COSTS AND BENEFITS OF GREEN TRAMWAY TRACKS*

E. Jakubcová[1], E. Horváthová[2]

[1]Czech University of Life Sciences Prague, Faculty of Agrobiology, Food and Natural Resources, Department of Landscape Architecture, Prague, Czech Republic
[2]Global Change Research Institute of the Czech Academy of Sciences, Department of Human Dimensions of Global Change, Prague, Czech Republic

In recent decades, green tramway tracks have still more often been installed in many cities as an alternative to standard rails placed on concrete sleepers or grooved rails since the vegetated tracks are beneficial to urban dwellers. In this article, we summarize and compare the benefits of grass and low-maintenance tramway tracks and link them with their investment and maintenance costs in two Czech cities. We conclude that grass surfaces offer a slightly higher rainwater retention capacity, while the rest of the benefits are similar for grass and low-maintenance surfaces. The investment costs are also similar, however, the maintenance costs are 30× higher for grass surfaces than for the low-maintenance ones.

urban greenery, green infrastructure, vegetated tram tracks, *Sedum*, Czech Republic

sciendo

doi: 10.2478/sab-2020-0012
Received for publication on September 9, 2020
Accepted for publication on October 23, 2020

INTRODUCTION

Vegetated tracks have increasingly been applied in different cities in recent years as an alternative to standard rails placed on sleepers or grooved rails on concrete sleepers. At first, tram rails and sleepers were placed on lawns but Sedum blankets became still more frequent as a ground cover during the last decades. For example, Le Mans (France) introduced *Sedum* tramway tracks in 2006 and Warsaw (Poland) in 2017 (Sempergreen, 2018, 2020). One of the main reasons for the growing popularity of the green tracks is that the area between the rails provides ample space for greenery, which is scarce especially in central urban areas (Dvorak et al., 2017; Hladikova, Jebavy, 2020). Similarly, like green roofs, these strips of greenery provide additional benefits to urban areas, e.g. reduce pollution and provide permeable surfaces. The green tracks benefit magnitude is mainly determined by the vegetation cover. This review provides a comparison of costs and benefits of the most common green tram tracks surfaces – low-maintenance and grass tramway. The benefits of these tracks and the traditional tracks are compared.

TYPES OF GREEN TRAMWAY TRACKS

Besides the traditional tracks (grooved rail or sleepers), we can distinguish two basic types of green tracks – rails laid into the grass (grassed tracks or tracks in a lawn) and low-maintenance tracks. The grass tracks are planted with different grass species while succulent species and mainly *Sedum* are planted on the low-maintenance tracks.

Sedum (a large genus of flowering plants of the family Crassulaceae) is a drought and wind tolerant species offering a great variety of colour types (Oberndorfer et al., 2007; Shafique et al., 2018). Due to its characteristics, *Sedum* is commonly planted in habitats with the extreme environment, e.g. on extensive green roofs and tracks. The ability of *Sedum* to survive in extreme environmental conditions

* Supported by the Czech Science Foundation (GACR), Project No. 20-18261S, and by the EU LIFE program, Project LIFE17 GIC/CZ/000107 LIFE TreeCheck: Green Infrastructure Minimising the Urban Heat Island Effect.

Table 1. Differences between short grass and *Sedum* affecting the benefits of vegetated tracks

	Grasses	*Sedum*
Best adapted to	C3 grasses (most grasses) – cool, wet environments C4 grasses – hot, sunny environments	very hot, dry environments
Stomata opened during	day	night
Water retention	higher due to higher transpiration	
Transpiration	higher	lower – stomata closed during the day to minimize water loss
Air pollution removal		lower – stomata closed during the day, less gaseous pollutant can enter the plant
Carbon storage		lower potential – slower growth rates

lies in its metabolism. *Sedum* displays crassulacean acid metabolism (CAM), which improves water-use efficiency by allowing stomatal opening and CO_2 storage during the night and closing stoma during the hot day. On the other hand, most grasses belong to the C3 and C4 groups (Begon et al., 2006; Osborne et al., 2014). Since the C3 species are adapted to a cool environment, they are poor in moisture management. The C4 species are better adapted to warm or hot seasonal conditions, they can better survive in habitats with low water but they are not adapted to the extremely dry environment as the CAM species. As the stomata of CAM plants are closed during the day, plant gas exchange occurs at night, thus reducing transpiration water loss (Nagase, Dunnett, 2012). Some *Sedum* species can even switch from C3 to CAM in response to a water deficit (Castillo, 1996), which enables them a quick growth during water abundant periods and to survive drought periods. Monterusso et al. (2005) and some other authors hypothesized that the ability to switch between CAM and C3 photosynthesis is the reason for their success in extreme environments like green roofs.

The differences in the grass and *Sedum* metabolisms affect also the rest of their characteristics and benefits. Table 1 compares the main characteristics of *Sedum* and grass affecting the benefits of green tracks. It shows that the advantage of *Sedum* to survive dry conditions reduces some benefits provided by the Sedum tracks. For example, *Sedum* has a lower rainwater retention rate and an air pollution removal potential since it closes stomata during the day to survive in a hot, dry environment. When the stomata are closed, water cannot evaporate through them but, at the same time, gases exchange is disabled (including carbon dioxide and other gaseous pollutants) resulting in lower carbon dioxide and pollutant consumption (Begon et al., 2006). Besides *Sedum*, CAM metabolism is characteristic also for some other species (e.g. from the families Portulacaceae, Crassulaceae, and Euphorbiaceae), which are suitable for planting on low-maintenance tramway tracks since they can survive periods without watering (Liu et al., 2012).

Due to the similar extreme environment on tracks and extensive green roofs, similar plant species are planted on extensive green roofs and tramway tracks. Shafique et al. (2018) summarize that the optimum vegetation for extensive green roofs should have, besides other things, the following characteristics: the ability to withstand drought and extreme climate conditions, general availability and cost-effectiveness, short roots, little maintenance requirements, higher evapotranspiration ability, and the ability to reduce heat island phenomena. All these characteristics are also important and often necessary for plants growing in tramway tracks due to many similarities in the environments on tramway tracks and extensive green roofs. Both habitats are not a favorable environment for the growth of plants because water availability strongly fluctuates and there is limited space for a deep growing medium (Rowe, 2011). Also, the construction of vegetated tramway tracks is very similar to that of extensive green roofs with only about 15 cm of growing medium both on the green roofs and the tramway tracks (Raji et al., 2015; Cascone, 2019).

Due to the similarity of habitats and growing conditions on tracks and extensive green roofs, we use information about the benefits of extensive green roofs because the benefits of green tracks have not been as much studied as in green roofs.

BENEFITS

It has been widely recognized that roadside vegetation brings significant multiple benefits for urban dwellers (see e.g. Saumel et al., 2016). In this section, we review and compare the benefits of vegetated tracks focusing on the differences between grass and *Sedum* surfaces.

Carbon storage and sequestration

Grass has a higher potential to store carbon due to its higher growth rates. However, there is limited space for growth on the tramway tracks and so the excess grass biomass has to be removed regularly. Its mowing increases maintenance costs and is an additional source of carbon dioxide emissions. Next, the carbon stored in mowed grass is quickly decomposed and released back into the environment. Hence, there is no significant difference between grass and *Sedum* in terms of carbon storage and sequestration.

Water retention

The rainwater retention potential of vegetated tracks depends on the type and thickness of growing substrate, type of drainage elements and their storage capacity, type of vegetation cover, precipitation totals, length of previous drought periods, and the slope of the area concerned (Rowe, 2011; Vijayaraghavan, 2016). The main processes affecting the rainwater retention by vegetation are evaporation (a physical process of water transfer from the soil into the atmosphere) and transpiration (a physiological process in plants by which water escapes through the stomata on leaves or the pores of the skin into the environment) (Cascone et al., 2019).

Grasses are more efficient at reducing water runoff than *Sedum* due to their different metabolisms. *Sedum* retains less water since it has lower water consumption due to lower transpiration. Hence less water is consumed between rain events and less water can be retained in the soil. A water capture in the soil is also affected by roots growth which is higher for grass than for *Sedum*. Hence several studies (e.g. Lundholm et al., 2010; Nagase, Dunnett, 2012; Mickovski et al., 2013) stated that tall grass species are more effective in reducing water runoff than *Sedum*.

Despite some studies suggest that runoff from *Sedum* surfaces is higher than that from grass (e.g. Nagase, Dunnett, 2012), other studies indicate that *Sedum* can reduce rainwater runoff significantly, too. Simmons et al. (2008) found that extensive green roofs retained all rain events lower than 10 mm, and the retention rate ranged between 26% and 88% for 12 mm rain events. Also, Silva et al. (2006) found that *Sedum* surfaces significantly reduced and slowed down rainwater runoff comparing to asphalt surfaces. Next, Van Woert et al. (2005) found that even substrate without vegetation can retain a substantial amount of water, which implies that even *Sedum* tramway tracks are more efficient in precipitation retention than standard tracks without vegetation. Similarly, Schreiter, Kappis (www) noted that the water runoff from a vegetated track is lower than the one coming from an unvegetated track.

The reduction in runoff from green tracks typically ranges from 50% (*Sedum*) to 70–100% (grass) of annual precipitation with the highest retention rate during summer (Van Leuven et al., 2010; Rowe, 2011; Shafique et al., 2018; Schreiter, Kappis, www). Besides the reduction of runoff, the green tracks also reduce peak outflows (Carter, Rasmussen, 2006; Silva et al., 2006) and thus moderate flash floods.

Water quality enhancement

Regarding the impacts of roadside vegetation on water pollutant concentrations, results are mixed. On the one hand, vegetation and a substrate can retain pollutants leading to the improvement of water quality. On the other hand, if the concentration of ions in the rainwater is lower than that in the substrate, some ions will then leach from the substrate leading to their even higher concentrations in runoff water (Vijayaraghavan, 2016). Next, the applications of fertilizers and pesticides are likely to affect water quality, too (Rowe, 2011). However, most authors (e.g. Kohler et al., 2002; Gregoire, Clausen, 2011; Rowe 2011) conclude that the overall effect of green roofs on water quality runoff is positive.

Factors influencing the runoff quality are the vegetation species composition, precipitation total, substrate depth and composition, local pollution sources, fertilization and maintenance techniques, type of drainage, and properties of pollutants (Alsup et al., 2010; Rowe, 2011; Shafique et al., 2018).

There seems to be no significant difference in water quality impacts between grass and *Sedum* surfaces. The only difference lies in the higher fertilization needs of grass which can potentially lead to water quality deterioration.

Urban heat island mitigation – microclimate regulation

It has been well documented that vegetated surfaces show lower temperature extremes and more balanced daily temperatures than unvegetated surfaces (Hesslerova et al., 2013). This is caused by the cooling effect of vegetation as well as by evapotranspiration, which experiences the lowest rates in built-up areas (Skalos et al., 2014).

Plants provide a cooling effect by evapotranspiration of water and by shading. Grasses have a higher potential to mitigate local temperature due to their higher transpiration rates and greater height (Liu et al., 2012). However, there is not space for tall grass on the tramway tracks, which decreases the grass cooling effect and the higher grass transpiration leads to increased demand for grass watering.

The thermal effect of vegetated tramway tracks is affected by many parameters, e.g. the vegetation type and diversity, coverage ratio, leaf area index, foliage height, and the plant biological processes like photosynthesis, respiration, and transpiration, the physical features of the growing medium like the thickness, water content and density, the site conditions including climate factors (Raji et al., 2015).

A very important factor for temperature cooling down is soil as it holds water and heat (Getter et al., 2009). The amount of retained water is affected by the depth of a substrate, with a shallower substrate retaining less moisture (Getter et al., 2009). These parameters are similar for grass and *Sedum* surfaces.

Green tramways alter the local climate also by reducing albedo (solar radiation reflectivity) because a surface temperature is mainly related to albedo (Lundholm et al., 2010). The albedo of vegetated surfaces is influenced by species richness and biomass variability, where greater biomass leads to higher albedo (Lundholm et al., 2010). The albedo of green roofs ranges between 0.7–0.85 (Berardi et al., 2014), which is higher than the albedo of paved surfaces (a typical albedo for asphalt ranges between 0.05 and 0.2, and for a concrete 0.25–0.7 (Kotak et al., 2015)).

Hence, despite grass has a higher potential to mitigate local temperatures due to its higher transpiration rate, there are no differences between grass and *Sedum* in other parameters affecting the thermal effect of vegetated tramway tracks, e.g. albedo or soil composition. It has been documented that succulent plants alone can mitigate temperatures. Butler, Orians (2011) found that *Sedum* decreased peak soil temperature by 5–7 °C. Similarly, Schreiter, Kappis (www) note that green tracks lessen rails heating since vegetation does not heat over 25–30 °C.

When considering the thermal effects of green tramway tracks, one must also take into account the scope of thermal effect. Tramway tracks go usually alongside asphalt roads, which experience much higher temperatures than vegetated surfaces since traffic is a source of anthropogenic heat (Sailor, 2011), and hence the cooling effect of vegetated tracks is likely to be suppressed by the roads. Next, even though vegetated surfaces have a lower temperature, grass has a little effect on local air temperatures and so has a little effect on human comfort (Armson et al., 2012).

Air quality improvement

Air pollution removal by vegetation is influenced by air pollutant concentrations, weather conditions, and the growth of plants (Yang et al., 2008). Plants can mitigate air pollution either by consuming gaseous pollutants through their stomata and filtering dust from the air or indirectly by modifying microclimate (Yang et al., 2008; Xing, Brimblecombe, 2019). Succulent species, e.g. *Sedum*, have a lower capacity to mitigate air pollution if compared to herbaceous species and trees due to differences in their metabolisms and greater leaf surface area (Rowe, 2011). Although grass has a higher air pollution mitigation potential, one must also consider a higher energy consumption (and associated emissions of pollutants) for grass maintenance (mowing, watering, and fertilization).

Although the potential for air pollution removal is higher in the grass than in *Sedum*, the latter is more efficient than standard tracks. In a study of tramway tracks conducted in Berlin (Van Leuven et al., 2010) *Sedum* was found to be more efficient in removing dust than the standard tracks. The main reason was higher deposition rates on *Sedum* than on gravel. Next, resuspension of dust from *Sedum* was almost zero which was lower than dust resuspension from gravel. The authors explain the differences in deposition and resuspension between *Sedum* and gravel by surface properties (cuticula and leaf shape in contrast to ballast), pore volume, and lower temperatures above the vegetation.

Although planting trees in urban areas has been shown as more effective in air pollution mitigation than the vegetation strips, due to limited space in urban areas, green tramway tracks are an acceptable alternative.

Noise reduction

Vegetated places have been reported to reduce traffic noise (Real et al., 2013; Renterghem et al., 2015). Panulinova (2017) found out that the noise difference between the vegetated tramway tracks and rails placed in panel blocks reaches up to 7 dB(A) but most studies report on lower noise mitigation by the vegetated tracks (Schreiter, Kappis, www). Even though the noise mitigation potential of vegetated tracks is limited (2–4 dB(A)), a psychological impact of green places affects subjective acoustic perception and green tracks are often viewed as less disturbing and less noisy by residents (Schreiter, Kappis, www).

Despite *Sedum* and grass may differ in their potential to mitigate noise (Van Leuven et al., 2010), the differences between these two surfaces are likely to be too small since their noise mitigation potential is small.

Aesthetic benefits

Green tramway tracks enhance the aesthetics of the area (Shafique et al., 2018) since the community perceives positively green areas within a city and greenery has a positive effect on residents' comfort (Carpenter, 2013). Dwellers react positively also to an increase in roadside vegetation (Weber et al., 2014). This aspect is especially important in highly sealed inner-city districts with no places for new green areas and where green areas produce a natural and calm environment (Van Leuven et al., 2010). Besides aesthetics, urban greenery provides also other cultural ecosystem services (Andersson et al., 2015).

Vegetated trails are more attractive than standard surfaces (Lee et al., 2014; Sikorski et al., 2018) but the differences in perception grass and *Sedum* have not been studied. Some studies point to a higher attractiveness of *Sedum* rather than grass tracks (Southon et al., 2017) mainly because *Sedum* provides a wide colour variety of different kinds of hybrid cultivars. On the other hand, other studies show high preferences for grass and grass surfaces due to their high aesthetic quality, too (Lee et al., 2014).

Biodiversity

In urban areas, every green spot can serve as a habitat for diverse organisms (Horak et al., 2018). Similarly, as green roofs create habitats for organisms in urban parts (Clemants et al., 2006; Shafique

Table 2. Benefits of short grass and low-maintenance tracks compared to standard tracks

	Grass tracks	Low-maintenance tracks
Environmental benefits		
Carbon storage	+/– (mowing)	+
Rainwater retention	70–100 %	50 %
Reduction of peak outflows/ slow down of outflow	+	+
Rainwater quality enhancement	+ (possible deterioration due to fertilization)	+
Micro-climate regulation	+ (a higher potential than low-maintenance tracks) (higher water retention)	+
Air pollution removal	++	+
Noise reduction	2–4 dB(A)	2–4 dB(A)
Oxygen production	+	+
Habitats creation	+	+
Social benefits		
Aesthetic benefits	+	+
Economic benefits		
Costs – installation	higher than standard tracks similar to low-maintenance tracks	higher than standard tracks similar to grass tracks
Costs – maintenance	higher than standard tracks	higher than standard tracks 30× lower than grass tracks
Reduced precipitation water treatment costs	higher reduction of precipitation water treatment costs in comparison to both standard and low-maintenance tracks due to higher water retention	higher reduction of precipitation water treatment costs in comparison to standard tracks

et al., 2018), green tramway tracks are also likely to serve as a habitat or a corridor for some organisms (Li, Yeung, 2014), e.g. those living in the soil. Moreover, *Sedum* flowers are attractive to bees and butterflies (Van Leuven et al., 2010). Besides the planted species, the green tracks can serve the growth of some other plants, too. Despite the tramway tracks are a specific anthropogenic habitat, a diverse plant species composition was found on green tramway tracks in Upper Silesia (Woznica et al., 2016).

The benefits of vegetated tracks are summarized in Table 2. Grass and low-maintenance tracks bring about the same positives in most categories, e.g. carbon storage, noise reduction, habitat creation. The only category of benefits, in which grass provides more positives than the low-maintenance tracks, is the water retention capacity.

COSTS

This section summarizes maintenance and investment costs on green tramway tracks. Data on costs are available only for Prague and Ostrava. However, it is highly probable that costs (both maintenance and investment) in other Czech cities are similar.

Table 3 presents maintenance and investment costs for grass (with automatic sprinkler systems) and *Sedum*

Table 3. Investment and maintenance costs for grass and low-maintenance (*Sedum*) tramway tracks (prices in 2019 EUR, exchange rate CZK/EUR: 25.5)

	Grass (with automatic sprinkler system)	Low-maintenance (*Sedum*)
Investment costs (m^2)	78.4–121.6	70.6–352.9
Investment costs (common m)	509.8–66.7	368.6–1,803.9
Maintenance costs (m^2)	4.7	0.16
Maintenance costs (common m)	24.3–30.6	0.78

tramway tracks reported for Ostrava and Prague in 2019. There were only grass tramway tracks in Prague and *Sedum* surfaces were tested in Ostrava in 2019. The price range refers either to costs in different cities (maintenance costs for grass in Prague and Ostrava) or to different planting technologies (Sedum Top vs. BRENS). Grass maintenance costs include maintenance of a sprinkler system, fertilization, mowing, and watering. For *Sedum* the maintenance costs are lower than for grass since *Sedum* requires fertilization only once or twice a year, no mowing, and watering only during extreme drought periods (Van Leuven et al., 2010). There are no maintenance costs of a sprinkler system in *Sedum* maintenance costs, too.

The investment costs for grass with an automatic sprinkler system and Sedum Top Mat are similar (78–122 EUR for grass and 71 EUR for *Sedum*). The investment costs for planting *Sedum* into BRENS system are 3–4.5 times higher than those for planting grass with an automatic sprinkler system (353 EUR), however, BRENS system provides additional noise control and water retention capacity (Eisenreich, Kamenicky, n.d.). This finding is in line with a study in Poland where Sikorski et al. (2018) stated that the establishment costs of different vegetation types (*Sedum*, grasses, or herbaceous vegetation) are comparable, and differences are only due to the method of vegetation application. We have no cost data on the establishment of standard tracks in the Czech Republic but Sikorski et al. (2018) noted that the technologies needed to cover the tramway with the substrate and vegetation layer are more expensive than standard open tramway tracks with wooden or concrete sleepers. We suppose green tracks in the Czech environment require higher investment costs, too.

The grass maintenance costs in Prague and Ostrava are the same (4.7 EUR per 1 m^2). Since the common width of a double-track is higher in Prague than in Ostrava (6.5 and 5.2 m, respectively) the maintenance costs per a common meter of a double-track are higher in Prague. Information on *Sedum* maintenance costs is available for Ostrava only (0.16 EUR per m^2), i.e. 0.78 EUR per 1 m of a double track. Hence maintenance costs for grass with an automatic sprinkler system are 30 times higher than those for low-maintenance tracks.

Last but not least, drivability for emergency vehicles has to be considered when designing green tramway tracks (Van Leuven et al., 2010) as these are not suitable for driving heavy emergency service vehicles (Pfautsch, Howe, 2018). If it is essential to allow passage of emergency vehicles on the tracks outside the crossing, it is necessary to take into account additional costs of green tracks.

Based on cost data from Prague and Ostrava we can conclude that the investment costs for grass and low-maintenance tracks are similar while the maintenance costs for grass are 30× higher than for low-maintenance surfaces.

CONCLUSION

The environmental, social, and economic benefits of tram tracks with grass and low-maintenance surfaces were summarized (Table 3). Even though the investment costs for grass and low-maintenance surfaces are higher than those for standard tracks, vegetated surfaces are significantly beneficial to urban areas. Grass tracks retain more rainwater, however, there are no significant differences as for the other benefits provided by grass and low-maintenance tracks. The potential of grass to bring some more positives has to be carefully weighed since the maintenance costs for grass surfaces are 30× higher than for *Sedum*.

ACKNOWLEDGEMENT

We thank Jan Ševčík and Marie Dvořáková (Municipality Ostrava) and The Prague Public Transport Company, a.s. for provision of data.

REFERENCES

Alsup S, Ebbs S, Retzlaff W (2010): The exchangeability and leachability of metals from selected green roof growth substrates. Urban Ecosystems, 13, 91–111. doi: 10.1007/s11252-009-0106-y.

Andersson E, Tengo M, McPhearson T, Kremer P (2015): Cultural ecosystem services as a gateway for improving urban sustainability. Ecosystem Services, 12, 165–168. doi: 10.1016/j.ecoser.2014.08.002.

Armson D, Stringer P, Ennos AR (2012): The effect of tree shade and grass on surface and globe temperatures in an urban area. Urban Forestry and Urban Greening, 11, 245–255. doi: 10.1016/j.ufug.2012.05.002.

Begon M, Townsend CR, Harper JL (2006): Ecology: From individuals to ecosystems. Blackwell Publishing.

Berardi U, GhaffarianHoseini AH, GhaffarianHoseini A (2014): State-of-the-art analysis of the environmental benefits of green roofs. Applied Energy, 115, 411–428. doi: 10.1016/j.apenergy.2013.10.047.

Butler C, Orians CM (2011): Sedum cools soil and can improve neighboring plant performance during water deficit on a green roof. Ecological Engineering, 37, 1796–1803. doi: 10.1016/j.ecoleng.2011.06.025.

Carpenter M (2013): From 'healthful exercise' to 'nature on prescription': The politics of urban green spaces and walking for health. Landscape and Urban Planning, 118, 120–127. doi: 10.1016/j.landurbplan.2013.02.009.

Carter TL, Rasmussen TC (2006): Hydrologic behavior of vegetated roofs. Journal of the American Water Resources Association, 42, 1261–1274. doi: 10.1111/j.1752-1688.2006.tb05611.x.

Cascone S (2019): Green roof design: State of the art on technology and materials. Sustainability, 11, 3020. doi: 10.3390/su11113020.

Cascone S, Coma J, Gagliano A, Perez G (2019): The evapotranspiration process in green roofs: A review. Building and Environment, 147, 337–355. doi: 10.1016/j.buildenv.2018.10.024.

Castillo FJ (1996): Antioxidative protection in the inducible CAM plant Sedum album L. following the imposition of severe water stress and recovery. Oecologia, 107, 469–477. doi: 10.1007/BF00333937.

Clemants SE, Marinelli J, Moore G, Peters E (2006): Green roofs and biodiversity. URBANhabitats, 4.

Dvorak J, Wittlingerova Z, Bicanova K, Skalos J (2017): Indicators for built-up area monitoring – a case study of the Czech Republic and the EU. Scientia Agriculturae Bohemica, 48, 142–153. doi: 10.1515/sab-2017-0021.

Eisenreich J, Kamenicky M (www): Track noise absorber with the function of water retention BRENS STERED.

Getter KL, Rowe DB, Cregg BM (2009): Solar radiation intensity influences extensive green roof plant communities. Urban Forestry and Urban Greening, 8, 269–281. doi: 10.1016/j.ufug.2009.06.005.

Gregoire G, Clausen JC (2011): Effect of a modular extensive green roof on stormwater runoff and water quality. Ecological Engineering, 37, 963–969. doi: 10.1016/j.ecoleng.2011.02.004.

Hesslerova P, Pokorny J, Brom J, Rejskova-Prochazkova A (2013): Daily dynamics of radiation surface temperature of different land cover types in a temperate cultural landscape: Consequences for the local climate. Ecological Engineering, 54, 145–154. doi: 10.1016/j.ecoleng.2013.01.036.

Hladikova L, Jebavy M (2020): Assessment of green spaces development in Prague during years 1901–2010. Scientia Agriculturae Bohemica, 51, 15–21. doi: 10.2478/sab-2020-0003.

Horak J, Rom J, Rada P, Safarova L, Koudelkova J, Zasadil P, Halda JP, Holusa J (2018): Renaissance of a rural artifact in a city with a million people: biodiversity responses to an agro-forestry restoration in a large urban traditional fruit orchard. Urban Ecosystems, 21, 263–270. doi: 10.1007/s11252-017-0712-z.

Kohler M, Schmidt M, Grimme FW, Laar M, de Assuncao Paiva VL, Tavares S (2002): Green roofs in temperate climates and in the hot-humid tropics – far beyond the aesthetics. Environmental Management and Health, 13, 382–391. doi: 10.1108/09566160210439297.

Kotak Y, Gul MS, Muneer T, Ivanova SM (2015): Investigating the impact of ground albedo on the performance of PV systems. In: CIBSE Technical Symposium, London, UK, 16 p.

Lee KE, Williams KJH, Sargent LD, Farrell C, Williams NS (2014): Living roof preference is influenced by plant characteristics and diversity. Landscape and Urban Planning, 122, 152–159. doi: 10.1016/j.landurbplan.2013.09.011.

Li WC, Yeung KA (2014): A comprehensive study of green roof performance from environmental perspective. International Journal of Sustainable Built Environment, 3, 127–134. doi: 10.1016/j.ijsbe.2014.05.001.

Liu T-C, Shyu G-S, Fang W-T, Liu S-Y, Cheng B-Y (2012): Drought tolerance and thermal effect measurements for plants suitable for extensive green roof planting in humid subtropical climates. Energy and Buildings, 47, 180–188. doi: 10.1016/j.enbuild.2011.11.043.

Lundholm J, MacIvor JS, MacDougall Z, Ranalli M (2010): Plant species and functional group combinations affect green roof ecosystem functions. PLoS ONE, 5, e9677. doi: 10.1371/journal.pone.0009677.

Mickovski SB, Buss K, McKenzie BM, Sokmener B (2013): Laboratory study on the potential use of recycled inert construction waste material in the substrate mix for extensive green roofs. Ecological Engineering, 61, 706–714. doi: 10.1016/j.ecoleng.2013.02.015.

Monterusso MA, Bradley Rowe D, Rugh CL (2005): Establishment and persistence of Sedum spp. and native taxa for green roof applications. HortScience, 40, 391–396. doi: 10.21273/hortsci.40.2.391.

Nagase A, Dunnett N (2012): Amount of water runoff from different vegetation types on extensive green roofs: Effects of plant species, diversity and plant structure. Landscape and Urban Planning, 104, 356–363. doi: 10.1016/j.landurbplan.2011.11.001.

Oberndorfer E, Lundhol J, Bass B, Coffman RR, Doshi H, Dunnett N, Gaffin S, Kohler M, Liu KKZ, Rowe DB (2007): Green roofs as urban ecosystems: Ecological structures, functions, and services. BioScience, 57, 823–833. doi: 10.1641/B571005.

Osborne CP, Salomaa A, Kluyver TA, Visser V, Kellogg EA, Morrone O, Vorontsova MS, Clayton WD, Simpson DA (2014): A global database of C4 photosynthesis in grasses. New Phytologist, 204, 441–446. doi: 10.1111/nph.12942.

Panulinova E (2017): Input data for tram noise analysis. Procedia Engineering, 190, 371–376. doi: 10.1016/j.proeng.2017.05.351.

Pfautsch S, Howe V (2018): Green track for Parramatta light rail – a review. APO, Western Sydney University. doi: 10.26183/5c05fc021efb3.

Raji B, Tenpierik MJ, van den Dobbelsteen A (2015): The impact of greening systems on building energy performance: A literature review. Renewable and Sustainable Energy Reviews, 45, 610–623. doi: 10.1016/j.rser.2015.02.011.

Real J, Zamorano C, Asensio T, Real T (2013): Study of the mitigation of tram-induced vibrations on different track typologies. Journal of Vibroengineering, 15, 2057–2075.

Rowe DB (2011): Green roofs as a means of pollution abatement. Environmental Pollution, 159, 2100–2110. doi: 10.1016/j.envpol.2010.10.029.

Sailor DJ (2011): A review of methods for estimating anthropogenic heat and moisture emissions in the urban environment. International Journal of Climatology, 31, 189–199. doi: 10.1002/joc.2106.

Saumel I, Weber F, Kowarik I (2016): Toward livable and healthy urban streets: Roadside vegetation provides ecosystem services where people live and move. Environmental Science and Policy, 62, 24–33. doi: 10.1016/j.envsci.2015.11.012.

Schreiter H, Kappis C (www): Network partner Enterprises Transport Companies. http://www.gruengleisnetzwerk.de/images/downloads/effects.pdf. Accessed 16 April, 2020

Sempergreen (2018): Warsaw is getting greener, track by track – Sempergreen. https://www.sempergreen.com/en/about-us/news/warsaw-is-getting-greener-track-by-track. Accessed 15 April 2020

Sempergreen (2020): Tramway Le Mans with Sedum groundcover. https://www.sempergreen.com/en/references/tramway. Accessed 15 April 2020

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

Sikorski P, Winska-Krysiak M, Chormanski J, Krauze K, Kubacka K, Sikorska D (2018): Low-maintenance green tram tracks as a socially acceptable solution to greening a city. Urban Forestry and Urban Greening, 35, 148–164. doi: 10.1016/j.ufug.2018.08.017.

Silva TFO, Wehrmann A, Henze H-J, Model N (2006): Ability of plant-based surface technology to improve urban water cycle and mesoclimate. Urban Forestry and Urban Greening, 4, 145–158. doi: 10.1016/j.ufug.2005.12.004.

Simmons MT, Gardiner B, Windhager S, Tinsley J (2008): Green roofs are not created equal: The hydrologic and thermal performance of six different extensive green roofs and reflective and non-reflective roofs in a sub-tropical climate. Urban Ecosystems, 11, 339–348. doi: 10.1007/s11252-008-0069-4.

Skalos J, Berchova K, Pokorny J, Sedmidubsky T, Pecharova E, Trpakova I (2014): Landscape water potential as a new indicator for monitoring macrostructural landscape changes. Ecological Indicators, 36, 80–93. doi: 10.1016/j.ecolind.2013.06.027.

Southon GE, Jorgensen A, Dunnett N, Hoyle H, Evans KL (2017): Biodiverse perennial meadows have aesthetic value and increase residents' perceptions of site quality in urban green-space. Landscape and Urban Planning, 158, 105–118. doi: 10.1016/j.landurbplan.2016.08.003.

Van Leuven A, Le Corre F, Schnieders I, Thijssen D, Schreiter H, Wragge V, Vanhonacker T, Hamoller G, Janig N, Rodriguez N, de Jong M, Rupp T (2010): Urban rail transport. Final Publishable Activity Report. https://cordis.europa.eu/docs/publications/1236/123652741-6_en.pdf. Accessed 16 April 2020

Van Renterghem T, Forssen J, Attenborough K, Jean P, Defrance J, Hornikx M, Kang J (2015): Using natural means to reduce surface transport noise during propagation outdoors. Applied Acoustics, 92, 86–101. doi: 10.1016/j.apacoust.2015.01.004.

VanWoert ND, Rowe DB, Andresen JA, Rugh CL, Xiao L (2005): Watering regime and green roof substrate design affect Sedum plant growth. HortScience, 40, 659–664.

Vijayaraghavan K (2016): Green roofs : A critical review on the role of components, benefits, limitations and trends. Renewable and Sustainable Energy Reviews, 57, 740–752. doi: 10.1016/j.rser.2015.12.119.

Weber F, Kowarik I, Saumel I (2014): A walk on the wild side: Perceptions of roadside vegetation beyond trees. Urban Forestry and Urban Greening, 13, 205–212. doi: 10.1016/j.ufug.2013.10.010.

Woznica P, Urbisz A, Urbisz A, Franiel I (2016): Tram tracks as specific anthropogenic habitats for the growth of plants. PeerJ Preprints, 4. doi: 10.7287/peerj.preprints.2606v1.

Xing Y, Brimblecombe P (2019): Role of vegetation in deposition and dispersion of air pollution in urban parks. Atmospheric Environment, 201, 73–83. doi: 10.1016/j.atmosenv.2018.12.027.

Yang J, Yu Q, Gong P (2008): Quantifying air pollution removal by green roofs in Chicago. Atmospheric Environment, 42, 7266–7273. doi: 10.1016/j.atmosenv.2008.07.003.

Corresponding Author:

Mgr. et Mgr. Eva H o r v á t h o v á, Ph.D., Global Change Research Institute of the Czech Academy of Sciences, Department of Human Dimensions of Global Change, V Jirchářích 6, 110 00 Praha 1, Czech Republic, phone: + 420 605 348 945,
e-mail: horvathova.e@czechglobe.cz.