Environmental Conservation

cambridge.org/enc

Perspectives

Cite this article: Winkler J, Vaverková MD, Koda E (2026) Waste-derived ecosystems: vegetation responses and sustainability challenges. *Environmental Conservation* **53**: 51–56. doi: 10.1017/S0376892926100320

Received: 23 September 2025
Revised: 20 January 2026
Accepted: 21 January 2026
First published online: 3 March 2026

Keywords:
Composting facilities; invasive species; landfill vegetation; SDG 11; SDG 12; SDG 13; SDG 15; sustainable waste management; synanthropic succession; waste-derived ecosystems

Corresponding author:
Magdalena Daria Vaverková;
Email: magdalena.vaverkova@mendelu.cz

© The Author(s), 2026. Published by Cambridge University Press on behalf of The Foundation for Environmental Conservation. This is an Open Access article, distributed under the terms of the Creative Commons Attribution licence (https://creativecommons.org/licenses/by/4.0/), which permits unrestricted re-use, distribution and reproduction, provided the original article is properly cited.

Waste-derived ecosystems: vegetation responses and sustainability challenges

Jan Winkler[1], Magdalena Daria Vaverková[1,2] and Eugeniusz Koda[2]

[1]Mendel University in Brno, Czech Republic and [2]Warsaw University of Life Sciences, Poland

Summary

Waste management is one of the major environmental challenges of the twenty-first century. This Perspective examines how vegetation dynamics at composting facilities and landfills both reflect and influence anthropogenic environmental change. We define our use of the Anthropocene as a human-dominated epoch that is functionally and stratigraphically distinct from the Holocene, and we argue that waste-derived ecosystems constitute model systems for detecting its signals through technogenic substrates and synanthropic succession. Although composting reduces pressure on landfills, incomplete processing of biowaste can disseminate propagules of invasive plant species. Landfills, shaped by disturbance and altered edaphic regimes, support synanthropic plant assemblages dominated by neophytes that act as bio-indicators of leachate stress and other pressures. At the same time, spontaneous vegetation provides functional benefits, including slope stabilization, organic matter accumulation and habitat provision during early successional stages. We bring together information on risks and functions, link ecological criteria to permitting, monitoring and post-closure management pathways, and outline practical considerations for integrating plant-based indicators with geochemical screening. These steps enable ecologically sensitive strategies to be implemented that mitigate biodiversity risks while leveraging succession to improve the resilience of waste-derived landscapes.

Introduction

The management of waste and its environmental impacts are among the most pressing challenges of our time, particularly given the growing human population and its consumption (Ang & Yin 2025). Landfills serve as concentration points for both biodegradable and persistent materials. The biodegradable fraction undergoes primary decomposition under anaerobic conditions, yielding methane and carbon dioxide. The emission rates of these gases are governed by the phase of the landfill, its moisture content and the composition of the microbial community (Hilger & Barlaz 2007, Stamps et al. 2016, Njoku et al. 2025). Conversely, the presence of plastics, metals and other non-biodegradable materials has been shown to lead to increased deposition of mass, resulting in alterations to the redox and moisture regimes that influence overall degradation dynamics. Consequently, landfills become long-term environmental hotspots that contribute to soil, water and air pollution. Additionally, they present management challenges related to greenhouse gas mitigation and biogas utilization (Vaverková & Koda 2023, Gavrila et al. 2025).

Concurrently, these sites are evolving into novel habitats shaped by distinctly anthropogenic environmental conditions. The vegetation present in landfill sites is indicative of the site-specific abiotic pressures to which it is exposed, such as leachate seepage and altered soils. These pressures give rise to characteristic successional pathways, as evidenced by numerous studies (Winkler et al. 2021, Popovych et al. 2024, Skrobala et al. 2024, Winkler et al. 2024, Zhou et al. 2024). Invasive and synanthropic taxa frequently dominate, with potential consequences for native community composition and adjacent ecosystems.

Because vegetation on waste-derived substrates develops under persistent disturbance and altered edaphic regimes, it often forms predictable disturbance-adapted assemblages. Although most existing studies in this area address waste-management technologies and vegetation succession separately, this Perspective highlights the need to consider them jointly and articulates conceptual linkages between these domains. By examining both composting and vegetation development in landfill settings, we outline how waste-management practices shape emerging ecological patterns. We discuss key environmental risks in waste-derived habitats, including invasive species spread and vegetation contamination, and we emphasize synanthropic flora as practical indicators of anthropogenic change. These insights support ecologically informed waste-management strategies that mitigate biodiversity risks while strengthening early warning approaches to ecosystem transformation.

The objective of this Perspective is to provide: (1) an overview of interactions between composting and vegetation management; (2) an overview of interactions between landfilling

and vegetation management; and (3) a synthesis of vegetation responses to waste-management stressors, with practitioner and research guidance for steering species composition.

Anthropocene framing used in this Perspective

The term 'Anthropocene' denotes an epoch characterized by human domination, exhibiting distinct functional and stratigraphic characteristics from the Holocene epoch. This distinction is marked by the presence of enduring technogenic signals in both sediments and biota. Within this paradigm, waste-derived ecosystems function as model systems due to their unique combination of clearly stratified anthropogenic substrates and predictable synanthropic vegetation trajectories. This Perspective operationalizes the framing by linking vegetation indicators to management actions in composting and landfill aftercare.

Vegetation impacts of composting systems

During the twentieth century, the global human population experienced an unprecedented growth rate (Lam 2025), which directly amplified the production of waste, including food, kitchen, garden and plant residues, as well as animal manure (Wei et al. 2021). Organic wastes have typically been treated by landfilling and incineration, which are costly and provide little exportable energy due to their high moisture content and low calorific value (Xin et al. 2020). The exploration of alternative applications for organic materials has given rise to more environmentally sustainable methods, such as composting (Wei et al. 2017, Saqib & Sadef 2025). Composting is an organic waste recycling method based on the biodegradation of organic matter under aerobic conditions to produce stabilized and sanitized compost (Chorolque et al. 2022, Saqib & Sadef 2025). The advantages and disadvantages of composting have been well explored (Zhou et al. 2022, Yıldırım 2025).

During the composting process, environmental problems can arise, including odorous or toxic gases (Wei et al. 2017, Elsabbagh et al. 2025), bioaerosols (Ferguson et al. 2021, Lu et al. 2025) and dust (Schlosser et al. 2018), which can create occupational and community nuisance risks (Elsabbagh et al. 2025). Reported outcomes include respiratory and mucosal irritation, allergic responses and infection susceptibility linked to airborne microorganisms, endotoxins, volatile organic compounds and particulate matter (Ferguson et al. 2021, Lu et al. 2025). This is particularly relevant for open-air composting facilities. Biowaste and composting have been studied from different perspectives, and several studies have focused on environmental issues using life cycle analysis methods (Zhou et al. 2022) and greenhouse gases accounting and composition (Chen et al. 2019). In addition to gaseous emissions, composting systems can also produce nutrient-rich leachate with a high organic load, which may require further biological treatment to mitigate its environmental impacts (Tahsini et al. 2024). Certain management practices, such as leachate reuse in kitchen-waste composting, may contribute to nitrous oxide emissions, adding complexity to greenhouse gas mitigation efforts (Chen et al. 2023).

Other risks include the import of biowaste, which contains plant diaspores that can alter the composition of local vegetation species (Winkler et al. 2021). Composting facilities have the potential to serve as sites for the dissemination of invasive plant species due to the presence of viable propagules, such as seeds, rhizomes or tubers, in biowaste. These propagules can withstand the conditions associated with improper or incomplete composting processes (Winkler et al. 2023).

Given the increasing use of composting to treat the organic fraction of municipal solid waste, large-scale industrial facilities play a critical role in ensuring effective sanitization and preventing the spread of invasive species. Proper management of industrial composting has been demonstrated to effectively neutralize the reproductive potential of numerous invasive species (Tomše et al. 2025). However, inadequate temperature maintenance, uneven aeration, insufficient frequency of turning or shortened composting cycles may result in the failure to fully inactivate seeds or vegetative propagules, thereby allowing these species to persist and spread (Winkler et al. 2023).

Vegetation response to landfill habitats

Mixed municipal waste is usually landfilled, constituting one of the most prevalent waste management methods worldwide (Wong et al. 2016, Hamid et al. 2018, Rasapoor et al. 2020, Sauve & Van Acker 2020, Vaverková & Koda 2023). Landfilling has several negative environmental impacts, including pollutants being released from landfilled waste and leachate. This phenomenon can result in the contamination of soil and water resources (Dąbrowska et al. 2018, Koda et al. 2018) and subsequent alterations in the composition, health and succession of vegetation growing on or in the vicinity of landfill sites (Iravanian & Ravari 2020, Vaverková et al. 2025).

Depending on the type of waste, three main groups of landfills can be distinguished: (1) municipal solid waste, (2) industrial waste and (3) mixed municipal and industrial waste. Although municipal solid waste landfills are primarily characterized by organic contamination, the origin of contamination in industrial and mixed landfills is much more diverse and, in some cases, hazardous to surrounding ecosystems, particularly vegetation that is exposed to toxic substances and altered soil conditions. This is particularly evident in the context of illegal landfills that lack effective control mechanisms (Vaverková et al. 2019).

Landfills have been identified as a persistent environmental concern in developed countries, including in Germany and Austria (Unegg et al. 2023, Clemente et al. 2024), Ireland (Curran & O'Sullivan 2022), France (Nicholls et al. 2021), Italy (Folino et al. 2024), Serbia (Tenodi et al. 2020) and the USA (Wang et al. 2021). This concern also extends to developing countries (Gupta et al. 2024, Rai et al. 2024, Hussain et al. 2025). Despite the success of methane capture and utilization systems in several countries – including the US Landfill Methane Outreach Program (LMOP), which has enhanced methane recovery efficiency and reduced emissions (Themelis & Bourtsalas 2021) – the deployment and performance of such systems exhibit significant variation worldwide. A significant number of landfills, particularly in low- and middle-income regions, continue to operate without the implementation of effective gas control measures. This has led to the persistent release of greenhouse gases and subsequent ecological consequences.

Potentially important signals include the presence of carbonaceous particles in fly ash (Rose 2015), plastic residues (Zalasiewicz et al. 2016), other technofossils (Zalasiewicz et al. 2016, Wagreich et al. 2023) and artificial radionuclides (Wagreich et al. 2023).

Landfill leachate is a serious potential source of surface and groundwater pollution in the affected area, especially in the case of illegal/non-sanitary landfills that do not have an insulating layer

https://doi.org/10.1017/S0376892926100320 Published online by Cambridge University Press

between the deposited waste and the underlying soil. Leachate characteristics depend on factors such as waste composition, decomposition stage and local hydrological and climatic conditions. Metals commonly detected in landfill leachate include As, Cd, Cr, Hg, Cu, Zn and Pb, with concentrations often being greater during early leachate formation because acidification driven by organic acid production during hydrolysis and microbial degradation enhances metal mobilization (Podlasek 2023, Jakovljević et al. 2024). Many of these changes leave a durable signal in the stratigraphic record (Waters et al. 2016). An investigation was conducted on soil quality and metal content at 56 sanitary and non-sanitary landfills in China. The investigation revealed that Cr was the dominant metallic pollutant, with a Nemero pollution index ranging from 22.7 to 44.3, indicating an extremely high level of contamination (Wang et al. 2022). A number of atypical/ruderal species can be found in areas where landfills are located.

Vegetation growing on landfills evolves over time, and the species composition gradually changes. In the early years following landfill reclamation, differences in plant communities can be observed across various sections of the landfill body. After c. 20 years, a noticeable decline in native and wetland species occurs, whereas drought-tolerant and neophytic taxa become more dominant (Winkler et al. 2021, Koda et al. 2022, Vaverková et al. 2025). The unique and often stressful conditions of landfills contribute to the development of specific plant assemblages. Invasive neophytes (i.e., invasive alien species that arrived in Europe after 1500 CE; Kowalska & Kołaczkowska 2024), such as *Acer negundo* L., *Solidago canadensis* L., *Conyza canadensis* (L.) Cronquist, *Erigeron annuus* (L.) Desf., *Galinsoga parviflora* Cav., *Iva xanthiifolia* Nutt., *Reynoutria sachalinensis* (F. Schmidt) Nakai and *Robinia pseudoacacia* L., tend to be highly represented. In addition, many widespread ruderal species capable of colonizing agricultural areas and other anthropogenic habitats, such as *Artemisia vulgaris* L., *Calamagrostis epigejos* (L.) Roth, *Elymus repens* (L.) Gould, *Tanacetum vulgare* L. and *Oenothera biennis* L., tend to be highly represented in Europe (Pyšek et al. 2022). Collectively, these patterns indicate a synanthropic flora characteristic of landfill habitats (Winkler et al. 2021) and a consistent trajectory of synanthropic succession shaped by human activities. In this trajectory, the vegetation dynamics are dominated by human-associated (ruderal and invasive) species that progressively replace native or wetland taxa under disturbed conditions.

Positive functional roles of spontaneous vegetation

Spontaneous vegetation has been shown to deliver near-term functional benefits in landfill environments, in parallel with invasion risks (Wong et al. 2016, Winkler et al. 2021, Koda et al. 2022). The aforementioned benefits include: improved soil cover, which serves to reduce erosion; initial slope stabilization on heterogeneous caps; accumulation of organic matter, which supports soil profile development; and microhabitat provisioning for selected invertebrate groups during early succession (Wong et al. 2016, Jakovljević et al. 2024, Zhou et al. 2024). The recognition of these functions facilitates a management approach that is proportionate and context-dependent. The strategic management of high-risk invasive species should be integrated with the preservation of non-problematic assemblages that safeguard the soil, promote ecosystem integrity and facilitate ecosystem maturation (Winkler et al. 2021, Zhou et al. 2024).

Vegetation management in composting and landfill ecosystems

At composting facilities, vegetation monitoring and control are critical to mitigating ecological risks. Biowaste inputs can introduce viable propagules. If composting is incomplete, invasive species may disseminate into the surrounding environment (Winkler et al. 2023, Tomše et al. 2025). Failure to address these issues may initiate a cascade of effects, alter species composition and destabilize local biodiversity. Composting facilities underscore the imperative for adopting ecologically sensitive waste management strategies that balance technological advancement with the protection of natural ecosystems.

In the context of landfill ecosystems, the vegetation exhibits characteristics that deviate significantly from those observed in natural, agricultural and urbanized environments (Winkler et al. 2021, Koda et al. 2022, Vaverková et al. 2025). It is crucial for management strategies to acknowledge that practices such as fertilization, fruit tree planting or agricultural utilization of landfill areas are often ill-advised. Soil constraints have been demonstrated to impede the successful establishment of new plantings, whereas nutrient enrichment has been shown to favour competitively strong species and to impede succession. Given the frequent dominance of high-risk neophytes, management should prioritize containment and targeted control to reduce propagule export to adjacent ecosystems.

Although synanthropic and invasive species frequently dominate and can threaten adjacent ecosystems, spontaneous vegetation also contributes structural habitat, soil protection and early productivity. Management should therefore be proportionate and succession informed. Intensive landscaping, fertilization or agricultural planting on landfill bodies can disrupt developing soil profiles and favour competitively strong species with undesirable spread. We recommend three principles: (1) prioritize selective removal of demonstrably problematic taxa while retaining soil-protective assemblages; (2) reduce disturbance to caps and cover soils to avoid reset of succession; and (3) align vegetation control windows with propagule phenology to limit dispersal pressure. Plant-based indicators, combined with simple geochemical screening, enable the early detection of leachate seepage and other pressure gradients.

Environmental context of landfills and the development of vegetation

Vegetation on technogenic substrates develops under persistent anthropogenic pressures, providing a useful system for linking vegetation patterns with waste-site gradients (Fig. 1). The transformation of flora and vegetation in landfills is a critical issue in modern ecology, one that is closely linked to human-induced pressures such as waste leachate seepage, soil salinization and pollutant exposure. For instance, sites exhibiting leachate seepage undergo alterations in plant species composition, characterized by an increase in halophytes and a decline in glycophytes (Koda et al. 2022). These shifts can function as early indicators of environmental degradation. These factors often trigger secondary autogenic succession, which enables the establishment of non-native or synanthropic plant species that can disrupt native plant communities and accelerate ecological change (Chu & Karr 2013, Rai & Singh 2020, Kim et al. 2021, Vinogradova et al. 2021). Landfill habitats are inherently disturbed environments, and synanthropic succession is especially pronounced in these locations, facilitating phytoinvasion processes (Philippova et al. 2025) that can threaten biodiversity and long-term ecological resilience (Konishchuk et al.

https://doi.org/10.1017/S0376892926100320 Published online by Cambridge University Press



Figure 1. Interactions between landfilling processes, waste accumulation and vegetation development: (a) demolition and construction waste; (b) vegetation colonizing a landfill body; and (c) municipal solid waste. Field photographs; no scale bars. *Photo source:* Vaverková (2024).

2020, Senator et al. 2020), constituting a global environmental challenge (Philippova et al. 2025).

Landfill ecosystems are characterized by vegetation dominated by disturbance-tolerant and invasive taxa, shaped by layered technogenic deposits and chronic exposure to waste-derived stressors. Synanthropic vegetation can pose risks to adjacent ecosystems through propagule pressure and community turnover, and plant tissues may also reflect contamination by hazardous substances released from waste. These deposits influence soil development and vegetation trajectories, providing a stratigraphically distinct, human-generated archive for examining Anthropocene ecological signatures. Vegetation structure and species turnover offer measurable proxies for landfill-related environmental gradients and long-term ecological shifts.

Recommendations

Vegetation-based evidence can be integrated into monitoring, permitting and after-care to improve the detection of stressors and invasion pathways in waste-derived systems. We identify several priorities to tackle these issues:

(1) Systematic vegetation monitoring frameworks: development of standardized, plant-based monitoring protocols for landfills and composting sites to detect early signs of ecological stress, leachate effects and invasive species. This includes standardized monitoring of the immediate vicinity of landfills and adjacent land.
(2) Evidence-based invasive species management: establishment of operational guidelines for preventing plant propagule escape from composting facilities and for targeted control of invasive taxa in landfills. Blanket landscaping interventions that disrupt natural succession need to be avoided.
(3) Succession-informed post-closure strategies: recognition of the role of spontaneous vegetation in soil stabilization and system maturation. Management interventions that support functionally robust, low-risk plant assemblages need to be designed, rather than imposing conventional planting schemes.
(4) Implementation pathways for policy, allowing integration of vegetation-based criteria into permitting, monitoring and after-care plans. In the European Union context, this includes: (i) aligning vegetation indicators and invasive species control with after-care obligations under Directive 1999/31/EC; (ii) fulfilling invasive species prevention and management duties under Regulation 1143/2014 by incorporating propagule-pathway controls at composting facilities and post-closure landfills; and (iii) linking biowaste acceptance and compost quality protocols to ecological outcomes near facilities, including buffer vegetation surveillance and propagule interception.
(5) Cross-disciplinary research on waste-ecosystem functioning: strengthening of collaboration among waste engineering, plant ecology, invasion biology and environmental geochemistry disciplines to understand waste-site gradients, plant functional traits and long-term ecosystem trajectories.

Vegetation acts as a sensitive bioindicator of anthropogenic pressures, thus offering valuable insights into the dynamics of ecosystem development. Research on the vegetation of landfills and composting facilities highlights conclusions that raise questions regarding the sustainability of waste landfilling and its hidden impacts on ecosystems. The future of the planet will depend on how we respond to these challenges. There is therefore a need to develop and implement innovative strategies for protecting and restoring ecosystems, ensuring effective waste management and finding new ways to sustainably develop human civilization.

Data availability. No data were collected for this study.

Acknowledgements. None.

Financial support. None.

Competing interests. The authors declare none.

Ethical standards. Not applicable.

https://doi.org/10.1017/S0376892926100320 Published online by Cambridge University Press

References

Ang LP, Yin X (2025) Offsite ecological impacts in the Anthropocene: definition, mechanisms, and challenges. *Global Change Biology* 31: e70242.

Chen M, Huang Y, Liu H, Xie S, Abbas F (2019) Impact of different nitrogen source on the compost quality and greenhouse gas emissions during composting of garden waste. *Process Safety and Environmental Protection* 124: 326–335.

Chen Z, Zhang S, Li Y, Guo Z (2023) Investigating nitrous oxide emissions and mechanisms in kitchen waste composting with leachate reuse. *Chemical Engineering Journal* 476: 146813.

Chorolque A, Pellejero G, Sosa MC, Palacios J, Aschkar G, García-Delgado C, Jiménez-Ballesta R (2022) Biological control of soil-borne phytopathogenic fungi through onion waste composting: implications for circular economy perspective. *International Journal of Environmental Science and Technology* 19: 6411–6420.

Chu EW, Karr JR (2013) Environmental impact, concept and measurement of. In: SA Levin (ed.), *Encyclopedia of Biodiversity*, 2nd edition (pp. 278–296). London, UK: Academic Press.

Clemente E, Domingues E, Quinta-Ferreira RM, Leitão A, Martins RC (2024) European and African landfilling practices: an overview on MSW management, leachate characterization and treatment technologies. *Journal of Water Process Engineering* 66: 105931.

Curran TP, O'Sullivan O (2022) How Ireland reduced its active landfills: a true tale of policy-driven change. In: *SDG11, Sustainable Cities and Communities* (pp. 58–79). New Delhi, India: Routledge India.

Dąbrowska D, Witkowski A, Sołtysiak M (2018) Representativeness of the groundwater monitoring results in the context of its methodology: case study of a municipal landfill complex in Poland. *Environmental Earth Sciences* 77: 1–23.

Elsabbagh YMHS, Sibak HAR, El-Sheltawy ST, El-Shimi H (2025) Advances in controlling composting odor: a review of the last decade. *Journal of Engineering and Applied Science* 72: 1–13.

Ferguson RM, Neath CE, Nasir ZA, Garcia-Alcega S, Tyrrel S, Coulon F, et al. (2021) Size fractionation of bioaerosol emissions from green-waste composting. *Environment International* 147: 106327.

Folino A, Gentili E, Komilis D, Calabrò PS (2024) Biogas recovery from a state-of-the-art Italian landfill. *Journal of Environmental Management* 367: 122040.

Gavrila GO, Vasile GG, Calinescu SM, Constantin C, Tanase G, Cirstea A, et al. (2025) Assessment of CH_4 and CO_2 emissions from a municipal waste landfill: trends, dispersion, and environmental implications. *Atmosphere* 16: 752.

Gupta A, Verma A, Rajamani P (2024) Impact of landfill leachate on ground water quality: a review. In: A Anouzla, S Souabi (eds), *A Review of Landfill Leachate: Characterization Leachate Environment Impacts and Sustainable Treatment Methods* (pp. 93–107). Cham, Switzerland: Springer.

Hamid H, Li LY, Grace JR (2018) Review of the fate and transformation of per- and polyfluoroalkyl substances (PFASs) in landfills. *Environmental Pollution* 235: 74–84.

Hilger HH, Barlaz MA (2007) Anaerobic decomposition of refuse in landfills and methane oxidation in landfill covers. In: CJ Hurst, RL Crawford, JL Garland, DA Lipson, AL Mills, LD Stetzenbach (eds), *Manual of Environmental Microbiology*, 3rd edition (pp. 818–842). Hoboken, NJ, USA: Wiley.

Hussain A, Deshwal A, Priyadarshi M, Pathak S, Sambandam G, Chand S, Shukla AK (2025) Landfill leachate analysis from selected landfill sites and its impact on groundwater quality, New Delhi, India. *Environment, Development and Sustainability* 27: 12537–12562.

Iravanian A, Ravari SO (2020) Types of contamination in landfills and effects on the environment: a review study. *IOP Conference Series: Earth and Environmental Science* 614: 012083.

Jakovljević K, Mišljenović T, Ranđelović D (2024) Spontaneous flora on post-industrial metalliferous sites. In: VC Pandey (ed.), *Biodiversity and Ecosystem Services on Post-Industrial Land* (pp. 53–95). Hoboken, NJ, USA: Wiley.

Kim E, Choi J, Song W (2021) Introduction and spread of the invasive alien species *Ageratina altissima* in a disturbed forest ecosystem. *Sustainability* 13: 6152.

Koda E, Miszkowska A, Sieczka A, Osiński P (2018) Heavy metals contamination within restored landfill site in Poland. *Environmental Geotechnics* 7: 512–521.

Koda E, Winkler J, Wowkonowicz P, Černý M, Kiersnowska A, Pasternak G, Vaverková MD (2022) Vegetation changes as indicators of landfill leachate seepage locations: case study. *Ecological Engineering* 174: 106448.

Konishchuk VV, Solomakha IV, Mudrak OV, Mudrak HV, Khodyn OB (2020) Ecological impact of phytoinvasions in Ukraine. *Ukrainian Journal of Ecology* 10: 69–75.

Kowalska A, Kołaczkowska E (2024) Invasive neophytes alter ecological functions and services of riparian hardwood forests. *Ecological Indicators* 166: 112386.

Lam D (2025). The next 2 billion: can the world support 10 billion people? *Population and Development Review* 51: 63–102.

Lu K, Zhang J, Li Z, Li Y (2025) Bioaerosols in various working and living environments and their control measure: a review. *Current Pollution Reports* 11: 24.

Nicholls RJ, Beaven RP, Stringfellow A, Monfort D, Le Cozannet G, Wahl T, et al. (2021) Coastal landfills and rising sea levels: a challenge for the 21st century. *Frontiers in Marine Science* 8: 710342.

Njoku PO, Piketh S, Makungo R, Edokpayi JN (2025) Quantification and modelling of methane and carbon dioxide surface emissions from a South African landfill. *Environmental Science: Advances* 4: 648–662.

Philippova A, Stroiteleva N, Gura D (2025) Characterization of woody and shrubby vegetation in synanthropic forests using three-dimensional laser scanning technology. *Forest Science and Technology* 21: 158–164.

Podlasek A (2023) Modeling leachate generation: practical scenarios for municipal solid waste landfills in Poland. *Environmental Science and Pollution Research* 30: 13256–13269.

Popovych VV, Bosak PV, Skyba TK, Popovych NP (2024) Floristic and ecological structure of the landfill vegetation in the western forest steppe of Ukraine. *Scientific Bulletin of National Mining University* 4: 99–105.

Pyšek P, Sádlo J, Chrtek J, Chytrý M, Kaplan Z, Pergl J, et al. (2022) Catalogue of Alien Plants of the Czech Republic (3rd edition): species richness, status, distributions, habitats, regional invasion levels, introduction pathways and impacts. *Preslia* 94: 447–577.

Rai PK, Singh JS (2020) Invasive alien plant species: their impact on environment, ecosystem services and human health. *Ecological Indicators* 111: 106020.

Rai S, Gurung A, Sharma HB, Ranjan VP, Cheela VRS (2024) Sustainable solid waste management challenges in hill cities of developing countries: insights from eastern Himalayan smart cities of Sikkim, India. *Waste Management Bulletin* 2: 1–18.

Rasapoor M, Young B, Asadov A, Brar R, Sarmah AK, Zhuang WQ, Baroutian S (2020) Effects of biochar and activated carbon on biogas generation: a thermogravimetric and chemical analysis approach. *Energy Conversion and Management* 203: 112221.

Rose NL (2015) Spheroidal carbonaceous fly ash particles provide a globally synchronous stratigraphic marker for the Anthropocene. *Environmental Science & Technology* 49: 4155–4162.

Saqib Z, Sadef Y (2025) Sustainable waste management through commercial composting: challenges, opportunities, and future directions for circular economy. *European Journal of Sustainable Development Research* 9: em0319.

Sauve G, Van Acker K (2020) The environmental impacts of municipal solid waste landfills in Europe: a life cycle assessment of proper reference cases to support decision making. *Journal of Environmental Management* 1: 110216.

Schlosser O, Robert S, Debeaupuis C, Huyard A (2018) Inhalable dust as a marker of exposure to airborne biological agents in composting facilities. *Waste Management* 81: 78–87.

Senator S, Tretyakova A, Vorontsov D (2020) Distribution of alien plant species of the Middle Volga region (south-east of the European part of Russia): a dataset. *Biodiversity Data Journal* 8: e59125.

Skrobala VM, Skyba TK, Popovych VV (2024) Ecological features of formation of landfill vegetation in Lviv region (Ukraine). *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu* 6: 86–93.

Stamps BW, Lyles CN, Suflita JM, Masoner JR, Cozzarelli IM, Kolpin DW, Stevenson BS (2016) Municipal solid waste landfills harbor distinct microbiomes. *Frontiers in Microbiology*, 7: 534.

Tahsini MJ, Nikaeen M, Nafez AH (2024) Biological treatment of compost leachate: assessing the efficacy of composting process and bioaugmentation of composting piles. *Environmental Technology & Innovation* 36: 103859.

https://doi.org/10.1017/S0376892926100320 Published online by Cambridge University Press

Tenodi S, Krčmar D, Agbaba J, Zrnić K, Radenović M, Ubavin D, Dalmacija B (2020) Assessment of the environmental impact of sanitary and unsanitary parts of a municipal solid waste landfill. *Journal of Environmental Management* 258: 110019.

Themelis NJ, Bourtsalas AC (2021) Methane generation and capture of US landfills. *Journal of Environmental Science and Engineering A* 10: 199–206.

Tomše S, Resnik M, Gorjan N, Krajšek SS (2025) Seeds and vegetative propagules of all selected invasive plants in Europe do not survive industrial composting. *NeoBiota* 97: 121–134.

Unegg MC, Steininger KW, Ramsauer C, Rivera-Aguilar M (2023) Assessing the environmental impact of waste management: a comparative study of CO_2 emissions with a focus on recycling and incineration. *Journal of Cleaner Production* 415: 137745.

Vaverková MD, Koda E (2023) Why landfill deposits are a distinguishing feature of the Anthropocene. *The Anthropocene Review* 10: 463–473.

Vaverková MD, Maxianová A, Winkler J, Adamcová D, Podlasek A (2019) Environmental consequences and the role of illegal waste dumps and their impact on land degradation. *Land Use Policy* 89: 104234.

Vaverková MD, Paleologos EK, Goli VSNS, Koda E, Mohammad A, Podlasek A, et al. (2025) Environmental impacts of landfills: perspectives on bio-monitoring. *Environmental Geotechnics* 12: 76–85.

Vinogradova YK, Tokhtar VK, Notov AA, Mayorov SR, Danilova ES (2021) Plant invasion research in Russia: basic projects and scientific fields. *Plants* 10: 1477.

Wagreich M, Meszar M, Lappé K, Wolf J, Mosser M, Hornek K (2023) The urban sediments of Karlsplatz, Vienna (Austria) as a reference section for the Anthropocene series. *The Anthropocene Review* 10: 316–329.

Wang S, Han Z, Wang J, He X, Zhou Z, Hu X (2022) Environmental risk assessment and factors influencing heavy metal concentrations in the soil of municipal solid waste landfills. *Waste Management* 139: 330–340.

Wang Y, Levis JW, Barlaz MA (2021) Life-cycle assessment of a regulatory compliant US municipal solid waste landfill. *Environmental Science & Technology* 55: 13583–13592.

Waters CN, Zalasiewicz J, Summerhayes C, Barnosky AD, Poirier C, Gałuszka A, et al. (2016) The Anthropocene is functionally and stratigraphically distinct from the Holocene. *Science* 351: aad2622.

Wei Y, Li J, Shi D, Liu G, Zhao Y, Shimaoka T (2017) Environmental challenges impeding the composting of biodegradable municipal solid waste: a critical review. *Resources, Conservation and Recycling* 122: 51–65.

Wei Y, Wang N, Lin Y, Zhan Y, Ding X, Liu Y, et al. (2021) Recycling of nutrients from organic waste by advanced compost technology – a case study. *Bioresource Technology* 337: 125411.

Winkler J, Koda E, Skutnik Z, Černý M, Adamcová D, Podlasek A, Vaverková MD (2021) Trends in the succession of synanthropic vegetation on a reclaimed landfill in Poland. *Anthropocene* 35: 100299.

Winkler J, Matsui Y, Filla J, Vykydalová L, Jiroušek M, Vaverková MD (2023) Responses of synanthropic vegetation to composting facility. *Science of the Total Environment* 859: 160160.

Winkler J, Vaverková MD, Koda E (2024) The path of human civilization in the Anthropocene: sustainable growth or sustainable development? *The Anthropocene Review* 11: 676–683.

Wong JTF, Chen XW, Mo WY, Man YB, Ng CWW, Wong MH (2016) Restoration of plant and animal communities in a sanitary landfill: a 10-year case study in Hong Kong. *Land Degradation & Development* 27: 490–499.

Xin L, Li X, Bi F, Yan X, Wang H, Wu W (2020) Accelerating food waste composting course with biodrying and maturity process: a pilot study. *ACS Sustainable Chemistry & Engineering* 9: 224–235.

Yıldırım R (2025) Comparative analysis of alternatives for sustainable management of biodegradable wastes. *Integrated Environmental Assessment and Management* 21: 1454–1464.

Zalasiewicz J, Waters CN, Do Sul JAI, Corcoran PL, Barnosky AD, Cearreta A, et al. (2016) The geological cycle of plastics and their use as a stratigraphic indicator of the Anthropocene. *Anthropocene* 13: 4–17.

Zhou Y, Tian A, Sun X, Chen Y, Luo X. Tang Q (2024) Taking spontaneous plants as a natural strategy for vegetation restoration in construction and demolition waste landfills: a case study in Suzhou, China. *Environmental Science and Pollution Research* 31: 25823–25835.

Zhou Y, Xiao R, Klammsteiner T, Kong X, Yan B, Mihai FC, et al. (2022) Recent trends and advances in composting and vermicomposting technologies: a review. *Bioresource Technology* 360: 127591.

https://doi.org/10.1017/S0376892926100320 Published online by Cambridge University Press