Scientific Review – Engineering and Environmental Sciences (2019), 28 (1), 118–130
Sci. Rev. Eng. Env. Sci. (2019), 28 (1)
Przegląd Naukowy – Inżynieria i Kształtowanie Środowiska (2019), 28 (1), 118–130
Prz. Nauk. Inż. Kszt. Środ. (2019), 28 (1)
http://iks.pn.sggw.pl
DOI 10.22630/PNIKS.2019.28.1.11

Ewa BURSZTA-ADAMIAK[1], Ewa FUDALI[2], Janusz ŁOMOTOWSKI[1], Karolina KOLASIŃSKA[1]

[1] Faculty of Environmental Engineering and Geodesy, Wroclaw University of Environmental and Life Sciences
[2] Faculty of Life Sciences and Technology, Wroclaw University of Environmental and Life Sciences

A pilot study on improve the functioning of extensive green roofs in city centers using mosses

Key words: green infrastructure, green roof challenges, moss roofs, longevity of vegetated roofs, simplified green roof design

Introduction

Concept of green roofs has developed as a way to mitigate such well-known urban environmental problems as storm water runoff disturbances due to an increase of impervious surfaces and loss of areas covered with vegetation, heat expansion and air pollution (Oberndorfer et al. 2007; Francis & Jensen, 2017). Generally, green roofs are divided into two main categories: extensive and intensive. Extensive green roofs are the most popularly deployed forms of green roofs because they should be by assumption light weight and low cost (Shafique, Kim & Rafiq, 2018a). These roofs are constructed as multi-layer systems, in which the vegetation layer (growing medium + plants) is the most external element. The vegetation layer not only creates good aesthetics, but is also beneficial for the environment. Plants on green roofs store water and can diminish the water quantity on green roofs by 20–99% (Szejba, Szatyłowicz & Gnatowski, 2017; Viola, Hellies & Deidda, 2017; Shafique, Kim & Kyung-Ho, 2018b), improve the city's microclimate through oxygen emission and carbon dioxide reduction, as well as through transpiration that increases the air moisture and makes the air cooler (Jim, 2012). Vegetated roofs also intercept more dust and suspended matter from the precipitation than roofs without vegetation layer (Whittinghill, Hsueh, Culligan & Plunz, 2016). Additionally, they create novel urban wildlife habitat, where many species of invertebrates and avifauna (Mayrand & Clergeau, 2018) can survive.

Despite of the many advantages of green roofs, today's investors (building's owners) recognize also several disadvantages of these systems, i.e. maintenance requirements and increased structural loads and increase of design and construction cost (Li & Yeung, 2014).

That technical problem arises from the need to maintain appropriate conditions (growing medium or substrate) for the development of vascular plants what increases structural loads. Extensive green roofs typically add between 50 and 200 kg·m^{-2} of loading to the roof of a structure. This increase in load has to be taken into account by the structure of the building. Existing roofs often require additional structural support for extensive green roof installation (Carter & Keeler, 2008). Increase of maintenance cost and increased design and construction costs are barriers to installing extensive green roofs on existing buildings. For these reasons modern green roof designs are heading towards the search for lightweight green roof systems so that they can be located also on rebuilt (modernized) buildings. The opinion that there is a current need to develop cost effective green roofs that can have multiple benefits in the urban area one can find also in the latest review of research on the green roofs (Shafique et al., 2018a). These authors find the cost of the green roofs as the challenge for their application.

Full exposure to environmental factors (insolation, high/low temperature, winds, wide amplitude of the moisture changes) makes roofs of many buildings highly unfavourable for the plant's development (Oberndorfen et al., 2007). That is a reason that only a relatively small group of plant species, mainly graminoids and succulents, can grow and last on extensive green roofs (Ishimatsu & Ito, 2013; Razzaghmanesh, Beecham & Kazemi, 2014). But the grass species often get diseases and die on extensive green roofs, both during highly dry and warm seasons (Heim, Lundholm & Philip, 2014) and very wet periods (Burszta-Adamiak, Pląskowska & Weber-Siwirska, 2011). Taking into account that most of environmental benefits of green roofs result from the presence of a vegetation layer it can be assumed that the death of the plant layer will worsen the functioning of green roofs.

Furthermore, unsuccessful establishment of plants will influence the green roof performance, i.e. esthetics. In turn the green roof performance will influence the long-term acceptance by the public. Thus, obtaining a permanent plant layer resistant to difficult urban conditions is a challenge for further studies on selection of plants.

Researchers who know plant's problems suggested few characteristics of extensive green roof plants i.e. they establish fast and reproduce efficiently, they are short in height and cushion-forming or mat-forming, their roots are shallow but spreading and their leaves are succulent or able to store water (Li & Yeung, 2014; Shafique et al., 2018a). Additionally Butler, Butler & Orians (2012) promoted the use of native plants on green roofs as those already well adapted to the local conditions. Model plants for extensive green roofs should not need watering irrigation, fertilizers or pesticides.

Since the year 2009, the authors have conducted research on extensive green roofs models (Burszta-Adamiak et al., 2011; Burszta-Adamiak, Stańczyk

& Łomotowski, 2019). During that time it was observed a spontaneous colonization and development of mosses on the green roofs, which seemed to be well suited to the roof's environmental conditions.

In the recent literature the question whether mosses may support the ecosystem services provided by green roofs has been addressed by few authors (Studlar & Peck, 2009; Anderson, Lambrinos & Schroll, 2010; Heim et al., 2014). Their studies documented the mosses ability to retain storm water (Anderson et al., 2010), reduce soil temperature relative to the bare substrate and facilitate growth of some vascular plants on green roofs (Heim et al., 2014). In the quoted experiments, clumps of mosses were collected from various habitats and put in the whole into the roof's substrate. Published observations have concerned one season of experiments, so durability of the moss layer created in such a mode is not known.

The presented work aimed to investigate whether a moss layer can develop, grow and sustain on roofs of simplified structure in comparison to typical green roofs designed for vascular plants. It would be an alternative design solution for installation of green roofs on already existing buildings and situated in the city centers as well as for rebuilt of vegetation layer on green roofs on which former plant layer has dead. Five detailed research tasks were formulated:

– Determination if the layer of mosses which occurred spontaneously develops and lasts (I stage of studies).
– Recognition of the moss layer species composition and its dynamic during some seasons to select the species well adapted to conditions in the city center (I stage of studies).
– Examination whether mosses will grow and create a green carpet on roof models of simplified structure after intentional introduction (transplantation) (II stage of studies).
– Comparison of the effectiveness of two methods of transplantation in relation to the growth rate and the size of the generated green layer (II stage of studies).
– Determination what is the average weight of the moss layer during the year and how it changes (III stage of studies).

Methods

Site description

Experimental green roof models sites were consisted of four roof platforms installed on the rooftop of the Science and Education Centre of the Wroclaw University of Environmental and Life Sciences (SEC) building, which has a height of 10 m and is located in the dense city centre and along a high traffic road. Thus, environmental conditions on the studied rooftop are typical for strongly urbanized areas with the high air pollution. Detailed description of the roof platforms with photos of the site is presented in the papers by Burszta-Adamiak (2012) and Burszta-Adamiak et al. (2019).

Wrocław, one of the biggest cities in Poland, is situated in the south-western part of the country, on a flat area in the Nizina Śląska. The annual rainfall is highly variable and ranges from 318 to 892 mm, and quite frequently there are a series of wet years with an annual rainfall higher than 600 mm. Average annual precipitation in the years 1971–2001 was 583 mm (Dubicki, Dubicka & Szymanowski, 2002).

During the years of 2009–2017 (the time period of studies for roof platforms study), the average annual rainfall amounted to 584 mm. During these years, nearly 60% of all rainfall registered for each year did not exceed 5 mm during the day. Heavy rainfalls exceeding daily 20 mm were observed sporadically (7%), but most of them were very intense and long lasting. They resulted in local flooding and the sewage system overloading in the years of 2009, 2010, 2012 and 2014.

Average day and night temperatures in Wrocław during the period of the experiments were 9.6°C, with a summer heat wave in August of 2015 and 2017 (> 30°C). In the centre of Wrocław, a city heat island occurs, and is the most intense during summer nights (Dubicki et al., 2002).

Research stages and their methodology

The first stage of studies was realized with use of four experimental modules having a form of roof platforms with external dimensions 2.40 × 1.20 × 0.35 m (length × width × height) inclined at an angle of 7.7% and an internal volume capacity of 0.6 m^3, installed in the year 2009 (Burszta-Adamiak, 2012). These extensive green roof platforms are multilayer systems consisting of vegetation + commercial substrate ("growing medium") + filter fabric + drainage layer + protective geotextile fabric + waterproofing membrane. The thickness of substrate layer was the same for every platform and amounted to 0.1 m. In each platform with the green roof, a protective gravel strip of 0.25 m width was formed. The vegetation layer consisted of one species of grass – *Festuca scoparia* (Hack.) A. Kern. and two species of succulents – *Sedum acre* L. "Yellow Queen", *Sempervivum tectorum* L. "Othello"), planted individually in diagonal rows with a distance of 0.2 m. Initially the vegetation layer of roof platforms was differentiated. On two (A, B) experimental modules both the grass and stonecrop were planted, on the site C – only stonecrop. The layer at fourth module (D) was overgrown with *S. tectorum*. The plant varieties applied are commonly used as green roof plants in the climate of Poland. At the beginning, the plants covered circa 50% of the roof platform. No agricultural maintenance operations (fertifization, irrigation) were done so as not to disturb measurements of the quantity and quality of runoff from green roofs.

Observation of the durability of moss cover which had developed spontaneously on the roof platforms in the previous years and their species composition was started in the spring of 2015. Then the plant layer on three platforms (A, B, C) consisted of dead grass remains and plant species that emerged as a result of natural succession, including mosses. On the fourth roof platform (D) the plant layer was built by the species introduced intentionally in 2009. A substrate among the plants was covered with mosses and some spontaneous herbs. Results of observation were documented four times in a year; regularly every three months a percentage of substrate's surface covered with mosses was estimated for each roof platform and moss species occurring on them were listed and their percentage cover was estimated and recorded. That stage allowed to select moss species best adapted to grow on roof, *Ceratodon purpureus* Hedw. which was used in the stages II and III.

To examine whether mosses will grow and create a green carpet on green roof models of simplified structure after intentional introduction (transplantation) three author's models of such roofs were constructed (stage II). They differed with the presence/lack of the drainage layer as well as with the character of the latter (Fig. 1). These were:

- N – roof model without the drainage layer; it consisted of: growing medium (seven-centimeter thick layer) + protective geotextile fabric;
- P – roof model with plastic drainage layer of five-centimeter height; it consisted of: growing medium (seven-centimeter thick layer) + filter fabric + drainage mat + protective geotextile fabric;
- S – roof model with drainage layer of small stones of five-centimeter height; it consisted of: growing medium (seven-centimeter thick layer) + filter fabric + gravel drainage layer + protective geotextile fabric.

Models of simplified roofs were constructed in plastic open-work boxes with dimensions 0.18 m width, 0.21 m length, 0.2 m height, each in four repetitions. In every roof model, the same commercial growing medium was applied. It contained volcanic lava, pumice-stone, expanded clay aggregate, gravel, smashed bricks and compost. Characteristics provided by the manufacturer were as follows: porosity was 60% of the capacity, reaction pH was 7.8, organic matter content was 2% of dry mass, water permeability was 60 $mm \cdot min^{-1}$.

Two methods of transplantation were applied for every simplified roof model (in two repetitions for each method): first through a transfer on the whole turf of the same dimensions (5 × 5 cm); and second through introduction into five-milimeter fragments of stems gained from the turf of the same size as first method. Transplant material was taken from the additional roof platform, where *Ceratodon purpureus* appeared spontaneously. Old decayed parts and immature capsules were removed. Before transplant, turfs

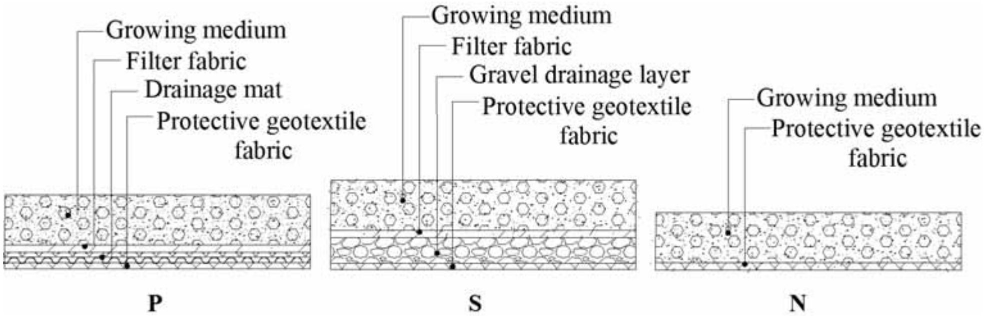

FIGURE 1. Cross-section through the green roof models of simplified structure P, S, N – roof models of simplified structure describe in the text

were also shaken up to remove other organic particles.

Transplanted samples were prepared in the April of 2015 and located near the green roof platforms to secure similar environmental conditions. During the first two weeks, the samples were watered every day, and later they were left only to the influence of the weather.

Once every month (about the 15th day), the condition of the moss layer was controlled. For the first transplant method, the turf dimensions were measured; for the second transplant method, it was checked whether surface of the substrate became green, the approximate percentage coverage of surface with mosses was estimated visually and then the average height of the turf was measured. For the results, the observed percentage coverage of the model roof surface with mosses was converted into the size of the area covered with the moss layer in [cm²].

The third stage was realized in the period from March of 2017 to March of 2018. To determine how does average weight of the moss layer change during the year the moss cover existing on roof platforms was used. Every week, three samples of the dimensions 5 × 5 cm were taken from each of the roof platforms to be weighed in the lab and later carried back on their place. Mean value of three repetitions was calculated for each roof platform. The results obtained were referred to the area of 1 m^2 of the roof as a more practical measure.

Results and discussion

Observation of the spontaneous moss layer longevity

During the four years of the observation the moss layer appeared permanently on all roof platforms showing small fluctuations during the season in relation to the percentage of cover (Fig. 2). In the last year it was observed a slight decrease in the roof coverage by mosses caused by its partial damage by birds (crow *Corvus corone*).

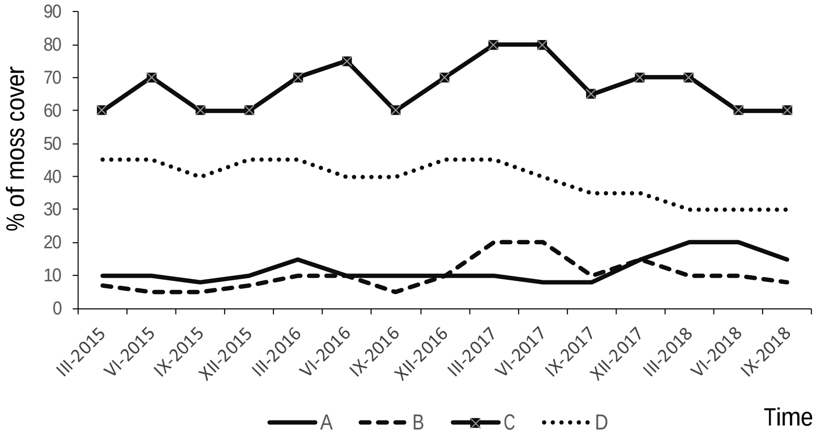

FIGURE 2. Changes in the % of the moss layer coverage of the roof platforms in the years 2015–2018. A, B, C, D – experimental roof platforms differing in the arrangement of structural layers, kind of growing medium and initial plant composition (own studies)

Species composition of moss layer during four years of observation

In total five species of mosses were registered, but all of them occurred only on the platform D. Numbers of moss species recorded on other roof platforms were lower, from 1 to 2. During the four years of observation the dominance of only one species *Ceratodon purpureus* Hedw. was stated (the table).

Ceratodon purpureus is a world-wide distributed ruderal moss occurring commonly in all urban habitats (Fudali, 1996, 2001). The species is resistant to moisture changes and has wide ecological amplitude in relation to the substrate reaction and trophy (Dierßen, 2001). During the experiment, the weather was very unstable, with alternating long periods of drought and high temperature (> 30°C) and wet periods with long-lasting rains. After each drought period, the mosses had lost aesthetic value, but they quickly regenerated.

Transplant experiment

For 11 months (from April of 2015 to February of the 2016), no new individual appeared in any mode of the transplant method, and in any variant of the roof structure (Fig. 3). In March of 2016, the growth processes started in both transplant methods, but with different extensions. In the first transplant method, a slight increase of the turfs introduced was observed from 2 to 6%, dependent on the roof model. In the transplant method (2), a low moss layer (height of 3 mm) appeared for every roof model and covered from 30 to 40% of the substrate area (Fig. 3).

TABLE. Occurrence of the moss species recognized on the particular roof-models and their % cover during four years of the observation. A, B, C, D as on Figure 2 (own studies)

Species	A				B				C				D			
	2015	2016	2017	2018	2015	2016	2017	2018	2015	2016	2017	2018	2015	2016	2017	2018
Ceratodon purpureus	9	11.8	7.3	17.8	5.8	8.5	16.1	9.1	60.3	68.8	73.8	63.3	43.2	41.8	38	26.2
Bryum argenteum	0.5	0.5	0.5	0.5	1	1	0.5	0.5	.	.	.	.	1	1	0.5	0.5
Bryum caespiticium	.	.	.	.	.	.	.	.	.	.	.	.	1	1.5	2	2
Funaria hygrometrica	.	.	.	.	.	.	.	.	.	.	.	.	0.25	0.25	0.25	0.25
Polytrichum juniperinum	.	.	.	.	.	.	.	.	.	.	.	.	0.1	0.2	0.4	0.5

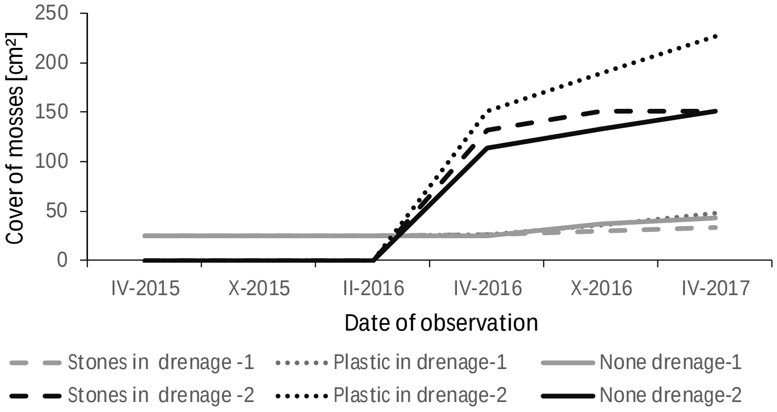

FIGURE 3. The moss layer development on three various models of green roofs where two variants of the transplant method were applied during two years of the experiment. 1 – through a transfer on the whole turf, 2 – through introduction of stems fragments of 5 mm; S, P, N – roof models of simplified structure (description in the text)

The next observation showed a continual, but still slow, increase of the moss layer in both transplant methods and every roof model, but differences in the growth rate of the green surfaces between them became more visible.

Two years after the start of the experiment, in April of 2017, areas of the moss layer varied in size markedly, in dependence of roof model and transplant method applied. In method (1), the size of turfs increased from 35% (stones drainage – S) to 90% (plastic drainage – P) with 74% of model without drainage (N); but in total, moss layer covered respectively: 8.96% of the area in model S, 12.59% in P and 11.5% in N. Turf height was 1.2 cm. In the second method, the moss layer covered from 40% (models S and N) to 60% (model P) of the roof model's substrate area, and its height was from 0.8 cm (model P) to 1.2 cm (models S and N). In all roof models sporophytes were observed. In May of 2017, the pecking traces by birds (crow *Corvus corone*) and partial damage of moss cover were observed on half of roof models.

Weight of the moss layer

The median of the moss layer weight on roof platforms was similar on the sites A and C as well as on sites B and D, and amounted respectively 2.2 and 1.8 $kg \cdot m^{-2}$ (Fig. 4). Average weight of the moss layer amounted respectively 2.5 $kg \cdot m^{-2}$ for sites A and C and 1.9 $kg \cdot m^{-2}$ for sites B and D. During the year it fluctuated in dependence from the meteorological conditions. Minimum weight was 0.3 $kg \cdot m^{-2}$ (samples were taken after few days without rainfall) while maximum was 6.9 $kg \cdot m^{-2}$ (sites B and C) and was noted immediately after rainfall.

Thus maximum weight of the mosses during the whole period studied did not exceed 7.0 $kg \cdot m^{-2}$. This is much less than weight of pre-cultivated vegetational mats soaked in water which usually amounted between 20–35 $kg \cdot m^{-2}$ (mat manufacturers' data). At present such

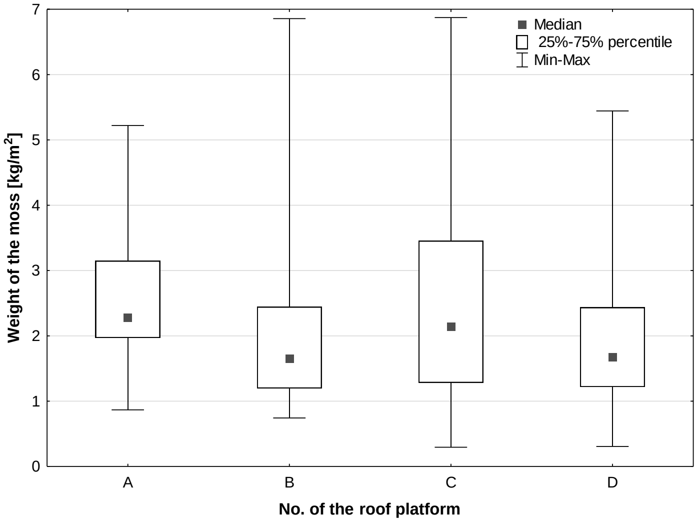

FIGURE 4. The weight of the moss layer on the green roof platforms studied in the period from the March of 2017 to the March of 2018

mats are commonly used in the practice of green roofs cultivation and their vegetation layer contains flowering herbs, various varieties of stonecrops (*Sedum* sp.) and sometimes mosses. Average weight of the moss layer studied (in relation to m^2 of the roof) was also lower than weight of the stonecrops and grasses seedlings ussually used for the vegetation layer installation, which is estimated as circa 10 kg·m^{-2}.

Vegetation is the key element in installing green roofs and their ecosystem services. Extensive green roofs are built in difficult urban conditions which limit the variety of plants able to survive there (Burszta-Adamiak et al., 2012; Heim et al., 2014). The survival rates of plants directly influence the aesthetic of the green roofs; hence influence the acceptance of the general public. These factors become obstacles in constructing extensive green roof. In a case of already established green roofs a state of their vegetation layer decides of the efficiency of their functioning. Improvement of habitat conditions for vascular plants through addition of more growing medium or fertilizers is associated with increased roof load and contamination of the storm waters runoff. Experiments presented here proved that formation of extensive green roofs with a moss cover ("moss roofs") in cities is both possible and advantageous regarding the longevity of vegetative layer. Mosses are poikilohydric what means that they are able to survive drought by drying out and can last an extended time in a drought state without damage. They are capable of rehydration in short time and able to start photosynthesis immediately after rehydration. They store water in external way, in capillaries among branches. Most nutrients they uptake mainly from wet deposition and only partly from the surface of substrate (Shaw & Geoffinet, 2000). Additionally, many common mosses can accumulate substantial amounts of trace elements and urban airborne polycyclic aromatic hydrocarbons without visible signs of toxicity (Krommer, Zechmeister, Roder, Scharf & Hanus-Illnar, 2007; Andić, Dragićević, Stešević, Jančić & Krivokapić, 2015) what increases their environmental service. We think that these plants can be applied on green roofs in two ways: the first as a main component of vegetation layer ("moss roofs") or the second as a complement to vascular plants on roofs, where the latter are in a bad health.

The ability of mosses to survive in harsh conditions like those on roofs in cities, their resistance to drought, small weight and lower than vascular plant requirements in relation to substrate quantity and quality are advantages that have been noted by other authors (Studlar & Peck, 2009; Heim et al., 2014). However, data documenting these advantages are scanty.

The presented transplant experiment showed that the most effective development of the moss layer occurred with the application of the five-milimeter fragments of stems into growing medium. But it should be stressed that growth was very slow in both transplant methods studied. The first changes were observed just after 11 months. Similar observations were reported by Park & Murase (2011) who noticed that it takes at least one year or more to produce moss mat for greening materials of popular in Japan moss species *Racomitrium japonicum* Dozy & Molk. However, Köhler (2006) found that *Ceratodon purpureus* was able to colonize spontaneously on a grassy green roof in the centre of Berlin in the second year of its functioning, and had overgrown its area by 80% five years after its establishment.

It seems that the design of green roofs with a moss vegetation layer could also bring economic advantages, such as a decrease in the cost of these roof's installation and exploitation. Mosses as root-less plants are able to grow on a shallow substrate. The presented transplant experiment showed that effective development of the moss layer occurred in all models of simplified green roofs applied.

Conclusions

Research proved that introduction of moss species *Ceratodon purpureus* into a vegetation layer of extensive green roofs might be the optimal solution for the improvement of the urban hydrology and ecology through forming long-lasting green cover able to survive in harsh urban environment and function during the whole year. Considering the difficulty in maintaining a permanent vegetative layer built of vascular plants it seems that it is worth changing the attitude towards mosses as a component of extensive green roofs. So far, they are considered mostly to be weeds.

Mosses which colonize and overgrow habitats unfavourable for other plants and develop on roofs of simple constructions with shallow substrate might be a perfect proposal in the case of buildings with limitations on the roof load, or the case of a developer wanting to minimalize costs of the green roof installation and exploitation for buildings where transport of large amounts of substrate (growing medium) is extremely difficult (dense or very high buildings).

The results obtained confirm the need for further experiments focused on a more efficient method of moss propagation to gain the moss layer in a quicker time. The long period of moss layer establishing in field terms could be perceived as a defect of the proposed solution for potential investors. Efforts should be also made to work out a substrate composition that is more suitable for moss growth, but free from substances potentially contaminating storm waters.

References

Anderson, M., Lambrinos, J. & Schroll, E. (2010). The potential value of mosses for stormwater management in urban environments. *Urban Ecosystems*, *13*(3), 319-332. DOI: 10.1007/ /s11252-010-0121-z

Andić, B., Dragićević, S., Stešević, D., Jančić, D. & Krivokapić, S. (2015). Comparative analysis of trace elements in the mosses – *Bryum argenteum* Hedw. and *Hypnum cupressiforme* Hedw. in Podgorica (Montenegro). *Journal of Materials and Environental Science*, *6*(2), 333-342.

Burszta-Adamiak, E. (2012). Analysis of stormwater retention on green roofs. *Archives of Environmental Protection*, *38*(4), 3-13.

Burszta-Adamiak, E., Pląskowska, E. & Weber-Siwirska, M. (2011). Grzyby występujące na wybranych gatunkach roślin zasiedlających „zielone dachy" Wrocławia. *Zeszyty Problemowe Postępów Nauk Rolniczych*, *562*, 29-38.

Burszta-Adamiak, E., Stańczyk, J. & Łomotowski, J. (2019). Hydrological performance of green roofs in the context of the meteorological factors during the 5-year monitoring period. *Water and Environment Journal*, *33*(1), 144--154. DOI: 10.1111/wej.12385

Butler, C., Butler, E., & Orians, C. M. (2012). Native plant enthusiasm reaches new heights: perceptions, evidence, and the future of green roofs. *Urban Forestry & Urban Greening*, *11*(1), 1-10. DOI: 10.2478/v10265-012-0035-3

Carter, T. & Keeler, A. (2008). Life-cycle cost–benefit analysis of extensive vegetated roof systems. *Journal of Environmental Management*, *87*(3), 350-363. DOI: 10.1016/ j.jenvman.2007.01.024.

Dierßen, K. (2001). Distribution, ecological amplitude and phytosociological-characterization of European bryophytes. *Bryophytorum Bibliotheca*, *56*, 1-289.

Dubicki, A., Dubicka, M. & Szymanowski, M. (2002). Klimat Wrocławia. In: K. Smolnicki, M. Szykasiuk (Eds.) *Informator o stanie środowiska Wrocławia 2002*, 9-25. Wrocław: Dolnośląska Fundacja Ekorozwoju.

Francis, L.F.M. & Jensen, M.B. (2017). Benefits of green roofs: A systematic review of the evidence for three ecosystem services. *Urban Forestry & Urban Greening*, *28*, 167-178. DOI: 10.1016/j.ufug.2017.10.015

Fudali, E. (1996). Distribution of bryophytes in various urban-use complexes of Szczecin [NW Poland]. *Fragmenta Floristica et Geobotanica*, *41*(2), 717-745. DOI: 10.1007/ s11252-014-0367-y

Fudali, E. (2001). The ecological structure of the bryoflora of Wroclaw's parks and cemeteries in relation to their localization and origin. *Acta Societatis Botanicorum Poloniae*, *70*(3), 229-235. DOI: 10.5586/asbp.2001.030

Heim, A., Lundholm, J. & Philip, L. (2014). The impact of mosses on the growth of neighbouring vascular plants, substrate temperature and evapotranspiration on an extensive green roof. *Urban Ecosystems*, *17*(4), 1119-1133. DOI: 10.1007/s11252-014-0367-y

Ishimatsu, K. & Ito, K. (2013). Brown/biodiverse roofs: a conservation action for threatened brownfields to support urban biodiversity. *Landscape and Ecological Engineering*, *9*(2), 299-304. DOI: 10.1007/s11355-011-0186-8

Jim, C.Y. (2012). Effect of vegetation biomass structure on thermal performance of tropical green roof. *Landscape and Ecological Engeeniring*, *8*(2), 173-187. DOI: 10.1007/ s11355-011-0161-4.

Köhler, M. (2006). Long-term vegetation research on two extensive green roofs in Berlin. *Urban Habitats*, *4*(1), 3-26.

Krommer, V., Zechmeister, H.G., Roder, I., Scharf, S. & Hanus-Illnar, A. (2007). Monitoring atmospheric pollutants in the biosphere reserve Wienerwald by a combined approach of biomonitoring methods and technical measurements. *Chemosphere*, *67*(10), 1956-1966. DOI: 10.1016/j.chemosphere.2006.11.060

Li, W.C. & Yeung, K.K.A. (2014). A comprehensive study of green roof performance from environmental perspective. *International Journal of Sustainable Built Environment*, *3*(1), 127-134. DOI: 10.1016/j.ijsbe.2014.05.001

Mayrand, F. & Clergeau, P. (2018). Green Roofs and Green Walls for Biodiversity Conservation: A Contribution to Urban Connectivity? *Sustainability*, *10*(4), 985. DOI: 10.3390/su10040985

Oberndorfer, E., Lundholm, J., Bass, B., Coffman, R.R., Doshi, H., Dunnett, N. & Rowe, B. (2007). Green roofs as urban ecosystems: ecological structures, functions, and services. *BioScience*, *57*(10), 823-833. DOI: 10.1641/B571005

Park, J.E. & Murase, H. (2011). Optimal Environmental Condition for Moss production in plant factory system. In *Preprints of the 18th IFAC World Congress Milano (Italy) 28.08.–02.09.2011* (pages 621-626). Retrieved from: http://folk.ntnu.no/skoge/prost/proceedings/ifac11-proceedings/data/html/papers/2773.pdf.

Razzaghmanesh, M., Beecham, S. & Kazemi, F. (2014). The growth and survival of plants in urban green roofs in a dry climate. *Science of the Total Environment*, *476*, 288-297. DOI: 10.1016/j.scitotenv.2014.01.014

Shaw, B.J. & Geoffinet, B. (2000). *Bryophyte biology.* Cambridge: Cambridge University Press.

Shafique, M., Kim, R. & Rafiq, M. (2018a). Green roof benefits, opportunities and challenges – A review. *Renewable and Sustainable Energy Reviews*, *90*, 757-773. DOI: 10.1016/j.rser.2018.04.006

Shafique, M., Kim, R. & Kyung-Ho, K. (2018b). Green Roof for Stormwater Management in a Highly Urbanized Area: The Case of Seoul, Korea. *Sustainability*, *10*(3), 584. DOI: 10.3390/su10030584

Studlar, S.M. & Peck, J.E. (2009). Extensive green roofs and mosses: reflections from a pilot study in Terra Alta, West Virginia. *Evansia*, *26*(2), 52-63. DOI: 10.1639/0747-9859-26.2.52

Szejba, D., Szatyłowicz, J. & Gnatowski, T. (2017). Water balance of a green roof on the example of object in the Ursynów district of the Capital City Warsaw. *Scientific Review Engineering and Environmental Sciences*, *26*(1), 66-74. DOI 10.22630/PNIKS.2017.26.1.06

Viola, F., Hellies, M. & Deidda, R. (2017). Retention performance of green roofs in representative climates worldwide. *Journal of Hydrology*, *553*, 763-772. DOI: 10.1016/j.jhydrol.2017.08.033

Whittinghill, L.J., Hsueh, D., Culligan, P. & Plunz, R. (2016). Stormwater performance of a full scale rooftop farm: Runoff water quality. *Ecological Engineering*, *91*, 195-206. DOI: 10.1016/j.ecoleng.2016.01.047

Summary

A pilot study on improve the functioning of extensive green roofs in city centers using mosses. Most of environmental benefits of green roofs results from the presence of a vegetation layer. However vascular plants quickly die in harsh urban conditions. This paper presents research involving moss species appearing spontaneously on green roofs in cities to test whether we can create a vegetation layer with simplified structure introducing that moss. It was checked using two transplant methods and three models of such roofs. Research evidenced that moss *Ceratodon purpureus* Hedw. is able to survive on green roofs in cities with high efficiency and can develop after transplant on roofs with a simple structure. Maximum weight of the moss layer during the year did not exceed 7.0 kg·m^{-2}.

Authors' address:
Ewa Burszta-Adamiak
(https://orcid.org/0000-0003-3755-2047)
Uniwersytet Przyrodniczy we Wrocławiu
Wydział Inżynierii Kształtowania Środowiska i Geodezji
Instytut Inżynierii Środowiska
pl. Grunwaldzki 24, 50-363 Wrocław
Poland
e-mail: ewa.burszta-adamiak@upwr.edu.pl

Janusz Łomotowski
(https://orcid.org/0000-0002-7302-1684)
Uniwersytet Przyrodniczy we Wrocławiu
Wydział Inżynierii Kształtowania Środowiska
i Geodezji
Instytut Inżynierii Środowiska
pl. Grunwaldzki 24, 50-363 Wrocław
Poland
e-mail: janusz.lomotowski@upwr.edu.pl

Ewa Fudali
(https://orcid.org/0000-0001-7923-8748)
Uniwersytet Przyrodniczy we Wrocławiu
Wydział Przyrodniczo-Technologiczny
Katedra Botaniki i Ekologii Roślin
pl. Grunwaldzki 24a, 50-363 Wrocław
Poland
e-mail: ewa.fudali@upwr.edu.pl