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Using Plants of Novel Ecosystems as Resources to Create Green Roofs in Cities' Adaptation to the Climate Change Process

Wykorzystanie roślin novel ecosystems jako zasobów do tworzenia dachów zielonych w procesie adaptacji miast do zmian klimatu

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Abstract: Using local wild plant resources to create green roofs in urban areas is a sustainable solution that supports cities' adaptation strategies to climate change. Creating extensive green roofs, in accordance with the Nature-Based Solutions concept, supports minimizing the effects of climate change, loss of biodiversity and human health. The aim of this paper is to identify, based on an analysis of published research results, the main criteria for selecting vegetation introduced to green roofs and the role of green roofs in minimizing the effects of climate change in the context of NBS. The data were collected by analyzing the results of studies published in the last 10 years, focusing on plant selection. It was found that species selection often fails to consider plant functional traits. The potential of wild plants in urban-industrial areas for creating green infrastructure and optimizing ecosystem services remains largely unrecognized. However, certain plants with desirable functional traits, originating e.g. from habitats such as post-industrial coal mining waste heaps, show promise in providing functional support to urban ecosystems in minimizing the effects of climate change.

Keywords: plant functional traits (PFT), novel ecosystems, extensive green roofs, nature-based solutions (NBS), habitat template approach

Streszczenie: Wykorzystanie lokalnych zasobów dzikich roślin do tworzenia zielonych dachów na obszarach miejskich to zrównoważone rozwiązanie, które wspiera strategie adaptacyjne miast do zmian klimatycznych. Tworzenie ekstensywnych dachów zielonych, zgodnie z koncepcją rozwiązań opartych na przyrodzie (NBS), wspiera minimalizację skutków zmian klimatycznych, utraty różnorodności biologicznej i zdrowia człowieka. Celem artykułu jest identyfikacja, na podstawie analizy opublikowanych wyników badań, głównych kryteriów wyboru roślinności wprowadzanej na zielone dachy oraz roli zielonych dachów w minimalizowaniu skutków zmian klimatu w kontekście NBS. Dane zebrano analizując wyniki badań opublikowanych w ciągu ostatnich 10 lat, skupiających się na selekcji roślin. Stwierdzono, że dobór gatunków najczęściej nie uwzględnia cech funkcjonalnych roślin. Potencjał dzikich roślin na obszarach miejsko-przemysłowych w zakresie tworzenia zielonej infrastruktury i optymalizacji usług ekosystemowych pozostaje w dużej mierze nierozpoznany. Jednakże niektóre rośliny o pożądanych cechach funkcjonalnych, pochodzące np. z siedlisk, takich jak hałdy odpadów powydobywczych węgla kamiennego, są obiecujące w zapewnianiu funkcjonalnego wsparcia ekosystemów miejskich w minimalizowaniu skutków zmian klimatu.

Słowa kluczowe: cechy funkcjonale roślin (PFT), novel ecosystems, ekstensywane dachy zielone, rozwiązania oparte na przyrodzie (NBS), szablon siedliska

Introduction

The ongoing climate change, anthropogenic activity and increased urbanization have become the greatest challenges for modern generations, causing a number of negative consequences for the environment. According to the United Nations report "Revision of World Urbanization Prospects 2018," by 2050, over 70% of people will be living in urban areas. The challenge for those managing these areas is to ensure the quality of life for residents and minimize the effects of climate change. In recent years, an approach aligned with the goals of sustainable development has been promoted, which involves increasing green space while considering their functions and ecosystem services provided (Getter et al. 2011, 3548). This is due to the destruction of natural systems and their replacement with grey infrastructure such as buildings, roads, and parking lots. In the current situation, where it is estimated that this may affect even two-thirds of urban areas (Ferguson 1998, 27), nature-based solutions (NBS) are used to create a multifunctional green infrastructure that refers to previously existing ecosystems while also providing benefits to society, the economy, and the environment (Christian et al. 2017, 315). Urban areas pose particular challenges for the implementation of NBS approaches (Cohen-Shacham et al. 2016, 23). Green roofs can play a crucial role as they perform functions such as retaining rainwater (Talebi et al. 2019, 2), regulating temperature (Bevilacqua et al. 2017, 318), reducing air pollution, and providing habitats for local fauna (Corada et al. 2021, 11). Green roofs offer specific locations that provide certain ecosystem services. To increase and improve the benefits of green roof ecosystems, they must be integrated and replicated in the urban landscape to function as multifunctional and decentralized units (Calheiros and Stefanakis 2021, 395). In addition to selecting the appropriate location, the choice of plant species is a crucial issue as it has a significant impact on thermal benefits and rainwater management, leading to energy savings (Li and Yeung 2014, 131). The aims of the paper was: 1) identification of the selection criteria for plants on extensive green roofs based on an analysis of published research results; 2) examination of the role of green roofs in minimizing environmental impacts within the context of NBS.

Therefore, an analysis was made of scientific articles published between 2013 and 2022 and available in the Scopus and Science Direct databases. The criteria for selecting works for further studies were keywords including "extensive green roof AND selection species AND climate change". Based on the content of the articles, the directions of research conducted to identify the criteria for selecting species for green roofs in extensive cultivation were indicated.

1. Green roofs as a part of urban infrastructure

The idea of green roofs dates back to the gardens of Babylon and the Roman Empire, where trees grew on building roofs (Peck 2002, 2). For over 100 years, they have become one of the key elements of urban space (Besir and Cuce 2018, 916-917). Köhler (Köhler 2006, 4) states that in Germany, the construction of green roofs began on a large scale at the end of the 19th century. Thanks to incentive programs from 1983-1996, green roofs were required for buildings in the central part of cities (Dunnett and Kingsbury 2004, 27). Currently, green roofs are widely spread in France, Switzerland, Germany, Norway and in other parts of the world. Green roofs are usually built in the city center (Li and Yeung 2014, 128, Caltano et al. 2018, 26). However, old city centers are often challenging to transform into green roofs because older buildings typically have steep, tiled roofs, unlike modern construction with flat roofs that are perfectly suited for green roof installation. In the UK, they are used in heavily built-up areas, allowing them to replace gardens or local parks at ground level (Herman 2003, 41). In Canada, the city of Toronto widely promoted the construction of green roofs to address environmental urban challenges (Missios et al. 2005, 4). In the 19th and 20th centuries, due to the rising costs of purchasing land for building parks in the centers of US cities, greenery was introduced on the roofs of buildings. Studies show that green roofs have advantages in collecting rainwater (Mentens et al. 2006, 224), combating urban heat islands (Akbari and Kolokotsa 2016, 836), providing thermal comfort (regulating temperature and humidity) (Alcazar et al. 2016, 306), reducing noise (Van Renterghem 2018, 227-228), and improving air quality (plants absorb CO2 and filter harmful particles) (Currie and Bass 2008, 411-412). Such solutions are becoming increasingly important in the context of global warming and in the face of more frequent heatwaves. The vegetation on green roofs keeps the roof cool in the summer and insulates the building from the cold in the winter (Getter et al. 2011, 3551). In addition, green roofs allow for an increase in habitat area without using additional ground surface by optimizing existing areas. Therefore, green roof technology can be one of the appropriate solutions to the problem of lack of vegetation in cities (Levallius 2005, 16).

In addition to technical aspects such as insulation, drainage, and substrate thickness, appropriate plant selection is a crucial element in creating green roofs that can perform ecosystem functions. The selection of plants affects the thermal benefits and stormwater runoff, leading to energy savings. Different types of green roofs require different vegetation types, which also necessitate different depths of growing medium (Missios et al. 2005, 42).

Considering the thickness of the substrate and the associated properties of the roofs, such as weight, green roofs are typically constructed with a substrate thickness of 5 to 15 cm (Besir and Cuce 2018, 918). These are called extensive roofs, where due to challenging growing conditions, such as low humidity, drought, and strong winds, main plants with low habitat requirements, such as sedums (*Sedum* spp.), are introduced (e.g. Vasl et al. 2017, 320-321). Sedum species have relatively shallow roots, can store water, and use crassulacean acid metabolism (CAM) to reduce water loss (Maclvor and Lundholm 2011, 226).

Research shows that native plant species are adapted to local climatic and habitat conditions. Once they are rooted, they do not require watering, fertilization, or the use of pesticides. They play a significant role in creating a functional ecosystem, providing niches for various organisms, including animals, mainly birds and butterflies, as well as microarthropods and microorganisms (Rumble et al. 2018, 4; 2022, 7). It has also been found that on a semi-intensive green roof with local plant species from natural habitats, there was more biomass, and the biodiversity was greater than on extensive roofs with non-native species. There are concerns that seeds of native plants from non-local sources may not survive during roof installation (Buttler et al. 2012, 5). The development of native vegetation on green roofs can also limit the emergence of non-native species, including invasive ones, which may result in increased maintenance costs for the native ecosystem on green roofs (Butler et al. 2012, 2). There is also no certainty whether non-native species will become invasive, which is why the use of native plants is a priority.

2. Plant functional traits and ecological function in the green roof's ecosystem

Due to the difficult conditions that plants face on extensive green roofs, research usually focuses on plant survival. This is understandable because it directly affects the aesthetics of green roofs, social acceptance, and the ability to fulfil their intended functions, such as regulating the city's climate. Gonsalves et al. (2022, 13) have shown that growth forms provide different ecosystem services. For example, it has been shown that plants with broad leaves are much more efficient at cooling the environment than succulents. However, it should be noted that similar to natural ecosystems, competition, environmental conditions, and demographic stochasticity can cause species to fall out of green roofs. Therefore, a major challenge is to create a biodiverse green roof with species that can coexist stably over a longer period of time. Inspiration can be drawn from ecosystems that develop spontaneously in areas with conditions that are difficult for plants, such as novel ecosystems, partly due to the mechanical composition of the substrate, water availability, salinity, and competition from coexisting species (Stalmachová and Sierka 2014, 54; Kompała et al. 2021, 9).

It seems that the heterogeneity of the green roof habitat (Lundholm and Heim 2020, 9-11) and combinations of plant functional traits can lead to the widest range/efficiency of ecosystem services. However, research is needed to determine which specific combinations of plant traits, possessed by species in urban-industrial areas, can promote coexistence in homogeneous and heterogeneous green roof environments. Plant functional traits can be defined as the morphological, physiological, and phenological features that manifest from the phenotypes of individual organisms (Díaz et al. 2013, 2959; Dawson et al. 2012, 16436). Recent studies on green roofs have shown that functional traits of plants play a crucial role in species survival and providing ecosystem services (Lundholm et al. 2015, 732). Additionally, combining species with different profiles of functional traits can improve green roof functionality, as different traits are associated with different ecosystem services (Sierka et al. 2022, 266). For example, compared to their counterparts, stiff-leaved plants are more effective at capturing airborne particulate matter (Weerakkody et al. 2017, 177), tall plants better limit stormwater runoff, and species with dense canopies more effectively reduce substrate temperature (Lundholm 2015, 732), while flowering species attract pollinators (Grimshaw-Surette 2020, 12-16). In green roof studies, plant functional traits are typically examined to determine which species are suitable for the green roof environment (Farrell et al. 2013, 193, Van Mechelen et al. 2014, 48-49) or to determine which traits stand out in providing a particular ecosystem service (Lundholm 2015, 732). However, further research is needed to understand how plant functional traits change over time. The results of such research could be used to create green roofs that optimally support stable coexistence and provide desired ecosystem services.

There is also a debate about whether native or non-native species should be introduced to green roofs. Native plants may provide shelter and food for native animals (Li and Yeung 2014, 128-129), as they are better adapted to local habitat conditions. Disturbance-adapted species are likely to colonize green roofs, and the composition of resident native species assemblages on green roofs strongly affects patterns of colonist composition (Aloisio et al. 2018, 8).

3. Novel ecosystems as a potential for the city's green infrastructure

In recent years, there has been a growing awareness of the necessity to green urban environments as a strategy for mitigating climate change. Extensive green roofs (EGRs), which provide spaces for planting grasses, shrubs, and other vegetation, can cool urban areas more effectively and efficiently, for instance, through water evaporation, compared to the monoculture of moss (Cao et al. 2019, 48-49). The same holds true when it comes to planting Sedum sp. on the roof, where a cooling effect of 1.5 K has been achieved compared to gravel-covered roofs (Tanaka et al. 2017, 96-97). There is still room for further minimizing the effects of global warming in urbanized areas. Heatwaves are a consequence of climate change and the Urban Heat Island (UHI), and research shows that green roofs have the potential as a cooling tool. Buildings account for about 48% of total energy consumption. EGRs reduce energy loss through roof surfaces and allow for cooling of urban surfaces through evapotranspiration (Cascone et al. 2019, 338).

The widespread use of EGRs would reduce energy consumption and could contribute to achieving the European low-emission target by 2050 by providing improved technology (Peng et al. 2019, 249). The little is known about the role of plants introduced as plantings on green roofs, the importance of their functional traits for retaining rainwater and snowmelt (Beck et al. 2011, 2012), and creating biodiversity. Regarding the number of species, it has been proven (Cook-Patton and Bauerle 2012, 87) that different plant species should be used for N and P management instead of a monoculture. Therefore, in research on optimizing the selection of plants for green roofs, it is essential to consider their functional traits and use plant resources that inhabit areas created as a result of human activity and are referred to as novel ecosystems (Hoobs et al. 2006, 2-3).

On coal mine spoil heaps created from shales, mudstones, sandstones, siltstones, and coal shales, extreme abiotic conditions prevail (e.g., unfavourable texture, lack of water or poor water retention, low availability of organic matter and nutrients, high temperature, and salinity). Plants growing in these habitats exhibit traits that will most likely allow them to adapt to the challenging environmental conditions in urbanized areas on green roofs (Filazzola et al. 2019, 2133). This adaptation involves modifying the mechanisms of physiological processes (Kompała-Bąba et al. 2021, 2-3) or producing substances that protect critical elements of metabolism, such as flavonoids. One can also apply the method of assisted succession (Stalmachova and Sierka 2014, 33-45), which involves preparing the roof substrate and leaving it to be colonized by species naturally, as is done, for example, in Germany (Knapp et al. 2019, 2), Canada (Landholm 2010, 5), in accordance with the idea of the template habitat approach (Landholm 2006). However, this is a lengthy process, and its effects have not been evaluated. It seems that introducing diverse forms of plants from anthropogenic ecosystems, including those from coal mine heaps, could provide an innovative and eco-friendly solution to the challenges of greening urban environments.

Conclusions

The results of research on the content of scientific publications indicated that the topic of selecting plant species for extensive green roofs in the aspect of climate change has not been the subject of numerous studies. Ten papers were identified, published between 2013 and 2022 in the Scopus database and 40 in the Science Direct database.

The work covered the following issues:

- Plant survival in experimental substrates with various admixtures, e.g. compost.
- The recommended species are: *Sedum album, S. sediforme, S. sexangulare* are species recommended for use on extensive green roofs, while *S. spurium,* especially the "Coccineum" variety, has some limitations in their use, mainly due to the shape, and structure of the plant, pigmentation and lack of adaptation to winter conditions.
- Plant survival in various climatic conditions.
- Recommended species are *Paepalanthus alpinus* and *Echeveria ballsii* in neotropical mountain climate conditions.
- Plant requirements regarding sunlight, water access and winter tolerance.
- Recommended species are *Sedum acre, Frankenia thymifolia* and *Vinca major*, which have good tolerance and growth performance characteristics and offer the best energy demand and carbon dioxide emissions in cold and dry climates.
- Roof structure and reducing its weight – soilless cultivation.

The recommended species is *Origanum dictamnus* L. (Lamiaceae) a perennial herb endemic to the Greek island of Crete, widely used for preparing tea, medicinal purposes and flavuring food, as well as an ornamental plant. This is an example of the use of a wild species.

Generally the analyzed works did not indicate the possibility of using wild plants. Therefore, the current research and implementation trend is using solutions that function in nature, considering the ecosystem services provided. However, it is not common to deliberately use species from plant communities developing spontaneously on coal mine spoil heaps areas for planting green roofs. This may be due to the lack of awareness and knowledge of plant species' biological potential, whose growth and development occur in habitats where numerous environmental stresses are identified (Biela et al. 2023, 275).

Typical plant selection approaches in public landscapes include matching suitable species to site constraints and resource limitations, in addition to aesthetic, cultural and functional criteria (Hoyle et al. 2017).

Adapting species from novel ecosystems to the conditions of green roofs seems to be possible. However, it must consider the inhabitants' current sense of aesthetics. Plant functional traits (PFT) are rarely considered when selecting plant species. PFTs are the key scope of knowledge for creating ecosystem elements. Each performs specific functions, allowing the maintenance of dynamic balance, as is the case in ecosystems with natural features.

Currently, attempts are being made to identify the most important features of plants necessary to survive and perform functions in urban ecosystems subject to climate change (Farrell et al. 2022).

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