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Macrofauna-environment interactions and their potential in restoring degraded landscapes in the context of Sub-Saharan Africa: A review of current knowledge

Mukanzala Kasimbo[a,b,*], Todd Johnson[b], Theodore M. Mwamba[a,d], Agnes Uwimbabazi[a,c], Stephen Syampungani[a,c,e]

[a] Chair of Environment and Development, Oliver R. Tambo Africa Research Chairs Initiative (ORTARChI), Copperbelt University, P. O. Box 21692, Kitwe, Zambia
[b] Department of Biological Sciences, School of Mathematics and Natural Sciences, Copperbelt University, P. O. Box 21692, Kitwe, Zambia
[c] Department of Plant and Environmental Sciences, School of Natural Resources, Copperbelt University, P. O. Box 21692, Kitwe, Zambia
[d] Faculty of Agriculture and Environmental Sciences, University of Lubumbashi, P.O. Box 1825, Lubumbashi, Democratic Republic of the Congo
[e] Forest Science Postgraduate Program, Department of Plant & Soil Sciences, Plant Sciences Complex, University of Pretoria, Private Bag x20, Hatfield, Pretoria 0002, South Africa

A R T I C L E I N F O

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A B S T R A C T

Restoring degraded landscapes, such as those induced by mining activity, is essential for recovering lost ecosystem services. This requires innovative nature-based solutions, especially in sub-Saharan Africa (SSA). This review summarizes current knowledge on soil macrofauna in degraded SSA landscapes, an otherwise overlooked component of ecological restoration. A systematic literature review was conducted, yielding 31 relevant publications that were analyzed to identify patterns in macrofauna assemblages across land-use types in SSA including agricultural, forest, bushland, grassland, savannah, dumpsite and reclaimed mine site landscapes. Bibliometric analysis showed minimal studies before 2014, with research increasing after 2017, mostly in southern and eastern Africa. West Africa remains underrepresented. We found more studies on agricultural systems type (28 of the 32 reviewed studies), reporting seven classes, while less studies were conducted on mining wasteland (3 of 31 reviewed studies) reporting only one class. This highlights the urgent need for more macrofauna research in mine wastelands to pursue restoration. Variations in macrofauna composition (at both class and order level) are also viewed in relation to their physiological and environmental plasticity adaptations. In addition, potential macrofauna functional roles, such as bioturbation, organic matter breakdown, nutrient cycling, as well as other attributes such as tolerance to harsh environments and bioindication of biodiversity recovery, that may support landscape restoration were considered as well. Macrofauna groups with potential in future bioaugmentation strategies (the deliberate introduction of beneficial soil organisms to enhance ecological functions) include earthworms (Oligochaeta), termites (Isoptera) and ants (Hymenoptera: Formicidae). Opportunities and challenges of their integration into restoration planning are also discussed, especially in the context of SSA mining landscapes, which are often characterized by severe ecological degradation such as surface water contamination and heavy metal pollution. Although there is a gradual increase in publications on macrofauna in Southern Africa, their practical inclusion in ecological restoration efforts across SSA remains

* Corresponding author.
E-mail address: mukanzalakasimbo@gmail.com (M. Kasimbo).

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limited. The lack of a better understanding of macrofauna tolerance mechanisms, particularly to environmental stressors such as temperature fluctuations, chemical pollution, and habitat alterations, and the precise nature of their interactions with both biotic and abiotic environmental factors is identified as an avenue for future investigations.

Introduction

Land degradation is the continuous decrease in the land's ability to produce [1] and is one of the world's most pressing environmental problems, with potential to worsen if remediation actions are not taken. Globally, about 25 % of the total land area has been degraded [2], with consequences affecting multidimensional aspects of our society, encompassing ecosystem functionality, human health, thus the sustainable development of nations [3,4,5]. Land degradation is a significant issue in Africa, with the sub-Saharan African region considered to experience the worst scenario of land degradation in the world due to the combination of widespread degradation, acute ecological impacts, and a disproportionate number of people whose livelihoods are threatened directly [6–8]. The main drivers of land degradation in sub-Saharan Africa (SSA) include habitat transformation, biological invasion, and other climate change-linked events, which are generally associated with the dependence on natural resources to satisfy the development demands of an ever-growing population [9].

Although mining activity globally occurs on approximately 0.3–0.6 % of ice-free land, it is a major contributor to landscape degradation as its impacts are far-reaching [10]. These impacts include persistent soil and water contamination from heavy metals, disruption of soil structure, dust emissions, destruction of vegetation cover, and long-term alterations of ecosystem processes, often exceeding beyond the immediate mined area [11]. In SSA, about 469 formal mines cover approximately 3055 km^2, a small fraction of SSA's total land area (~24.5 million km^2). This estimate, however, does not account for the many undocumented artisanal and small-scale mining operations, which likely increase the affected area substantially [12,10]. Long-term mining operations result in different types of mine waste covering vast areas of land [13]. There are two major mine wastes and these are tailing dams and overburden. Mining countries in SSA have some of their regions covered in mine waste. For instance, the Copperbelt region of Zambia has about 45 tailings dams covering roughly 9125 ha, while overburden materials cover about 20,646 ha [14,15]. Given the extent of damage already sustained, current approaches in SSA emphasize not only prevention but also remediation and restoration of these impacted landscapes [6].

In recent years, restoration of landscapes impacted by mining activities has received increased attention, and many restoration techniques have been applied, including in mining impacted landscapes. Restoration techniques have been classified into three categories, namely, physical, chemical and biological techniques [16]. Traditionally, the physical and chemical methods (such as vitrification, soil replacement, chemical leaching etc.) have been used to remediate contaminated soils [17]. However, these methods have a number of limitations: they are expensive, often require site-specific customization, may be ineffective in large or heterogeneously contaminated areas, and generally produce environmentally toxic by-products, making them environmentally disruptive ([18,17]; Lacalle et al., 2020). Because of these challenges, it is necessary to engage in ecological restoration, involving biological techniques such as gentle remediation options (GRO). They involve the use of plant-, fungal-, and/or bacterial-based remediation solutions, with or without the use of soil amendments. GROs are a potential area of cutting-edge technologies in the remediation of degraded lands. This has indeed drawn a lot of interest in the recent past. Studies demonstrate that GROs can offer a net improvement in ecological soil function as well as efficient environmental risk management ([19–21]).

Macrofauna are underrepresented in scientific literature despite their substantial contributions to soil and plant health. This may be due to the increasing use of molecular techniques, which are better suited to studying microfauna because of their small size, high diversity, and the difficulty of identifying them through traditional morphological methods ([22,23]. Sampling of soil macrofauna (which is often done by hand-sorting) is also a very time-consuming and labor-intensive process [24]. Macrofauna play a number of ecological roles that are vital to soil health and function. For instance, millipedes (Diplopoda) act as litter fragmenters by breaking down organic material into smaller particles. However, it is important to note that the influence of macrofauna on litter decomposition is not universally positive or accelerating. Soil macrofauna function as modulators whose influence varies depending on litter quality, functional traits, ecosystem type and nutrient availability [25]. In some contexts, macrofauna play a limited role in decomposition, with the effects being largely dependent on the litter substrate [26]. Earthworms (Oligochaeta) and some insect larvae are bioturbators that enhance soil structure and aeration through burrowing and mixing activities. Certain species also act as decomposers, accelerating nutrient cycling by feeding on organic matter [27,28]. Beyond direct feeding on organic matter, macrofauna also contribute indirectly by fragmenting litter to increase microbial colonization surfaces and regulating detrital food webs [29]. Overall, these macrofauna ecological roles influence nutrient and energy flow and form a connection between above- and belowground food chains [30]. Long-term soil function is thus influenced by the soil engineering processes of soil macrofauna [31]. Therefore, they are crucial elements to restoration as they directly influence soil ecosystems by modifying physical and chemical properties. These improvements enhance soil health, which will in turn support the regeneration of vegetation and the broader recovery of degraded landscapes [32].

Studies have shown that macrofauna diversity and functions are influenced by a variety of environmental factors such as vegetation, soil physicochemical properties and season/microclimate, which can vary markedly even at local scales (such as across different land-use types within a few kilometers) as well as across broader regional gradients [33–35]. Environmental factors differ significantly in disturbed and undisturbed ecosystems. This has led scientists to hypothesize that macrofauna communities respond differently in these ecosystems [36]. Macrofauna diversity and function may also be influenced by land-use change, especially soil biota such as

Oligochaeta and Isoptera, which are extremely sensitive to disturbances in their habitat [37,32]. Land uses such as forest plantations and intensive agriculture influence soil processes by altering soil structure, nutrient cycling, and organic matter content [38]. These changes are often driven by human practices associated with land uses such as pesticides application, deep tillage and mining. These anthropogenic activities often lead to soil contamination and pollution, thereby negatively affecting soil biota by reducing their abundance, species richness and functional diversity [39,40]. Soil fauna often exhibit pronounced beta diversity, with marked changes in community structure and function across sites. As such, the diversity and function of macrofauna may vary from one site to another [26]. Understanding macrofauna responses to different biophysical environments, and how they shape environmental conditions and ecosystem functionality is cardinal in prospects of ecological restoration.

Much information has been provided on macrofauna diversity and abundance in different ecosystems, with examples of works by Sofo et al [31] relating to macrofauna communities in agrosystems of Europe and macrofauna communities in afforested post-agricultural lands in the same region by Malica et al [41]. These reviews highlighted an array of soil macrofauna such as Oligochaeta, Formicidae, Isoptera, Stylommatophora, Orthoptera and Oribatida, while revealing the pattern of macrofauna interactions with their environments towards improving soil health. However, a comprehensive picture of macrofaunal distribution in degraded

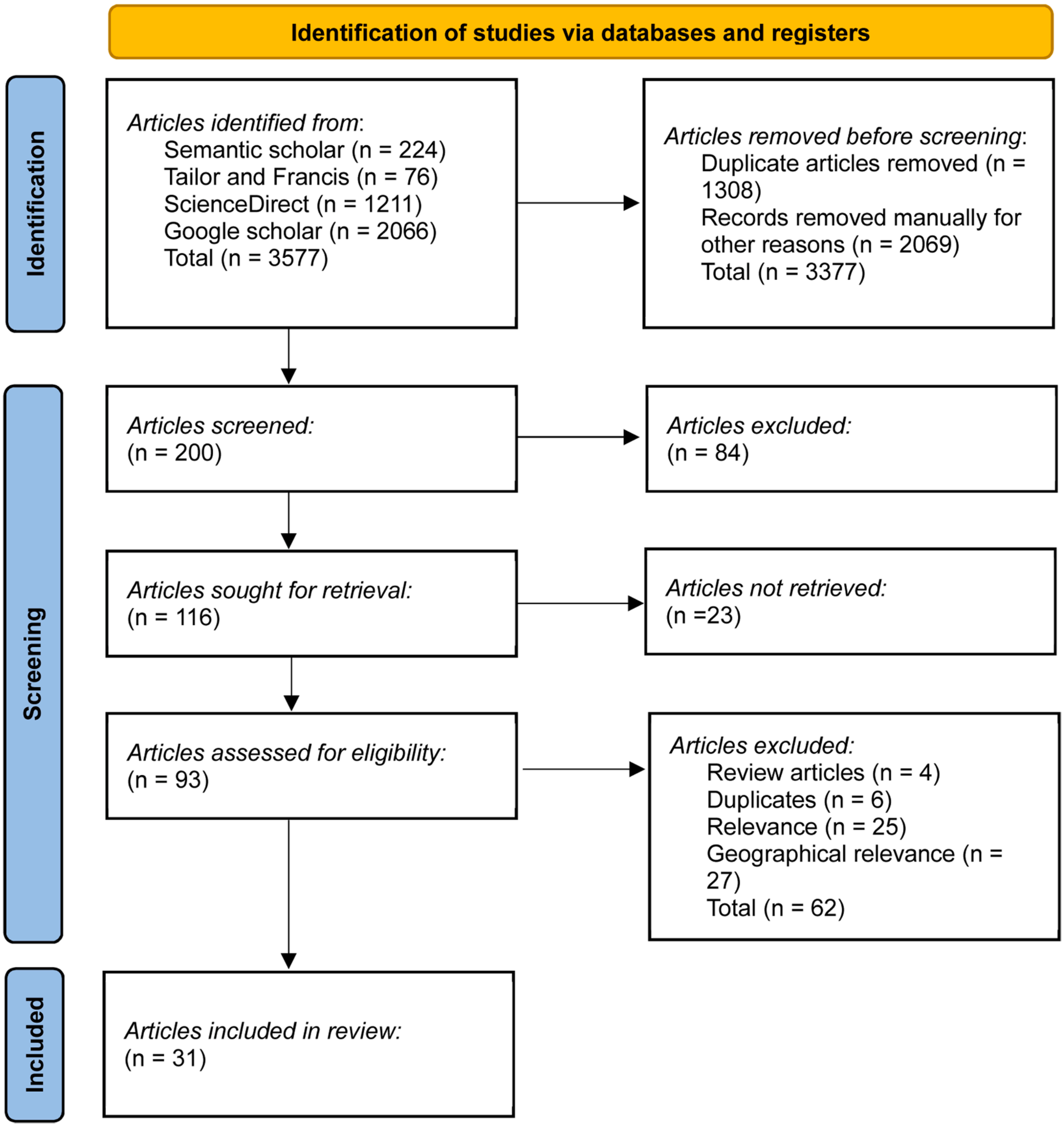

Fig. 1. Outcomes from the PRISMA protocol for identifying, screening, and including literature for the review. Other reasons for manual removal of records in initial screening include: (i) irrelevant title, (ii) geographic irrelevance (iii) wrong publication type, (iv) language restrictions and (v) no abstract.

landscapes and the prospect for bioremediation is missing. Notably, few studies have been conducted in SSA where land degradation is widespread and ecological restoration efforts are urgently needed. Therefore, this review seeks to address the following questions: (i) What does existing literature reveal about the dynamics of soil macrofauna across different land-use systems in SSA, (ii) Which environmental factors have been documented to influence macrofauna ecological behavior in SSA, (iii) What is the potential for applying macrofauna-based approaches in the restoration of degraded landscapes in SSA, (iv) What are the knowledge gaps in current macrofauna research relevant to land restoration in SSA.

Methodology

Scope of literature search

This systematic review employed literature search that included articles addressing interactions between macrofauna and their environment, together with their potential application in restoring degraded landscapes of SSA. Articles used in this review were restricted to original research written in English and published between January 2000 and December 2024 to identify 'gold-standard' literature on degraded land restoration with the help of soil macrofauna, highlighting their ecological roles towards soil health and factors that might affect this. The scarcity of studies for our topic warranted a broad search window (2000 to 2024) to allow for a more comprehensive synthesis of limited yet valuable contributions to this emerging field.

For the identification, screening and inclusion of articles used in this review, we employed the preferred reporting items for systematic review and meta-analysis (PRISMA) method [42] (Fig. 1). Relevant publications were found by searching academic databases such as Semantic Scholar, Tailor and Francis, ScienceDirect and Google Scholar [43]. We undertook detailed searches for literature using the following key search terms: "soil macrofauna", "ecosystem functions", "macrofauna functional roles", "soil health", "soil ecosystem engineers", "macrofauna-environment interactions", "soil properties", "degraded landscapes", "land degradation", "soil pollution", "mining activities", "restoration", "reclamation", "phytoremediation", "entomoremediation", "bioindicators", "Africa" and "Sub-Saharan Africa". These terms were used both individually and in search equations. A representative search equation used was: ("soil macrofauna" OR "soil ecosystem engineers" OR "macrofauna functional roles") AND ("ecosystem functions" OR "soil health" OR "soil properties") AND ("degraded landscapes" OR "soil pollution" OR "mining activities") AND ("restoration") AND ("Africa" OR "Sub-Saharan Africa"). From the included articles, the following information was extracted: (i) title, (ii) authors, (iii) year of publication (iv) region of origin (v) main objective (vi) methods of collection (vii) land-use types (viii) soil macrofauna diversity and abundance (ix) factors affecting soil macrofauna attributes (x) key findings, limitations and recommendations.

Article screening and extraction

Articles resulting from the database searches were imported into Mendeley reference software (Mendeley Ltd) in preparation for screening. The first stage of screening involved the authors reviewing the titles and abstracts of the literature to determine whether they fit within the inclusion criteria. Articles not fitting within the selection criteria as well as duplicates were excluded. In the second stage, articles included in the first stage were sought for retrieval. Retrieved articles proceeded to the final stage of screening which involved the full review of articles to determine their eligibility in order to retain relevant and complete literature. Full texts of these articles were assessed against specific inclusion criteria such as (i) the study must be conducted in Sub-Saharan Africa, (ii) it must address macrofauna in terrestrial ecosystems and (iii) it must provide data or discussion on interactions between macrofauna and environmental variables (biotic or abiotic). Due to the limited number of studies in SSA that specifically address these criteria, only 31 articles met all inclusion requirements. While this may appear small relative to the initial search pool, this number reflects the current state of research in this emerging field and was deemed sufficient to synthesize meaningful patterns and knowledge gaps related to macrofauna-environment interactions and their potential in restoring degraded landscapes in the context of Sub-Saharan Africa.

For this review, macrofauna were categorized by class and order according to Gullan and Cranston (2014). While recent phylogenetic studies have reclassified termites from the order Blattodea, this review follows the classification framework of Gullan and Cranston (2014), which retains Isoptera as a distinct order, to ensure consistency with the terminology used in majority of the reviewed literature.

Description of land-use types and degradation status

The land-use types represented in the review studies include post and reclaimed mining sites, dumpsites, grass-savanna, grasslands, bushland, secondary forests, primary forests, and agricultural land. Primary and gallery forests were generally characterized by minimal human disturbance, higher vegetation cover, and relatively intact soil profiles. Secondary forests and bushlands were identified as regenerating ecosystems following previous disturbance. Grasslands and grass-savannas varied widely in their management intensity, with some under grazing or fire regimes and others more ecologically stable. Agricultural lands ranged from subsistence farms to intensively managed croplands and agroforestry systems. Post-mining sites and dumpsites were typically highly disturbed and often nutrient-depleted, with disrupted soil structure and limited vegetation cover. These, along with certain agricultural lands described as heavily tilled or chemically managed, were considered degraded due to prolonged anthropogenic pressure, reduced vegetation, and compromised soil quality.

Bibliometric analysis

We conducted a bibliometric analysis on the information extracted based on the year of publication, authors, region, aim, macrofauna groups, land-use types, soil physicochemical properties and plant/tree species composition. The PRISMA filtering protocol provided our review with 31 articles relevant to the research area, geographical location and study period. As shown in Fig. 2A, limited studies on soil macrofauna in the SSA were reported between 2005 and 2014, represented by one to two publications in certain years (2007, 2009, 2015) while no publication could be recorded for other years (2005, 2006, 2008, 2010–2014, 2016). A progressive increase in the number of publications was noticed from 2017 onwards. The observed inconsistent research output in the past decade appears to be an indication that soil macrofauna may have been a niche topic dented by a few challenges such as limited recognition of

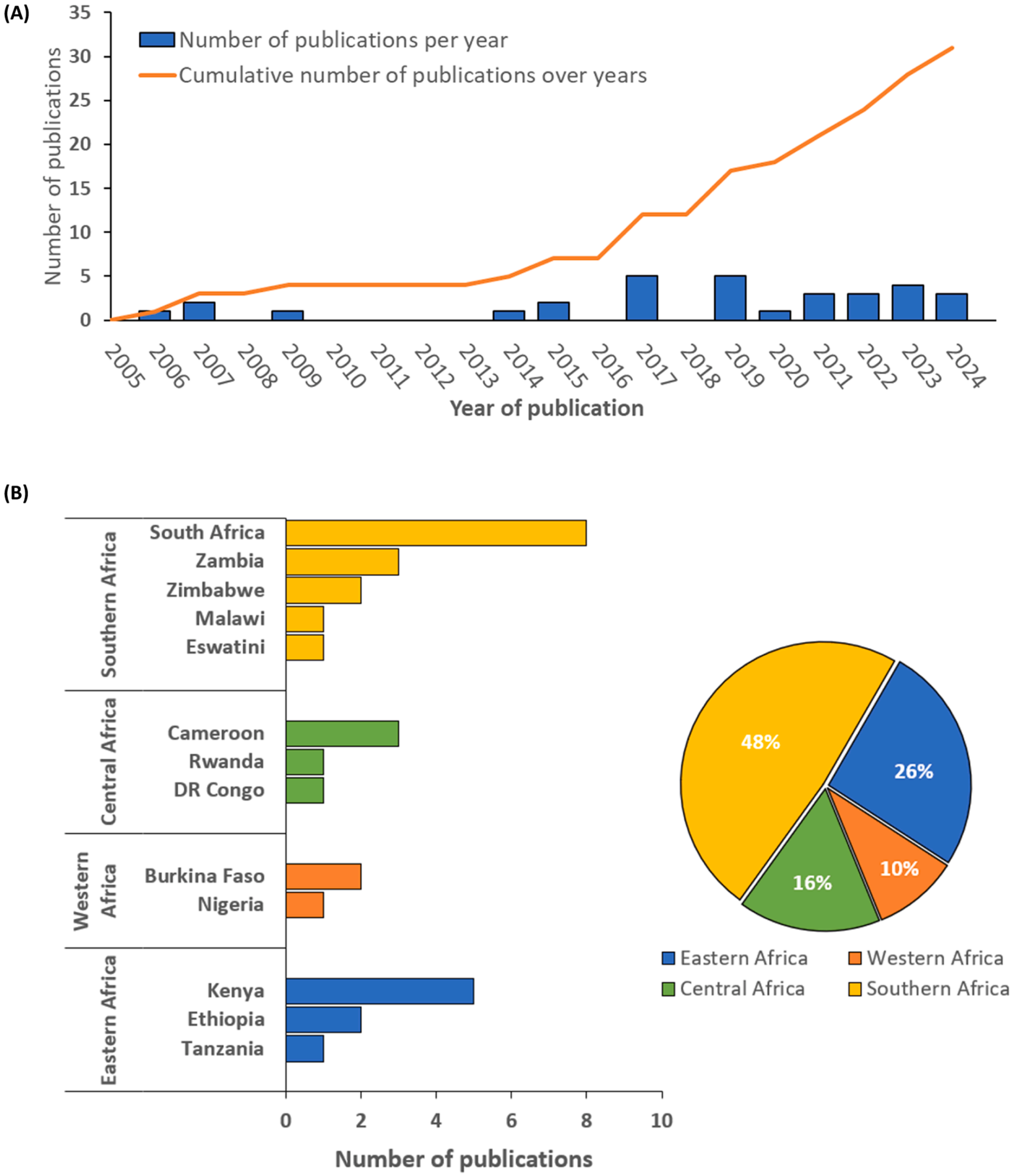

Fig. 2. Results of the bibliometric analysis with (A) the annual and cumulative number of publications and (B) the regional proportions on macrofauna in Sub-Saharan Africa.

their ecological importance, limited scientific/funding interest, or methodological challenges. However, in recent years, there has been a gradual shift, with growing scientific interest and improved understanding of their ecological significance. This shift is reflected in the increasing number of publications, likely supported by associated improvement in research funding focused on soil biodiversity [44,31]. As for the sub-regional repartition of the explored publications, a larger proportion of investigations have been conducted in southern Africa (48 %), followed by East Africa (26 %) and Central Africa (16 %), whereas West Africa is the least represented sub-region (10 %) (Fig. 2B).

Soil macrofauna communities in SSA

Sub-Saharan Africa (SSA) encompasses a wide range of countries within a variety of climatic zones and land-use types; as such, the region is likely to present a variation in the composition of macrofauna communities. Macrofauna assemblages in SSA are often highly context-dependent, shaped by localized vegetation and soil heterogeneity [45]. East Africa spans a broad range of altitudes and rainfall patterns, resulting in varied ecosystems from highland forests to arid savannas. Land use in this region is primarily characterized by mixed crop-livestock farming and smallholder agriculture [46]. In West Africa, semi-arid to sub-humid climates dominate, with land-use types primarily characterized by shifting cultivation, subsistence farming, and agroforestry practices [47,48]. Central Africa is largely humid and forested, with relatively low-intensity land use but increasing deforestation caused by logging and agricultural expansion [49]. In contrast, Southern Africa features diverse biomes ranging from subtropical zones to drylands, where land use includes mining, commercial agriculture and plantation forestry [50,51]. Land-use management has a significant effect on soil and its ability to support ecosystem processes. For instance, activities such as deforestation and intense agriculture often lead to notable changes in vegetation and soil physicochemical properties, which are likely to have an impact on the communities of soil invertebrates [32].

Based on a systematic review of literature, a regional analysis of macrofauna communities across SSA revealed both shared and region-specific patterns in taxonomic composition. Comparison across SSA regions was done based on the number of distinct macrofauna groups (primarily at the order level). The highest number of taxonomic groups of macrofauna were reported for the Southern (26 orders) and Eastern (25 orders) regions, followed by Central Africa (23 orders), while less groups were reported for Western Africa (13 orders). The comparatively lower representation of Western Africa potentially reflects limited research coverage or more constrained ecological sampling in that region. Several macrofauna orders were reported across all four regions, notably Araneae, Blattodea, Coleoptera, Hymenoptera, Orthoptera and Diplopoda. Region-specific observations show that Eastern Africa supports a broad range of macrofauna orders, including both decomposers (e.g. Isopoda, Oligochaeta) and predators (e.g. Scorpiones, Araneae), alongside less commonly reported orders such as Lumbriculida, Parasitiformes, and Sarcoptiformes, likely due to its diverse habitats ranging from moist highlands to arid savannas [46]. In contrast, West Africa hosts fewer orders overall but includes some unique groups such as Embioptera and Solifugae, which may reflect narrower ecological conditions or limited taxonomic focus in existing studies [52,32]. Central Africa presents a particularly rich assemblage of deep-soil and microarthropod taxa, including Protura, Diplura, Entomobryomorpha, and Symphyla, possibly due to sampling in dense tropical forests with high organic matter and moisture. Southern Africa had the most reported groups, including a wide array of both soft-bodied (e.g, Stylommatophora, Neogastropoda) and hard-bodied fauna (e.g., Coleoptera), as well as both epigeic and endogeic organisms such as Solifugae, Neuroptera, and Thysanura. This may be attributed to more comprehensive, long-term ecological studies and more developed research infrastructure in that region [53,54]. Although ecological and methodological factors may have played a role in the observed regional differences [37,52,32], we

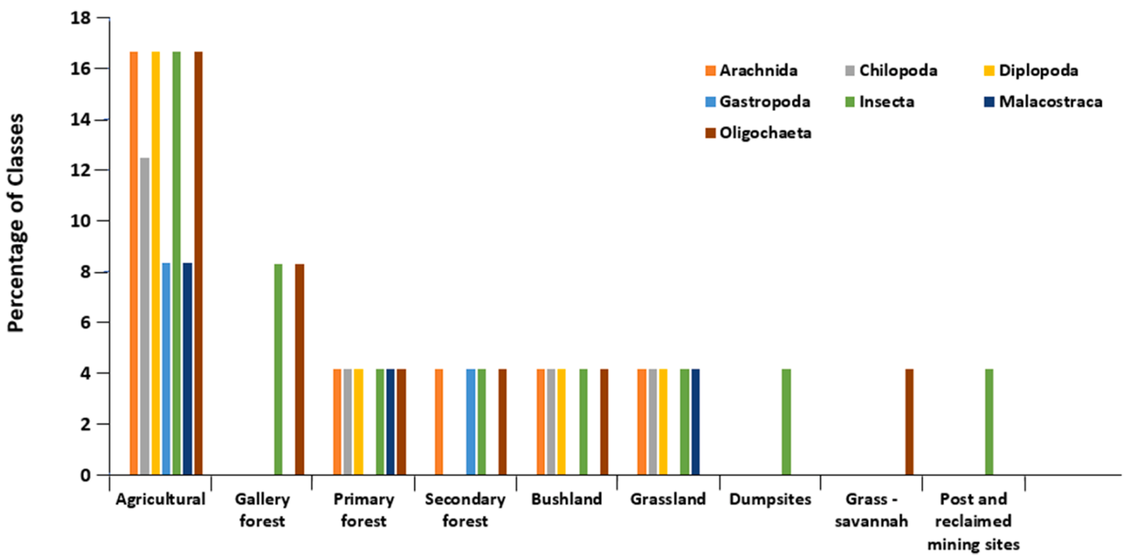

Fig. 3. Relative abundance distribution (%) of major macrofauna classes across different land-use types in SSA.

cannot rule out that observed results could also be influenced by potential bias regarding groups studies in different regions in the available literature.

Soil macrofauna in agricultural landscapes

Africa hosts the second largest area of agricultural land in the world, at 23 % just behind Asia which is at 33.8 % [55]. Agricultural lands consist of three major types: arable land (including cropland with temporal crops, e.g. maize, and fallows), land with permanent crops (such as fruit trees and plantations), and pastures and hayfields [55].

As illustrated in Fig. 3, findings from the literature search comprising 31 studies reveal that agricultural land in SSA is home to a variety of soil macrofauna. Agricultural landscapes were included in 28 of the 31 studies reviewed. A total of seven classes, i.e. Arachnida, Chilopoda, Diplopoda, Gastropoda, Insecta, Malacostracans and Oligochaeta, contributed the most to the overall percentage of macrofauna of the agricultural land-use types, showing the highest percentage of reported macrofauna classes than any other type of land-use considered in our review. Correspondingly, the agricultural landscape is also singled for the greatest number of soil macrofauna orders (43), with orders such as Solifugae (Arachnida), Tetramerocerata (Pauropoda), Symphyla (Symphyla), Protura (Insecta), Collembola (Insecta), Scolopendromorpha (Chilopoda), Amphipoda (Malacostraca) and Phasmatodea (Insecta) recorded solely in agricultural landscape, in comparison to other land-use types investigated in this review as can be seen in Table 1. The relatively high number of macrofauna groups reported in agricultural landscapes may partly reflect research bias, as these areas often receive more scientific attention due to their direct link to food production, human livelihoods, and land management concerns. As a result, the number of macrofauna groups in less-studied landscapes, such as natural or post-mining areas, may be underrepresented in the literature [37,56,44]. A study by Wale and Yesuf [57] in Ethiopia observed 17 orders in agricultural land-use types, while the same number (17) was reported under similar land-use types in a Zambian study by Sileshi and Mafongoya [58]. Studies conducted in other regions such as Indonesia [59], under complex and simple agroforestry, yielded the same number of orders, with many of them being similar to what is observed in SSA. This suggests that similar macrofauna assemblages in agroforestry systems across different regions may point to common ecological responses to this land-use type, irrespective of geographic context. Normally, it is expected that agricultural landscapes would exhibit less diversified soil macrofauna taxa than forests. This is because certain agricultural practices (e.g., conventional tillage, herbicide and pesticide use, and inorganic fertilizer application) can negatively affect soil macrofauna by causing physical disturbances and disrupting their habitat [60,61,62]. For example, pesticide use in southern African farming systems has markedly negative effects on soil macrofauna, leading to declines in abundance and diversity of key functional groups such as Oligochaeta and Isopoda [63]. Wale and Yesuf [57] recorded the highest macrofauna diversity in the forest system, followed by grassland, while cultivated lands had the least macrofauna diversity in Ethiopia. Nonetheless, some other studies indicate that soil macrofauna in agricultural landscapes can decline in the beginning, as a consequence of the initial disturbance, then increase with time under cultivation [64,65]. This is commonly attributed to ameliorative farming practices that involve moderate soil disturbance while promoting organic matter input. However, this trend may not hold in systems dominated by industrial agricultural practices, such as extensive tilling, monocropping, and intensive use of herbicides and pesticides, which can have prolonged negative impacts on soil biodiversity [66] . The higher macrofauna groups in SSA agricultural landscapes, as revealed by this review plausibly points to this explanation. Identifying agricultural practices that support macrofauna abundance, diversity, and functional group richness may

Table 1
Summary of macrofauna classes and their corresponding orders per land-use type in SSA from the 31 studies included in this review.

Land-use type	Class	Order	References
Bushland	Insecta, Oligochaeta, Chilopoda, Diplopoda, Arachnida	Hymenoptera, Coleoptera, Isoptera, Orthoptera, Blattodea, Hemiptera, Lepidoptera, Oligochaeta, Chilopoda, Diplopoda, Araneae	[67]
Natural forest	Insecta, Malacostraca, Arachnida, Chilopoda, Diplopoda, Oligochaeta	Blattodea, Orthoptera, Diptera, Isoptera, Hymenoptera, Coleoptera, Hemiptera, Mantodea, Isopoda, Amphipoda, Aranea, Opiliones, Geopholomorpha, Scolopendromorpha, Lumbriculida, Polidesmida, Lithobiomorpha, Thysanoptera, Scorpiones, Sarcoptiformes, Trombidiformes, Parasitiformes, Collembola	[68,57]
Grassland and savannah	Insecta, Arachnida, Diplopoda, Chilopoda, Oligochaeta	Hymenoptera, Isoptera, Isopoda, Araneae, Coleoptera, Polidesmida, Lepidoptera, Lithobiomorpha, Thysanoptera, Hemiptera, Orthoptera, Scorpiones, Sarcoptiformes, Trombidiformes, Parasitiformes, Collembola, Haplotaxida	[69,57]
Secondary and gallery forest	Insecta, Arachnida, Gastropoda, Oligochaeta	Haplotaxida, Isoptera, Hymenoptera, Coleoptera, Araneae, Stylommatophora, Diptera, Isoptera	[70,69,71,72]
Agricultural	Insecta, Arachnida, Chilopoda, Diplopoda, Gastropoda, Crustacea, Oligochaeta	Coleoptera, Collembola, Haplotaxida, Araneae, Isoptera, Diplopoda, Dermaptera, Isopoda, Chilopoda, Oligochaeta, Orthoptera, Stylommatophora, Lithobiomorpha, Blattodea, Polidesmida, Neogastropoda, Geophilomorpha, Juliformia, Solifugae, Acariformes, Thysanura, Neuroptera, Araneae, Embioptera, Opiliones, Scorpiones, Diptera, Symphyla, Julida, Trombidiformes, Diplura, Isopoda, Entomobryomorpha, Hymenoptera, Hemiptera, Scolopendromorph, Lumbriculida, Amphipoda, Phasmatodea, Thysanoptera, Sarcoptiformes, Parasitiformes, Stylommatophora	[54,57,58, 67–69,71, 73–88]
Post-mining sites and dump site	Insecta	Coleoptera, Isoptera	[89–91]

provide insights for improving soil health in agricultural systems and, where appropriate, inform context-specific approaches to restoring certain types of degraded landscapes. In this regard, the use of organic amendments, minimal soil disturbance, introduction of vegetation cover, inoculating degraded soils with beneficial macrofauna species and promoting agroforestry may improve soil health and ecological functioning in degraded landscapes. This may contribute to sustainable land management and context-specific restoration efforts.

Soil macrofauna in forest landscapes

Sub-Saharan Africa forests span 582 million hectares and exhibit high ecological and biological diversity, with only South Africa and Sudan having significant plantations [92]. Forests favor the development of diverse and abundant soil macrofauna because their diversified vegetation enhances litterfall production, which in turn provides energy inputs, microclimate stability and increased microhabitats [26,93,32]. Our review considered soil macrofauna in primary forests and other forest ecosystems such as secondary/replanted and gallery forests. Forest landscapes were included in six of the 31 studies reviewed. Based on the data compiled in this review, natural forests are the second most represented land-use type in terms of the number of macrofauna groups, after agricultural landscapes. They are represented by six macrofauna classes, i.e. Arachnida, Chilopoda, Diplopoda, Insecta, Malacostraca and Oligochaeta. Comparison across forest types places primary forest on top of the list in terms of macrofauna groups, followed by secondary forest with four classes (Arachnida, Gastropoda, Insecta, Oligochaeta) and gallery forest with only two classes (i.e. Insecta and Oligochaeta). Gallery forest refers to narrow strips of forest associated with creeks and rivers in an otherwise unforested landscape [94]. The absence of Gastropoda from primary forest systems may reflect methodological limitations in detection or ecological conditions not favorable to their abundance or sampling visibility [95]. A total of 23 macrofauna orders were recorded under primary forests. In contrast, other forest ecosystems had only eight orders, and many of the orders observed in primary forests (i.e. Blattodea, Orthoptera, Araneae, Amphipoda, and Geophilomorpha) were absent. The differences in class and order numbers between the forest types could be attributed to the history of disturbance and soil degradation. Secondary forests are regrowing forests with past disturbances that may have greatly impacted their vegetation and soils, which influence soil macrofauna communities. Likewise, gallery forests often experience flooding [96], which may disrupt soil macrofauna habitats. Hence, primary forests may have accumulated organic matter for soil macrofauna over centuries, whereas secondary forests will have lower organic input as young trees in the regrowing forest [97]. Due to their periodic flooding, gallery forests may experience both the removal and deposition of organic matter. However, in cases where forests are adjacent to larger streams, water movement can wash away surface organic matter, thereby reducing the availability of food for soil macrofauna [94]. Key food sources that might be displaced include decaying wood and leaf litter, which are essential for litter feeding groups, such as Coleoptera, Diplopoda and Isopoda [98]. The rate of organic matter accumulation thus constitutes a key aspect underlying the observed differential level of macrofauna diversity across different types of forest landscapes. There is evidence that primary forests sustain higher soil fauna abundance and richness because greater litterfall productivity increases energy inputs, enhances microclimate stability and creates diverse microhabitats that support more soil fauna groups [26,93,44]. This represents a critical avenue for future research, particularly in informing restoration strategies for degraded landscapes.

While this review revealed a total of 23 macrofauna orders in SSA, similar studies in South America recorded 13 macrofauna orders from undisturbed forests [99]. Notably, some orders, including Blattodea, Isoptera, Coleoptera, Isopoda and Araneae, were observed to be common in both the SSA and South America. However, some orders like Lithobiomorpha, Collembola and Scorpiones recorded in the SSA were not part of the findings in South America. This potentially reflects biological distinctions, habitat specificity, or differences in sampling methods, all of which merit further investigation [100].

Soil macrofauna in mine wastelands

Africa has a long history of mining mainly as small-scale, artisanal mines scattered throughout the landscape [101,102]. Artisanal mining is defined as mining by individuals, groups, families or cooperatives with minimal or no mechanization, often in the informal (illegal) sector of the market [103]. Today, it is one of the key economic activities in Africa, especially with mining activities growing throughout SSA as local and foreign investments have purchased or opened new mines [104]. Mining activities are present in at least 50 % of African nations [105,106]. Given that the African Copperbelt (a region in Africa that straddles Zambia and the Democratic Republic of Congo) contains some of the world's richest deposits of copper ore, mining activities are particularly anticipated to increase in total mineral production in the near future for SSA countries such as Zambia and the Democratic Republic of Congo [107,108].

Mining activities over the years have left soils contaminated with numerous potentially toxic elements (PTEs), often rendering them unfit for agricultural use and unsuitable as habitats for soil macrofauna. PTEs accumulation in soils leads to a reduction in soil fertility, consequently decreasing plant growth and productivity [109,110]. PTEs generally cause stress to multiple aspects of biodiversity and ecosystem functioning through cascading effects within food webs [111]. This review has shown that very few studies (three out of the 31 studies reviewed for this paper) have been conducted focusing on macrofauna in mine wastelands in SSA, which coincidentally also showed the lowest number of macrofauna classes observed. These sites also presented the least number of macrofauna orders, with Coleoptera and Isoptera being the only orders recorded (Table 1).

A decrease in soil macrofauna abundance and diversity in polluted soils is commonly reported and can be attributed to the exertion of toxic effects on macrofauna [112,91]. PTEs are indeed known to bioaccumulate in soil animals, causing body size alterations and population size declines (e.g., Oligochaeta) [113,114], and are considered among the major drivers of soil biodiversity loss and decline [115]. Because macrofauna are sensitive to PTEs in soil, they can be used as bioindicators of soil health. Emerging evidence suggests that some macrofauna may have built up resistance to PTEs in highly polluted areas such mine wastelands through higher survival rates, increased fecundity, and physiological or behavioral adaptations [116]. As shown in this review, the presence of members of the Class Insecta as the sole group of soil macrofauna colonizing mine wastelands is a clear indication of their particular ecosystem functions, allowing them to thrive under harsh environments. This suggests strong environmental filtering, where only taxa with specific functional traits (measurable characteristic (morphological, physiological, phenological or behavioral features) of individual organisms or its colony that has a clear link to the organism's fitness and/or its effect on other organisms and/or the environment [117, 118]) can persist. This limited colonization points to poor habitat quality and restricted functional diversity, with implications for the recovery potential of such degraded systems [119]. Members of the Class Insecta seem to have some form of intrinsic resistance traits, explaining their dominance in polluted soils. These traits include a chitinous exoskeleton that provides a barrier against contaminants, enhanced enzymatic detoxification systems, and mobility via wings [120,121]. The study by Venter [91] investigating community structure changes along a soil gradient in South Africa revealed a positive correlation of insects with heavy metals, while those in the Class Clitellata and one in Arachnida correlated negatively. However, ex-situ studies on an Isoptera species as a bioremediation tool of polluted dump soil sites in Nigeria also demonstrated that Isoptera were able to significantly decrease chemical load levels in soil samples collected from two dumpsites [90]. Similarly, a study in China [122] revealed that Formicidae (no specific species detailed) and Hemiptera (*Stibaropus formosanus*), members of the Class Insecta, exhibited a high tolerance to rare earth elements. This finding reinforces the potential role of certain members of the Class Insecta in persisting and potentially functioning in polluted environments, aligning with observations made in this review.

To explain the ecological significance of insects in degraded landscapes, existing empirical data point to the potential of this class of macrofauna as bioindicators of biodiversity recovery, with Formicidae revealed as the group showing the greatest potential as a bioindicator of reclamation success in post-mining areas [123]. However, the mechanistic understanding of macrofauna functional roles is still in its infancy, lacking real direction. This currently hampers prospects to adequately explore the potential of identified resistant macrofauna species to facilitate land recovery in degraded landscapes in SSA and other regions globally.

Factors influencing macrofauna communities in these land-use types

Soil macrofauna communities are a critical component of ecosystem functions and resilience due to their ecological functions. However, the main drivers of macrofauna communities are poorly understood and are a subject of recent research (Decaëns, 2010; [124–127]). Soil biota, including macrofauna, are generally sensitive to changes in the environment [128]. Furthermore, due to their low tolerance and limited ability to migrate, their taxonomic compositions and distribution patterns at patch level (a small, localizes area of habitat within a larger landscape) are vulnerable to environmental changes [129,130]. In instances where soil biota are able to migrate, changes in the environment cause changes in their vertical distribution patterns [131]. Human mediated activities, such as tillage, crop rotation and the transfer of soil between plots, can disrupt native assemblages and facilitate the spread of invasive species, thereby influencing local diversity [132]. Previous research indicated that macrofauna communities and their functions can be influenced by variations in environmental factors such as vegetation, soil physicochemical properties and seasons. For example, soil fauna respond to seasonal shifts and microclimate stresses by migrating vertically, retreating deeper during dry or cool periods and resurface when conditions improve [26]. In the context of SSA as summarized in this review, soil physicochemical properties and plant cover/vegetation were noted to have a significant effect on macrofauna communities in different land-use types (Table 2).

Soil physicochemical properties

Soil physicochemical properties significantly impact macrofauna [134]. Examples of these properties include soil temperature, texture, bulk density, pH etc. Temperature is a physical property of soil and is affected by climate, water content of soil and soil color, depth in soil profile, soil cover, as well as air and water flow within soil (Minnesota Pollution Control [135]). Temperature is known to influence the abundance and activity of macrofauna. For example, during dry seasons when high temperatures reduce soil surface moisture, soil macrofauna migrate away from the surface layer [26]. A study conducted on an agricultural land-use type in Ethiopia [73] showed a negative correlation between Oligochaeta biomass and soil temperature, indicating that higher temperatures may have adverse effects on Oligochaeta populations, while cooler temperatures are more favorable. Temperature indeed has effects across all levels of biological organization, rooted in the relationships among temperature, metabolism and body mass [136,137].

An association between macrofauna and soil properties has also been established with soil bulk density. Being a key determinant of soil hydraulic conductivity and infiltration, bulk density influences how soil macrofauna respond to land use. Higher bulk density,

Table 2
Factors reported to affect soil macrofauna communities in different land-uses in SSA.

Land-use type	Factors affecting soil macrofauna	Reference
Natural Forests	Soil physicochemical properties (texture, organic matter, bulk density, altitude, moisture content), tree species (*Juniperus procera* and *Podocarpus falcatus*)	[57,68–70]
Agricultural (mixed cropping systems with scattered tree components)	Soil physicochemical properties (organic matter, moisture content), leguminous tree species (*Faidherbia albida*)	[58,73,133,76,70,77, 79,69,71,84]
Wastelands (dumpsites, mine wastelands)	Sparse vegetation cover, physicochemical properties (low organic matter and pH), and high heavy metal (e.g., lead, zinc) concentrations	[90,91]

often resulting from intensive or mechanized land, has been found to negatively correlate with macrofauna abundance and diversity. This could be likely due to reduced porosity and aeration [138]. A study conducted on agricultural land-use types in South Africa observed high positive correlations between bulk density and soil macrofauna communities [139]. While this observation seems rather counterintuitive, it may be explained by a favorable moisture content, resulting from reduced water loss in soil with higher bulk density.

Soil pH influences a wide range of soil chemical and biological processes, including nutrient availability and soil fauna activity [140,141]. Studies by Nsengimana et al [84] in Rwanda and Churu [133] in Kenya observed positive correlations between soil macrofauna and pH ranges of 5.2 to 6.1 in agricultural land-use types. Macrofauna habitats, especially those for Oligochaeta, are affected by soil pH. A decrease in soil pH was also revealed to have a negative impact on the population of Oligochaeta [133]. This sensitivity is often attributed to their physiology, especially their permeable skin, as well as their soil-ingesting habits [142].

Results from these SSA studies are altogether consistent with those conducted in other regions. Gao et al [143] observed that a long duration of high temperature events in the summer had a negative effect on the abundance and diversity of the soil macrofauna community. A study on an agroforestry land use in Brazil reported similar results [144] regarding the effects of average temperature on the soil macrofauna community. In addition to average temperature, minimum, maximum and variability (e.g. standard deviation) are also likely to influence soil macrofauna abundance and richness. For instance, Castillo-Avila et al [26] found significant positive relationships between minimum surface temperature and both soil fauna richness and soil fauna abundance.

While cases of land use-mediated effects on soil properties are reported for land-use types such as agricultural landscapes, it is worth noting that related information remains scarce for mine wasteland ecosystems on the continent, thus highlighting this aspect as a promising path for further investigations in the field of macrofauna interaction with the environment.

Vegetation cover and organic matter inputs

Besides soil properties, our review included literature on the effect of plants/vegetation cover on soil macrofauna communities in the context of sub-Saharan Africa. Information in this regard primarily revolves around the significance of both the quality and quantity of organic inputs from plant and vegetation cover. A study on Oligochaeta communities conducted by Mathurin et al [69] in Cameroon demonstrates the positive correlation between land cover and Oligochaeta functional group abundance. An investigation on the quantity and quality of organic inputs from coppicing leguminous trees had a significant influence on the abundance of soil macrofauna in maize crops in eastern Zambia [58]. The term coppicing refers to the cutting down of trees at the stump every three to five years to allow new shoots to grow back for the next harvest cycle. Although litter quality and quantity were found to have an impact on all studied macrofauna groups (i.e. Oligochaeta, Formicidae, Isoptera, Coleoptera, Spirobolida), only a minimal impact was noted for taxonomic groups such as centipedes and arachnids, suggesting a differential response of macrofauna groups, probably due to possible differences in their nutritional behavior [52]. For example, litter transformers, such as some Coleoptera and Spirobolida, have been impacted directly because they consume biomass incorporated in the soil. A similar observation was made in Rwanda, where native tree species (e.g. *Entandrophragma excelsum, Podocarpus falcatus, Polyscias fulva*), compared to exotic tree species (e.g. *Eucalyptus maidenii, Cedrela serrata, Grevillea robusta*), showed significantly higher association with diversity and abundance of soil-litter-arthropods in different land uses [84]. Another study on surface coal mines with reclaimed areas in South Africa demonstrated enhanced activity of Coleoptera (dung beetles) on reclaimed mine sites with the provision of cattle dung [91].

Besides the direct effects related to the quality of organic inputs from vegetation cover or other external sources, we cannot rule out the fact that organic input may contribute to improving macrofauna abundance and diversity through their indirect effects on soil properties such as surface soil temperature, moisture content and hydraulic conductivity, hence creating a favorable habitat for macrofauna [58].

Bioremediation potential of soil macrofauna

Unattended degraded landscapes in SSA, especially those left over from mining, tend to endanger environmental health in general, through persistent contamination of soil and water resources, habitat fragmentation, and disruption of ecosystem functions [145]. In addition, degraded mine wastelands represent a loss of opportunity for other land uses such as agriculture, forestry, housing and ranching. This is because loss of vegetation, severe soil compaction and contamination render the land unsuitable for productive use [14]. Despite mines accounting for less than 1 % of the land area considered in this review, their environmental impacts and potential for long-term ecological damage warrant closer attention. There is, therefore, a great need to restore degraded lands.

Methods for restoration of degraded lands that have been in use and those of recent developments around the world include physical methods such as ploughing and topsoil addition, chemical methods such as addition of lime, fertilizers or nanoparticles and biological methods such as the use of microbes, phytoextraction and phytostabilization [146]. However, some of these methods have disadvantages such as high cost and they are environmentally disruptive, often destroying soil biota [147,18]. Due to these limitations, biological methods that are less invasive and respectful of the environment have emerged in the last decades [21].

Macrofauna have been exploited for their potential in remediating degraded landscapes. Macrofauna such as Oligochaeta, Formicidae, Isoptera, and certain Coleoptera are often termed ‘ecosystem engineers’ due to their ability to modify the environment in distinct ways. Oligochaeta modify the environment through soil mixing and aggregation, Formicidae and Isoptera through bioturbation and nutrient redistribution via mound building, while Coleoptera (e.g., dung beetles) through organic matter breakdown and nutrient recycling. Together, their complementary functions influence soil structure, organic matter dynamics, edaphic conditions and biogeochemical processes. This underscores the ecological value of maintaining diverse macrofauna assemblages [148].

In SSA, a few studies have been conducted to explore the bioremediation potential of soil macrofauna. A study by Kaiser et al [75] in Burkina Faso investigated the ecosystem services provided by Isoptera in the traditional soil restoration and cropping systems. It was observed that soil turnover, likely by Isoptera foraging activity, decreased from the old forest towards degraded barren land. It is well known that microporosity induced by Isoptera improves soil aeration and enables root growth and establishment [149]. It is also worth mentioning that Kaiser et al [75] observed that the effect of Isoptera is dependent on the species as well as their ecological requirements, with fungus-growing Isoptera (e.g. *Odontotermes* and *Macrotermes)* spotlighted for their higher efficiency in the restoration of degraded soil. Another study by Mamabolo [79] in South Africa characterized soil macro- and mesofauna diversity as well as their contribution to soil health in grain agroecosystems, revealing that soil macrofauna contributed significantly to litter decomposition. The integrated and conservation farming sites in Mamabolo's study were observed to have the highest decomposition estimates due to favorable habitat conditions that allowed a balance of varied functional soil macrofauna populations. Temperature, soil moisture and land use intensity were found to affect the contributions of soil macrofauna to decomposition rates. These findings demonstrate that agricultural systems with reduced soil disturbance, lower chemical inputs, and greater plant diversity (e.g., agroforestry or organic farming) preserve macrofauna functional biodiversity that enhance litter decomposition and nutrient cycling [150].

In Cameroon, Tsufac et al [88] also proved that soil macrofauna diversity and abundance in cocoa-based agroforestry systems greatly influenced soil fertility, revealing the existence of direct non-causal and causal relationships between soil macrofauna diversity and soil fertility. A significant direct relationship was also found between the abundance of some soil macrofauna (Isoptera, Formicidae, Oligochaeta, Stylommatophora, Orthoptera, Coleoptera, Isopoda) and soil fertility enhancement. Complementary actions of different macrofauna can be put forth to account for this. For example, Formicidae have been known to displace the most soil (bioturbation) after Oligochaeta (Decaëns et al., 2001). When building nests, Formicidae create galleries that help aerate the soil and increase soil porosity, which affects water infiltration and circulation. Further, it is believed that Formicidae also increase the availability of resources for microorganisms and plants [151].

The beneficial effects of the Isoptera species, *Macrotermes bellicosus* were linked to their potential to bioaccumulate PTEs found in soil such as heavy metals in Nigeria, in a process referred to as entomoremediation [90]. This study verified that Isoptera activities could, to a certain degree, reduce the fraction of available PTEs, thus contributing to lowering the level of soil toxicity, rendering the explored areas favorable to biodiversity recovery.

Macrofauna have a significant impact on the ecosystem, due in part to their relatively large body size, which is associated with stronger soil engineering effects such as bioturbation and organic matter redistribution [148]. From the studies discussed in this review, macrofauna have a documented influence on soil physicochemical and biological parameters that determine soil health in the context of SSA. Some soil macrofauna, such as Formicidae, have shown resilience in unfavorable conditions due to physiological traits like compact body size, exoskeletons that reduce desiccation, and flexible nesting behavior [122,152]. High trait diversity among soil arthropods contributes to their resilience in eco-agricultural mosaics, enabling persistence despite environmental variability across land-use types [153]. These attributes, namely large body size, physiological robustness and behavioral adaptability, make certain macrofauna suitable candidates for the restoration of degraded landscapes.

The use of soil macrofauna to restore degraded land (whether through the intentional introduction of beneficial species or by enhancing environmental conditions that support their neutral recolonization and functional activity) offers both challenges and opportunities. One major challenge is that degraded lands usually exhibit harsh conditions. Mine wastelands, for instance, are characterized by altered soil physicochemical properties, including highly compacted soils and extreme metal contamination, leading to poor plant growth and productivity [154,155]. Likewise, soil properties in degraded agricultural landscapes are negatively impacted by practices such as excessive use of pesticides, fertilizers and intensive tillage, affecting soil quality and macrofauna [156,157]. These factors altogether severely impede the survival and activity of macrofauna, hampering the potential to explore soil macrofauna-based approaches to restore degraded landscapes.

Nonetheless, a few opportunities are still offered to us in prospect to leverage soil macrofauna to assist the restoration of degraded land. Soil macrofauna play pivotal roles in shaping ecosystems and contributing to the intricate web of life on our planet by their interactions with both biotic and abiotic factors in the environment [158]. SSA harbors considerable climate variability, rich and varied vegetation, as well as marked soil heterogeneity, all contributing to offering a high diversity of soil macrofauna, with highly diverse functional traits and functional roles. Functional roles ranging from bioturbators, decomposers, nutrient redistributors, PTEs accumulators have been highlighted for soil macrofauna in SSA, providing a basis to ponder contextualized applications of macrofauna-based restoration approaches. Notably, specific macrofauna groups with proven beneficial attributes could be targeted for bioaugmentation in degraded landscapes where restoration efforts are taking place. The documentation regarding macrofauna bioaugmentation for the restoration of degraded lands is indeed still scarce for the SSA region, especially for mine wastelands.

For example, vermiremediation, the gentle remediation option involving the use of Oligochaeta, can be envisaged to improve soil structure, water infiltration, aeration and plant root penetration due to the burrowing activities of Oligochaeta. However, the introduction of non-native Oligochaeta species must be approached with caution, as it can lead to unintended ecological consequences, including displacement of native species and disruption of local soil processes [159,160]. Macrofauna morphological traits, such as body size, allow them to directly move and mix sediments during their burrowing and feeding activities [161]. Polychaete worms have elongated or flattened bodies that allow them to move through soil efficiently. Some macrofauna have appendages, such as claws or setae, that enable them to dig and manipulate soil. Other macrofauna secrete mucus which stabilizes burrows and improves soil particle cohesion [162].

Formicidae, Isoptera (notably the fungus-growing Isoptera) and Spirobolida can also be targeted for their capacity to break down organic matter and increase the rate of nutrient release into the soil [163]. They have morphological traits that make them excellent candidates for organic matter breakdown and nutrient release. Formicidae and Coleoptera, for example, have strong mandibles that assist in plant debris breakdown, thus facilitating microbial decomposition [31]. Arthropods like Spirobolida have specialized appendages that assist in shredding organic material, thus increasing microbial activity surface area [158]. Additionally, high trait diversity among soil arthropods contributes to their resilience in eco-agricultural mosaics, enabling persistence despite environmental variability across land-use types [153]. Oligochaeta can also be involved in this process, promoting microbial colonization and nutrient mineralization by producing mucus that binds soil particles and organic matter (Lavelle et al., 2008). Additionally, their intestinal enzymes have been shown to stimulate microbial activity in the soil for two to three weeks after excretion, further enhancing decomposition and nutrient cycling [164].

Some soil macrofauna have also developed traits to support their tolerance to PTEs, by accumulation in less sensitive tissue, e.g. exoskeleton (metal sequestration) [112]. These macrofauna, of which the Isoptera, *Macrotermes bellicosus*, is a prominent example, have potential for entomoremediation and can be used to rid soils of PTEs, as they could immobilize or redistribute PTEs [90]. Other groups identified with the ability to break down organic pollutants with their feeding activities (i.e. some Oligochaeta) can also be considered in this regard, as they contain gut microbiota that are capable of detoxifying heavy metals by binding to them and preventing them from being absorbed into the body [165]. However, it is important to note that exposure to high levels of heavy metals can also lead to physiological stress in Oligochaeta, often resulting in reduced body size and reproductive output, which may limit their effectiveness in long-term bioremediation strategies [113,114]. Apart from these functional attributes, soil macrofauna are capable of enhancing microbial communities and forming mutualistic relationships with them (e.g. Oligochaeta and Spirobolida [166] may have potential roles in future restoration strategies, especially for bioaugmentation purposes.

The above bioaugmentation strategies can be applied on their own or in combination with other remediation technologies such as phytoremediation and bioremediation, provided that the tolerance level of targeted macrofauna groups is proven against the environmental pressures considered, and their positive interaction with candidate plant species and microorganism strains is verified, through experiment-based approaches in the SSA setup. Beyond ecological insights, macrofauna-based interventions also carry economic and policy relevance. Practices such as organic amendments or agroforestry, which support macrofauna diversity, can offer low-cost and sustainable alternatives to conventional and land restoration approaches [167]. However, their wider adoption in SSA is often limited by the absence of targeted policies, funding incentives, and institutional support [168]. Integrating soil biodiversity considerations into national restoration policies and land-use planning frameworks could mainstream macrofauna-based practices. Future research should indeed focus on the identification of PTE-tolerant macrofauna groups up to the species level. Additionally, developing an understanding of the mechanisms by which these macrofauna species survive the contaminated environment provides a good basis for incorporating them in the restoration of contaminated landscapes. This represents a fascinating area of future research activities, which is underexplored to date.

Several facts in this review also revealed the considerable role pertaining to the quality of organic matter inputs in magnifying macrofauna abundance in degraded landscapes. This can be used to the advantage of reclaiming degraded landscapes by encouraging land-use types that improve soil physical and chemical properties for the survival, optimum reproduction and functioning of soil macrofauna. While provision of external organic matter is amenable in other land-use types like agricultural landscapes, this option seems not feasible for application at a large scale in mine wastelands, where the only realistic option for organic input relies on in-situ vegetation cover. The choice of plant species for phytoremediation of these mine wastelands is therefore cardinal, calling for extension of the selection criteria for candidate plant species beyond their tolerance to the environment, and include additional criteria to consider the quantity and quality of biomass produced, thereby contributing to the maintenance of diverse soil macrofauna. Legume plant species among others, have been highlighted and should be prioritized in restoration initiatives.

Conclusion

This review provides a synthesis of current knowledge on soil macrofauna and their potential contributions for restoring degraded landscapes in Sub-Saharan Africa (SSA). It highlights an increasing trend of research on soil macrofauna in SSA since 2017 but also reveals strong geographical differences, with West Africa remaining notably underrepresented in terms of studies conducted and number of macrofauna groups reported. Addressing this gap is essential to build a more comprehensive understanding of soil macrofauna ecology across Africa. This review highlights that soil macrofauna communities were not reported equally across different land-use types, as more macrofauna groups were reported in agricultural landscapes, coinciding with the greater number of studies reported in this land use type (28 out 31 studies reviewed). Comparatively, only three of the 31 reviewed studies focus on macrofauna in mine wastelands, highlighting a major knowledge gap in this ecosystem, thereby emphasizing the need for targeted research to inform restoration strategies. Environmental factors (i.e. soil properties and vegetation cover) influencing their ecological roles and distribution have also been highlighted. Likewise, macrofauna groups with known ecological benefits for restoration (particularly Oligochaeta, Isoptera and Formicidae) have been highlighted along with their contributions to key ecosystem functions (e.g., bioturbation, organic matter decomposition, nutrient cycling). Additionally, the role of insects is explored in the context of their value as bioindicators of ecological recovery in mine wastelands, with emphasis on the prevalence and indicative potential of Coleoptera and Isoptera.

These findings are discussed in relation to their implications in prospect of exploring the use of soil macrofauna in bioremediation and landscape restoration within SSA contexts, including mining-impacted areas.

Given the taxonomic variability and limitations in the reviewed data, this review employed broad macrofauna groups to synthesize regional patterns. We acknowledge the limitations of this approach and emphasize the importance of future studies adopting finer taxonomic resolutions, where data permit, to provide more nuanced insights.

Despite the recognized ecological importance of macrofauna, findings from this review show that their integration into restoration efforts in SSA over the past decade remains limited. This underscores a broader research gap where soil macrofauna are still largely underrepresented in the region's ecological restoration agenda. In order to address the current research gaps, future studies should focus in priority on: (i) What are the roles of macrofauna in local ecosystems across SSA, especially in underrepresented regions such as West Africa (ii) Which plant species are most effective for phytoremediation and recovery of soil macrofauna communities in degraded mining landscapes? (iii) How the policy mechanisms and institutional frameworks may be effective for integrating soil macrofauna into national restoration strategies in SSA?

Credit author statement

Mukanzala Kasimbo: Writing – original draft, Writing – review & editing, Formal analysis, Software, Data curation. **Agnes Uwimbabazi**: Writing – original draft, Writing – review & editing, Formal analysis, Data curation. **Todd Johnson:** Writing – original draft, review & editing, Software, Formal analysis, Data curation, Supervision. **Theodore M. Mwamba:** Writing original draft, review & editing, Methodology, Visualization, Supervision. **Stephen Syampungani:** Writing – original draft, review & editing, Resources, Formal analysis, Supervision, Visualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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