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REVIEW

Defining biodiverse reforestation: Why it matters for climate change mitigation and biodiversity

Samantha E. Andres[1] | Rachel J. Standish[2] | Paige E. Lieurance[3] | Charlotte H. Mills[4,5] | Richard J. Harper[2] | Don W. Butler[6] | Vanessa M. Adams[7] | Caroline Lehmann[8,9] | Sasha G. Tetu[3] | Peter Cuneo[10] | Catherine A. Offord[10] | Rachael V. Gallagher[1]

[1]Hawkesbury Institute for the Environment, Western Sydney University, Penrith, New South Wales, Australia

[2]Environment and Conservation Sciences, Murdoch University, Perth, Western Australia, Australia

[3]School of Natural Sciences, Macquarie University, Sydney, New South Wales, Australia

[4]AirSeed Technologies, Sydney, New South Wales, Australia

[5]School of Biological, Earth & Environmental Sciences, UNSW, Sydney, New South Wales, Australia

[6]College of Law, Australian National University, Canberra, ACT, Australia

[7]School of Geography, Planning, and Spatial Sciences, University of Tasmania, Hobart, Tasmania, Australia

[8]Tropical Diversity, Royal Botanic Garden Edinburgh, Edinburgh, UK

[9]School of Geosciences, University of Edinburgh, Edinburgh, UK

[10]Australian Institute of Botanical Science, Royal Botanic Gardens & Domain Trust, Australian Botanic Garden Mount Annan, Mount Annan, New South Wales, Australia

Correspondence

Rachael Gallagher, Hawkesbury Institute for the Environment, Western Sydney University, Locked Bag 1797, Penrith, New South Wales, 2751, Australia.
Email: rachael.gallagher@westernsydney.edu.au

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Societal Impact Statement

Mixed species plantings present an attractive alternative to monoculture reforestation through their added benefits to biodiversity. Yet there is ambiguity in the use of the term 'biodiversity' in carbon and biodiversity markets, which may create perverse outcomes when designing schemes and projects. Here, we review how the concept of biodiversity is defined and applied in reforestation projects, and restoration more broadly. Improved transparency around the use of the term biodiversity is urgently needed to provide rigour in emerging market mechanisms, which seek to benefit the environment and people.

Summary

Reforestation to capture and store atmospheric carbon is increasingly championed as a climate change mitigation policy response. Reforestation plantings have the potential to provide conservation co-benefits when diverse mixtures of native species are planted, and there are growing attempts to monetise biodiversity benefits from carbon reforestation projects, particularly within emerging carbon markets. But what is meant by 'biodiverse' across different stakeholders and groups implementing and overseeing these projects and how do these perceptions compare with long-standing scientific definitions? Here, we discuss approaches to, and definitions of, biodiversity in the context of reforestation for carbon sequestration. Our aim is to review how the concept of biodiversity is defined and applied among stakeholders (e.g., governments, carbon certifiers and farmers) and rights holders (i.e., First Nations people) engaging in reforestation, and to identify best-practice methods for restoring biodiversity in these projects. We find that some stakeholders have a vague understanding of diversity across varying levels of biological organisation (genes to ecosystems). While most understand that biodiversity underpins ecosystem functions and services, many stakeholders may not appreciate the difficulties of restoring biodiversity akin to reference ecosystems. Consequently, biodiversity goals are rarely explicit, and project goals may never be achieved because the levels of restored biodiversity are inadequate to support functional ecosystems and desired ecosystem services. We suggest there is significant value in integrating biodiversity objectives into reforestation projects and setting specific restoration goals with transparent reporting outcomes will pave the way for ensuring reforestation projects have meaningful outcomes for biodiversity, and legitimate incentive payments for biodiversity and natural capital accounting.

KEYWORDS

agriculture, carbon credits, climate action, conservation planning, ecological restoration, indigenous engagement, life on land, net zero

1 | INTRODUCTION

Research suggests that the reforestation of degraded land that previously supported forest ecosystems may significantly increase atmospheric carbon capture and mitigate the effects of climate change (Bastin et al., 2019; Cunningham et al., 2015; Harper et al., 2007). Moreover, there is emerging evidence that planting a diverse mix of species native to a region of interest with characteristics representative of a reference ecosystem can facilitate the succession of functional biodiverse ecosystems over time and successfully address climate change and biodiversity loss simultaneously (Blowes et al., 2019; Otto-Portner et al., 2021; Turney et al., 2020). Biodiversity (in the broad sense; Table 1) refers to the variety of life on our planet at all levels (from genes to ecosystems) and encompasses the evolutionary, ecological, and cultural processes that sustain life on Earth (The Convention on Biological Diversity, 2006). Here, our focus is on the role that plant species, and their genetic and functional diversity, may play in restoring biodiversity and capturing carbon, recognising also the important and complementary role played by other components of biodiversity in the carbon cycle such as soil microorganisms. To tackle both climate change and biodiversity loss, the ideal reforestation project would include a diversity of species in its planting protocol. In reality, many reforestation projects vary widely in their contributions to biodiversity due to differences in fundamental understandings of what '*biodiversity*' means and, therefore, how it is incorporated into plantings (Figure 1). The terms *reforestation* and *afforestation* are as defined by the United Nations Framework Convention on Climate Change (UNFCCC, 2022; Table 1).

TABLE 1 Definitions for major terms used in this paper

Term	Definition
Reforestation	*The planting of trees on land which previously supported tree-dominated ecosystems* (UNFCCC, 2022)
Afforestation	*The planting of trees on land which previously supported non-tree-dominated ecosystems* (UNFCCC, 2022)
Biodiversity	*The variety of life on our planet at all levels (from genes to ecosystems) and encompasses the evolutionary, ecological, and cultural processes that sustain life on Earth* (The Convention on Biological Diversity, 2006)
Restoration	*The process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed* (Society for Ecological Restoration, 2022)
Biodiverse planting	*A planting which references an intact plant community, is self-sustaining and resilient to disturbance and contains a mix of native with functional traits which support key functions of the reference community*
Degradation	*The reduction/loss of the biological or economic productivity and complexity of land ecosystems resulting from land uses or from a combination of processes arising from human activities and habitation patterns* (PRAIS, 2022)

Some reforestation efforts make minimal contributions to biological diversity such as the planting of tree monocultures (Seddon et al., 2021) or afforestation (planting trees in the wrong places) (e.g., former grasslands or savannahs; Bond et al., 2019; Coleman et al., 2021; Holl & Brancalion, 2020; Seddon et al., 2021; Veldman et al., 2019; Wang et al., 2022). Environmental risks associated with these efforts (e.g., altered hydrology, Jackson et al., 2005; fire behaviour, Bond et al., 2019; and increased spread of invasive species, Kull et al., 2019) along with evidence suggesting mixed species plantings can sequester carbon at rates comparable to tree monocultures while providing additional ecosystem services has supported a shift towards multispecies reforestation efforts (Cunningham et al., 2015; Hulvey et al., 2013; Standish & Prober, 2020). Additionally, mixed species reforestation efforts for carbon sequestration can aim towards the *restoration* of an ecosystem, where a mix of native plant species are established with physical, structural and functional characteristics comparable to a reference site to assist the recovery of the ecosystem pre-degradation (Standards Reference Group SERA, 2021). In sum, reforestation efforts need goals that go beyond simple tree-planting to realise benefits for biodiversity, ones that work within the abiotic constraints imposed by the environment to select suitable reference states.

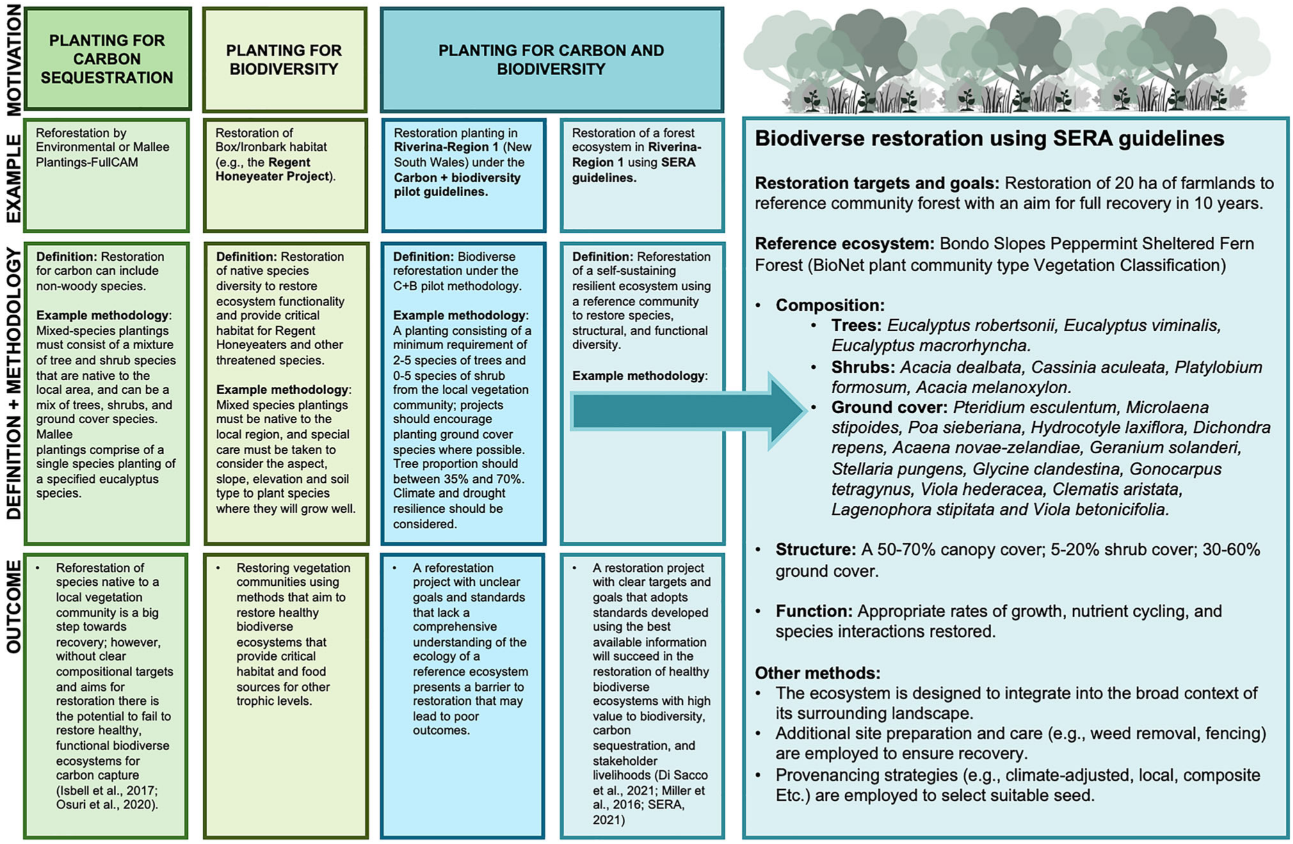

FIGURE 1 Motivations, methods and outcomes when planting for carbon, biodiversity and carbon + biodiversity. Existing examples are projects from the Riverina region of New South Wales, Australia, showing a comparison of planting efforts across a spectrum of methodologies for carbon capture and biodiversity (Reforestation by Environmental or Mallee Plantings-Full Carbon Accounting Model (FullCAM), Regent Honeyeater Project, Carbon + Biodiversity Pilot and Society for Ecological Restoration Australasia (SERA)) highlighting the differences in biodiversity outcomes.

1.1 | Biodiverse restoration—Why it matters

Biodiverse restoration presents an effective alternative to monocultures for carbon sequestration, with co-benefits for conservation (Bekessy & Wintle, 2008; George et al., 2012; Standish & Hulvey, 2014; Standish & Prober, 2020) and positive benefits to human health and wellbeing (Speldewinde et al., 2015; Turner-Skoff & Cavender, 2019). The provision of ecosystem services is higher when diverse mixtures of native species are selected for restoration plantings compared to tree monocultures (Bullock et al., 2011; Hua et al., 2022; Lamb, 2018; Standish & Hulvey, 2014). For example, biodiverse plantings provide improved provisioning services such as water quality and habitat structure (Cunningham et al., 2015; Hua et al., 2016), increased soil nutrient availability (Cunningham et al., 2015), and greater productivity (Cardinale et al., 2012) relative to low diversity mixtures.

It is also likely that biodiverse plantings with native species yield increased regulating services in the long-term, because of their capacity to adapt to climate and disturbances such as fire, drought and herbivory (Cunningham et al., 2015; Gong et al., 2020).

For example, biodiverse plantings have been found to provide increased functional resilience to stressors such as invasive species or pathogens (Oliver et al., 2015; Speldewinde et al., 2015), and more stable carbon stores during climate extremes (e.g., heatwaves and drought) compared to species-poor plantations (Hutchison et al., 2018; Isbell et al., 2017; Osuri et al., 2020). Moreover, biodiversity delivers important cultural services to people such as improved mental health (Berman et al., 2012), increased physical activity (Bell et al., 2008), and greater community ties (Turner-Skoff & Cavender, 2019). These benefits to people will, however, only be sustainable where restoration is maintained over the long term through management (e.g., logging prevention, and weed or fire risk mitigation). Therefore, long-term strategies to maintain carbon sequestration benefits must recognise and incorporate the explicit role people and their values play in the managment of plantings.

Effective restoration has been identified as a major land management action to reduce risks associated with land degradation and meet conservation and climate change adaptation targets (Jung et al., 2021; Mappin et al., 2019; Strassburg et al., 2020). Estimates suggest that up to 20% of Earth's surface is considered degraded (Sutton et al., 2016), costing US$231 billion per year in economic losses (Nkonya et al., 2016) and contributing to 22% of the global carbon footprint (IPCC, 2019). Recent global initiatives, such as the United Nations Decade on Ecosystem Restoration, and the Kew Declaration to protect and restore the world's forests (Declaration Drafting Committee, 2022) are helping to drive high quality restoration efforts with positive co-benefits for carbon sequestration, people and biodiversity. Biodiverse restoration is also relevant to the international sustainable finance agenda, where investment decisions are increasingly being made based on the environmental impact of projects. For example, there is a growing global interest in accounting for ecosystem services, with markets for biodiversity rapidly emerging (Jenkins et al., 2004; Kareiva et al., 2011; Lambooy et al., 2018).

1.2 | How is the concept of biodiversity included in carbon markets?

The global carbon market could play an important role in incentivising biodiversity restoration for voluntary and compliance purposes through regulating the production and trading of carbon and biodiversity credits. We anticipate this role may grow in importance and eventually overtake historical motivations for restoration such as reinstating cultural and environmental values (Clewell & Aronson, 2006; Jellinek et al., 2019; Prober et al., 2017). The growing appreciation for nature through natural capital accounting, and the appetite for businesses to consider the nature-related opportunities and risks, such as the developing Taskforce on Nature-related Financial Disclosures (https://tnfd.global/), will also incentivise biodiversity restoration.

To ensure that various biodiverse plantings are equivalent, legislation and market standards set benchmarks for measuring and quantifying both aspects of carbon and biodiversity. Despite these benchmarks, differences among stakeholders in the way that biodiversity is defined and incorporated into reforestation projects remain, reflecting multiple interpretations about biological diversity and the ecology of restoration. In parallel, the scientific concept of biodiversity and ecosystems may not accommodate the profound connection to country and homelands of First Nations people the world over, with consequences for how reforestation may be valued and undertaken by and with them.

This paper reviews how the concept of biodiversity is defined and applied among stakeholders (e.g., governments, carbon certifiers and farmers) engaging in reforestation and identifies best-practice methods for restoring biodiversity in these projects. We also encourage greater recognition of the perspectives of First Nations people (who we term 'rights holders') in emerging carbon and biodiversity markets.

2 | METHODS

2.1 | Synthesising common narratives and definitions of 'biodiverse' plantings

Using information communicated in publicly available documents and organisational websites, we review perceptions of biodiversity among a suite of stakeholders commonly involved in reforestation (i.e., governments, carbon certifiers and farmers). We also attempt to place First Nations rights holders into our review, by exploring the intersection between scientific definitions of biodiversity and indigenous knowledge systems as communicated in public documents. We focus our study on Australia, where there is an active need to inform the development of meaningful biodiversity outcomes in the carbon market, as is the case for many regions globally. In Australia, formal methodologies for carbon reforestation based on underlying legislation have been developed (Commonwealth of Australia, 2014). This unique degree of regulation and systems in place could inform the implementation of biodiverse reforestation in countries with less regulation. Further, Australia has extensive areas of degraded woody ecosystems (e.g., *Eucalyptus* woodlands, *Acacia* woodlands, low closed forests and tall closed shrublands; ∼11 million ha; Mappin et al., 2022) where the planting of trees, supplemented by the addition of diverse mid and understorey vegetation, may return ecosystems to reference states providing benefits for both carbon and biodiversity. We acknowledge the potential for Australian perspectives to differ from those in other market schemes (e.g., DEFRA biodiversity metric 3.0 [UK], Conservation Banking [USFWS]).

We define a stakeholder as an organisation or individual engaging directly with the carbon sequestration aspect of restoration programmes (e.g., providing land, advising on plantings, conducting plantings, regulating plantings or buying and selling credits) (Figure 2). These stakeholders represent the market regulator (in this case government), carbon offset generators who are major landholders (famers) and market providers that act as clearing houses for unnamed landholders (termed here 'carbon certifiers'). We explore where gaps and commonalities lie between stakeholder groups and rights holders when defining biodiverse plantings and, importantly, how the definitions being used relate to long-standing scientific concepts about quantifying plant biodiversity.

3 | RESULTS

3.1 | How the science community defines biodiversity in restoration

Scientific definitions of biodiversity typically encompass multiple attributes within and among levels of biological organisation, including taxonomic, functional and phylogenetic diversity. The collection of organisms, functions and evolutionary lineages assembled at a given site is increasingly determined not only by abiotic conditions and complex trophic interactions but also by the impacts of people on the environment. In many locations globally, local biodiversity reflects both natural and human-accelerated disturbance regimes, which shape composition (e.g., fire regimes and land clearing). In the context of restoration plantings, there is often a focus on functional diversity, the goal being to establish a diverse mix of plant functional traits and types that support the key functions of the reference community (Hulvey et al., 2013; Pichancourt et al., 2014). Researchers also emphasise the role of taxonomic diversity (e.g., species richness and

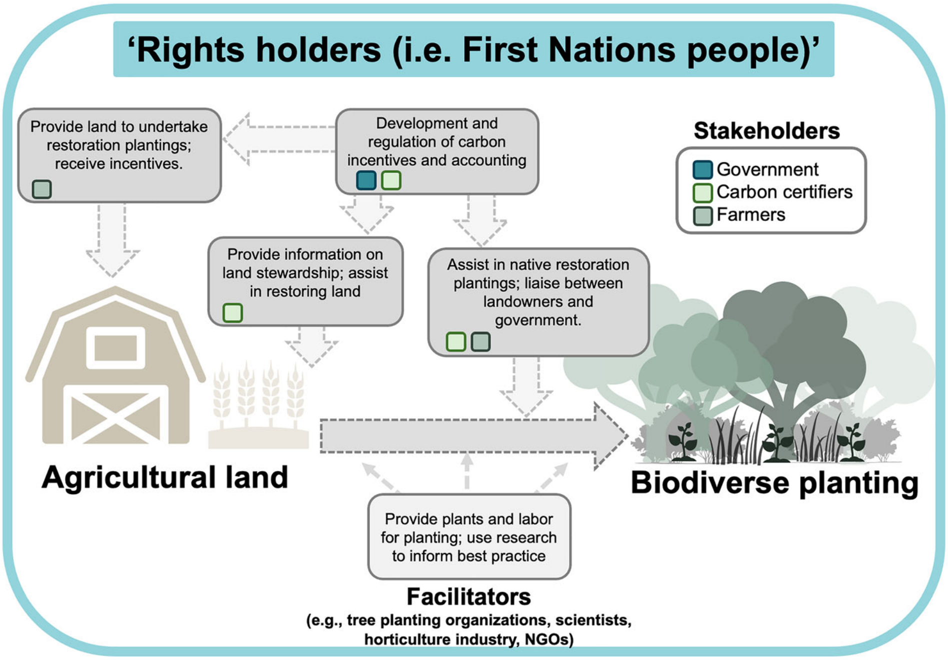

FIGURE 2 Schematic representation of a biodiverse planting pathway, illustrating the need to consider how rights holders such as First Nations groups wish to engage in carbon and biodiversity markets and the potential involvement of different stakeholder groups throughout the process. Facilitators (e.g., tree planting organisations, scientists, the horticultural industry and non-government organisations, NGOs) have also been included to highlight the practical role that these groups play in realising biodiverse reforestation.

species composition) (Martin et al., 2021; Pörtner et al., 2021; Standish & Hulvey, 2014) specifically the inclusion of native plant species whose composition, structure and function references the historical plant community of that region (Lewis et al., 2019; Seddon et al., 2021) and promotes symbiotic interactions with species from other trophic levels such as fungi, seed dispersers and pollinators (McAlpine et al., 2016; Steidinger et al., 2019). Restoration scientists may also define biodiversity in terms of high genetic diversity or provenance variability (Aerts & Honnay, 2011; Di Sacco et al., 2021; Hoban et al., 2020). Increasingly, biodiversity is considered for its contribution to resilience under projected climate change or stochastic environmental disturbances (Booth et al., 2012; Booth & Williams, 2012). Here, the focus is on restoring function, rather than species composition of historic reference ecosystems, which may be an appropriate goal when restoration to a historic reference is unrealistic (Hobbs et al., 2014). These nuanced definitions of biodiversity reflect many decades of debate and refinement and offer robust benchmarks for the inclusion of biodiversity in carbon markets.

The scientific definition of what constitutes a biodiverse planting can, therefore, be recognised as *one that references an intact plant community, is self-sustaining and resilient to disturbance and contains a mix of native species from different provenance origins with functional traits that support key functions of the reference community*. This is reflected in the National Standards for the Practice of Ecological Restoration in Australia (SERA, 2021), which defines biodiverse restoration by how well the restored system mimics a local and native reference ecosystem, in terms of species composition, structure, physical characteristics and function. Under these guidelines, the best recovery rating defines biodiversity in restoration practice as containing >80% of the species composition, in addition to physical, structural and functional characteristics comparable to a reference site (Standards Reference Group SERA, 2021). These standards also provide clear strategies for ecological restoration activities, which include planning, implementation and monitoring methodologies, as well as a framework for evaluating overall restoration outcomes. We believe biodiverse reforestation activities for carbon capture should aim for ecosystem restoration where possible and consider the adoption of these standards as best-practice (Figure 1).

Increasingly, the scientific community have acknowledged the existence of novel ecosystems and no-analogue ecological futures, which challenge the aspirational goals of the SERA standards (Hobbs et al., 2014; Munera-Roldan et al., 2022). New frameworks have been developed for making decisions to benefit biodiversity and people in these modified landscapes (Magness et al., 2022). Climate change is of particular concern as it will require (1) a re-framing of what we mean by 'local' biodiversity as species move to track their preferred climate and (2) strategies for restoration where local native species are unlikely to persist under climate change (Prober et al., 2015). Furthermore, seed limitations are another constraint to restoration that may require practitioners to focus on planting species that restore particular functions of a reference site over native taxonomic composition (e.g., functional analogues or preferentially selecting native species where seeds are available), which may be an appropriate goal when restoration to a historic reference is unrealistic due to germplasm limitations, germination or establishment constraints or disease introductions (Hobbs et al., 2014; Laughlin, 2014; Young et al., 2009). It is an open question as to when the novel ecosystem becomes the reference system, or when naturalised species are considered a part of local biodiversity or catalysts for restoration (Schlaepfer et al., 2011), but the answer is likely informed by stakeholder values and attachment to place and how ecosystems and plants are utilised by people.

3.2 | Stakeholder approaches to biodiversity

It is widely recognised that biological diversity supports the maintenance and function of ecosystems, which, in turn, provide important services to people (Pörtner et al., 2021). However, benchmarks of biodiversity in carbon projects depend on the stakeholder groups involved, their motivations, resources and end goals (Torabi, Cooke, et al., 2016). Notably, different stakeholders are interested or motivated by different levels of biological organisation (genes, species, populations, communities and ecosystems), and functions of biodiversity (e.g., carbon capture, resilience to disturbance and habitat provisioning). Different stakeholders are also motivated by different parts of the process; some are focused on carbon sequestration (and associated revenue), while others are primarily focused on restoring lost biodiversity and carbon credits are a financial mechanism that allows them to do so or to increase their impact.

3.3 | Governments

Australian governments have a long history of funding land restoration initiatives (e.g., National Landcare Program, Caring for our Country, Biodiversity Fund Program, Environment Restoration Fund, 20 Million Trees Project and Natural Heritage Trust); however, the carbon credit market provides an opportunity to achieve greater outcomes for restoration because landholders are directly compensated for the loss of land otherwise committed to agricultural production or other land uses and also provides funding to allow the restoration to occur. The Reforestation by Environmental or Mallee Plantings Methodology under the federal *Carbon Credits (Carbon Farming Initiative) Act* significantly boosted the potential for biodiversity restoration by farmers seeking to earn carbon credits. However, in practice this methodology allowed the planting of either species mixes or single-species monocultures of mallee eucalypts, with no requirement to reference a historical forest or woodland (Commonwealth of Australia, 2014).

Recently, the Australian Government has explored combining carbon and biodiversity outcomes through the 2021 Carbon + Biodiversity Pilot programme (Department of Agriculture, Water and the Environment, 2021). This rewards farmers who plant native trees consistent with planting protocols developed by the former Department of Agriculture, Water, and the Environment. If plantings are in accordance with these protocols, participants receive biodiversity payments in addition to carbon credits. Under these protocols, biodiverse plantings must mimic a local vegetation community or consist of a low richness mix of tree and shrub species native to the local area. Under the Carbon + Biodiversity Pilot, minimum species requirements for biodiversity credits are grouped as trees or shrubs with no requirement to plant grasses or other herbaceous vegetation to receive biodiversity payments. The minimum species requirements under the pilot vary by bioregion and consist of 2–5 tree species and 0–5 shrub species. The pilot protocol also suggests the inclusion of plants that are resilient to drought and the potential effects of climate change, sourced from local tube stock and seed and a that a diverse mix of mid-storey and ground cover species are planted.

3.4 | Carbon certifiers

To mitigate the effects of climate change, various carbon offset organisations work with landholders, especially farmers, to restore native woodlands and forests with a focus on biodiverse plantings. Some Australian organisations involved in these projects define biodiversity and what constitutes a biodiverse planting as follows:

1. CO_2 Australia defines their biodiverse plantings as a mix of native trees and shrubs, focusing on those that are densely planted to shelter adjacent crops and tolerant to drought, disease and fire. Species are also selected based on their ease of integration into existing cropping paddocks (CO_2 Australia, 2019).
2. Greenfleet defines biodiversity as a mix of native species that are native to the local area with an emphasis on highly functional groups that are resilient to climate change and are assumed to improve soil and water quality and provide habitat or resources to native wildlife (Greenfleet, 2020).
3. Carbon Neutral Australia selects native species with diversity and composition relative a reference ecosystem and specifies quantitative targets for their projects. Depending on the site being restored, Carbon Neutral defines a biodiverse planting as consisting of between 20 and 30 different tree, shrub, and grass species (Carbon Neutral, 2021). Carbon Neutral also independently measures and monitors changes in the diversity, density and health of each planting site for up to 5 years after planting using the preplanting condition as a baseline.

3.5 | Farmers

Many landholders, including graziers and farmers, are seeking to restore cleared land with the aim to earn carbon credits through sequestration, while also encouraging biodiversity and providing ecosystem services for crops and livestock (Torabi, Cooke, et al., 2016; Torabi, Mata, et al., 2016). There is a growing recognition among farmers that planting a diverse mix of native species can increase agricultural productivity by providing crops with shade, shelter, and salinity control (Campbell et al., 2017), erosion mitigation (Isbell et al., 2017), pollination services (Gardon et al., 2020) and decreased impacts of flash floods and drought (Gardon et al., 2020). These additional benefits are a major motivator for farmers to engage in biodiverse native restoration plantings.

Prior to the announcement of the Carbon + Biodiversity pilot, the Australian Farm Institute conducted a critical review on the critical success factors required to effectively implement an on-farm biodiversity scheme (McRobert et al., 2020). This review summarised the outcomes from many workshops with Australian farmers in which many interviewees expressed the need to clearly define how biodiversity might be assessed and implemented into on-farm biodiversity schemes (e.g., species richness and soil health). Additionally, a review discussed the efficacy of voluntary biodiversity markets and also found the vague definition of tradable biodiversity metrics within the market to be a key barrier to implementation and success (KMPG, 2019; Needham et al., 2019). These concerns further justify the need to provide clear definitions to farmers of what constitutes a biodiverse planting when implementing reforestation projects.

3.6 | Rights holders and concepts of biodiversity

Indigenous knowledge systems remain an integral part of land management practices globally, and Indigenous rights are increasingly recognised through legislative means. For instance, in Australia approximately 40% of the continent is recognised, by law, as Indigenous owned where the rights and interests to land and waters according to traditional law and customs is provided (Federal Court of Australia, 2020). First Nations communities hold deep local, historical and cultural knowledge that must be recognised and respected when undertaking reforestation activities (Renwick et al., 2014; Saunders et al., 2002). For First Nations communities, the concept of biodiversity embeds people among all living things and their interrelationships (Walsh et al., 2014). Biodiversity remains central to many of these communities with respect to culture, identity, medicines and food (Latz, 1996; Rose et al., 2011).

Many First Nations communities wish to preserve biodiversity, which is culturally significant, and may see the economic and cultural benefit of sharing their knowledge and practices with those seeking to restore degraded land (Renwick et al., 2014; Walsh et al., 2014). In this way, reforestation or broader restoration plantings represent an emerging opportunity to provide a revenue stream for First Nations communities, noting that their aspirations and intentions for land use are self-determined. Carbon Offsets Australia is one Indigenous-owned environmental organisation that delivers biodiverse plantings for carbon sequestration. This organisation selects species that are native to the area being restored and recognises the importance of restoring soil health when implementing biodiverse plantings (Carbon Offsets Australia, 2021). More broadly, where guided by First Nations people, biodiverse plantings may be built around the inclusion of culturally significant species (Rose et al., 2011), species that provide habitat for native animals (Di Sacco et al., 2021) and species that existed in the original community prior to contact (Walsh et al., 2014). Securing full consent and engagement when planning biodiverse plantings is integral to identifying culturally appropriate ways to sequester carbon that benefit biodiversity and First Nations livelihoods (Renwick et al., 2014). It is therefore important to collaborate meaningfully and economically with First landowners and elders when selecting appropriate species to include in biodiverse plantings, due to the differing values that may exist (Di Sacco et al., 2021).

4 | DISCUSSION

4.1 | Where do the gaps and commonalities lie in definitions of biodiverse plantings?

The features of biodiverse plantings most common to the stakeholders described are the inclusion of native species and *some* proportion of the diversity present in the original reference ecosystem. However, our findings show that some approaches to biodiversity are not common between stakeholders and researchers, and there is substantial untapped potential for augmenting scientific approaches to biodiverse reforestation with First Nations perspectives.

=Although some of the planting protocols and guidelines we have summarised give quantitative targets, many are not explicit with defining or quantifying biodiversity and, as a result, do not give targets at which such plantings should aim. Where targets are proposed, further research is required to explore the efficacy and practicality of different protocols in restoring functional, resilient ecosystems in the long-term, particularly under future climates. Researchers suggest that setting clear, quantifiable targets is an essential foundation for successful reforestation projects (Miller et al., 2017; Shackelford et al., 2013). To set adequate targets, it is suggested that projects aim to restore species diversity, and structural composition comparable to a healthy reference ecosystem (Ruiz-Jaen & Mitchell Aide, 2005). Additional factors that should be considered when setting targets may include ensuring the restored site contains a diverse suite of ecological traits (Engst et al., 2017; Gallagher et al., 2021; Garbowski et al., 2020; Laughlin, 2014) and genetic diversity (Hoban et al., 2020) allowing it to withstand environmental disturbances and long-term climatic change (Lake, 2013; McNellie et al., 2020); and whether the project has been designed for landscape integration (Shackelford et al., 2013; Thomson et al., 2009). This is an important over-arching goal of biodiverse restoration that underscores the need to come to a consensus about what constitutes a biodiverse planting across landscapes and contexts.

We also see that some stakeholders are vague with their definitions of what constitutes a biodiverse planting. Research suggests a biodiverse planting should consist of at least 20 to 30 different native species per hectare or >80% of the species composition of the reference site and include representation of different strata or plant functional types (e.g., trees, shrubs, herbs and grasses). Although this is consistent with the species diversity Carbon Neutral defines when planting (Carbon Neutral, 2021), the minimum number of species required under the initial guidelines of the Carbon + Biodiversity Pilot offset scheme for some regions is as little as two with encouragement to but no requirements to plant herbaceous or grass functional types. While biological diversity may increase over time without further intervention as plants and animals colonise a site, this may not be the case for some species (e.g., native herbs) (Parkhurst et al., 2021). Further research is needed to determine what species might need further intervention and how these interventions might be monitored and incentivised through biodiversity payment schemes.

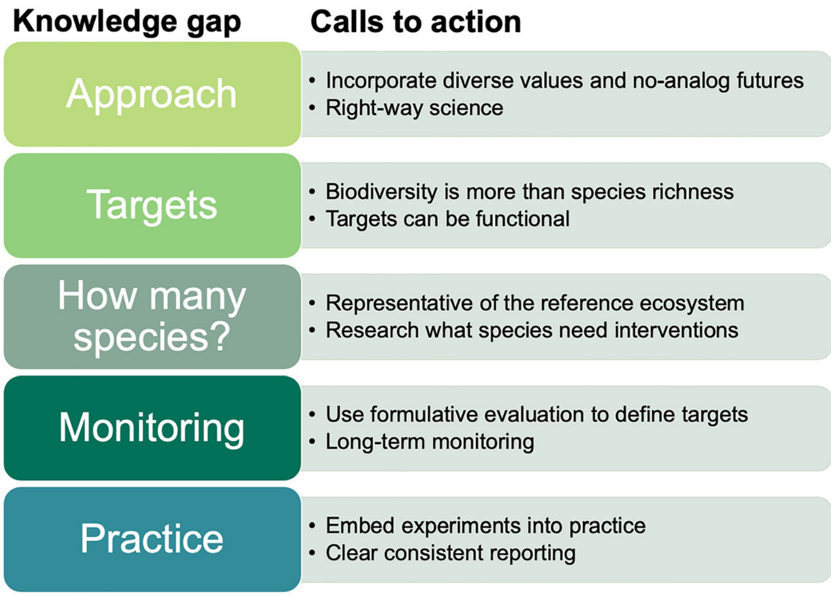

FIGURE 3 'Calls to action' for key knowledge gaps in biodiverse plantings identified from this study designed to maximise benefits of biodiverse plantings for carbon sequestration and ecological restoration

We acknowledge that rigid quantitative guidelines of what constitutes 'biodiversity' are limited in what they can offer in real world biodiverse reforestation scenarios. We suggest that practitioners consider undertaking formulative evaluation processes to identify potential and actual influences on restoration outcomes when designing monitoring programmes, such as the use of bioindicators or functional groups related to particular ecosystem functions, as these have been useful in biodiversity monitoring, agroecological and restoration schemes (Cavender-Bares et al., 2017; Chiatante et al., 2021; Gallagher et al., 2021; Moonen & Barberi, 2008; Muramoto & Gleissman, 2020). We also recommend standards for clear and consistent reporting over the life of biodiverse plantings projects be put in place to enhance learning opportunities and value of current projects to future practitioners.

5 | CONCLUSION

Biodiverse plantings for carbon sequestration and biodiversity restoration necessitate long-term commitments from stakeholders and right-holders. This underscores the importance of reaching a consensus on biodiverse plantings from the outset. While carbon projects have introduced a new norm for some farmers and foresters given the 100-year permanency requirement, biodiverse carbon projects may require more planning and additional intervention (e.g., weeding and infill planting) (Brancalion et al., 2019; Galatowitsch & Bohnen, 2020). Research on trade-offs between cost-effectiveness and species diversity, planting scale, propagule type and site management will help to ensure resource limitations do not come at the cost of a restoration project's end goal (Ager et al., 2017; Brancalion et al., 2019; Cole et al., 2011; Wilkerson et al., 2014). Similarly, it will be critical to assess the success of the biodiversity payments scheme as a funding model to adequately support restoration activities beyond the initial planting.

In summary, only by clarifying the utility of and standards for biodiverse plantings are we able to maximise their value to biodiversity, carbon sequestration and livelihoods (Figure 3). Moreover, incorporating both qualitative and quantitative values upheld by right-holders and stakeholders in the planning phase will create stronger links between people and biodiversity and help pave the way for increased dialogue between right-holders, stakeholders and researchers when undertaking the science and practice of reforestation. We acknowledge that we have provided little consideration of biological diversity other than plant species diversity and genetic diversity of key plant species. We also acknowledge that biodiversity loss poses an enormous threat to human existence (and all life), and we should aim to conserve any and all native ecosystems we can to mitigate this threat rather than simply offsetting our impacts. Carbon markets also have a role to play in protecting such ecosystems, through avoided deforestation protocols, however these are not discussed in this paper. While incorporating plant diversity into biodiverse carbon projects is a significant step, there is a need to test assumptions that doing so will restore other components of biological diversity such as soil biota and fauna. Finally, learnings from embedding clearer definitions of biodiversity into reforestation projects where restoring trees is the primary goal can be applied more broadly to the restoration of non-woody ecosystems to avoid perverse outcomes in emerging carbon and biodiversity markets.

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CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

AUTHOR CONTRIBUTIONS

RVG, RJH and RJS conceived the initial ideas. PEL, RVG, CMH and SGT wrote the initial draft, which was expanded by SEA, RJS and RVG in collaboration with all authors (PEL, CMH, RJH, DWB, VMA, CL, SGT, PC and CAO).

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no datasets were generated or analysed during the current study.

ORCID

Samantha E. Andres https://orcid.org/0000-0001-5477-6611
Rachel J. Standish https://orcid.org/0000-0001-8118-1904
Paige E. Lieurance https://orcid.org/0000-0001-5444-2777
Charlotte H. Mills https://orcid.org/0000-0001-5823-4924
Richard J. Harper https://orcid.org/0000-0003-0268-2917
Vanessa M. Adams https://orcid.org/0000-0002-3509-7901
Caroline Lehmann https://orcid.org/0000-0002-6825-124X
Sasha G. Tetu https://orcid.org/0000-0002-8943-3499
Peter Cuneo https://orcid.org/0000-0002-5217-370X
Catherine A. Offord https://orcid.org/0000-0002-9553-6590
Rachael V. Gallagher https://orcid.org/0000-0002-4680-8115

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