Dortmund, Germany, is the first survey of bryophytes in that area. The bryophytes that occurred in 5 or more of the 14 sampling plots are ***Amblystegium serpens*** (Figure 66), ***Atrichum undulatum*** (Figure 67), ***Brachythecium rutabulum*** (Figure 68), ***Ceratodon purpureus*** (Figure 69-Figure 70), ***Eurhynchium praelongum*** (Figure 71), ***Grimmia pulvinata*** (Figure 72), ***Hypnum cupressiforme*** (Figure 73), ***Orthotrichum affine*** (Figure 49), ***Rhynchostegium confertum*** (Figure 74), and ***Tortula muralis*** (Figure 75). Smith *et al*. (2010) examined bryophyte species in 61 domestic gardens in the city of Sheffield, UK. They similarly found that only 10% of the bryophyte species occurred in more than half of the gardens. In the Bartlett Arboretum Forest (Figure 44) in Stamford, Connecticut, the mix of bryophytes was different, but there was no quantification in the study (Morgan *et al*. 2008). Only ***Atrichum undulatum*** (Figure 67), ***Brachythecium rutabulum*** (Figure 68), and ***Ceratodon purpureus*** (Figure 69-Figure 70) occurred here in common with those in 5 or more plots at the Botanic Garden Rombergpark.

Figure 65. Botanic Garden Rombergpark in Dortmund, Germany, where 10 species of bryophytes occurred in 5 or more of the 14 plots. Photo by Frank Vincentz, through Creative Commons.

Figure 66. ***Amblystegium serpens*** with capsules, a species that occurs in 5 or more of 14 plots at the Botanic Garden Rombergpark, Germany. Photo by Hugues Tinguy, with permission.

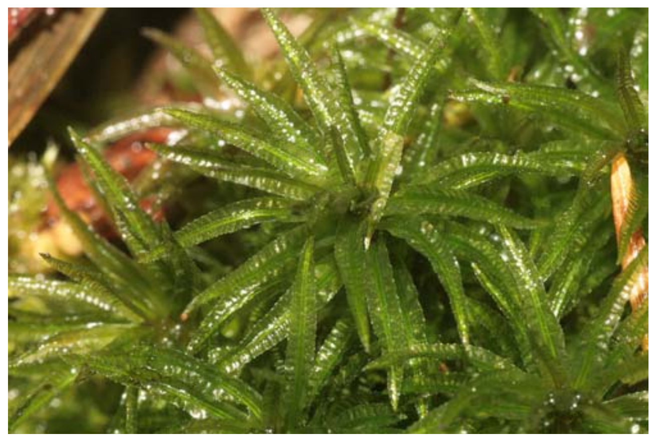

Figure 67. ***Atrichum undulatum***, a species that occurs in both the Bartlett Arboreum Forest in Connecticut, USA, and at the Botanic Garden Rombergpark, Germany. Photo by Hermann Schachner, through Creative Commons.

Figure 68. ***Brachythecium rutabulum*** with capsules, a species that occurs in both the Bartlett Arboreum Forest in Connecticut, USA, and at the Botanic Garden Rombergpark, Germany. Photo by Sharon Pilkington, with permission.

Figure 69. ***Ceratodon purpureus***, a species that occurs in both the Bartlett Arboreum Forest in Connecticut, USA, and at the Botanic Garden Rombergpark, Germany. Photo by Claire Halpin, with permission.

Figure 70. ***Ceratodon purpureus*** with capsules and dry leaves, a ubiquitous species, including in parks. Photo by Michael Lüth, with permission.

Figure 71. ***Eurhynchium praelongum*** with capsules, a species that occurs in 5 or more of 14 plots at the Botanic Garden Rombergpark, Germany. Photo by Andrew Spink, with permission.

Figure 72. ***Grimmia pulvinata*** with capsules, a rock-dwelling species that occurs in 5 or more of 14 plots at the Botanic Garden Rombergpark, Germany. Photo by Claire Halpin, with permission.

Figure 73. ***Hypnum cupressiforme***, a species that occurs in 5 or more of 14 plots at the Botanic Garden Rombergpark, Germany. Photo by Claire Halpin, with permission.

Figure 74. ***Rhynchostegium confertum*** with capsules, a species that occurs in 5 or more of 14 plots at the Botanic Garden Rombergpark, Germany. Photo by Claire Halpin, with permission.

Figure 75. ***Tortula muralis*** with capsules, on rock, a species that occurs in 5 or more of 14 plots at the Botanic Garden Rombergpark, Germany. Photo by David T. Holyoak, with permission.

Lunularia cruciata (Figure 76) is the only liverwort to appear in as many as 5 plots at the Botanic Garden Rombergpark, Germany (Figure 65). Interestingly, ***Lunularia cruciata*** is the only one of these species listed by Essl and Lambdon (2009) as alien species in Europe.

Figure 76. ***Lunularia cruciata***, the only liverwort appearing in five or more plots at the Botanic Garden Rombergpark, Germany. Its gemmae spread from rain and sprinklers. Photo by Hermann Schachner, through Creative Commons.

Among the 90 species of bryophytes in the tropical Cibodas Botanical Garden, Indonesia (Figure 77) (Nadhifah *et al*. 2018), there were no species in common with temperate Bartlett Arboretum Forest (Figure 44) in Stamford, Connecticut (Morgan *et al*. 2008) or the Botanic Garden Rombergpark, Germany (Figure 65) (Fukarek 2006), but several genera seem to be common in such gardens in widespread regions, boreal to tropical and both hemispheres. These include the thallose liverworts ***Marchantia*** (Figure 34) and ***Riccia*** (Figure 78), the leafy liverwort ***Frullania*** (Figure 79), and the mosses ***Barbula*** (Figure 80), ***Bryum*** (Figure 81), ***Campylopus*** (Figure 82), ***Fissidens*** (Figure 83), ***Leucobryum*** (Figure 5), ***Plagiomnium*** (Figure 9), and ***Sphagnum*** (Figure 84).

Figure 77. Cibodas Botanical Garden, Indonesia, a tropical garden with very different bryophytes from those in the temperate zone. Photo by Hullie, through public domain.

Figure 78. ***Riccia sorocarpa***; the genus ***Riccia*** is frequent in parks throughout the world. Photo by Claire Halpin, with permission.

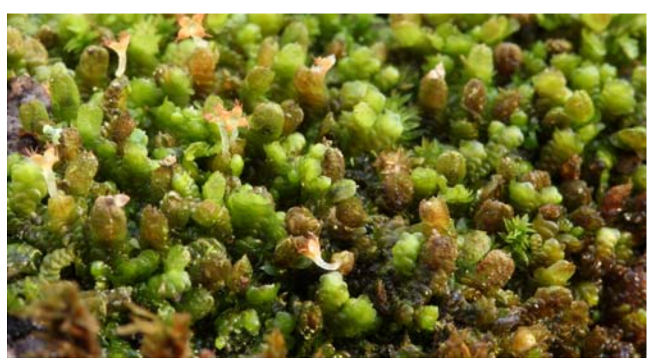

Figure 79. ***Frullania dilatata*** with capsules dehiscing; the genus ***Frullania*** is frequent in parks throughout the world. Photo by Claire Halpin, with permission.

Figure 80. ***Barbula unguiculata*** with capsules, a species that occurs in multiple botanical gardens in Hungary, representing a common genus in parks throughout the world. Photo by Claire Halpin, with permission.

Figure 81. ***Bryum argenteum***, a species that occurs in multiple botanical gardens in Hungary, representing a common genus in parks throughout the world. Photo by Claire Halpin, with permission.

Figure 82. ***Campylopus introflexus***, an invasive species; the genus ***Campylopus***, including this species, is frequent in parks throughout the world. Photo by WildWind, through Creative Commons.

Figure 83. ***Fissidens taxifolius*** with immature capsules, member of a genus that occurs in multiple gardens worldwide, including the tropical Cibodas Botanical Garden in Indonesia. Photo by Bob Klips, with permission.

Figure 84. ***Sphagnum fallax***, member of a genus that occurs in multiple gardens worldwide, including the tropical Cibodas Botanical Garden in Indonesia. Photo by Bob Klips, with permission.

Fastanti and Wulanasari (2021) found 30 species (27 moss species, 3 liverwort species) of bryophytes in the 189 ha of Cibinong Science Center-Botanical Garden, Indonesia. There were no hornworts. In sharp contrast, the 4.3 ha of the Szent István University Gödöllő Botanical Garden in Hungary had 69 bryophyte species with 3 liverwort and 66 moss species (Fintha *et al*. 2021). Most of these were common in Hungary and many also occur in other Hungarian botanical gardens, including ***Amblystegium serpens*** (Figure 66), ***Barbula unguiculata*** (Figure 80), ***Brachythecium rutabulum*** (Figure 68), ***Brachythecium salebrosum*** (Figure 1), ***Bryum argenteum*** (Figure 81), ***Calliergonella cuspidata*** (Figure 86), ***Ceratodon purpureus*** (Figure 69-Figure 70), ***Fissidens taxifolius*** (Figure 83), ***Grimmia pulvinata*** (Figure 72), ***Homalothecium lutescens*** (Figure 87), ***Homalothecium sericeum*** (Figure 88), ***Hypnum cupressiforme*** (Figure 73), ***Leskea polycarpa*** (Figure 89), ***Orthotrichum affine*** (Figure 49), ***Orthotrichum diaphanum*** (Figure 50), ***Eurhynchium hians*** (=***Oxyrrhynchium hians***; Figure 90), ***Plagiomnium cuspidatum*** (Figure 9), ***Syntrichia ruralis*** (Figure 91), ***Tortula muralis*** (Figure 92).

Figure 85. ***Brachythecium salebrosum***, a species that occurs in multiple botanical gardens in Hungary. Photo by Michael Lüth, with permission.

Figure 86. ***Calliergonella cuspidata***, a species that occurs in multiple botanical gardens in Hungary. Photo by Claire Halpin, with permission.

Figure 87. ***Homalothecium lutescens***, a species that occurs in multiple botanical gardens in Hungary. Photo by Claire Halpin, with permission.

Figure 88. ***Homalothecium sericeum***, a species that occurs in multiple botanical gardens in Hungary and elsewhere. Photo by Kristian Peters, through Creative Commons.

Figure 89. ***Leskea polycarpa*** with capsules, a species that occurs in multiple botanical gardens in Hungary and elsewhere. Photo by David T. Holyoak, with permission.

Figure 90. ***Eurhynchium hians*** (=***Oxyrrhynchium hians***), a species that occurs in multiple botanical gardens in Hungary and elsewhere. Photo by David T. Holyoak, with permission.

Figure 91. ***Syntrichia ruralis*** in rock crevice, a species that occurs in multiple botanical gardens in Hungary and elsewhere. Photo by Darkone, through Creative Commons.

Figure 92. ***Tortula muralis*** with capsules, a species that occurs in multiple botanical gardens in Hungary and elsewhere. Photo by David T. Holyoak, with permission.

On the other hand, five species [***Brachythecium glareosum*** (Figure 93), ***Dicranella varia*** (as *Dicranella howei*; Figure 94), ***Didymodon insulanus*** (Figure 95, ***Fissidens bryoides*** (as *Fissidens viridulus*; Figure 96), ***Orthotrichum obtusifolium*** (as *Nyholmiella obtusifolia*; Figure 97)] were listed as near threatened on the Hungarian Red Data List (Fintha *et al*. 2021). However, since three have been reclassified into widely distributed species, it is possible they were not legitimately red-listed.

Figure 93. ***Brachythecium glareosum***, a near threatened species found at the Szent István University Gödöllő Botanical Garden in Hungary. Photo by Sharon Pilkington, with permission.

Figure 94. ***Dicranella varia*** with capsules, a near threatened species found at the Szent István University Gödöllő Botanical Garden in Hungary. Photo by David T. Holyoak, with permission.

Figure 95. ***Didymodon insulanus***, a near threatened species found at the Szent István University Gödöllő Botanical Garden in Hungary. Photo by Claire Halpin, with permission.

Figure 96. ***Fissidens bryoides*** with capsules, a tiny moss that often occurs on wet rocks, and among the mosses found at the Szent István University Gödöllő Botanical Garden in Hungary. Photo by Janice Glime.

Figure 97. ***Orthotrichum obtusifolium*** with capsules, a near threatened species found at the Szent István University Gödöllő Botanical Garden in Hungary. Photo by Hermann Schachner, through Creative Commons.

In the preparation of this chapter, I compiled a total species list for 30 studies of bryophytes in parks, cemeteries, and botanical gardens to provide an estimate of the most frequent species. This is a crude list because of the huge variation in size and the worldwide distribution of the gardens. Nevertheless, some species seem to be everywhere.

Hornworts are notably absent in most gardens, with only ***Anthoceros agrestis*** (Figure 99) present in as many as three. Liverworts varied widely in number of species with some gardens lacking them entirely [*e.g.* 1500 ha forest park at Hôrka, Slovakia (Figure 98) (Mišíková *et al.* 2007)] and others having numbers of liverwort species exceeding those of the mosses [*e.g.* 1480 ha in restinga in Setiba State Park, Espírito Santo State, Brazil, has 25 liverworts and 9 mosses (Visnadi & Vital 1995)].

Figure 98. Forest path above the tunnel, Malkovská Hórka location, Prešov forest park, Slovakia, a park devoid of liverworts. Photo by Jozef Kotu, through Creative Commons.

In Serra da Canastra National Park (Figure 100), Minas Gerais, Brazil, with more than 71,000 hectares, Marchi do Carmo and Peralta (2016) found the hornwort ***Phaeoceros laevis*** (Figure 101). Among the liverworts, there were 53 species of the **Lejeuneaceae** (Figure 102). The park supported 289 species of bryophytes, most of which are widely distributed in Brazil.

Figure 99. ***Anthoceros agrestis***, the only hornwort present in as many as three parks out of 30 published species lists. Photo by Hermann Schachner, through Creative Commons.

Figure 100. Serra da Canastra National Park, Minas Gerais, Brazil - Rasga Canga Falls, a park with more liverworts than mosses. Photo by Halley Pacheco de Oliveir, through Creative Commons.

Figure 101. ***Phaeoceros laevis*** with sporophytes, the only hornwort found in Serra da Canastra National Park, Minas Gerais, Brazil in more than 71,000 ha. Photo by David T. Holyoak, with permission.

Figure 102. **Lejeuneaceae**, a leafy liverwort family with 53 species in Serra da Canastra National Park, Minas Gerais, Brazil. Photo by George Shepherd, through Creative Commons.

In the park of Mátrai Gyógyintézet Sanatorium, NE Hungary, Szűcs *et al*. (2018) found 65 bryophytes, of which only 3 were liverworts. Red-listed species for the territory, but found in the park, included ***Brachythecium glareosum*** (Figure 93), ***Cirriphyllum piliferum*** (Figure 103), ***Orthotrichum pumilum*** (Figure 104), ***Rhynchostegiella tenella*** (Figure 105), and ***Syntrichia latifolia*** (Figure 57-Figure 59).

Figure 103. ***Cirriphyllum piliferum***, a red-listed species found in the park of Mátrai Gyógyintézet Sanatorium, NE Hungary. Photo by Claire Halpin, with permission.

Figure 104. ***Orthotrichum pumilum*** with capsules, a red-listed species found in the park of Mátrai Gyógyintézet Sanatorium, NE Hungary. Photo by Hugues Tinguy, with permission.

Figure 105. ***Rhynchostegiella tenella*** with capsules, a red-listed species found in the park of Mátrai Gyógyintézet Sanatorium, NE Hungary. Photo by Hugues Tinguy, with permission.

Szűcs and Fintha (2019) reported 54 bryophyte species from the Erdőtelek Arboretum in Hungary. It is interesting that among these were the red-listed ***Brachythecium glareosum*** (Figure 93), ***Cirriphyllum piliferum*** (Figure 103), and ***Orthotrichum obtusifolium*** (Figure 97), also present in the park of Mátrai Gyógyintézet Sanatorium, NE Hungary (Szűcs *et al*. 2018) or Szent István University Gödöllő Botanical Garden in Hungary (Fintha *et al*. 2021). Based on this and other studies, the common species in these parks and botanical gardens are ***Amblystegium serpens*** (Figure 66), ***Barbula unguiculata*** (Figure 80), ***Brachythecium rutabulum*** (Figure 68), ***Bryum argenteum*** (Figure 81), ***Ceratodon purpureus*** (Figure 69-Figure 70), ***Hypnum cupressiforme*** (Figure 73), ***Leskea polycarpa*** (Figure 89), ***Orthotrichum anomalum*** (Figure 106), ***Orthotrichum diaphanum*** (Figure 50), ***Eurhynchium hians*** (=***Oxyrrhynchium hians***; Figure 90), ***Radula complanata*** (Figure 107), ***Syntrichia ruralis*** (Figure 91), and ***Tortula muralis*** (Figure 75).

Figure 106. ***Orthotrichum anomalum*** with capsules, one of the common species in Hungarian parks and botanical gardens. Photo by Claire Halpin, with permission.

Figure 107. ***Radula complanata*** on bark, one of the common species in Hungarian parks and botanical gardens. Photo by Jutta Kapfer, with permission.

Europe

Numbers of species vary widely among the parks in Europe. Nevertheless, they provide a glimpse of the abundance of mosses vs liverworts vs hornworts, the substrate distribution, and the effects of urban vs suburban vs natural habitats.

In the Azorean parks and gardens of the Reserva Florestal de Recreio do Pinhal da Paz on São Miguel Island (Figure 108), an Island of Portugal, Polaino-Martin *et al*. (2020) identified 43 bryophyte species, of which 19 were liverworts and 1 hornwort. These represented 17 sites about 100 m apart on rocks, soil, and tree bark, but concentrated on the "most striking" species. Three of these are endemic to Macaronesia. Others are endemic to Europe. This compares with 279 taxa known from the Serra de Sintra in Portugal (Figure 109) (Cacciatori *et al*. 2015).

Figure 108. Pinhal da Paz, Ponta Delgada, São Miguel, Açores, site of 43 bryophyte species. Photo by José Luís Ávila Silveira & Pedro Noronha e Costa through public domain.

Figure 109. Serra de Sintra, Portugal, home of 279 bryophyte taxa. Photo by Vitor Oliveira, through Creative Commons.

Segarra Moragues *et al*. (2021) investigated the bryophytes in 94 sampling sites in the city of Valencia, Spain. They identified 96 moss and 6 liverwort species. The greatest taxon richness occurred in locations with a variety of natural and relatively undisturbed substrates such as those found at the Botanical Garden (Figure 110), Viveros Garden (Figure 111), and the Turia River Garden (Figure 112).

Figure 110. Valencia Botanical Garden, Spain, where natural substrates favor bryophyte richness. Photo by Pablo Enzo, through Creative Commons.

Figure 111. Viveros Garden Entrance, Valencia, Spain, where natural, undisturbed substrates favor bryophyte richness. Photo by Thelma Datter, through Creative Commons.

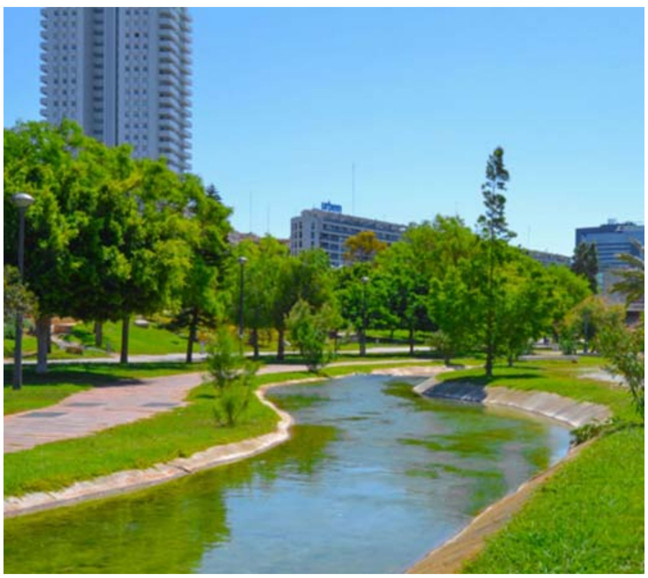

Figure 112. Turia River Garden, a park with a variety of natural substrates that support bryophytes. Photo by through Creative Commons 1 Stefan Majewski, through Creative Commons.

In Germany, Stech (1996) found 80 species (9 liverworts, 80 mosses) in the outdoor area of the Botanical Gardens of the University of Bonn (Figure 113). The greenhouses (Figure 114) had 11 liverworts and 41 mosses. In the UNESCO Heritage Park Sanssouci in Potsdam, Germany (Figure 115), Müller (2014) found 118 species of bryophytes. Of these, 25 were red-listed as threatened. This was in part due to a large re-colonization of epiphytes following the reduced air pollution. (See also Müller 2015).

Giordano *et al*. (2004) examined the biodiversity of epiphytic bryophytes in urban and nearby sites in southern Italy. Their interest was in the use of these as indicators through their bioaccumulations. As indicated by Segarra Moragues *et al*. (2021) they showed clearly that the number of species was lower in more urban areas. They also found that acrocarpous mosses and vegetative reproduction occur more frequently in more urban areas.

Figure 113. Botanical Garden, University of Bonn, Germany, home of 9 liverwort and 80 moss species. Photo by Carson DeLake, through Creative Commons.

Figure 114. Botanical Gardens of the University of Bonn greenhouses, home of 11 liverwort and 41 moss species. Photo by Elekes Andor, through Creative Commons.

Figure 115. UNESCO Heritage Park Sanssouci in Potsdam, Germany, home of 118 species of bryophytes, including 25 red-listed species. Photo by Wolfgang Pehlemann, through Creative Commons.

In Wroclaw, Poland, Fudali (2001, 2005) found only 81 bryophyte species in 22 town parks and 6 cemeteries. These were more specialized in their substrates, with more

than 40% occurring on only one type. Epiphytes were rare, but did seem to occur at the bases and first 30 cm of the tree trunks. Only the outer locations had forest species. In cemeteries, a higher number of species correlated with the age of monuments and dimensions of the object areas. In a wider study, Fudali (2006) found 125 species on 145 sites in 94 parks and 51 cemeteries in Poland. These were comprised of 11 liverwort and 114 moss taxa. The number of taxa was not significantly correlated with area of the study site, emphasizing the importance of even small parks in maintaining diversity of bryophytes. Parks on the outskirts typically had more diversity than did those in the city center. Frequent mosses were similar to those found in other studies of parks, including ***Amblystegium serpens*** (Figure 66), ***Bryum argenteum*** (Figure 81), ***B. caespiticium*** (Figure 116), ***Ceratodon purpureus*** (Figure 69-Figure 70), and ***Funaria hygrometrica*** (Figure 117). As in many other locations, epilithic species included ***Barbula unguiculata*** (Figure 80), ***Grimmia pulvinata*** (Figure 72), ***Orthotrichum diaphanum*** (Figure 50), ***Ptychostomum capillare*** (=***Bryum capillare***; Figure 118), ***Schistidium apocarpum*** (Figure 119), and ***Tortula muralis*** (Figure 75); frequent terrestrial species included ***Barbula convoluta*** (=*Streblotrichum convolutum*; Figure 120), ***Brachythecium rutabulum*** (Figure 68), and ***Eurhynchium hians*** (=***Oxyrrhynchium hians*** Figure 90). ***Marchantia polymorpha*** (Figure 34) was the only liverwort found in the city interiors. Fudali *et al*. (2015) reported 171 bryophyte taxa from the 8483 ha Roztocze National Park in Poland (Figure 121). These included 43 species protected by law in Poland, 20 of which are strictly protected and 13 as threatened in Poland. Furthermore, 36 species were new for the region.

Figure 117. ***Funaria hygrometrica*** with capsules, a species common in parks and cemeteries of six cities in Poland. Photo by Hugues Tinguy, with permission.

Figure 118. ***Ptychostomum capillare*** with capsules, an epilithic species common in parks and cemeteries of six cities in Poland. Photo by Wouter Van Landuyt, through Creative Commons.

Figure 116. ***Bryum caespiticium*** with capsules, a species common in parks and cemeteries of six cities in Poland. Photo by Bob Klips, with permission.

Figure 119. ***Schistidium apocarpum*** with capsules, an epilithic species common in parks and cemeteries of six cities in Poland. Photo by Christophe Quintin, through Creative Commons.

Figure 120. ***Barbula convoluta*** with capsules, a terrestrial species common in parks and cemeteries of six cities in Poland. Photo by David T. Holyoak, with permission.

Figure 121. Roztocze National Park in Poland, home of 171 bryophyte taxa. Photo by Rysy, through Creative Commons.

In an experimental and teaching garden at the University of Lodz, Poland, Wolski *et al*. (2012) found 41 species of mosses and only 1 liverwort. These represented the epigeic, epilithic, epiphytic, epixylic, and aquatic habitats. The epigeic (soil) habitat had the most species (34), whereas the aquatic habitat had the least (1). These urban parks, nevertheless, exhibit a large diversity of species of bryophytes, especially species not found elsewhere in the city.

In Slovakia, Godovičová *et al*. (2020) found 12 liverwort and 92 moss species in 14 historical parks and gardens. Among these, ***Amblystegium serpens*** (Figure 66), ***Brachythecium rutabulum*** (Figure 68), ***Bryum argenteum*** (Figure 81) and ***Tortula muralis*** (Figure 75) were present in all 14 study sites. Small urban parks had fewer bryophyte species than did rural areas, with the most species on soil and least on wood. As in some other studies, a rare species (***Ptychostomum bornholmensis*** – see Figure 122) used the parks as a refuge.

Figure 122. ***Ptychostomum creberrimum***; ***Ptychostomum bornholmensis*** is a rare species occurring in historical parks and gardens in Slovakia. Photo by Wayne Lampa, through Creative Commons.

In the forest park of Hôrka (Figure 98), located in the center of the town Veľký Krtíš, Slovakia, Mišíková *et al*. (2007) found 37 bryophyte species, but no liverworts or hornworts. In a broader study, Mišíková *et al*. (2015) found 81 bryophyte species in ten villages in Slovakia. These were not parks, where the bryophytes are afforded some degree of protection. Nevertheless, with the 81 species in total, species richness of individual localities ranged 17 to 57 species. They suggested that the cooler, more humid climate in the northern part of central Slovakia favored a greater species richness there. They also found that cemeteries and parks contributed to higher diversity. The highest numbers of species occurred on bare damp soil or on concrete and stony walls.

Godovičová (2019) explored the bryophytes in the Horský Park protected area (Figure 123) in the urban Bratislava, Slovakia. This forest park had 57 bryophytes, with 6 liverworts and no hornworts. Two red-listed species [***Fissidens exilis*** (Figure 124) and ***Rhynchostegium rotundifolium*** (Figure 125)] occurred there. As in many other studies, the greatest number of species (19) occurred on exposed soil and the least along streams (6).

Figure 123. Bratislava Horský Park, a forested park with 57 bryophyte species, including 6 liverworts. Photo by Peter Zelizňák, through Creative Commons.

Figure 124. ***Fissidens exilis*** with capsules, a red-listed species that occurs in the Horský park, Slovakia. Photo by Hugues Tinguy, with permission.

Figure 125. ***Rhynchostegium confertum*** with capsules, a red-listed species that occurs in the Horský park, Slovakia. Photo by Claire Halpin, with permission.

In the Central Park Archbishop's Garden in Eger, Hungary (Figure 126), Szűcs *et al*. (2020) found 55 moss and 4 liverwort taxa. Of these, 49% were from only three families (**Orthotrichaceae**, **Pottiaceae**, and **Brachytheciaceae**). The species composition and life strategies of bryophytes in this park differed remarkably from that of other Central and Eastern European parks.

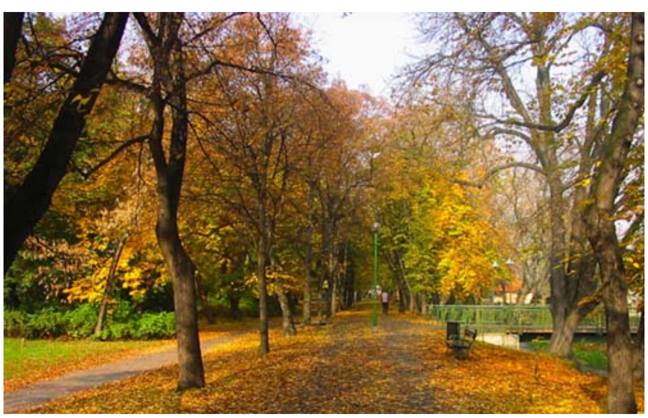

Figure 126. Central Park Archbishop's Garden in Eger, Hungary, home to 55 moss and 4 liverwort species, with nearly half in only three families. Photo by Zolchew, through Creative Commons.

In eastern Serbia, Sabovljević (2006) found 82 bryophyte species, including 11 liverworts, in the Djerdap National Park (Figure 127). Although this seems like a large number, the park occupies 63,786 ha with a wide range of habitats.

Figure 127. Djerdap National Park on the Danube. Photo by Milan Paunović, with permission.

In the Vrana Park (<40 ha), Sofia city, Bulgaria, Gospodinov *et al*. (2018) found 68 bryophyte species, four of which are of conservation importance. In Loven Park, in the same city, only 31 species of mosses and 5 of liverworts were found, despite the larger size (243 ha) of the park (Natcheva & Gospodinov 2020). The researchers considered the lack of habitat diversity and microrelief, a dense understory of shrubs and saplings, and invasion of ivy (*Hedera helix*) on soil and tree trunks to be the reasons for the low diversity.

In 2018, Mamchur *et al*. found 143 moss species in the Pohulyanka forest park, Ukraine (Figure 128). They compared the bryophytes in this study to earlier records in the last 50-100 years and found that 34 species could no longer be located. On the other hand, 72 species in this study were not found in those earlier studies. Among the current species, 25 are rare for the **nemoral** (pertaining to groves or woodlands) and forest steppe zones. The number of epiphytic species has increased, a fact that the researchers attribute to anthropogenic activity.

Figure 128. Pohulyanka forest park, Ukraine, home to 143 moss species, with 72 that were not present 50 years earlier. Photo by M. Sha, through public domain.

Asia

Lu and Jing (2019) reported on the ground bryophytes of 11 parks in Nanjing, China. They found only 51 bryophyte species, with 35% of them in only three families (**Pottiaceae**, **Bryaceae**, **Brachytheciaceae**). The most common ones were ***Barbula unguiculata*** (Figure 80), ***Brachythecium rutabulum*** (Figure 68), ***Haplocladium angustifolium*** (Figure 129), ***Haplocladium microphyllum*** (Figure 130), ***Physcomitrium sphaericum*** (Figure 131), and ***Taxiphyllum taxirameum*** (Figure 132). The first two of these are widespread and common in various parks and gardens. The number of species per park ranged from 3 to 20, with turfs as the main life form. They found an interesting correlation of environmental factors with diversity. Humidity, human disturbance, canopy density, and distance to main roads were the important factors. The latter variable is one that seems not to be considered in most studies.

Figure 129. ***Haplocladium angustifolium***, among the most common species in 11 parks in Nanjing, China. Photo by Dale A. Zimmerman Herbarium, Western New Mexico University, with permission.

Figure 130. ***Haplocladium microphyllum***, among the most common species in 11 parks in Nanjing, China. Photo by Bob Klips, with permission.

Figure 131. ***Physcomitrium sphaericum*** with capsules, among the most common species in 11 parks in Nanjing, China. Photo by Štěpán Koval, with permission.

Figure 132. ***Taxiphyllum taxirameum*** with capsule, among the most common species in 11 parks in Nanjing, China. Photo by Bob Klips, with permission.

Liu *et al.* (2015) found 83 species in saxicolous communities in urban habitats in Chongqing, China. Soil communities supported only 46 species, contrasting with European studies cited above. Surprisingly to me, diversity indices of both of these communities were higher on campuses than in parks, natural scenic resorts, or the Jinyunshan National Nature Reserve (Figure 133). The environmental parameters differed in importance, with canopy density being most important for saxicolous communities in parks and campuses. In natural science scenic resorts and the nature reserve, altitude, relative humidity, and human disturbance were most important. In the soil communities, *p*H, canopy density, and human disturbance were of major importance in parks and campuses. In the natural scenic resorts and nature reserve, altitude, relative humidity and water content of the soil were the most important determinants of the soil bryophyte communities.

Figure 133. Jinyunshan Nature Reserve with karst topography in Chongqing, China, an area with lower bryophyte diversity than urban areas in the province. Photo by Bernt Rostad, through Creative Commons.

The Japanese are famous for their moss gardens, which are discussed elsewhere in this chapter. Nakamura and Suga (1997) instead studied the bryophytes in various urban and natural environments, including a nature park, agricultural area, urban park, street residential district, housing complex district, commercial district, and industrial district. These study sites had 83 bryophyte species in 1975, but in 1995, only 78 were located (Figure 134). Nevertheless, the number of species at individual sites increased for most sites. Only the agricultural site experienced a decrease in species. **Erect** forms increased at all sites, whereas **prostrate** forms decreased in both the nature park and the agricultural district. On the other hand, **thalloid** forms increased in the nature park site. In the industrial site, **erect** forms were the only remaining type. Like several sites in Europe, soil was the most common substrate, followed by tree trunks and then concrete. The number of bryophyte species was positively correlated with the woody vegetation cover, indicating a dependence on shade and perhaps moisture.

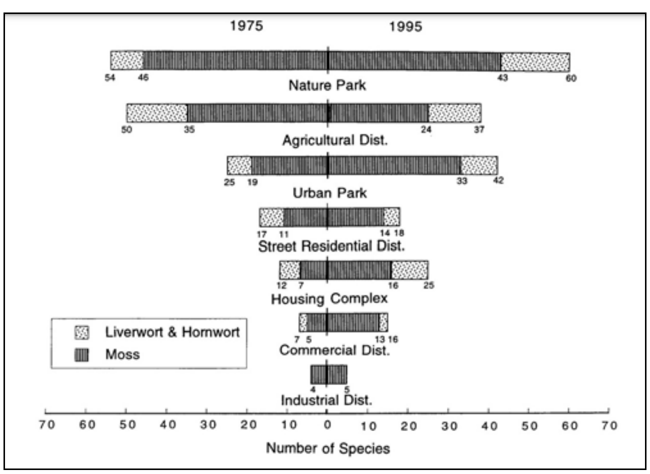

Figure 134. Changes in moss, liverwort, and hornwort species from 1975 to 1995 in Chiba City and Yotsukaidou City, Japan. Image slightly modified from Nakamura & Suga 1997.

Tropics

In the Chapada Diamantina National Park, Brazil (Figure 135), Bastos *et al.* (1998) found only 27 species of mosses and 4 species of liverworts. Most of these species were restricted to this high altitude complex. Later, Sierra *et al.* (2018) studied the bryophyte flora of the Jaú National Park (Figure 136) in Brazil. In their extensive collecting of 712 collections, they found 150 species. Of these, 20 were rarely collected Amazonian endemics.

Figure 135. Chapada Diamantina National Park, Brazil, home to 27 species of mosses and 4 species of liverworts. Photo by Roney, through Creative Commons.

Figure 136. Jaú National Park, Brazil, home to 150 bryophyte species, 20 of which are rare Amazonian endemics. Photo by Dalia McGill, through Creative Commons.

In the more tropical Panama, Gradstein and Salazar Allen (1992) sampled the bryophytes along an elevational gradient in the Dárien National Park (Figure 137). The inundated lowland, hillside-lowland, submontane, and montane elfin forest had distinctly different species assemblages. They found the largest number of exclusive species as well as the greatest bryophyte biomass in the montane forest. The submontane forest, however, has the greatest overall species richness. The lowland forest had the lowest diversity. Forty liverwort taxa in the park were reported as new to Panama.

Figure 137. Dárien National Park, where the montane forest has the most exclusive bryophyte species and greatest bryophyte biomass among the five elevational zones. Photo by Harvey Barrison, through Creative Commons.

North America

In the Taum Sauk Mountain State Park, Missouri, USA (Figure 138), Holmberg and Atwood (2014) documented 123 bryophytes, with 103 mosses, 18 liverworts, and 2 hornworts in 3035 ha.

Figure 138. Taum Sauk Mountain State Park, Slippery Rock, Missouri, a temperate park with 103 mosses, 18 liverworts, and 2 hornworts. Photo by Yinan Chen, through Creative Commons.

Australia

In Mungo National Park in arid Australia (Figure 139), Downing and Selkirk (1993) found that the number of species did not differ significantly between sites representing differences in soils, topography, and tracheophytes. Bryophytes were well represented in soil crusts. Ephemerals were censused by soil cultures. Factors influencing the bryophyte vegetation included soil texture, *p*H, conductivity, nutrient status, vascular plant vegetation, light level, leaf litter, and fire frequency. The species are typical of calcareous substrates throughout the desert area.

Ramsay *et al*. (1990) found more than 90 species in the Mount Tomah Botanic Garden in Australia (Figure 140), a 30 ha park. In the Royal Botanic Gardens, Sydney (Figure 141), Ramsay *et al.* (1993) found 70 moss, 24 liverwort, and 1 hornwort species. These included many species and genera noted in other parks and gardens around the world, including ***Amblystegium serpens*** (Figure 66), ***Barbula*** (2 spp.; Figure 80), ***Brachythecium rutabulum*** (Figure 68), ***Bryum argenteum*** (+ 9 other ***Bryum*** spp., Figure 81), ***Campylopus*** (6 species; Figure 82), ***Ceratodon purpureus*** (Figure 69-Figure 70), ***Eurhynchium praelongum*** (Figure 71), ***Fissidens*** (8 spp.; Figure 83), ***Leucobryum*** (1 sp.; Figure 5), ***Ptychostomum capillare*** (=***Bryum capillare***; Figure 118), ***Syntrichia laevipila***, (+ 1 other ***Syntrichia*** sp.; Figure 55-Figure 56). ***Tortula muralis*** (Figure 75), and the liverworts ***Frullania*** (3 spp.; Figure 79), ***Lunularia cruciata*** (Figure 76), ***Marchantia polymorpha*** (Figure 34), and ***Riccia*** (4 spp.; Figure 78). Some of these species may have arrived from other parts of the world.

Figure 139. Mungo National Park, Lake Mungo, Australia, a site with soil crusts where bryophytes were well represented. Photo by Dhum Dhum, through Creative Commons.

Figure 140. Mt. Tomah Botanical Gardens, Australia, home to 70 moss, 24 liverwort, and 1 hornwort species. Photo by L. Walsh84, through Creative Commons.

Figure 141. Pond in Royal Botanic Gardens, Sydney, Australia, a park with 70 moss, 24 liverwort, and 1 hornwort species known. Photo by J. Bar, through Creative Commons.

Other botanical garden investigations include those of Nohl (1977), Menzel (1984), Al Araj and Klotz (1989), Ziegler (1996), Kiessling & Stetzka (1997), De Bruyn & Homm (2009), and Teutsch (2021).

Value

Public gardens cover a wide range of purposes. This translates into a variety of sources for any bryophytes found there. Bryophytes can serve as aesthetic enhancement, but they can also provide protected places where experimentation is possible. Since gardens are likely to be encouraged by use of fertilizers, response of bryophytes can be studied by providing invisible (hidden) markers and following the responses of the bryophytes to the fertilizers. This might be complicated, however, when one tries to create a suitable control.

Among the 90 species of bryophytes in the Cibodas Botanical Garden, Indonesia (Figure 77), Nadhifah *et al*. (2018) found 42 species with potential use and 42 species with potential use in medicine, ornamental purposes, agriculture, and environmental services.

Perhaps one of the most valuable uses would be to track dispersal and its mechanisms. Plants in botanical gardens often come from all over the world, or at least from some place else. Hence, these gardens can have species that arrived as hitchhikers with the tracheophytes that were planted there. This provides an opportunity to see what survives in both the short and long term. But, of course, these hitchhikers are a problem beyond the confines of the garden. They can become invasive species, as seen for ***Pseudoscleropodium purum*** (Figure 142) and others.

Figure 142. ***Pseudoscleropodium purum***, an invasive species. Photo by Claire Halpin, with permission.

Bryophyte Volunteers in Personal Gardens

Smith *et al*. (2010) studied the bryophytes in 61 domestic gardens in Sheffield, UK. They recorded 67 bryophytes, with individual gardens having 3-24 species. The mean richness was 11.3. Slightly over 20% of the bryophyte species occurred in grass lawns, and these species were the most widespread compared to those of other habitats. Only 10% occurred in more than half the gardens. Area, substrate richness, and altitude explained 39.1% of the bryophyte richness.

Dick Lister (Bryonet 5 February 2022) provided us with a species list from the Royal Horticultural Society's garden tour at Wisley, Surrey, England. Of the 8 categories of gardens, the most common bryophyte taxa, occurring in at least 4 of the 8 are ***Brachythecium rutabulum*** (Figure 68), ***Bryum dichotomum*** (Figure 143), ***Campylopus introflexus*** (Figure 82), ***Ceratodon purpureus*** (Figure 69-Figure 70), ***Cratoneuron filicinum*** (Figure 144), ***Eurhynchium praelongum*** (as ***Kindbergia praelonga***; Figure 71), ***Funaria hygrometrica*** (Figure 117), ***Hypnum cupressiforme*** (Figure 73), ***Zygodon viridissimus*** (Figure 145). Of these, all are common elsewhere in gardens except ***Cratoneuron filicinum*** and ***Zygodon viridissimus***. In addition to these frequent species, these gardens had many additional species and genera that are frequent in the public parks and gardens elsewhere, including the liverworts ***Lunularia cruciata*** (Figure 76), ***Marchantia polymorpha*** (Figure 34), and ***Riccia sorocarpa*** (Figure 78), the hornwort ***Anthoceros*** (Figure 99), and the mosses ***Amblystegium serpens*** (Figure 66), ***Atrichum undulatum*** (Figure 67), ***Barbula convoluta*** (Figure 120), ***Barbula unguiculata*** (Figure 80), ***Bryum argenteum*** (Figure 81), ***Ptychostomum capillare*** (as ***Bryum capillare***; Figure 118), ***Eurhynchium hians*** (as ***Oxyrrhynchium hians***; Figure 90), ***Fissidens*** (Figure 83), ***Grimmia pulvinata*** (Figure 72), ***Homalothecium sericeum*** (Figure 88), ***Orthotrichum affine*** (Figure 49), ***Orthotrichum anomalum*** (Figure 106), ***Orthotrichum diaphanum*** (Figure 50), ***Orthotrichum lyellii*** (Figure 51-Figure 52), ***Rhynchostegium confertum*** (Figure 74), ***Syntrichia laevipila*** (Figure 55-Figure 56), ***Syntrichia latifolia*** (Figure 57-Figure 59), ***Syntrichia ruralis*** (Figure 91), ***Tortula muralis*** (Figure 75), and ***Ulota phyllantha*** (Figure 54).

Figure 143. ***Bryum dichotomum***, a species that is frequent in private gardens in Wisley, Surrey, England, but not in gardens and parks elsewhere. Photo by Claire Halpin, with permission.

Figure 144. ***Cratoneuron filicinum***, a species that is frequent in private gardens in Wisley, Surrey, England, but not in gardens and parks elsewhere. Photo by Claire Halpin, with permission.

Figure 145. ***Zygodon viridissimus*** with capsules, a species that is frequent in private gardens in Wisley, Surrey, England, but not in gardens and parks elsewhere. Photo by David T. Holyoak, with permission.

Alien Species

It would appear that bryophytes should be able to invade new areas such as gardens more easily than most tracheophytes (Essl & Lambdon 2009). Their dispersal by spores is easier than that by seeds, making colonization easier. On the other hand, their very limited cultivation use results in few deliberate introductions. Their impacts, due to their small size, are small. Nevertheless, we have almost no understanding of the long-term effects of invasive bryophytes.

Essl and Lambdon (2009) noted that we have little information regarding the invasion history of bryophytes. Their spore dispersal is efficient, giving them a greater colonizing ability than that of tracheophytes. Deliberate introductions are rare because they are seldom used in gardens. Because of their small size, we assume that they have little measurable impact on the ecosystems they invade. This is an area that needs to be considered by the scientific community, particularly as their use in green technology and gardening is increasing and their availability through internet orders is increasing.

In Europe, Essl and Lambdon (2009) identified 45 species that seem to be alien in at least parts of Europe (Table 1). These include at least 21 mosses and 11 liverworts, but no hornworts. Of these, ***Campylopus introflexus*** (Figure 82) and ***Orthodontium lineare*** (Figure 146) have become widespread mosses and the Mediterranean liverwort ***Lunularia cruciata*** (Figure 76) has exhibited great northward expansion. A number of tropical species were present only in glasshouses, including ***Marchantia pappeana*** (Figure 147), ***Vesicularia reticulata*** (Figure 148), and ***Zoopsis liukiuensis*** (Figure 149). Glasshouses seem to be the only places outside California to find ***Lunularia cruciata*** in North America (Schuster 1992).

Table 1. Alien bryophytes in Europe, ranked by decreasing number of invaded countries/regions. Only species invading >3 countries/regions are shown. From Essl and Lambdon 2009.

Campylopus introflexus	21
Orthodontium lineare	15
Didymodon australasiae	11
Ricciocarpos natans	8
Leptophascum leptophyllum	6
Hennediella stanfordensis	4
Tortula bolanderi	4
Lunularia cruciata	12
Riccia rhenana	12
Scopelophila cataractae	7
Dicranoweisia cirrata	4

Figure 146. ***Orthodontium lineare*** with capsules, on soil bank, an invasive species in parts of Europe. Photo by Claire Halpin, with permission.

Figure 147. ***Marchantia pappeana***, a species that has invaded glass houses in Europe. Photo by Rob Palmer, through Creative Commons.

Figure 148. ***Vesicularia reticulata***, a species that has invaded glass houses in Europe, most likely arriving in the aquarium trade. Photo by Tan Sze Wei, with permission.

Figure 149. ***Zoopsis leitgebiana***; ***Zoopsis liukiuensis*** has invaded glass houses in Europe. Photo from Auckland Museum, through Creative Commons.

Although most of the alien bryophytes remain rare in their new locations, several have become rather widespread and have the potential to impact their ecosystems (Essl & Lambdon 2009). At present, these are ***Campylopus introflexus*** (Figure 82) and ***Orthodontium lineare*** (Figure 146). The thallose liverwort ***Lunularia cruciata*** (Figure 76) continues to spread, but it seems to be rather restricted in its habitat, mostly surviving in glass houses outside its normal range. Essl and Lambdon concluded that the alien bryophyte species in Europe tend to occur in disturbed habitats where humans have played a major role, including gardens, roadsides, and walls.

We must first ask ourselves what impacts invasive bryophyte species **might** have. Essl and Lambdon (2009) suggest that they could compete with native bryophytes and lichens or even with germinating seedlings by blocking light, sequestering nutrients, or occupying space. It appears that the only documented strong impact by an invasive bryophyte is that of ***Campylopus introflexus*** (Figure 82). Its dense mats significantly reduce the diversity of both bryophytes and lichens (Hahn 2006). In other cases, this species has colonized thatched roofs in southern England

where they could replace the diminishing populations of ***Leptodontium gemmascens*** (pers. comm. by Ron Porley, in Essl & Lambdon 2009).

As interest has grown regarding invasive species, Essl *et al*. (2013) have provided us with a glimpse of the forces behind invasive bryophytes. Of the 139 bryophytes considered to be alien in Europe, they consider 34 to be hitch-hikers (34 species) or companions (27 species) with ornamental plants, constituting the most important means of introduction. Fortunately, most of these seem to be successful only in habitats created by humans and seem unable to become established in natural ecosystems.

Impacts of alien bryophytes on biodiversity and socio-economy are a recent phenomenon, with >85 % of impacts on biodiversity, and 80 % of impacts on socio-economy recorded since 1990 (Essl *et al*. 2014). On average, 40 years (impacts on biodiversity) and 25 years (impacts on socio-economy) elapsed between the year a bryophyte species was first recorded as alien in a region and the year impacts were first recorded. They found that since the first reported invasion occurred, the number of records has increased rapidly. Based on this trend, they concluded that the impacts of these invaders will continue to increase.

Essl *et al*. (2015) began to explore the macroecology of bryophyte invasions. Most naturalizations occurred in complementary regions of the opposite hemisphere (Essl *et al*. 2015). And the Southern Hemisphere has experienced more invasions with naturalizations than has the Northern Hemisphere. Hence, naturalizations are most likely to occur in biogeographically separated regions that exhibit climates similar to that of the location of origin.

Bryophytes in Glass Houses

France (2019) interviewed the horticultural staff at the Ferns and Fossils House at the Royal Botanic Garden Edinburgh (Figure 150). He recommended raising the status of bryophytes in botanic gardens and increasing the diversity of living collections.

Figure 150. Greenhouse, Royal Botanic Garden of Edinburgh, an opportunity to include more bryophytes in a public place. Photo by Eldubhe, through Creative Commons.

Botanical gardens and greenhouses often import and cultivate non-native species. Essl and Lambdon (2009) assessed the reasons for studying bryophyte invasions. They considered them to be poorly recorded and thus provide little information upon which to assess their invasion history. They have efficient dispersal by spores and have a greater ability to naturalize than other major taxonomic groups. They are seldom cultivated, so deliberate introductions are few. Their small size makes their impact on the environment small. On the other hand, the possibility that these invasions have long-term effects has never been explored.

For whatever reason, ***Lunularia cruciata*** (Figure 76) is particularly common in glass houses (Sabovljević & Marka 2009), often in parts of the world where it is unknown outside these structures.

Educational Displays

A number of gardens serve educational needs. This may be the entire garden, or only small portions. This education is usually accomplished by signs. Some gardens include a feel garden, especially pitched toward the blind, but can also be attractive to children. Mosses offer a wide range of textures that can be a delight to those meeting them for the first time. Additional information can be provided in Braille.

The Moss House (Figure 151-Figure 152) in India is designed for teaching. The bryophytes are planted and the species patch is outlined with white rocks (Figure 153-Figure 154). A label is placed on a stake in the patch. A simpler design without the feel of a garden is to plant bryophytes in pots and provide them with a label (Figure 155).

Indoor gardens like the Moss House require watering. This is best done with an automatic misting system (Figure 156), but care must be taken to create the appropriate regime. A filtering system might be needed to remove chlorine and unwanted minerals from the water. A fan may be needed to prevent mold.

Figure 151. Moss house where mosses are inside a shaded greenhouse. Photo courtesy of Virendra Nath.

Figure 152. Moss greenhouse in preparation, showing a fountain that will help to maintain moisture. Photo courtesy of Virendra Nath.

Figure 153. Labelled bryophytes in the Moss House, showing the white rock and label system used to identify the species. Photo courtesy of Virendra Nath.

Figure 154. ***Plagiochasma appendiculatum*** showing white rocks and labelling. Photo courtesy of Virendra Nath.

Figure 155. Labelled pots with species name, family, common name, and location of origin. Photo courtesy of Virendra Nath.

Figure 156. Misting indoor moss garden in India. Photo courtesy of Virendra Nath.

Labelling

In an arboretum labels (Figure 153-Figure 155) help us to learn the names of the trees. Few gardens exist where a similar education is available for bryophytes. I quickly learned one of the problems of providing such labels for bryophytes. I learned that the field trip I had been asked to lead would have 60 participants. I went armed with a stack of pink computer cards. At each bryophyte, I placed a card with the name of the species. But the bryophytes were small and the cards were large. Many of the cards touched several species. That is only part of the problem in a bryophyte garden. As time passes, the species that is labelled can expand or get overgrown by other bryophytes. Furthermore, to most people, all bryophytes look pretty much the same. One Botanical Garden has attempted to solve the problem by locating a large patch of the bryophyte and attaching a label, then posting information explaining the characters used to identify the bryophyte and providing other useful information about it (Figure 157).

Figure 157. Labelling of the leafy liverwort ***Frullania dilatata*** in a Botanical Garden. Photo courtesy of Stefan Schneckenburger.

Summary

Public gardens occur all over the world, and many have sections with bryophytes, especially in Japanese gardens. These bryophytes require caretakers who understand the differences in the needs of bryophytes, avoiding fertilizers and maintaining boundaries between species. Watering may also be necessary.

Moss gardens are best known from Japan, but a number have mimicked the Japanese style of moss gardens in other countries.

Local species can be preserved in parks that serve as refuges in city landscapes. The number of species depends on the size of the park, the number of habitat types, and degree of human disturbance. Climate affects the parks in the same way it does non-park areas.

Bryophytes may enter the country or local area in pots of other plants that become a part of these gardens, whether public or private. These tend to be more successful in the human disturbance areas like parks and gardens than they do in nature. These aliens are most likely to arrive from the opposite hemisphere from areas with similar climates. ***Campylopus introflexus*** and ***Orthodontium lineare***, in particular, have become well established in many areas as invasive species. Glass houses may have bryophytes that arrive in pots from all over the world. ***Lunularia cruciata*** exists in many locations only in glass houses.

Teaching gardens are often enhanced for learning by having labels. These need to be carefully monitored to be sure the same species remains with its label.

Acknowledgments

Dale Sievert made this chapter possible with his images of gardens with mosses from all over the world, and especially from North America. Virendra Nath contributed images from the Moss House that formed the basis of the Educational Displays section.

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