CHAPTER 7-5
GARDENING: PUBLIC GARDENS

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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.

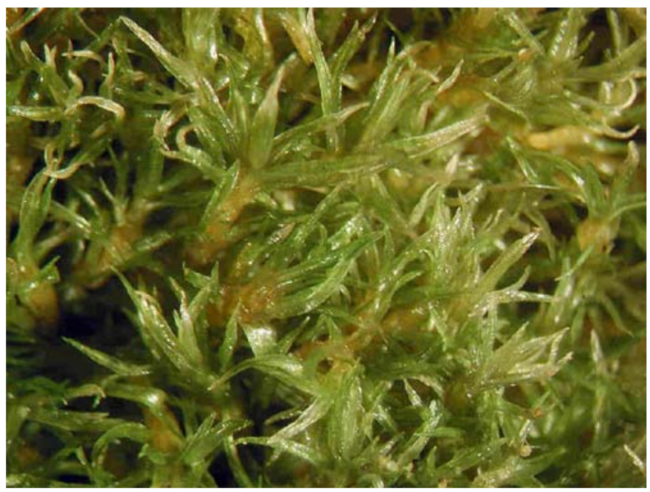

Figure 46. ***Didymodon umbrosus***, an introduced species in the Old Botanical Garden in Göttingen, Germany. Photo by Michael Lüth, with permission.

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.

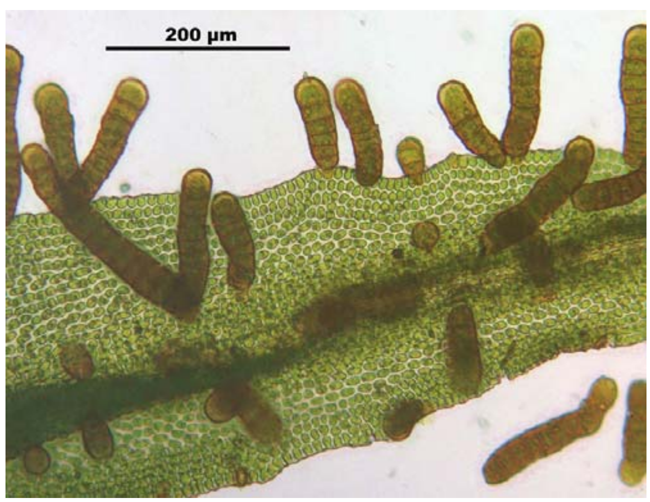

Figure 52. ***Orthotrichum lyellii*** leaf with gemmae, a possible means for its arrival in the botanical garden of Aarhus, Denmark. Photo by Hermann Schachner, through Creative Commons.

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.

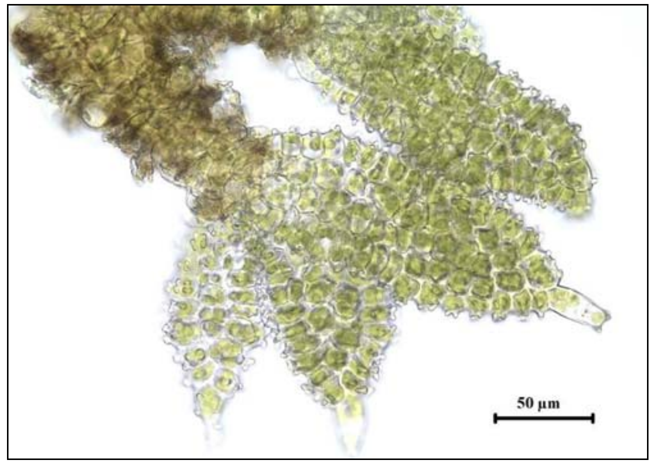

Figure 56. ***Syntrichia laevipila*** gemmae, a possible means for arrival of this species in the botanical garden of Aarhus, Denmark. Photo by Hugues Tinguy, with permission.

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.

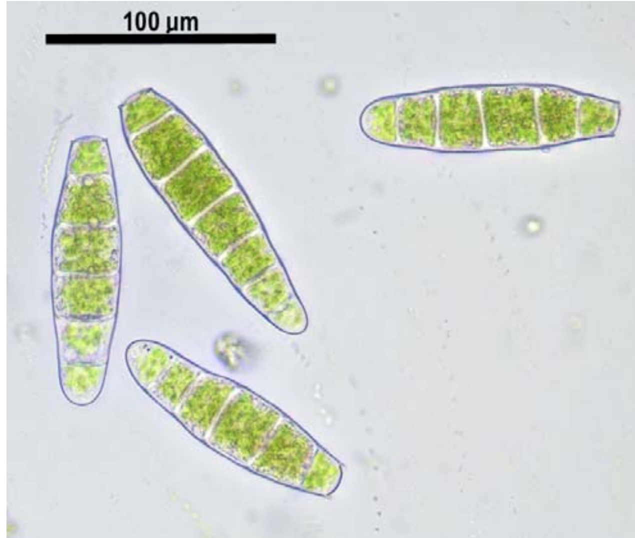

Figure 62. ***Zygodon conoideus*** gemmae, possible dispersal units to reach the botanical garden at Aarhus, Denmark. Photo by Claire Halpin, with permission.

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.

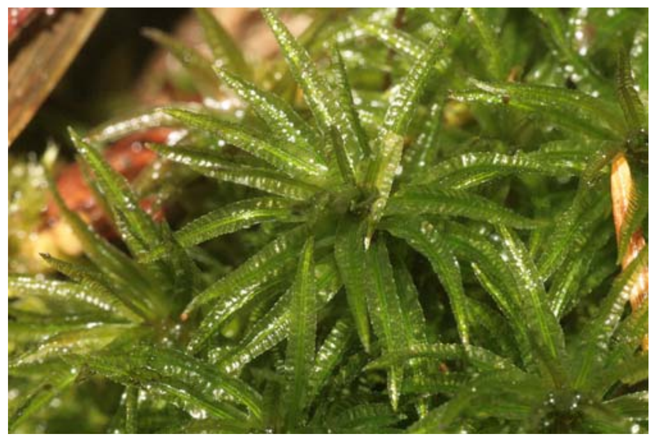

Figure 67. ***Atrichum undulatum***, a species that occurs in both the Bartlett Arboreum Forest in Connecticut, USA, and at the Botanic Garden Rombergpark, Germany. Photo by Hermann Schachner, through Creative Commons.

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).

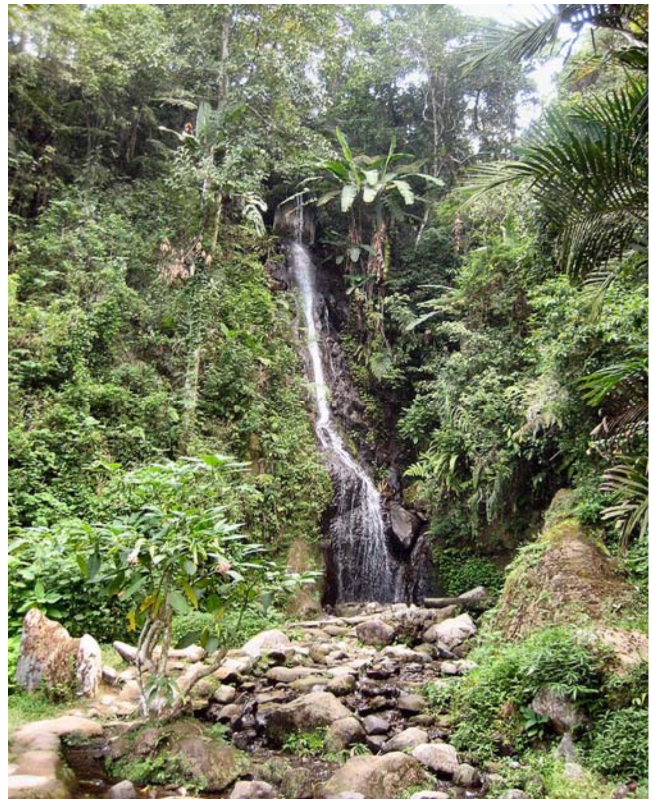

Figure 77. Cibodas Botanical Garden, Indonesia, a tropical garden with very different bryophytes from those in the temperate zone. Photo by Hullie, through public domain.

Figure 78. ***Riccia sorocarpa***; the genus ***Riccia*** is frequent in parks throughout the world. Photo by Claire Halpin, with permission.

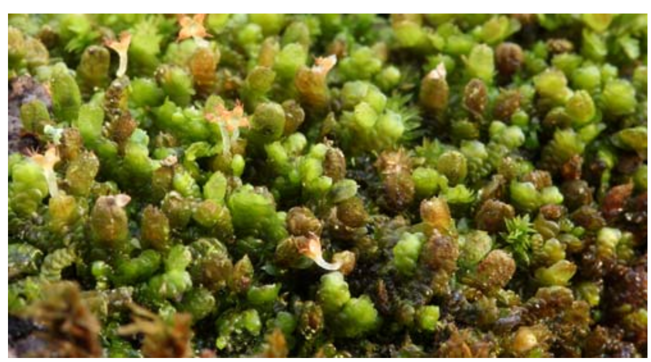

Figure 79. ***Frullania dilatata*** with capsules dehiscing; the genus ***Frullania*** is frequent in parks throughout the world. Photo by Claire Halpin, with permission.

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.

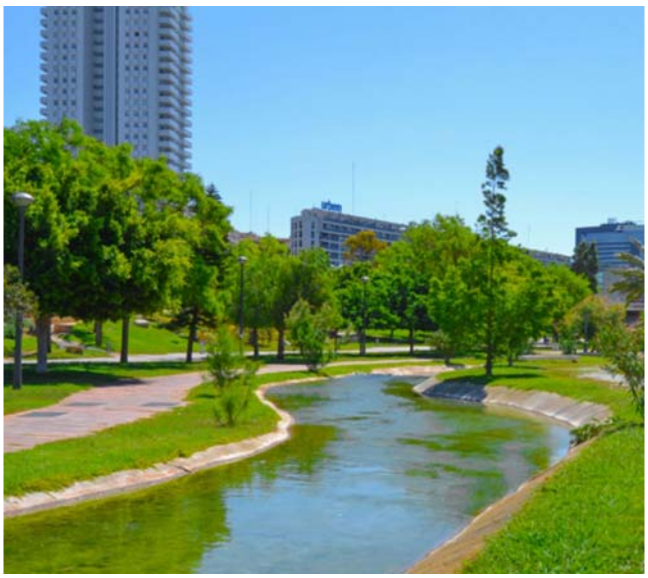

Figure 112. Turia River Garden, a park with a variety of natural substrates that support bryophytes. Photo by through Creative Commons 1 Stefan Majewski, through Creative Commons.

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.

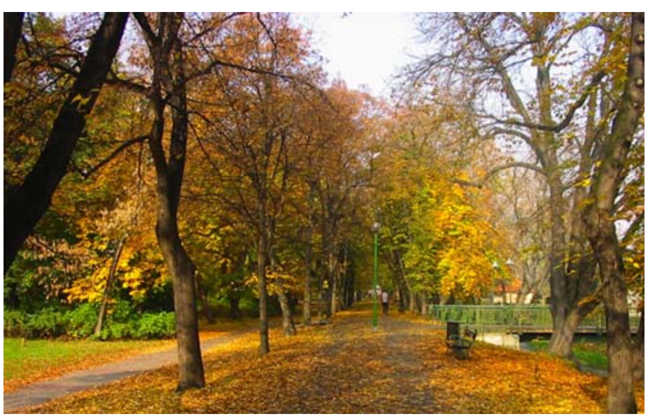

Figure 126. Central Park Archbishop's Garden in Eger, Hungary, home to 55 moss and 4 liverwort species, with nearly half in only three families. Photo by Zolchew, through Creative Commons.

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.

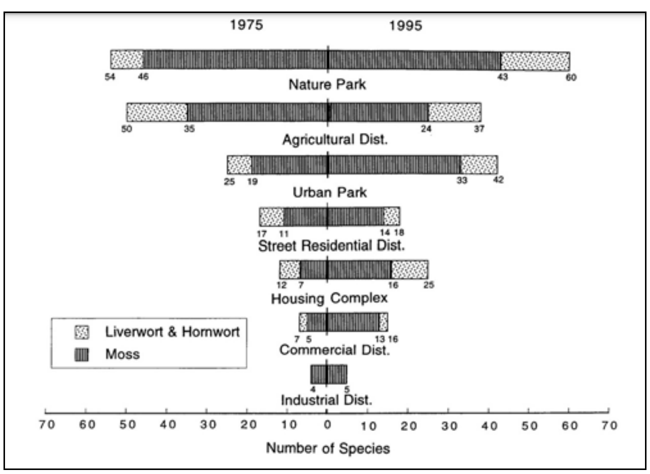

Figure 134. Changes in moss, liverwort, and hornwort species from 1975 to 1995 in Chiba City and Yotsukaidou City, Japan. Image slightly modified from Nakamura & Suga 1997.

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.

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