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Review

Ecological Grassland Restoration—A South African Perspective

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Abstract: The principal drivers of Grassland Biome conversion and degradation in South Africa include agricultural intensification, plantation forestry, urban expansion and mining, together with invasive non-native plants and insidious rural sprawl. This biome is poorly conserved and in dire need of restoration, an ecologically centred practice gaining increasing traction given its wide application to people and biodiversity in this emerging culture of renewal. The pioneering proponent of restoration in South Africa is the mining industry, primarily to restore surface stability using vegetation cover. We noticed a historical progression from production-focussed non-native pastures to more diverse suites of native species and habitats in the restoration landscape. This paradigm shift towards the proactive "biodiversity approach" necessitates assisted natural regeneration, mainly through revegetation with grasses, using plugs, sods and/or seeds, together with long-lived perennial forbs. We discuss key management interventions such as ongoing control of invasive non-native plants, the merits of fire and grazing, and the deleterious impacts of fertilisers. We also highlight areas of research requiring further investigation. The "biodiversity approach" has limitations and is best suited to restoring ecological processes rather than attempting to match the original pristine state. We advocate conserving intact grassland ecosystems as the key strategy for protecting grassland biodiversity, including small patches with disproportionately high biodiversity conservation value.

Keywords: assisted natural regeneration; biodiversity approach; ecological restoration; grasslands; perturbations; rehabilitation; rest; soil conservation; South Africa; target achievement

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1. Introduction

Ecosystem restoration is principally an ecological matter and should therefore be guided by ecological theory and practice [1]. Restoration is undertaken globally as a response to the degradation and transformation of ecosystems [2] and has emerged as an important tool to stem the biodiversity crisis [3,4] and reverse a negative trajectory towards one of rebuilding and renewal [2]. Restoration has a host of benefits, not only limited to directly stabilising biodiversity and ecosystem integrity. Improving human well-being, alleviating poverty and socio-economic inequality, buffering the effects of climate change and protecting the integrity of diverse cultures are also attributed to restoration practices [2,5–7]. Restoration of natural capital is a key strategy to ensure sustainability [8]. For such reasons, restoration became a global priority after the Convention on Biological Diversity set a 2010 Aichi target to restore at least 15% of degraded ecosystems globally [4]. More recently, the United Nations declared 2021–2030 as the Decade on Ecosystem Restoration, with the aim of preventing, halting and reversing the degradation of ecosystems globally [7].

Despite grasslands being among the largest terrestrial biomes and accounting for many biodiversity hotspots with extremely high conservation value [9–12], grassland conservation and restoration has received disproportionally little attention compared with forest and freshwater habitats [11,13–15]. This is alarming since grasslands, particularly temperate grasslands, are the most imperilled terrestrial biome on the planet with the highest rates of conversion [15–17]. Misconceptions around the origins and age of many of the world's grasslands [18] have led to an under-appreciation of their value [16,19] and a consequent paucity of grassland restoration research, policy and practice [20].

South African grasslands share many parallels with grasslands across the world—they are hyper-diverse and offer an immense array of ecosystem services and ecological infrastructure, which contribute significantly to livelihoods and economic growth [21–23]. They are also highly transformed, poorly conserved and in dire need of restoration [22,24], an ecological practice gaining increasing traction given its wide application to people and biodiversity in this emerging culture of renewal [25]. The development pressures in South Africa are such that many grasslands have been, and continue to be, transformed or impacted by various competing land-use types. Agricultural intensification (especially row-cropping and pastures), plantation forestry, urban expansion and mining are primarily responsible for transforming grasslands in the Grassland Biome [26–29] (Table 1, Figure 1), together with invasive non-native plants and insidious rural sprawl. These drivers of transformation, underpinned by persistent human disturbance [30], are shared with grasslands worldwide [15]. The Grassland Biome has been a low priority for conservation—only ca. 2% is formally conserved—possibly the lowest rate of protection in the world [22,28]. The high levels of grassland transformation and historical paucity of restoration policy and practice reflect this dire state. Over the past decade, however, there has been an increasing awareness of the value of grasslands for biodiversity conservation, ecosystem services and climate change mitigation (especially carbon sequestration and albedo-induced cooling) [16]. Recognising these values is also central to reforming grassland restoration policies and practices—restoration paradigms have shifted in recent years towards an ever-increasing emphasis of the "biodiversity approach," which harnesses sound ecological principles and nature-based solutions to restore ecosystem resilience. We therefore make a strong case for undertaking grassland restoration in the region as a "due diligence" form of land care that can restore biodiversity and ecological processes; re-establish ecosystem, pollinator and watershed services; mitigate climate change and promote soil conservation.

Table 1. Land-use types responsible for the greatest transformation in the Grassland Biome of South Africa, Lesotho and Eswatini [24,28]. These drivers account for a cumulative transformation total of ca. 32%. Large impoundments (ca. < 0.2%), formal protected areas (ca. 2%) and extensive farming practices for livestock and wildlife (ca. 66%) account for the remaining grassland area. This spatial assessment was based on a GIS analysis using ArcGIS (WGS84 datum–Lo29 projection). Areas of transformation were derived from the National Land Cover 2000 coverage (satellite imagery).

Land-Use Type	Transformation (km^2)	Transformation (%)
Cultivation	75,833	21.00
Degraded lands	22,041	6.10
Plantation forestry	9932	2.80
Urban and industrial areas	5843	1.62
Mines and quarries	933	0.26
Total	114,582	31.78

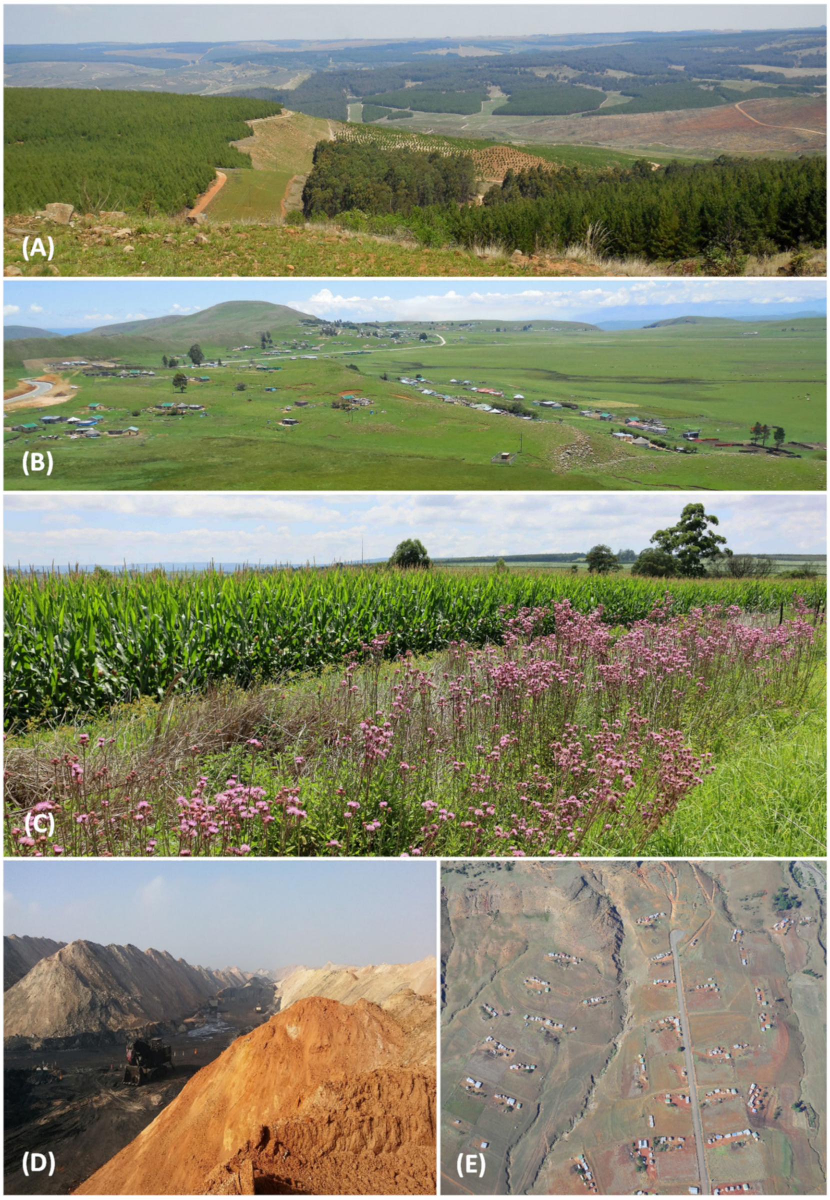

Figure 1. Photographic examples of key threats to the Grassland Biome in South Africa: (**A**) commercial plantation forestry, Badplaas, Mpumalanga (14 October 2017); (**B**) insidious rural sprawl in the KwaZulu-Natal Midlands, KwaZulu-Natal (11 January 2018); (**C**) cropping with corn, *Zea mays* L. (Poaceae) (background) and encroachment of invasive non-native plants such as Pompom Weed, *Campuloclinium macrocephalum* (Less.) DC. (Asteraceae) (foreground), KwaZulu-Natal Midlands, KwaZulu-Natal (21 January 2021); (**D**) mines such as Khwezela Colliery, Witbank, Mpumalanga (29 April 2017); (**E**) settlement expansion and formalisation, Mnweni, KwaZulu-Natal (14 November 2017). All photos by C. Carbutt except Figure 1D, credited to G.N. Le Roux and used with permission.

2. Geographical Focus, Methods and Aims

South Africa is a heterogeneous country characterised by nine vegetation biomes, the second largest of which is the Grassland Biome [31]. This largely contiguous expanse of grassland stretches across the heartland of eastern South Africa (but also throughout the much smaller enclaved country of Lesotho and western uplands of Eswatini), covering ca. 28% of this land area (Figure 2). The Grassland Biome (25–33° S latitude) is defined on the basis of vegetation structure in combination with the amount of summer rainfall and minimum winter temperature [31]. The Grassland Biome forms part of the global Temperate Grassland Biome and has therefore been referred to locally as such [22] since it occupies the mid- to higher elevations of the region (ca. 1200–3482 m a.s.l.). This biome comprises four bioregions (three moist types) and 72 grassland vegetation types (Figure 3). Its origins are attributed to a period of cooling, aridification, increased seasonality of rainfall and a lower CO_2 environment during the Late Oligocene–Early Miocene (34–20 Ma), when C_4 grassland expansion benefitted from being more competitive in a lower CO_2 fire-prone environment [32–35]. This synthesis applies largely to the mesic (moist) grasslands of the summer-rainfall Grassland Biome, receiving at least 500–700 mm annual rainfall [31]. However, some of the principles of this restoration paper may also apply to the mesic coastal grasslands associated with the eastern seaboard (Indian Ocean Coastal Belt Biome). This paper focusses on the restoration of the non-woody aspect of grasslands and excludes the grass-dominated components of savannas and wetlands. This paper also does not delve into the economics and costing of restoration efforts and consequent financial management. Although the boundaries of the Grassland Biome extend into two small countries neighbouring South Africa (accounting for all of Lesotho and a small part of Eswatini), the focus of this paper is South Africa, which accounts for the majority of the biome and restoration research.

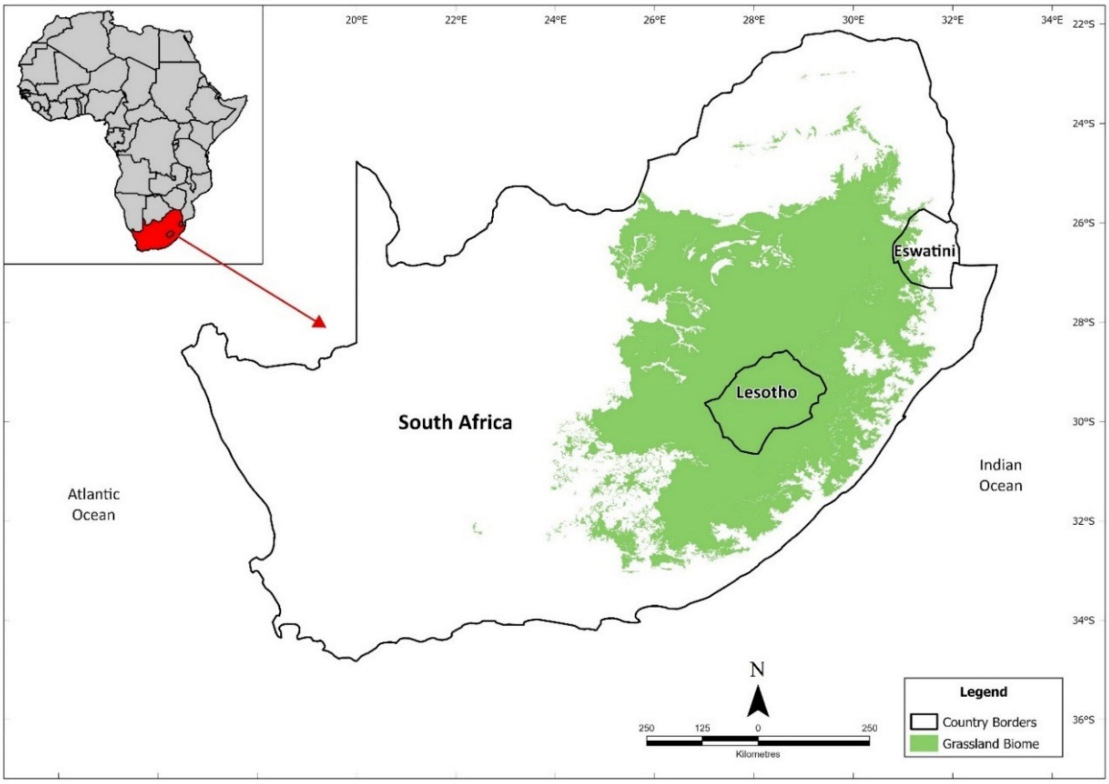

Figure 2. Extent of the Grassland Biome in South Africa, Lesotho and Eswatini. Grassland coverage is derived from the National Vegetation Map, South African National Biodiversity Institute (2006–2018), The Vegetation Map of South Africa, Lesotho and Eswatini; Mucina, L., Rutherford, M.C., Powrie, L.W., Eds.; online: http://bgis.sanbi.org/SpatialDataset/Detail/18; version 2018 (accessed on 22 February 2022).

We present the first synthesis of ecological grassland restoration in the Grassland Biome of South Africa. This synthesis was based on an extensive literature review, as well as personal institutional knowledge given that both authors have been involved in restoration activities. Relevant published peer-reviewed scientific literature was sourced through Google® (Mountain View, CA, USA), Google Scholar® (Mountain View, CA, USA), ScienceDirect (Amsterdam, The Netherlands), and SpringerLink (New York City, NY, USA). Unpublished institutional grey literature was also consulted. This synthesis included seminal publications from 1946 to 1969, as well as a highly representative spectrum of literature up to 2022. A total of 182 references were consulted. The literature is a good balance between local and international case studies and perspectives.

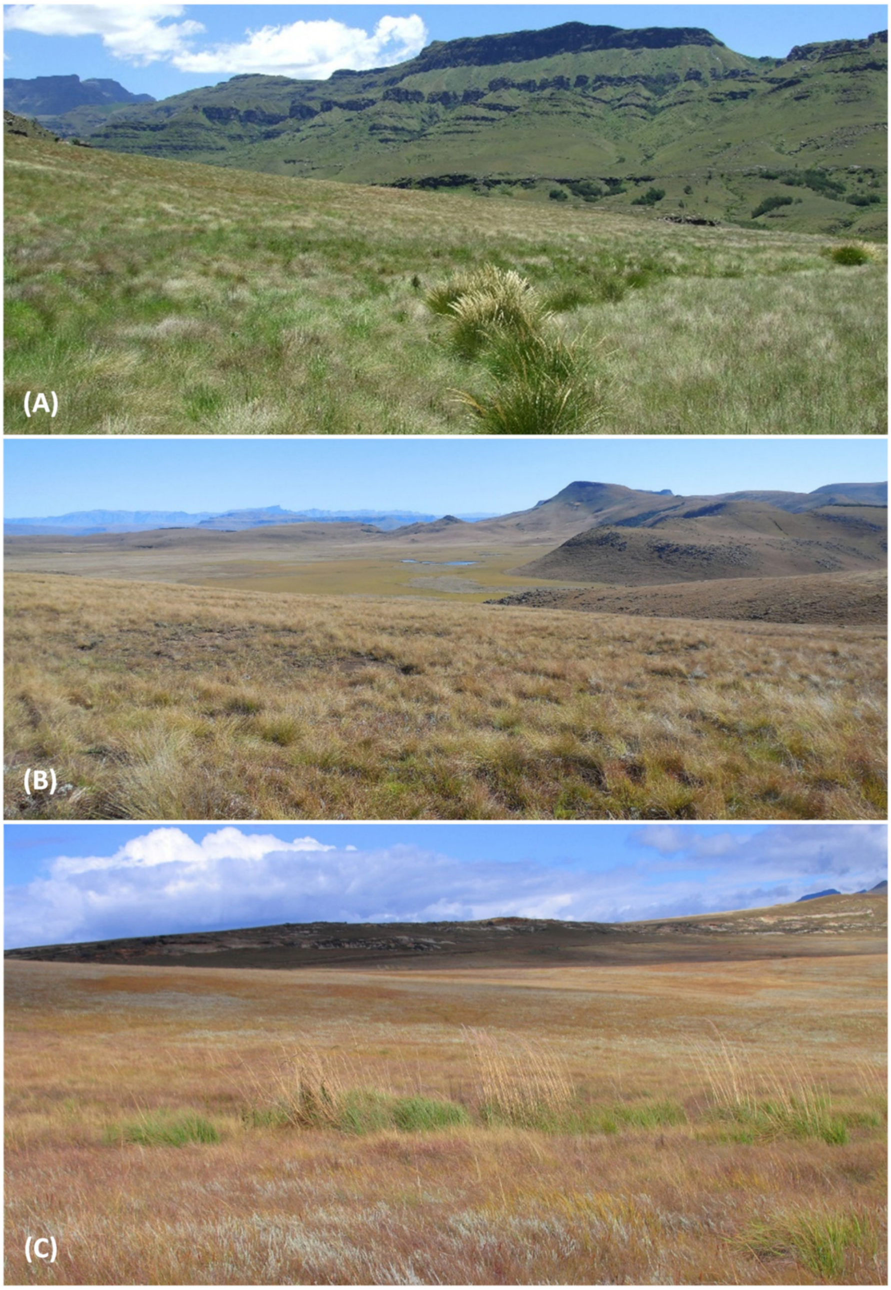

Figure 3. Representative examples of grasslands from the three moist grassland bioregions in the Grassland Biome of South Africa: (**A**) Drakensberg Grassland Bioregion (southern KwaZulu-Natal Drakensberg) (19 November 2012); (**B**) Sub-Escarpment Grassland Bioregion (KwaZulu-Natal Midlands) (14 May 2015); (**C**) Moist Highveld Grassland Bioregion (eastern Free State) (6 May 2010). All photos by C. Carbutt.

Grasslands are excellent model systems for restoration ecology [14]. Knowledge of dynamics and restoration in grasslands is lacking [11]. This synthesis will make a significant contribution to arresting this information gap. The aim of this paper was to therefore share insights and experiences from undertaking grassland restoration in South Africa. We consolidate such thinking in the form of a holistic synthesis explicitly following the stages of the restoration process, underpinned by sound ecological theory, while simultaneously highlighting areas of research requiring further investigation. This restoration focus also follows a historical progression and contributes to a better ecological understanding of South African grasslands. We ask the following key questions: (1) Is it possible to restore disturbed or degraded areas, previously mesic grasslands, back to their former ecological state, particularly in light of the biodiversity approach? (2) What are the methods required to achieve this feat? (3) What areas of research are still in their infancy, requiring further investigation to make successful grassland restoration an achievable outcome? This synthesis will benefit academics and practitioners applying their trade in other grassland areas of the world.

3. Operational Definitions and Broad Approaches

We refer to "ecological restoration" as the framework encompassing all activities "assisting in the recovery of an ecosystem that has been damaged, degraded or destroyed" and "increasing the potential for native species and communities to recover and continue to reassemble, adapt and evolve" [36]. Its primary aim is to facilitate multiple intermediate states and trajectories to optimise restoration potential [4]. Embedded in this framework are a number of other terms with a more focussed and nuanced context requiring clarification. "Recovery" refers to the restoration of an ecosystem to the point that it has adequate biotic and abiotic resources to continue its development unaided in a trajectory towards recovering ecosystem composition, structure and function [37]. "Rehabilitation," "revegetation" and "reclamation" often refer to efforts to improve the condition of a degraded system, usually with a focus on reinstating landscape function or specific ecosystem processes or services and mostly focus on stabilisation and a return to some form of beneficial land use (not necessarily biodiversity). This implies use of only one to a few species that form a secondary state not necessarily reflecting the pre-transformed or historical environment [38,39]. However, others regard "rehabilitation" as achieving the previous condition in synonymy with "restoration" [40]. Finally, the more recently coined term "rewilding" refers specifically to restoring wildlife impacted by habitat loss to either new or restored landscapes [41–43].

Historical restoration tends to follow three basic approaches [13,44]: (1) the ameliorative approach (improving the physical and chemical nature of the site for restoration purposes); (2) the adaptive approach (emphasis being the careful selection of suitable species, cultivars or ecotypes to meet the rigours of the prevailing conditions under which restoration has to take place); and (3) the agricultural approach (revegetation using agricultural species to restore agricultural production). Considerable overlap of the three approaches does take place in practice [44].

4. Pioneers of Restoration in South Africa

South Africa is blessed with significant mineral resources that underpin its economy [45]. Social and legislative contexts now require South African mines to have land rehabilitation goals and guidelines after mine closure, often determined prior to granting planning and operating permits [13,46–48]. The pioneering proponent of restoration in South Africa is therefore the mining industry, having invested a significant amount of resources into often large-scale operations aimed at rehabilitating highly disturbed, extremely low- or high-pH environments with an emphasis on arresting acid mine drainage, soil dispersivity and sodicity (high exchangeable sodium), and restoring surface stability using vegetation cover on discarded waste material (spoil or tailings) after the removal of over-burden [49–51]. These efforts have restored some form of functionality to large open-cut mined areas, thereby minimising further erosion and environmental degradation, protecting water quality and enabling some form of alternative land use [13]. Mine rehabilitation usually involves heavy machinery to add lime (calcium carbonate) to neutralise the acidic environment and arrest ecotoxicity from heavy metals, augmented by the addition of topsoil, subsoil and even organic matter to counter harsh soil and moisture conditions [1,50,52].

In the early 1970s, mine rehabilitation focussed on preventing erosion by stabilising soil surfaces and landscapes through rapid establishment of vegetation cover [53,54]. This was followed by a progression towards establishing monospecific production-focussed pasture grasslands [53,55–57] and later a diverse suite of native species and habitats, including nitrogen-fixing legumes, to stabilise areas under rehabilitation [53]. Diverse plant communities of native species are increasingly being used in mine rehabilitation [51,54,58] as they are well adapted to regional climate and soils [51].

In the South African mining context, seed mixtures commonly sown over a prepared surface usually comprise a species suite capable of establishing a rapid vegetation cover [59], such as the annual nurse crop *Eragrostis tef* (Tef), as well as perennial species such as *Chloris gayana* (Rhodes Grass), which uses a range of physiological mechanisms to mediate salt toxicity [60], *Digitaria eriantha* (Common or Smuts Finger Grass), *Eragrostis curvula* (Weeping Love Grass; primarily for hay production), *Cenchrus ciliaris* (Blue or Foxtail Buffalo Grass), and *Paspalum notatum* (Lawn Paspalum or Bahia Grass). Erosion-prone steeper slopes are best stabilised by the highly aggressive rhizomatous species *Cynodon dactylon* (Kweek or Couch Grass) and *Cenchrus clandestinus* (Kikuyu) [53,61]. More recently, *Themeda triandra* (Red Grass), *Hyparrhenia hirta* (Common Thatching Grass) and the tree *Vachellia sieberiana* (Paperbark Acacia) have been utilised in South African mine rehabilitation trials [61]. A number of the aforementioned "South African" grasses are also used to revegetate open-cut coal mines in Australia [62]. Seeding rates (kg ha^{-1}) depend on a number of factors—the degree of soil drainage and slope, cover required in a specified time period and available budget. This approach emphasises establishment of vegetation cover primarily, and recreating some agricultural value in the form of forage production for grazing livestock and wildlife, especially on more gentle gradients, as a reclamation tool [57,63]. Initial forms of mine rehabilitation did not consider biodiversity losses and gains and ecosystem services [50]. Vegetation cover has historically been the key component of the biodiversity pool, while the soil biotic community and faunal species have been neglected, even though they often provide important indications of long-term productivity and successional pathways [13]. The effects of grazing animals on pastures established on mining-disturbed land are under-studied in South Africa [50,64].

Soil compaction is arguably the single biggest cause of rehabilitation failure in mines because it results in excessive runoff (through increased soil bulk density and decreased hydraulic conductivity) as well as restricted plant growth through its impact on soil biotic activity [54,65–68]. Effective management of topsoil is critical for rehabilitation success [50,52,65,69].

The science and practice of rehabilitating mined areas in former grassland landscapes in South Africa has benefited enormously from the Coaltech Research Association (Johannesburg, South Africa) and Coaltech 2020 Research Programme established in 1999. Coaltech is a voluntary, collaborative not-for-profit organisation addressing the research needs of the South African coal industry by developing technologies and applying research findings to make South Africa's coal mining industry competitive and sustainable [70].

5. A Paradigm Shift

More recently, restoration paradigms in South Africa have shifted towards an increasing emphasis of historical species assemblages, biodiversity conservation and carbon sequestration [71]. This proactive fourth approach, termed the "biodiversity approach," should either be applied as "standard policy remediation" in this dispensation of renewal or as a mechanism to penalise unlawful activities through legal instruments such as the National Water Act No. 36 of 1998 and the National Environmental Management Act No. 107 of 1998, particularly Section 28's "Duty of Care" and "Polluter Pays" principles. Use of the biodiversity approach is encouraged as land-use types such as plantation forestry and cultivation impact heavily on South African grasslands [72] and it has the potential to improve connectivity with other high biodiversity value grasslands. Furthermore, some grassland vegetation and ecosystem types are critically endangered, which by definition acknowledges that the amount remaining in a natural state is less than the conservation target. Restoration using the biodiversity approach may be the only means possible to achieve targets.

6. Synthesis of Step-Wise Methods Used in Grassland Restoration in South Africa

6.1. Management of Surplus Vegetation after Clear Felling

Occasionally, the first phase of grassland restoration in South Africa commences after the instructed removal of unlawfully propagated plantations or the abandonment of operations in the agroforestry sector. This has particular application to the biodiversity approach. This "consolidation phase" involves post-harvest management of Eucalypts (*Eucalyptus* spp.), Black Wattle (*Acacia mearnsii*) and Pine (*Pinus* spp.) following clear fell. This includes addressing regrowth from coppice or seed banks, management of brush piles, soil erosion control measures and disposal of unwanted harvested material. These methods are well documented in best-practice handbooks [73,74].

Afforestation impacts heavily on the soil environment, which can hamper restoration efforts. Organic acid leachates from brush material result in soil acidification and high levels of exchangeable aluminium which may reach toxic levels in roots [75–77]. Afforestation impacts microbial biomass mainly through altering the composition of microbial functional genes [78]. Changes in soil biogeochemistry therefore have implications for soil productivity and the ability of disturbed soils to recover in the long term.

6.2. Ongoing Post-Emergent Control of Invasive Non-Native Plants

Invasive non-native plants (INNPs) are a global biodiversity threat [79] and a key threat to grassland conservation and restoration [80,81], including in South Africa [82,83]. INNPs alter community structure and function, as well as ecosystem processes such as primary productivity, decomposition, hydrology, nutrient cycling, and disturbance regimes [84]. INNPs also impact ecosystem services and human well-being [85].

Areas under restoration are disturbed, early successional environments of high resource availability and low levels of competition with many open sites primed for colonisation [86,87]. Controlling INNPs is therefore a key aspect of the restoration process, particularly those in the "transformer" mould. Non-native grasses are particularly invasive in areas under restoration [80]. Native grass species in South Africa are particularly sensitive to competition from INNPs [71]. Fire, herbicides and hoeing are used to control INNPs in restoration [80]. Mowing is another effective tool but must be applied regularly as mowed areas are prone to secondary invasions [81]. Continual long-term management is essential for suppressing emergence of INNPs from dense seed banks [88].

6.3. Assisted Natural Regeneration

A significant aspect of proactive restoration makes use of assisted (or accelerated) natural regeneration (ANR), involving the application of sound management interventions, underpinned by ecological theory, to accelerate the natural process of succession [89,90]. This approach is often preferred over unassisted immigration of species with appropriate dispersal mechanisms ("spontaneous secondary or old-field succession") [91]. ANR is critical to the biodiversity approach, and supplemental plantings form the cornerstone of this intervention. Depending on the scale of operation, available resources, and initial biodiversity value of the site, ANR may involve proactive measures to physically reintroduce key "missing" species (a process known as "enrichment planting") in the form of seeds, plugs and/or sods (for grass species) and seeds and storage organs (for forbs) sourced from legitimate plant recovery exercises or nurseries. ANR may also involve "blanking," a follow-up process replacing mortalities ("blanks") from initial plantings. Another dimension of ANR is the addition of topsoil and organic matter as an "inoculant" by re-releasing soil microbes to rejuvenate natural soil processes arrested during perturbation [53]. However, the source of topsoil is of paramount importance. In highly enriched environments that were intrinsically nutrient poor, topsoil is instead removed to arrest fertility [91,92].

6.3.1. Revegetation—An Introduction

Denuded landscapes are of considerable ecological interest as they provide insights into the processes of ecosystem reconstruction and successional development [1,93]. Careful selection of species adapted to the site is the first phase of "technical restoration" [1,94,95]. Such species can facilitate colonisation by other species, thus setting a trajectory towards increased richness and diversity, while inappropriate selection may lead to dominance by a few species and stifle any increase in richness and diversity [96]. The success of the revegetation process is also dependent on the method and timing of establishment [44].

Re-establishing vegetation cover minimises soil loss by wind and water erosion, reinstates soil nutrient cycling and microbial biomass, improves physical soil properties, and restores aesthetics and biodiversity value of the site. Revegetation also establishes important habitat for a range of fauna, serving as refugia and corridors within a broader transformed landscape. Revegetation offers the opportunity to sequester carbon—grasslands (particularly below-ground biomass) are second only to forests in the amount of carbon they sequester [97]. We support the stance that grasslands should be restored to grasslands and not forests or other tree planting initiatives [98,99]. Revegetation constitutes the most widely accepted method to improve soil fertility of degraded mined lands [69]. The best approach to revegetation measures, particularly from a biodiversity perspective, should be that of "mosaic plantings," which involves the use of multiple species serving as "nuclei" or "donor sites" [39,53]. Some practical guidelines for grassland restoration best practice in South Africa are summarised in Appendix A.

6.3.2. Revegetation with Grasses

Mesic grasslands in South Africa comprise simple, short-statured, single-layered herbaceous communities of tussock (or bunch/tufted) perennial grasses and long-lived perennial forbs with large below-ground storage reserves [34,100]. Since grasslands are predominantly herbaceous systems, it is no surprise that grasses (Family Poaceae) are the largest contributor to grassland biomass and often dominate restoration efforts. Since grass species compete amongst one another for light and nutrients differentially under varying grazing and burning regimes, it is difficult to predict how each suite of selected grass species will perform in the area under restoration and its particular management regime. This is an ongoing area of research in South Africa.

Grasses are choice agents for restoration in South Africa because of their relatively rapid germination and growth rates, extensive fibrous root systems, general hardiness and meristems close to ground level [101]. Perennial grasses are generally used, because they are denser, offer greater coverage, and are longer lived than annuals. An exception may be the use of annual grass species as temporary "nursery plants" to initially secure an area against soil erosion and prevent the establishment of weed seedlings after clearing [101]. Although widespread use of creeping (rhizomatous) grasses should be discouraged, they sometimes serve a useful purpose. For example, *C. dactylon* (Couch Grass or Kweek) is very effective at stabilising soil, including on steep slopes, but it out-competes tussock grass species at high grazing pressure [102]. Another popular creeping grass is *C. clandestinus* (Kikuyu), but it is highly invasive and susceptible to winter frosts. *Chrysopogon zizanioides* (Vetiver Grass), although not invasive, produces a deep root system which is difficult to remove and is unpalatable. Its use has therefore been discontinued by the South African Roads Department. Creeping grasses should only be used in exceptional circumstances, such as severely eroded areas requiring urgent cover to bind topsoil, or as cover to bind mine tailings comprising heavy metals [103]. Further research is required into the efficacy of *C. dactylon* as a nursery host for the establishment of native grasses of conservation significance [103]. The non-native creeping species, Kikuyu and Vetiver Grass, can grow on nutrient-poor subsoils and have been used to rehabilitate severely eroded gullies with high levels of success [104,105].

6.3.3. Revegetation with Grasses—Plugs

Plugs refer to vegetative material used as start-up sources of growth usually established from nursery speedling trays [103]. This method can provide a fairly rapid form of cover when planted at high densities and is an effective option from a biodiversity perspective (Figure 4A). Creeping grass plugs are highly competitive and outcompete tufted grass plugs [61] and should therefore be applied with caution. Plugs are an effective alternative to seed since South Africa's mesic tufted grasses are not easily propagated from seed (see Section 6.3.5.). Planting densities of 5–10 plugs m^{-2} (50,000–100,000 plugs ha^{-1}) for smaller tufted species and 2–5 plugs m^{-2} (20,000–50,000 plugs ha^{-1}) for larger tufted species have been prescribed [106]. Use of set, evenly spaced intervals may result in large isolated tufts with poor cover in between [107]. Plugs can grow slowly, providing little basal cover to protect soil from erosion and providing insufficient biomass to burn and kill emergent INNP seedlings. This method requires fairly intensive post-planting management, and can prove costly. Creeping species, if selected for soil conservation, can be planted further apart. Plugs on mined land are an excellent choice when slopes for a seed planter machine are too steep, and in establishing buffers against pasture grass intrusion into ecologically sensitive areas [61].

6.3.4. Revegetation with Grasses—Sods

Grass sods, essentially aggregates of grass swards, may be obtained directly from natural grasslands under discretion. This technique is most appropriate following a recovery operation from an area authorised for development. This method provides a fairly rapid form of cover if sufficient volumes of material are used. Use of grass sods, however, can be labour intensive [106]. Grass sods can be further split into tufts and constituent tiller units but should not be planted out if the likelihood of frosts or a successive number of days exceeding 32 °C is high [106]. Creeping rhizomatous grasses can be split into manageable sections (ca. 15–20 cm in length) [106]. Watering may be required during the initial establishment phase. Success rates of sod plantings are species specific [108]. Field trials using 12 grass species have shown that *E. curvula* was the most successful (gauged by survival rate and tuft area), whilst *T. triandra* and *T. leucothrix* exhibited average success [108]. Use of *E. curvula* should be discouraged, particularly the "Ermelo" ecotype from the Highveld, as it is a vigorous competitor [96]. The choice of the most appropriate candidate for restoration should also be determined by (vegetative) life history traits, particularly those impacting invasiveness and invasibility through competitive effects [96]. Field trials have shown that short, slow-growing grasses that produce few tillers with low leaf mass are the most invasible by forbs, thereby allowing for an increase in species richness [96].

6.3.5. Revegetation with Grasses—Seeding

Propagules of native grass species may be absent from areas requiring restoration. Reliance on natural means of dispersal (wind, water, fauna, etc.) is untenable given low inputs of seed and limited dispersal ability [109]. Therefore, seed from natural stands of grass may have to be collected for revegetation purposes. Seeds are either sown over a prepared soil surface (Figure 4B) or in the case of over-seeding ("thatching"), mown stands of grassland in full seed are applied to the recovery surface [53]. Timing of seed collection, seed storage methods, seed bed preparation, seed mix composition and sowing rates, position on the terrain unit (soil toposequence), and rest from grazing during establishment are all important factors to consider [73,110–112].

Re-establishing grass cover from seed is a relatively complex process and an emerging field of research in South Africa. This method has had limited success to date, but new research and technologies will increase the viability of this option in the future. Some successful results have been achieved using seed of *Cymbopogon* spp., *E. curvula* and *Hyparrhenia* spp. These late successional species tend to form monospecific stands. Attempts to sow seed of late successional grass species in early successional environments may account for poor rates of germination in certain species (e.g., *T. triandra*). The key challenge is to achieve a diverse self-sustaining community of grasses from seed [71].

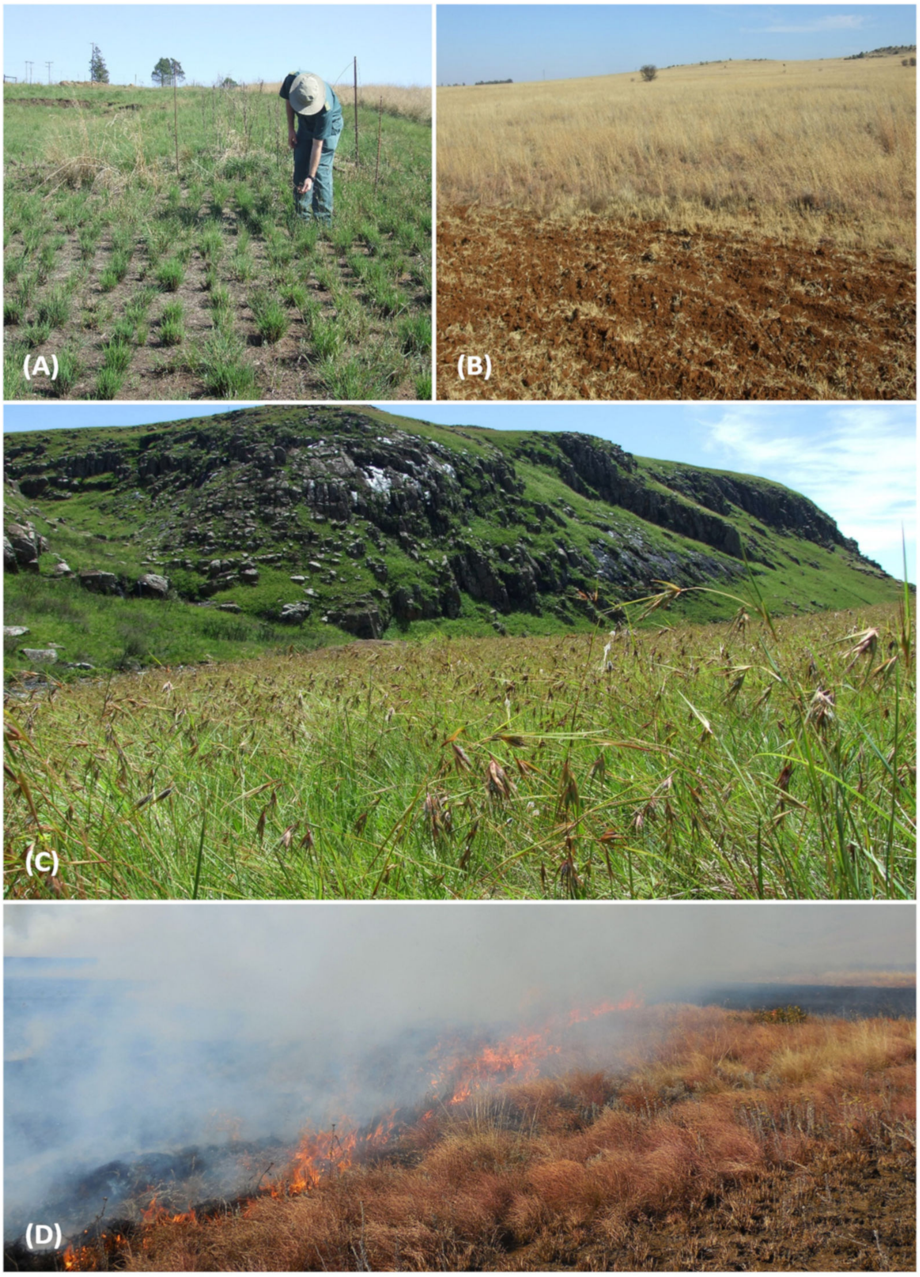

Figure 4. Assisted natural regeneration: (**A**) *Themeda triandra* Forssk., a popular choice for grassland restoration, particularly from vegetatively propagated tufted plugs (4 October 2013); (**B**) a ripped experimental soil surface prepared for reseeding (23 July 2014); (**C**) *T. triandra*, a keystone grass species associated with high biodiversity and high rangeland value grasslands in South Africa (23 November 2012); (**D**) fire is a key ecological driver and restoration management tool in South Africa's frost-cured pyrogenic grasslands (11 June 2019). All photos by C. Carbutt except Figure 4A, credited to J. Longmore and used with permission.

The major constraint to seeding (or reseeding) is that recruitment from seed does not readily occur naturally in South Africa's mesic grasslands. The role of grass seed is surprisingly unimportant despite copious seed production [71]. A prime example is *T. triandra* (Figure 4C), a keystone species with high rangeland value and indicative of healthy, biodiverse grasslands in South Africa [113]. Prominent South African ecologist

John Acocks described *T. triandra* "spreading slowly by seed at a rate of about one to three feet per year" [114]. Inefficient seed dispersal is a further constraint [71]. Rather, mesic grasses in South Africa rely on vegetative spread via "tillering," another slow process [115]. Furthermore, the frost-cured and fire-prone mesic grasses of South Africa are constrained by coat-imposed dormancy which can be overcome through a single season of storage and various scarification techniques. Fire-derived smoke is one of the most important cues stimulating seed germination in flammable ecosystems [116]. Use of smoke volatiles to break *T. triandra* seed dormancy has received some attention in South Africa [117–120] as well as plant traits associated with smoke-responsive species [121]. More research is required into the effect of smoke volatiles on other grass species, as well as the most effective means of expediting seed dormancy as a whole. Other limitations to the seeding method include the time-consuming nature of seed collection (particularly obtaining seed in sufficient quantities for large-scale operations), poor seed viability and vigour (Appendix B), high levels of seed predation, and ease of dispersal away from the site [44]. Although seed sowing of grass mixtures is a feasible tool for restoring grasslands at large scales, the resulting vegetation usually has low biodiversity, and a high density of INNP seeds in the soil seed bank for several years after restoration [88].

Sown grass species are generally more successful that sown forb species [122,123]. Diverse mixes are preferable as subsequent recruitment opportunities may be limited [112] and will increase the likelihood of responding favourably to myriad global change scenarios [14]. High-diversity seed mixtures tend to work better in smaller areas and can function as rich source patches ("donor sites") for spontaneous colonisation of nearby areas [91]. Low-diversity seed mixtures are recommended to create basic grassland vegetation in large areas and/or in a short time period [91].

6.3.6. Revegetation with Forbs

Long-lived forbs with significant below-ground biomass are a key component of South Africa's mesic grasslands; they constitute over 80% of its species richness [124] and usually include the most threatened taxa (particularly the petaloid or non-graminoid monocots). Restoration efforts in South Africa have failed to focus on forb reintroductions, probably due to the paucity of information and historical focus on grasses. There is an urgent need for such research given the rate of grassland transformation and the pressing need to maintain biodiversity value and ecosystem function in diminishing high biodiversity value grasslands. A further key research need is the study of competitive interactions between grasses and forbs in the restoration landscape. Forbs should be sourced from relevant nurseries or under permit from legitimate plant rescue operations preceding authorised irreversible land transformation activities. They can be established from seed or as adults with below-ground organs intact. Conditioning of wild-sourced forbs is an area requiring further research in South Africa. Restored grasslands in South Africa previously under agroforestry are forb-poor compared to surrounding natural sites and lack recruitment, making restoration of the forb component in grasslands difficult [123]. Restored afforested grasslands are therefore assigned a unique land cover class in spatial mapping exercises, to make the distinction from untransformed grasslands [125]. Some 95% of grassland forbs in South Africa's mesic grasslands are xenogamous and therefore pollinator dependent [126]. Recruitment via seed is heavily constrained in fragmented landscapes due to limited pollinator access [127,128], adding a further challenge to grassland restoration success in South Africa.

6.4. Why Should Restored Grasslands Generally Not Be Fertilised?

Significant tracts of South Africa's mesic grasslands are nutrient impoverished, either due to underlying lithologies of intrinsically low base status, or in the case of higher elevation grasslands, are cool-temperature mediated resulting in suppression of nitrogen mineralisation [129,130]. These grasslands are therefore characterised by high levels of competition and low resource availability, particularly plant available nitrogen and phosphorus [50,87].

Elevated soil nutrients will militate against the establishment of most native species, and instead favour non-native grasses and weedy ruderals [51]. Grass and forb species are rapidly and seemingly irreversibly lost from mesic grassland in South Africa when nutrients are applied [131]. These declines arise when critical nitrogen loads exceed ecosystem thresholds [132]. Grasses and forbs that dominate under high-nutrient conditions are few, and are generally tall and robust and outcompete smaller plants [133]. Most of these dominant grasses are unpalatable, do not contribute to grazing capacity and are likely to develop "arrested succession," where succession culminates in a secondary grassland dominated by *E. curvula*, *E. plana*, *Sporobolus africanus* and *S. pyramidalis*, which, along with *H. hirta*, are very effective at dominating old croplands in South Africa indefinitely [134]. Late successional grass species such as *T. triandra* and *T. leucothrix* are replaced by early successional *Eragrostis* species and *C. dactylon* when fertilised [135,136]. Fertilising enhances photorespiration, placing late successional grasses at a competitive disadvantage over early successional grasses [137].

Fertilisation also increases the productivity of mesic grasslands in South Africa [138–140]. Biomass increases are correlated with a decline in species richness [138,141–144]. This effect also relates to forbs, often long-lived perennial species of high conservation value [142,145–147]. This outcome is attributed to intense ground-level competition for light (shading effects), root competition and changes in successional dynamics [148–152]. The sterilising effect of fertilisers on grassland diversity has been well demonstrated through the Nutrient Network globally distributed grassland mesocosm experiments [153]. Nutrient additions also have a profound impact on soil microbial activity [154–156]. The long-term impacts of these changes are uncertain and require further research. Management options for mitigating elevated nutrients include the use of fire, cutting and removing biomass in the form of hay to remove excess nutrients, and reintroduction of native herbivores [152].

Fertilisers and pH ameliorants are therefore generally not appropriate in native primary grassland restoration, particularly using the biodiversity approach. The focus should rather be on defoliation management [50]. This is also a cost-saving mechanism. Under rarer circumstances, highly nutrient-impoverished soils (such as those that have lost topsoil) could be stabilised for restoration using slow-release fertilisers such as Bounce, 2:3:2, Multicote urea or Plantacote Plus [106,157]. *T. triandra* responds positively to slow-release fertilisers [157].

6.5. Use of an Appropriate Fire Regime

The pyrogenic grasslands of South Africa have co-evolved with an equally ancient abiotic driver, namely fire [34,158–160]. Grassland restoration should therefore make use of fire as a key ecological driver and management tool in South Africa's grassland ecosystems (Figure 4D). The fire management plan should adhere to South Africa's statutory requirements outlined in the Veld and Forest Fire Act (Act 101 of 1998).

Biennial burns in late winter or early spring are prescribed for South Africa's mesic grasslands and should also be applied to restored landscapes (Appendix C). This fire regime maintains grass bud banks and important grass species at desired levels of abundance [115,161] to ensure long-term grassland equilibrium and stability that can resist change and ensure healthy and resilient grassland communities and water catchments [115,162–164]. The stabilising effect of fire is similar to the stabilising effect of biodiversity on grasslands [30] and should help mitigate nutrient enrichment effects, woody encroachment and invasion by INNPs in grasslands under restoration. The latter applies especially to *A. mearnsii* (Black Wattle) and non-native grasses, by depleting the seed bank [74,80]. Fire treatment responses differ across global grassland landscapes and should therefore consider local dominant species traits [131]. The influence of a potentially stabilising grassland driver such as fire on a disturbed, unstable restoration landscape requires further research.

6.6. Temporary Use of Restricted Access and Rest

An important and neglected aspect of restoration is the use of restricted access and "rest". A brief period of quiescence should improve the vigour of individual grass tufts and afford better success of establishment. Enclosures (or exclosures) may be established to exclude grazers, protecting soils and vegetation while they re-establish. A further aspect of rest involves the absence of fire, possibly for one or two growing seasons. Forbs should be introduced after a fire. These restrictions should not be employed indefinitely as grazing and fire are important drivers of grasslands, with fire in particular also important in the suppression of INNPs. Their application is for the short term in the establishment phase. Further research is required to assess the importance and timing of rest.

6.7. Post-Establishment Integrated Management and Monitoring

The final stages of restoration are the most challenging to achieve [3]. An important aspect of successful restoration is post-establishment integrated management and monitoring. Long-term monitoring provides useful information on the trajectory of communities [81,112] and should also include analysis of soil seed banks [88]. Integrated, objective-based monitoring is applied to rehabilitated mines in South Africa [165] and evidence-based research [166] will improve biodiversity management on restored lands.

Restoration should increase ecological integrity and ecosystem resilience such that restored areas should become more self-sustaining [167] but the notion of "forever" should be defined against operational objectives [40]. Integrated management should consider all options for long-term success. Therefore, in addition to the use of fire discussed previously, another key grassland "disturbance" driver to consider is grazing. Grasslands have also co-evolved with grazing—therefore using only fire as a management tool is sometimes insufficient for biodiversity maintenance [168]. Management of restored grasslands may benefit from using fire and grazing in concert. Studies have shown that pyric herbivory—the synergistic application of fire and mixed-species grazing—ensures that grasslands are more resilient to woody encroachment and nitrogen deposition while at the same time enhances profitability and resilience of livestock production systems [12,169]. Mowing (e.g., hay cutting) and the re-establishment of grazing has enhanced biodiversity and maintained diverse communities in restored grasslands [122,168]. While grazing is considered useful for restoration purposes [152], there is also evidence that under certain circumstances herbivory can limit recruitment in oldfield succession, thus inhibiting the rate of secondary succession [170]. Grazing of high biodiversity mesic grasslands by domestic ungulates in South Africa is a contentious topic. Evidence points to grazing depleting forb species diversity [124]. The impacts of grazing (and mowing) appear to be highly area and landscape specific and therefore need to be carefully weighed before application. Lighter stocking rates are prescribed [124] and these may also be more preferable in restored grasslands in South Africa. Land-use legacies limit the efficacy of key grassland drivers to restore grasslands. Switches or deviations from historical processes, particularly the removal of indigenous fire and the introduction of livestock grazing, can result in the local extinction of fire-dependent and grazing-sensitive native species, and an increase in INNPs [109]. This is an ongoing area of research in South Africa.

7. The "Penalty Factor" for Unlawful Grassland Conversion

The "biodiversity approach" to restoration should be mandatory when high biodiversity value grasslands have been disturbed or cleared without necessary authorisation. The penalty should be such that the perpetrator must demonstrate an attempt towards restoring the biodiversity value of the site. If correctly enforced, the onerous, costly and time-consuming burden will hopefully serve as a deterrent to unlawful activities.

However, a word of caution is advised. Efforts to restore biodiversity value beyond a natural threshold may be a futile exercise, and would not warrant the inputs in terms of costs and effort. We do not advocate that every unlawfully disturbed site should be replaced with high biodiversity grassland. An inspection of the site and its surrounds, and a brief desktop study of the site's historic vegetation type will assist in assessing the former biodiversity value of the grassland and the form of remediation required.

8. Restoration of Grassland Fauna—A Short Note

The UN Decade on Ecosystem Restoration provides a global policy framework to integrate a rewilding component into ecosystem recovery; this explicit target can facilitate a resurgence of large mammal populations [43]. A comprehensive restoration programme should therefore consider rewilding with native fauna once native vegetation cover has been re-established. Timing of introductions should allow for the prior development of structural habitat complexity [42] and necessitate a species-centric approach [171]. Variables to consider include the size of the restored area, fiscal constraints, species biology, native ranges and potential for human–wildlife conflict. Successful reintroductions of keystone faunal species with low functional redundancy and disproportionally large impact on their environment would be the pinnacle of all restoration activities. Relatively immobile species, particularly earthworms, should also be introduced [1]. Other faunal reintroductions should include pollinators, landscape engineers, soil fauna, invertebrate and vertebrate grazers and apex predators. For example, the ability of pollinator networks to recover from disturbance is critical to ensuring restoration success [172]. If rewilding using certain elements of native fauna is deemed inappropriate, grazing by non-native ungulates may serve the dual purpose of restoring the ecological process of grazing and providing commercial gains at appropriate carrying capacities. This approach may be best suited to restored areas of lower biodiversity value, or in areas requiring grazing to reduce biomass and fuel loads where application of fire to maintain grasslands is deemed risky (e.g., urban/peri-urban environments). The impact of reintroducing native fauna, especially bulk grazers, keystone and gregarious burrowing species, on restored grasslands in South Africa requires further investigation.

9. Some Final Observations and Future Research Needs

Restoration generally aims to restore ecosystem functionality rather than a pristine state [167] because recovering ecosystems rarely recover completely [3–5,112,152], depending largely on positioning along the productivity–stress gradient [95]. Disturbed ecosystems have a "recovery debt" [173] or "colonisation credit" [174], an interim reduction in ecological integrity that restoration generally cannot overcome. Impediments to the process are an irreversibly transformed soil microbiome, enhanced soil fertility and acidification, impoverished seed banks and limited dispersal ability in fragmented landscapes [11,50,109,122,132]. Passive (or spontaneous) recovery can also be considered as a more cost-effective option for ecosystem recovery under conditions of minimal disturbance or when no rapid result is required [91,95]. If rates of passive recovery are insufficient to achieve project goals, then active restoration strategies should be tailored to local ecological and socioeconomic conditions [3]. This is essentially a value judgement based on knowledge of what is physically and financially possible [40].

Piecemeal site-by-site restoration projects are not always adequately addressing ecosystem collapse. At larger spatial scales in complex social landscapes, ecological restoration should be better integrated with conservation, biodiversity and ecosystem management, and climate change mitigation [2]. A more integrated, holistic approach applying "allied restorative activities" has been proposed [2,36,175]. Government and industry partnerships with scientists, local communities and stakeholders will be critical to achieving restoration goals [3]. This proactive and positive multi-suite narrative will contribute towards a highly relevant and timeous global restorative culture recognising the fundamental linkages between ecosystems and human health, and consider biodiversity as fundamental to personal, community, and cultural well-being and resilience [2,175].

Assessing restoration success is complex due to the diversity of objectives and actions employed and the heterogeneity of data collected [4]. It is therefore imperative to identify repeatedly measurable variables that are easily monitored and reported [40,176]. Since ecological restoration is a young science with many research needs [3], carefully designed experiments and syntheses of current knowledge for informing management, policy and future research needs are required [11,166]. General ecosystem recovery rates over long periods of time require further investigation [3]. More research is needed on persistence as a long-term measure of stability [14]. Research on climate change-adaptive restoration is needed to parry global change threats. Remote sensing techniques for up-scaling monitoring capacity in larger restoration projects is also required [11]. Evidence-based restoration using evidence syntheses are a powerful tool to identify the most effective strategies to conserve and restore ecosystems [166]. Restoration goals and standards with strong metrics against which to measure performance need to be developed [3,40,176]. Restoration of soil microbial diversity using inoculants also requires further investigation. A better understanding of the tight coupling between above- and below-ground components of biodiversity is necessary to restoration success [177].

There are many areas of grassland restoration in South Africa requiring further investigation. Many have already been discussed under particular sections. Most results of restoration efforts are species and/or site specific and therefore lack generality and wider application. Use of plant traits instead of taxonomic identity to determine responses to restoration measures may be more feasible [178]. This has not been undertaken in South Africa from a restoration perspective—studies of grass traits have only predicted range size and invasion potential [96,179]. Grassland research in South Africa has followed multiple spatial scales, from mesocosm through catchment to landscape scales [180]. Grassland restoration research in South Africa is encouraged to upscale accordingly from parochial plot scales to larger spatial scales and longer time frames.

10. Conclusions

The Grassland Biome in South Africa has been a low priority for conservation (only ca. 2% formally conserved), and the high levels of transformation and historical paucity of restoration policy and action reflect this dire state. Over the past decade, however, there has been increasing awareness of the value of grasslands for biodiversity conservation, ecosystem services and climate change mitigation (especially carbon sequestration). Recognising these values is also central to reforming grassland restoration policies and practices—restoration paradigms have shifted in recent years towards an ever-increasing emphasis of the "biodiversity approach," which harnesses sound ecological principles and nature-based solutions to restore ecosystem resilience. Whether on a voluntary basis, or as a "penalty" for unlawful conversion, restoration of perturbed grasslands towards a former stable state should be recognised as a conservation and land care priority.

Despite the increasing realisation of the necessity to restore disturbed and transformed grasslands, our understanding of how to do this remains limited, particularly at scales that are relevant [19,181]. Attempts at thinking retrospectively to achieve "the original state" may be misguided as natural systems are constantly evolving and adapting to novel conditions to counter global change in the Anthropocene [14,40,167]. The biodiversity approach is plausible, perhaps even possible, but preferably in smaller contexts (and therefore more manageable and cost effective). The exception should be where high biodiversity value grasslands have been unlawfully transformed and the biodiversity approach should be mandatory penance. This approach, however, will likely only improve biodiversity value rather than reinstate it.

Focussed, integrated management interventions paying attention to key grassland drivers will be necessary to attempt the reassembly of diverse grassland communities. This involves assisted natural regeneration (mainly through revegetation with grasses, using plugs, sods and/or seeds, together with long-lived perennial forbs) as well as ongoing control of INNPs and the use of fire and grazing. These are costly and time-consuming processes. We therefore advocate conserving intact grassland ecosystems as the key strategy for protecting biodiversity [3]. The remaining high biodiversity value grasslands of South Africa should therefore be sacrosanct and a high conservation priority since their typical slow-assembly old-growth nature may take hundreds to thousands of years to restore [50,147]. This includes small to very small patches that have disproportionately high biodiversity conservation value [182].

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Appendix A

Box A1. Summary of some practical guidelines for grassland restoration best practice in the Grassland Biome of South Africa. These guidelines were distilled from personal experience and from principles outlined in this synthesis.

1. Attempt to use native species adapted to local climatic conditions (local bioclimatic region).
2. Attempt to use local ecotypes of grass species.
3. Such species may be sourced from the closest indigenous nursery, or from legitimate plant rescue operations in the vicinity.
4. Stockpile the plants in a temporary nursery to allow them time to condition and "harden off".
5. Attempt to initiate revegetation practices at the onset of the warmer and wet growing season.
6. Attempt to provide temporary watering/irrigation during dry spells, particularly in the early stages of establishment.
7. If finances allow, and the area to restore is of small scale, immerse the root systems of grasses into an anti-desiccant hydro-gel called Terra-Sorb® or Aqua-Sorb® (a super-absorbent, potassium-based co-polymer gel that significantly increases the water-holding capacity of soil). This will negate the need to water on a regular basis in the establishment phase.
8. If possible, restore the most degraded and highly disturbed areas first.
9. If possible, and having considered the above point, restoration measures should commence up-slope and progress down-slope in order to limit the loss of topsoil and concomitant sedimentation of water courses.
10. A combination of reseeding and vegetative propagation may be the most successful and rapid method. Seed may be over-sown in the second season in the gaps between vegetative tufts that have been planted the previous growing season.
11. It is better to harvest grass sods on cool, humid, or even wet days (preferably during or immediately after a period of wet weather). The root systems are more easily removed with less disturbance, and the grass swards stand less chance of desiccating. It is best to trim back (heavily prune) the above-ground biomass to limit transpiration and ensure that the root systems do not desiccate.
12. It is better to harvest grass seeds on hot, dry days with low relative humidity. The probability of fungal infection is far lower under such conditions, thereby improving the survivorship of seeds.
13. Acidifying fertilisers such as ammonium sulphate and ammonium nitrate are the most deleterious for forbs (most ammonium-based fertilisers promote soil acidification). Non-acidifying fertilisers (e.g. LAN, potassium nitrate and sodium nitrate) are more forb-friendly.

Appendix B

Box A2. Important terms to consider when dealing with restoration measures involving seeding.

Seed viability refers to whether the seed is dead or alive, and indicates seed germinability. Viability is tested using the "Tetrazolium" biochemical test.
Seed vigour refers to the ability of the germinated seed to persist in its environment.
Seed filling refers to the seed maturation process whereby embryonic tissues develop in their fullness; lack of seed filling implies that the embryonic tissues have aborted, rendering the seed "empty".

Appendix C

Box A3. Summary of some practical guidelines for the use of fire in grassland restoration best practice in the Grassland Biome of South Africa. These guidelines were distilled from personal experience and from principles outlined in this synthesis.

1. Burn only during the dormant period, and not during a period of active plant growth.
2. Burn as close to the growing season as possible to minimise soil loss.
3. Although the standard practice is to wait until after the first 25 mm of rainfall in spring, this is not always a feasible option. The 25 mm may be preceded by smaller rainfall events which stimulate a green flush; burning after 25 mm of rainfall may damage already actively growing plants.
4. Therefore attempt to burn only within the four-week period prior to the expected commencement of the first spring rains.
5. Burn when there is an accumulation of dead moribund material that may pose a threat to the initiation of tillers, particularly grass species that tiller above-ground. Burning will also open up the sward, thereby preventing the shading-out of light-dependent forbs.
6. Burn to control the spread of invasive non-native plant species.
7. Burn to simulate natural fire characteristics. Avoid high intensity fires and rather make use of cooler fires (achieved when the air temperature is < 20 °C and the RH $> 50\%$, usually before 11h00 and after 15h30). Cooler fires are recommended as hot fires may kill grass tufts still in the process of establishment.
8. The exception of using cool fires is the use of hot fires to control regenerating wattle and wattle seeds.
9. Biennial (every second year) or triennial (every third year) burns are generally better for promoting forb diversity.
10. Burn on a day that is not hot or windy.
11. Notify adjacent land owners in advance.
12. Secure the necessary permission to burn from the local Fire Protection Association.
13. Make use of a team of qualified and experienced people, adequately equipped and protected.
14. Spray tracer lines in March/April in preparation of burning firebreaks.
15. Burn from the top of a slope towards the bottom of the slope, to slow the spread of fire and make it easier to control.
16. Burn away from a forest patch (if present), not towards it.
17. Burn the site before the translocation of forbs, not after their establishment. Burning the site before will also stimulate wattle seed germination (if applicable), allowing the wattle seedlings to be treated and killed.

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