RESTORATION ECOLOGY
The Journal of the Society for Ecological Restoration
SER SOCIETY FOR ECOLOGICAL RESTORATION

RE-NEW (OPINION) ARTICLE

Urban post-industrial landscapes have unrealized ecological potential

Laura Merwin[1], Lauren Umek[2], Alison E. Anastasio[3,4]

Urbanized and post-industrial sites often host considerable biodiversity but are too frequently dismissed by conservation professionals, in part because current species assemblages differ from the site's natural history. Given the dramatic and often irreversible changes to these sites, we conclude that historic ecosystems do not provide a useful reference for restoration. However, seen through a novel ecosystem lens, these landscapes already have conservation value and thus require nuanced restoration planning that recognizes their current and potential community composition. We highlight slag-dominated sites in the brownfields of the Calumet region as an example of a post-industrial landscape that may serve both as a recreational area for humans and a refuge for native biodiversity.

Key words: **brownfields, Chicagoland, ecosystem services, novel ecosystems, post-industrial landscapes, species refugia, urban ecology**

Implications for Practice

- Brownfield remediation is difficult and expensive; as a result, sites are often left in limbo. Land managers should be on the lookout for self-assembled ecosystems at such sites hosting valuable biodiversity or providing other ecosystem services.
- Where volunteer ecosystems have desirable characteristics, land managers should consider maximizing conservation value of the extant ecosystem rather than replacing it.
- Land managers should seek out habitat analogs for novel ecosystems to use as guides to traits and species likely to persist and as models for restoration goals in lieu of historic baselines.
- Esthetically and ecologically valuable species that persist on slag can be introduced to other similar habitats, increasing the conservation value of these spaces.

Land managers and conservation professionals frequently must prioritize areas for protection and/or restoration. High-quality remnants of historical ecosystems are generally ranked first, followed by degraded remnants with the potential for ecological restoration (Gann et al. 2019). On a practical level, financial and logistical barriers often limit efforts to these two types of ecosystems. However, depending on the management entity and location(s) involved, management plans and budgets may also encompass ahistorical but culturally important landscapes that provide ecosystem services. Such areas can include agricultural or pastoral landscapes, gardens and parks, parkways, and green roofs.

These categories, however, fail to account for all potential ecosystems, especially in heavily human impacted areas. Vacant lots, railroad rights-of-way, road verges, abandoned industrial sites, and other brownfields—characterized by the presence of built structures, pollutants, non-native species, and evidence of past or current human disturbance—are often dismissed as totally ecologically degraded.

While conservation professionals may ignore these spaces, public entities often do not. The need for green space in urban, suburban, and exurban landscapes means that the value of brownfields as potential recreational spaces is frequently recognized. Public land-owning agencies have an established history of acquiring and repurposing lands unsuitable for typical private development due to pollution or other modifications from previous use. These types of sites have been redeveloped as parks, golf courses, sledding hills, and trails. Notable examples include Freshkills Park in New York City, Houtan Park in Shanghai, Gas Works Park in Seattle, Chicago's Bloomingdale Trail/606 and Harborside International Golf Center, and at least two sledding hills known as Mount Trashmore (Evanston, IL and Virginia Beach, VA).

Author contributions: LM, LU, AEA together conceived the ideas and wrote and edited the manuscript; AEA compiled the figure and table.

[1]Division of Natural, Math, and Computer Sciences, Concordia University Chicago, 7400 Augusta Street, River Forest, IL 60305, U.S.A.
[2]Department of Cultural and Natural Resources, Chicago Park District, 541 N. Fairbanks, Chicago, IL 60611, U.S.A.
[3]Program on the Global Environment, University of Chicago, 1155 E. 60th Street, Chicago, IL 60637, U.S.A.
[4]Address correspondence to A. E. Anastasio, email aea@uchicago.edu

doi: 10.1111/rec.13643

These examples demonstrate that such approaches can produce useful and culturally valuable recreation spaces, but they tend to rely on strategies, like extensive topsoil capping or excavation, that efface existing characteristics of the site (with the common exception of remnant built structures with perceived historical or cultural value). Rarely is the current ecological quality of brownfields preserved or even considered, despite the common presence of volunteer species and ongoing ecosystem processes. We argue that despite discontinuity with historical ecosystems, many such sites are indeed capable of providing important ecosystem services without wholesale community replacement (Kowarik 2011; Nassauer & Raskin 2014). Thus, we feel they may in some cases be better labeled and managed as novel ecosystems.

The definition and usefulness of the term "novel ecosystems" has been much debated, but the concept generally refers to ecosystems that are compositionally and/or functionally distinct from historical norms as the result of direct or indirect human activity (Hobbs et al. 2006). In addition, they are to some degree self-sustaining without ongoing human intervention (Hobbs et al. 2014). Kowarik (2018, 2021) has described urban-industrial sites dominated by autonomous biotic processes (e.g. colonization, dispersal, and proliferation of plant and animal species) and abiotic processes (e.g. soil formation and erosion). He identifies such sites as a new type of "wilderness," even though they may be set in an environment heavily altered by human activities and contain both native and non-native species. There is a growing realization among ecologists that such ecosystems can be important providers of ecosystem services and sites for conservation (Kowarik 2011; Hobbs et al. 2014; Twerd & Banaszak-Cibicka 2019; Spotswood et al. 2021).

To date, however, the conservation value of novel urban ecosystems has not been widely embraced by land managers. Landschaftpark in Duisburg, Germany, and the High Line in New York City are two repurposed industrial sites where park designers explicitly considered an existing spontaneous plant community in making functional and esthetic choices. Both have been celebrated for their beauty, uniqueness, historical value, and ecological interest. The sustained popularity of these non-traditional parks and their non-traditional plant communities demonstrates that they provide valuable cultural ecosystem services, particularly esthetic. However, these two parks can best be described as *inspired* by novel ecosystems that have now been replaced with heavily managed simulacra.

In one rare example of a true novel ecosystem approach, the steel company ArcelorMittal, former owner of two steel mills in East Chicago and Burns Harbor, IN, established natural areas on company property in partnership with local conservation organizations (O'Gorman 2020). This is atypical in more than one way, as brownfield site restorations are far more likely to be attempted by public agencies due to the high cost and low opportunity for short-term return on investment.

Based on these examples, we suggest that sites hosting novel ecosystems might be allowed to retain some autonomous ecosystem function and that such a management approach might fulfill esthetic, recreational, social, and conservation aims. Here, we highlight post-industrial sites in the Calumet region of Illinois and Indiana that we believe lend themselves to a novel ecosystems approach.

The Calumet region, located at the southernmost point of Lake Michigan, is a nexus of three major biomes (eastern deciduous forest, northern boreal forest, tall grass prairie), providing a striking heterogeneity of landscape and associated biodiversity (Chew 2009). Various types of wetlands, dune ecosystems, woodlands, oak savannas, and prairies are characteristic ecosystems of the region. Located on the Mississippi flyway, many migrating birds, including dozens of rare species, utilize its shoreline, wetland, and upland habitats (Labus et al. 1999; Schroeder 2004; Bouman 2020).

During the late nineteenth and most of the twentieth century, the region hosted a high concentration of heavy industry (e.g. sand mining, oil refining, and steel production) subject to little or no environmental regulation. As a result, Calumet habitats suffered fragmentation, degradation, and wholesale destruction. Among other insults, steel companies disposed of heavy-metal-rich byproducts of steel smelting—slag—across the region, especially in wetland areas (Kay et al. 1997; Bouman 2020). Slag was dumped from railcars while still molten, cooling to form an exceptionally hard substrate with a gravel or pavement-like appearance (see Fig. 1). Today, these sites can resemble abandoned building foundations or parking lots (Brown 2018). Despite this history of intensive modification

Figure 1. Visual comparison between (A) Illinois dolomite prairie (used with permission by Kelly Mikenas), (B) Swedish alvar (by JGrahn CC BY-SA 3.0), and (C) Chicago slag (by the author, AEA).

and associated species loss (Bouman 2001), a surprising number of habitat remnants remain from which degraded sites may be repopulated (Bouman 2020).

Widespread industrial plant closures beginning a few decades ago eventually resulted in the transfer of many brownfield sites to the aegis of public agencies like the Chicago Park District and the Forest Preserve District of Cook County. Publicly owned post-industrial sites in the Calumet collectively comprise a significant expanse of land within a major metropolitan area and thus have considerable potential for recreational use. Additionally, as these sites have been colonized by volunteer species, there is increasing evidence that they also constitute areas of ecological value (Table 1).

A challenge for pursuing conservation goals at these sites, however, is that established restoration practices that aim to return an ecosystem to some sort of local historical baseline are obviously inappropriate. Sites like those on slag no longer physically resemble historical norms (Alagona et al. 2012; Kopf et al. 2015; Higgs et al. 2018), so an historic baseline of any kind is inadequate to determine what species will thrive in the future. Nevertheless, these sites offer opportunities to enhance regional biodiversity, protect rare native species, and reduce habitat fragmentation, in addition to offering traditional recreational spaces for humans (Braidwood et al. 2018; Vosloo 2018; Bonthoux et al. 2019; Planchuelo et al. 2019). Active management could further augment ecosystem services provided by these sites.

Table 1. iNaturalist observations identified on Calumet steel industry waste (as defined in iNaturalist (n.d.) from 2007 to 2021 of 854 unique species of plants, fungi and animals by class (out of 3,396 total observations) (iNaturalist Observers 2021). This is a conservative estimate of species number because (1) species that are locally threatened or endangered have their location obscured on iNaturalist and will not be included in location-based queries and (2) only observations with enough information to yield a positive identification at the species level were included in the analysis. Of the 453 plant species, 306 are classified as "native to United States" though note that iNaturalist can be incomplete in native/non-native status, especially for fungi and invertebrates.

Taxon	*Total*
Animalia	370
Actinopterygii	10
Amphibia	7
Arachnida	12
Aves	159
Bivalvia	1
Gastropoda	6
Insecta	153
Mammalia	13
Reptilia	9
Fungi	31
Agaricomycetes	22
Dacrymycetes	1
Lecanoromycetes	6
Sordariomycetes	1
Taphrinomycetes	1
Plantae	453
Bryopsida	7
Liliopsida	94
Lycopodiopsida	1
Magnoliopsida	345
Marchantiopsida	1
Pinopsida	2
Polypodiopsida	3
Total no. of species	854

Basic surveys of local slag sites in the region by the authors have revealed considerable extant biodiversity. Weedy non-native species that readily colonize low-value disturbed habitats are present, but plants with high coefficients of conservatism (Wilhelm & Rericha 2017) are also able to persist here (e.g. *Carex crawei*, *Carex aurea*, *Lobelia kalmii*, *Polygala verticillata*, *Eleocharis* sp., *Bouteloua curtipendula*, *Rhus aromatica*) (iNaturalist n.d.). Observations of animal diversity at these sites include seasonally high densities of pollinators (butterflies and bees), other insects, birds, especially waterbirds, mammals like deer and coyote, and, surprisingly, reptiles and amphibians (Table 1).

Thus, these sites *do* fit basic definitions of novel ecosystems, sustaining plant and animal communities and ecosystem processes even in the absence of active management. Hobbs et al. (2014) argue that management of novel ecosystems involves defining goals based on ecosystem function and desired land use rather than site history (or see also Westphal et al. 2010). This strategy accommodates past modification and, ideally, allows for ongoing uses beneficial to both human and non-human community members. This may result in decisions counterintuitive to managers of high-quality remnant ecosystems. For example, non-native species, even those generally considered problematic invasives, may be tolerated or even encouraged on slag sites if they are enhancing ecosystem functionality (by hosting pollinators, for instance) and if they do not threaten native biodiversity at nearby high-quality remnant sites.

While abandoning impractical or impossible fidelity to historical conditions may grant practitioners more freedom in management choices (Higgs et al. 2018), it may also leave them struggling to identify the most appropriate approaches. Thus, it may be helpful to look for analogous ecosystems with similar physical characteristics and species assemblages regionally and even globally (Tomlison et al. 2007; Lundholm & Richardson 2010; Ksiazek-Mikenas et al. 2021). Dolomite prairies in the American Midwest (Molano-Flores et al. 2015) and alvar ecosystems in Canada and Sweden (Catling & Brownell 1999; Rosén 2006) share at least some of the physical features of slag ecosystems, including an exposed, relatively impenetrable substrate (limestone in the case of dolomite prairie and alvar); thin soils, low organic matter content, and low water retention; herbaceous and graminoid plant species that persist with low nutrient and water availability and high sun exposure; and few trees (Fig. 1). Such analogs may inspire a set of hypotheses that could inform management decisions (Richardson et al. 2010). For example, dolomite prairie species assemblages might highlight plant functional traits likely to contribute to survival and reproduction in such systems or even suggest possible successful colonizers for slag sites. These may include endangered plants from the dolomite prairie like the leafy prairie clover (*Dalea foliosa*) and lakeside daisy (*Tetraneuris herbacea*).

We speculate that specific management activities undertaken at these sites will not adhere to typical restoration practices because they will be driven by extant communities and processes that are currently unknown. Spontaneous communities on brownfields are understudied both because they are frequently dismissed as valueless and because they are often ephemeral, not due to any inherent ecological characteristics, but because they are removed when sites are cleared for redevelopment. The novel ecosystem management approach we advocate prioritizes assessment of existing biodiversity and ecosystem function before formulating specific conservation goals. While we see no philosophical reason to refrain from deliberately altering an existing ecology (in contrast to managers of more pristine ecosystems), enhancing existing, rather than creating new, ecosystem services seems a parsimonious approach.

Conclusion

Conservation of "pristine wilderness" landscapes has long been the focus of environmentalists and ecologists, and this effort remains critical to the preservation of biodiversity and the long-term health of the planet. We argue that explicitly broadening conservation goals to incorporate anthropogenically impacted sites and novel ecosystems will benefit both humans and non-humans. A growing body of evidence points to urban, suburban, and exurban sites as important refugia for a variety of plant and animal species, including those that are rare and threatened (Ives et al. 2016; Braidwood et al. 2018; Shaffer 2018; Planchuelo et al. 2019; Soanes & Lentini 2019).

A corresponding body of evidence points to benefits to human physical and mental health from contact with the urban natural world (Tzoulas et al. 2007; Pickard et al. 2015; Kondo et al. 2018; Labib et al. 2020). This may be particularly critical in post-industrial landscapes, like those of the Calumet, found in human communities with limited access to high-quality green and recreational space. Such communities simultaneously face the social, economic, and human health burdens of polluting industries and their legacies (Schell et al. 2020). Environmental injustices are only one of many reasons why ecologies embedded in urban communities demand equal representation from the social and natural sciences in order to interrogate human-nature entanglements (Jorgensen & Tylecote 2007).

As well as providing ecosystem services to surrounding human communities, we believe novel ecosystems on brownfields are also valuable as labs for testing ecological and evolutionary hypotheses. The intellectual requirements of a mature science and the growing practical challenges of the Anthropocene both necessitate that ecological theory be applicable across a wide variety of ecosystem types. Unprecedented combinations of species can offer unique insights into universal ecological processes like ecosystem function and assembly (Gallagher et al. 2008, 2018), trait filtering (Planchuelo et al. 2019), and succession (Zou et al. 2019) and contribute to the construction of robust ecological theory (Nassauer & Raskin 2014; Botzat et al. 2016).

Places like the Calumet are largely ignored in both theoretical and practical discussions of land management and conservation. Taken altogether, however, we believe they deserve philosophical consideration and rigorous scientific attention from ecologists, conservationists, restoration professionals, and social scientists as potentially valuable "natural" areas.

Acknowledgments

The authors would like to thank an anonymous reviewer for comments that improved the manuscript, B. Tsang for helpful conversations, cassi saari for insight and advice in the field and with iNaturalist, and many iNaturalist contributors for the observations cited here.

LITERATURE CITED

Alagona P, Sandlos J, Wiersma YF, International Association for Environmental Philosophy (2012) Past imperfect: using historical ecology and baseline data for conservation and restoration projects in North America. Environmental Philosophy 9:49–70. https://doi.org/10.5840/envirophil2012914

Bonthoux S, Voisin L, Bouché-Pillon S, Chollet S (2019) More than weeds: spontaneous vegetation in streets as a neglected element of urban biodiversity. Landscape and Urban Planning 185 (May):163–172. https://doi.org/10.1016/j.landurbplan.2019.02.009

Botzat A, Fischer LK, Kowarik I (2016) Unexploited opportunities in understanding liveable and biodiverse cities. A review on urban biodiversity perception and valuation. Global Environmental Change 39 (July):220–233. https://doi.org/10.1016/j.gloenvcha.2016.04.008

Bouman M (2001) A mirror cracked: ten keys to the landscape of the Calumet region. Journal of Geography 100:104–110. https://doi.org/10.1080/00221340108978425

Bouman M (2020) The Calumet Region: A line in the sand. In: City of Lake and Prairie. History of the urban environment. University of Pittsburgh Press

Braidwood DW, Taggart MA, Smith M, Andersen R (2018) Translocations, conservation, and climate change: use of restoration sites as Protorefuges and Protorefugia. Restoration Ecology 26:20–28. https://doi.org/10.1111/rec.12642

Brown S (2018) The Human Role in the Formation of South Works: Iron, Limestone & Slag

Catling PM, Brownell V (1999) Alvars of the Great Lakes Region. Pages 375–391. In: Savannas, barrens, and rock outcrop plant communities of North America. Cambridge University Press

Chew R (2009) Discovering the Calumet. Chicago Wilderness Magazine (Spring), https://cdn.ymaws.com/www.chicagowilderness.org/resource/collection/0625B160-07C5-482A-8BDF-D86381B9FC77/2009-Spring.pdf

Gallagher F, Goodey NM, Hagmann D, Singh JP, Holzapfel C, Litwhiler M, Krumins JA (2018) Urban re-greening: a case study in multi-trophic biodiversity and ecosystem functioning in a post-industrial landscape. Diversity 10:119. https://doi.org/10.3390/d10040119

Gallagher FJ, Pechmann I, Bogden JD, Grabosky J, Weis P (2008) Soil metal concentrations and vegetative assemblage structure in an urban brownfield. Environmental Pollution 153:351–361. https://doi.org/10.1016/j.envpol.2007.08.011

Gann GD, McDonald T, Walder B, Aronson J, Nelson CR, Jonson J, Hallett JG, et al. (2019) SER international principles and standards for the practice of ecological restoration. Second edition. Restoration Ecology 27 (S1): 13035. https://doi.org/10.1111/rec.13035

Higgs ES, Harris JA, Heger T, Hobbs RJ, Murphy SD, Suding KN (2018) Keep ecological restoration open and flexible. Nature Ecology & Evolution 2: 580. https://doi.org/10.1038/s41559-018-0483-9

Hobbs RJ, Arico S, Aronson J, Baron JS, Bridgewater P, Cramer VA, Epstein PR, et al. (2006) Novel ecosystems: theoretical and management aspects of the new ecological world order. Global Ecology and Biogeography 15:1–7. https://doi.org/10.1111/j.1466-822X.2006.00212.x

Hobbs RJ, Higgs E, Hall CM, Peter Bridgewater F, Chapin S, Ellis EC, Ewel JJ, et al. (2014) Managing the whole landscape: historical, hybrid, and novel ecosystems. Frontiers in Ecology and the Environment 12:557–564. https://doi.org/10.1890/130300

iNaturalist (n.d.) "Calumet Steel Industry Waste Zone Map." https://www.inaturalist.org/places/calumet-steel-industry-waste (accessed 24 Sept 2021)

iNaturalist Observers (2021) "Observations in Calumet Steel Industry Waste Area, January 2007–May 31 2021" https://www.inaturalist.org/observations?d2=2021-05-31&place_id=128755&verifiable=any (accessed 19 June 2021)

Ives CD, Lentini PE, Threlfall CG, Ikin K, Shanahan DF, Garrard GE, Bekessy SA, et al. (2016) Cities are hotspots for threatened species. Global Ecology and Biogeography 25:117–126. https://doi.org/10.1111/geb.12404

Jorgensen A, Tylecote M (2007) Ambivalent landscapes—wilderness in the urban interstices. Landscape Research 32:443–462. https://doi.org/10.1080/01426390701449802

Kay R, Greeman T, Duwelius R, King R, Nazimek J, Petrovski D (1997) Characterization of fill deposits in the Calumet region of northwestern Indiana and northeastern Illinois. U.S. Geological Survey

Kondo M, Fluehr J, McKeon T, Branas C (2018) Urban green space and its impact on human health. International Journal of Environmental Research and Public Health 15:445. https://doi.org/10.3390/ijerph15030445

Kopf RK, Finlayson CM, Humphries P, Sims NC, Hladyz S (2015) Anthropocene baselines: assessing change and managing biodiversity in human-dominated aquatic ecosystems. Bioscience 65:798–811. https://doi.org/10.1093/biosci/biv092

Kowarik I (2011) Novel urban ecosystems, biodiversity, and conservation. Environmental Pollution 159:1974–1983. https://doi.org/10.1016/j.envpol.2011.02.022

Kowarik I (2018) Urban wilderness: Supply, demand, and access. Urban Forestry and Urban Greening 29:336–347. https://doi.org/10.1016/j.ufug.2017.05.017

Kowarik I (2021) Working with wilderness: a promising direction for urban green spaces. Landscape Architecture Frontiers 9:92–103. https://doi.org/10.15302/J-LAF-1-030025

Ksiazek-Mikenas K, Chaudhary VB, Larkin DJ, Skogen KA (2021) A habitat analog approach establishes native plant communities on green roofs. Ecosphere 12:e03754. https://doi.org/10.1002/ecs2.3754

Labib SM, Lindley S, Huck JJ (2020) Spatial dimensions of the influence of urban green-blue spaces on human health: a systematic review. Environmental Research 180 (January):108869. https://doi.org/10.1016/j.envres.2019.108869

Labus P, Whitman RL, Becker Nevers M (1999) Picking up the pieces: Conserving remnant natural areas in the post-industrial landscape of the Calumet Region. Natural Areas Journal 19:180–187

Lundholm JT, Richardson PJ (2010) Mini-review: Habitat analogues for reconciliation ecology in urban and industrial environments: Habitat analogues. Journal of Applied Ecology 47:966–975. https://doi.org/10.1111/j.1365-2664.2010.01857.x

Molano-Flores B, Phillippe LR, Marcum PB, Carroll-Cunningham C, Ellis JL, Busemeyer DT, Ebinger JE (2015) A floristic inventory and vegetation survey of three dolomite prairies in Northeastern Illinois. Castanea 80:153–170. https://doi.org/10.2179/14-040

Nassauer JI, Raskin J (2014) Urban vacancy and land use legacies: a frontier for urban ecological research, design, and planning. Landscape and Urban Planning 125 (May):245–253. https://doi.org/10.1016/j.landurbplan.2013.10.008

O'Gorman M (2020) An evolving relationship. Pages 1–22. In: Strategic corporate conservation planning: a guide to meaningful engagement. Island Press, Washington, D.C.

Pickard BR, Daniel J, Mehaffey M, Jackson LE, Neale A (2015) EnviroAtlas: a new geospatial tool to Foster ecosystem services science and resource management. Ecosystem Services 14:45–55. https://doi.org/10.1016/j.ecoser.2015.04.005

Planchuelo G, von Der Lippe M, Kowarik I (2019) Untangling the role of urban ecosystems as habitats for endangered plant species. Landscape and Urban Planning 189:320–334. https://doi.org/10.1016/j.landurbplan.2019.05.007

Richardson PJ, Lundholm JT, Larson DW (2010) Natural analogues of degraded ecosystems enhance conservation and reconstruction in extreme environments. Ecological Applications 20:728–740. https://doi.org/10.1890/08-1092.1

Rosén E (2006) Alvar vegetation of Öland – changes, monitoring, and restoration. Biology and Environment: Proceedings of the Royal Irish Academy 106B:387–399. https://doi.org/10.1353/bae.2006.0016

Schell CJ, Dyson K, Fuentes TL, Roches SD, Harris NC, Miller DS, Woelfle-Erskine CA, Lambert MR (2020) The ecological and evolutionary consequences of systemic racism in urban environments. Science 369:4497. https://doi.org/10.1126/science.aay4497

Schroeder HW (2004) Special places in the Lake Calumet area. USDA Forest Service, North Central Research Station. https://www.nrs.fs.fed.us/pubs/gtr/gtr_nc249.pdf

Shaffer HB (2018) Urban biodiversity arks. Nature Sustainability 1:725–727. https://doi.org/10.1038/s41893-018-0193-y

Soanes K, Lentini PE (2019) When cities are the last chance for saving species. Frontiers in Ecology and the Environment 17:225–231. https://doi.org/10.1002/fee.2032

Spotswood EN, Beller EE, Grossinger R, Grenier JL, Heller NE, Aronson MFJ (2021) The biological deserts fallacy: cities in their landscapes contribute more than we think to regional biodiversity. BioScience 71:148–160. https://doi.org/10.1093/biosci/biaa155

Tomlison S, Matthes U, Richardson PJ, Larson DW (2007) The ecological equivalence of quarry floors to alvars. Applied Vegetation Science 73–82

Twerd L, Banaszak-Cibicka W (2019) Wastelands: their attractiveness and importance for preserving the diversity of wild bees in urban areas. Journal of Insect Conservation 23:573–588. https://doi.org/10.1007/s10841-019-00148-8

Tzoulas K, Korpela K, Venn S, Yli-Pelkonen V, Kaźmierczak A, Niemela J, James P (2007) Promoting ecosystem and human health in urban areas using green infrastructure: a Literature review. Landscape and Urban Planning 81:167–178. https://doi.org/10.1016/j.landurbplan.2007.02.001

Vosloo P (2018) Post-industrial urban quarries as places of recreation and the new wilderness – a south African perspective. Town and Regional Planning 72:4. https://doi.org/10.18820/2415-0495/trp72i1.4

Westphal LM, Gobster PH, Gross M (2010) Models for renaturing brownfield areas. In: Hall M (ed) Restoration and history: the search for a usable environmental past. Routledge Studies in Modern History. Routledge, New York, NY. https://www.nrs.fs.fed.us/pubs/jrnl/2010/nrs_2010_westphal_001.pdf

Wilhelm G, Rericha L (2017) Flora of the Chicago region: a floristic and ecological synthesis. Indiana Academy of Sciences

Zou H-X, Anastasio AE, Pfister CA (2019) Early succession on slag compared to urban soil: A slower recovery. PLOS ONE 14:e0224214. https://doi.org/10.1371/journal.pone.0224214

Coordinating Editor: Stephen Murphy

Received: 6 December, 2021; First decision: 22 December, 2021; Revised: 4 February, 2022; Accepted: 5 February, 2022