


Bridging Indigenous Knowledge Systems and Western ecological science approaches through language: the role of language in ecosystem restoration and invasive alien species management

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Dates

Submitted: 5 March 2025
 Accepted: 21 January 2026
 Published: 9 March 2026

How to cite this article:

Nxele, B.J., 2026, 'Bridging Indigenous Knowledge Systems and Western ecological science approaches through language: the role of language in ecosystem restoration and invasive alien species management', *African Biodiversity & Conservation* 56(2), a1. <http://dx.doi.org/10.38201/abc.v56.2.a1>

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Ecosystem restoration initiatives frequently overlook vital contributions of Indigenous knowledge, especially the linguistic and cultural dimensions that shape ecological understanding. Principle 6 of United Nations Decade on Ecosystem Restoration 2021–2030 emphasises the incorporation of diverse knowledge systems into restoration and promotes mutual learning. However, mainstream restoration practices often favour scientific discourse, neglecting language barriers that limit the participation of Indigenous Peoples and Local Communities (IPLCs). This paper advocates for the integration of Indigenous knowledge into mainstream restoration through translation of conservation terminology and naming invasive alien species in Indigenous languages. The study proposes a participatory framework that bridges scientific and traditional ecological knowledge. It emphasises linguistic translation and culturally grounded communication strategies to promote mutual understanding between restoration practitioners and IPLCs. The approach is grounded in co-learning and acknowledgment of linguistic diversity as a cornerstone of equitable knowledge exchange. Integrating Indigenous languages and perspectives into restoration enhances comprehension of environmental challenges within local contexts. It improves community participation in decision-making, strengthens native biodiversity conservation, and supports efforts to manage invasive alien species. The process fosters legitimacy and long-term commitment to restoration initiatives among IPLCs. Embedding Indigenous knowledge and language into restoration practices ensures initiatives are ecologically sound, culturally meaningful and socially inclusive. This integration empowers IPLCs to actively engage in restoration and supports equitable governance and reinforces ecosystem resilience. Recognising and valuing linguistic and cultural diversity strengthens global restoration efforts through collaborative, bottom-up action.

Keywords: Indigenous Peoples and Local Communities, IPLCs, socio-ecological systems, biological invasions, knowledge sharing, lexicon, inclusivity.

Introduction

Natural ecosystems provide essential services that sustain human livelihoods (IPBES 2019; Nyathi et al. 2025). Since ecosystem services are intrinsically linked to biodiversity, poor ecosystem management degrades livelihoods and reduces food production (Ahrends et al. 2015; Birhane et al. 2025). Human population growth and global environmental changes intensify pressure on natural systems, threatening biodiversity and ecosystem functionality (Adger 2003; Kumar et al. 2019; Birhane et al. 2025). In response, global restoration commitments emphasise structured, science-based frameworks to guide

effective interventions (Gann et al. 2018; Rong et al. 2025). When implemented sustainably, restoration enhances biodiversity, human well-being and economic prosperity (Gann et al. 2019; Birhane et al. 2025), whereas poorly executed efforts may deepen ecological degradation and social vulnerabilities (Kumar et al. 2019; Osborne et al. 2021; Birhane et al. 2025).

A critical yet often overlooked dimension of restoration is the participation of Indigenous Peoples and Local Communities (IPLCs). Western ecological science has historically marginalised Indigenous Knowledge Systems (IKS) in environmental management (Matemba & Lilemba 2015; Magni 2017; McAllister et al. 2019; Shabalala 2025). Inclusive restoration, anchored in co-learning, knowledge exchange and IPLC participation, can enhance cultural relevance, equity and sustainability (Reyes-Garcia et al. 2019; Bulmer et al. 2024). Integrating IKS with Western science offers valuable pathways for addressing human-driven ecological decline (Bulmer et al. 2024).

Principle 6 of the United Nations Decade on Ecosystem Restoration 2021–2030 emphasises that ‘ecosystem restoration draws on all types of knowledge, promotes their exchange and integration throughout the process’ (FAO, IUCN CEM and SER 2021). Yet effective knowledge integration requires platforms where different worldviews can be negotiated meaningfully, and language remains a major barrier (Hughes et al. 2023). Historically, IPLCs have been relegated to labour roles rather than informing decision-making processes (Dai et al. 2025; Sahana 2025). To ensure socially inclusive restoration, foundational steps such as translating conservation terminology, as well as naming invasive alien species in Indigenous languages are essential in facilitating effective communication and informed decision-making, particularly in culturally diverse contexts like South Africa (Nxele et al. 2021; Osborne et al. 2021; Li & Liu 2023; Dai et al. 2025).

Nearly 40% of the global population lacks access to education in their native languages, limiting participation and self-expression in environmental decision-making

situations where the medium of conversation is not in their native languages (Walter & Benson 2012). Since vast ecological knowledge is embedded within IKS, bridging linguistic gaps and challenges through indigenous language integration can unlock this shortfall (UNESCO 2016; Leighton 2022). Understanding ecological concepts in one’s native language improves comprehension, information processing and communication (World Bank 2021; Farangi & Naami 2024; Igarashi et al. 2024).

Creating enabling environments for linking IKS to mainstream science can encourage and improve IPLC participation in collaboratively managing ecosystems that sustain their livelihoods (Eyong 2007; Franco-Moraes et al. 2021; Osborne et al. 2021; Dai et al. 2025). IPLCs, collectively, manage over half of the world’s landscapes, including forests and grasslands shaped by socio-cultural norms (Pearce 2016; Costanza et al. 2017; Sangkachai et al. 2025; D’Ambrosio et al. 2026). However, exclusionary policies, cultural barriers and language barriers often marginalise their contributions, undermining biodiversity, public health and food security (Andrianto et al. 2019; Gammelli et al. 2022). Addressing these barriers and challenges through inclusive governance strengthens the ecological, economic and social pillars of restoration and mitigates threats such as biological invasions (Szalkiewicz et al. 2020; Nxele et al. 2024).

The study aimed to (a) advance the integration of Indigenous knowledge into mainstream ecosystem restoration by emphasising linguistic inclusion as a pathway to equitable participation. Specifically, it sought to (b) strengthen awareness, communication and inclusivity in restoration processes through the translation of conservation terminology and the Indigenous naming of invasive alien species (see Tables 1 and 2). By doing so, the study aspired to (c) bridge knowledge systems, foster cultural relevance in restoration discourse, and empower Indigenous communities as active partners in environmental stewardship. To achieve this, we examined past large-scale restoration projects to assess IPLC participation as an opportunity for Indigenous knowledge integration. Specifically, we analysed (1) the extent to which IPLCs were involved in restoration

Table 1. Some of the terms commonly used in conservation, which do not have direct, well-known terms in isiZulu, and the translation of which, whenever attempted, will differ from one translator to the next. When there is no commonly known, indigenous term used, confusion and/or loss of meaning during translation, is bound to take place

Conservation terminology	isiZulu context
Adaptation	‘ <i>Ukuthatha isimo</i> ’, but there is no commonly known term.
Aquifer	‘ <i>Idwala elingaphansi komhlaba, elinamanzi</i> ’, but no common term.
Biodiversity	‘ <i>Imvelo nokwehluka-hlukana kwayo</i> ’, interchangeably used with ‘nature’.
Biodiversity stewardship	No definition within isiZulu lexicon.
Bio-indicator	No definition within isiZulu lexicon.

Table 1. Some of the terms commonly used in conservation, which do not have direct, well-known terms in isiZulu, and the translation of which, whenever attempted, will differ from one translator to the next. When there is no commonly known, indigenous term used, confusion and/or loss of meaning during translation, is bound to take place (continued)

Conservation terminology	isiZulu context
Biome	No definition within isiZulu lexicon.
Bioprospecting	'Uhlelo lokuthungathwa kwamalunga emvelo', but no definite term in isiZulu.
Biosphere	No definition within isiZulu lexicon.
Buffer zone	No definition within isiZulu lexicon.
Community participation	No direct definition in isiZulu, signifying the initiator.
Ecotone	No definition within isiZulu lexicon.
Ecosystem	'Ubudlelwanomvelo', but no definite term in isiZulu.
Ecosystem degradation	No definition within isiZulu lexicon.
Ecosystem restoration	No definition within isiZulu lexicon.
Ecosystem services	'Izinsizakuphila', but no definite term in isiZulu.
Ecosystem Support Area	'Indawo eyeseka ubudlelwanemvelo obukhona kwenye indawo', but no definite term in isiZulu.
Ex situ conservation	No definition within isiZulu lexicon.
Genetically modified	No definition within isiZulu lexicon.
Genetic material	No definition within isiZulu lexicon.
Green economy	No definition within isiZulu lexicon.
Habitat	No definition within isiZulu lexicon.
In situ conservation	No definition within isiZulu lexicon.
Invasive	No definition within isiZulu lexicon.
Invasive alien plants	'Isimila esikhula ngokudlondlobala endaweni esingatholakali kuyona ngokwemvelo', but no definite, commonly known term in isiZulu.
Invasive alien species	'Isimila noma isilwane esikhula ngokudlondlobala endaweni esingatholakali kuyona ngokwemvelo', but no definite, commonly known term in isiZulu.
Micro-organism	No definition within isiZulu lexicon.
Mitigation measure	No commonly known term in isiZulu.
Overgrazing	No definition within isiZulu lexicon.
Pollination	No definition within isiZulu lexicon.
Pollution	No commonly known definition in isiZulu.
Rehabilitation	No definition within isiZulu lexicon.
Riparian zone	No definition within isiZulu lexicon.
Savanna	No definition within isiZulu lexicon.
Socio-ecological	No definition within isiZulu lexicon.
Succession	No definition within isiZulu lexicon.
Sustainable Development Goals	No definition within isiZulu lexicon.
Systematic Conservation Planning	No definition within isiZulu lexicon.
Topography	No definition within isiZulu lexicon.

Table 2. Some Invasive Alien Species, after co-existing with IPLCs, are given names that are also used for indigenous species, or get intertwined with culture as they get referenced in idioms of that culture

English common name	Scientific name	IsiZulu context (indigenous language dominantly spoken in KwaZulu-Natal, South Africa)
Brazilian pepper	<i>Schinus terebinthifolius</i>	'Isibhaha', name also used for <i>Warburgia salutaris</i> , which is an indigenous plant in South Africa (SA) (Nxele et al. 2019).
House Crow	<i>Corvus splendens</i>	'Igwababa lokufika', no officially regulated* name (unpublished work by Nxele et al.).
Lebbeck tree	<i>Albizia lebbeck</i>	'Usolo' but the name is also used for <i>Albizia adianthifolia</i> , which is an indigenous plant in SA. (Nxele et al. 2019).
Leucaena	<i>Leucaena leucocephala</i>	'Uboobo', name also used for <i>Adenopodia spicata</i> , which is an indigenous plant in SA. (Nxele et al. 2019)
Madeira vine	<i>Anredera cordifolia</i>	'Idungasivande', no officially regulated name until article published in 2021 (Nxele et al. 2021).
Mauritius thorn	<i>Caesalpinia decapetala</i>	'Uboboluncane' name also used for <i>Adenopodia spicata</i> , which is indigenous in SA (Nxele et al. 2019).
Pereskia	<i>Pereskia aculeata</i>	'Iqwaningi', name also used for <i>Capparis tomentosa</i> , which is an indigenous plant in SA (Nxele et al. 2019).
Pom-pom	<i>Campuloclinium macrocephalum</i>	'Indlolothi', name also used for <i>Moraea spathulata</i> , which is an indigenous plant in SA (Nxele et al. 2019).
Red-eared slider	<i>Trachemys scripta</i>	No name but found as an escapee in SA. Needs to be given a regulated name so that it is not given a name used for an indigenous species (Nxele et al. 2019).
Ringneck Parakeet	<i>Psittacula krameri</i>	No specific name yet but loosely referred to as 'upholi', which is a name for parrots. Ringneck Parakeets, an escapee species, are now found in the wild in SA.
Water hyacinth	<i>Eichhornia crassipes</i>	'Uzibo', reports indicate there is an indigenous plant called 'uzibolizibu' or 'amazibo', but not sure of the exact species (Nxele et al. 2019).
Water lettuce	<i>Pistia stratiotes</i>	'Indwane', no other plant has this name but is used in isiZulu saying 'umfula udla izindwane'. It has thus become part of the culture.
Yellow bells	<i>Tecoma stans</i>	'Insimbephuzi', had no officially regulated name until article published in 2019 (Nxele et al. 2019).

***regulated**, in this context, refers to a name that has been scrutinised through various relevant forums, including practitioners and local communities to ensure the name, proposed for an Invasive Alien Species, is not used for an indigenous species.

work; (2) whether IPLC perspectives were integrated into planning, goal setting and decision-making; and (3) missed opportunities where IPLCs could have been engaged but were not.

The study intends to underscore opportunities ecosystem restoration interventions have while IPLCs are involved in knowledge exchange by addressing language barriers first.

Methods and materials

Literature search

The literature search was conducted systematically to gather relevant and comprehensive information on the

topic (see Figure 1, below). Peer-reviewed journal articles, books and conference proceedings were primarily sourced from academic databases such as Google Scholar, Web of Science, CABI and Scopus. Keywords and phrases related to the research topic, such as 'community-based', 'large-scale', 'ecosystem restoration', 'ecosystem services' as well as 'biodiversity' were used to identify relevant studies.

Publication or year in which the activity occurred was not specified, which allowed us to observe changes in approach over time.

Data extraction and databases used

We applied the same data extraction methodology as used by Benayas et al. (2009), by searching titles and abstracts to identify citations related to community-based,

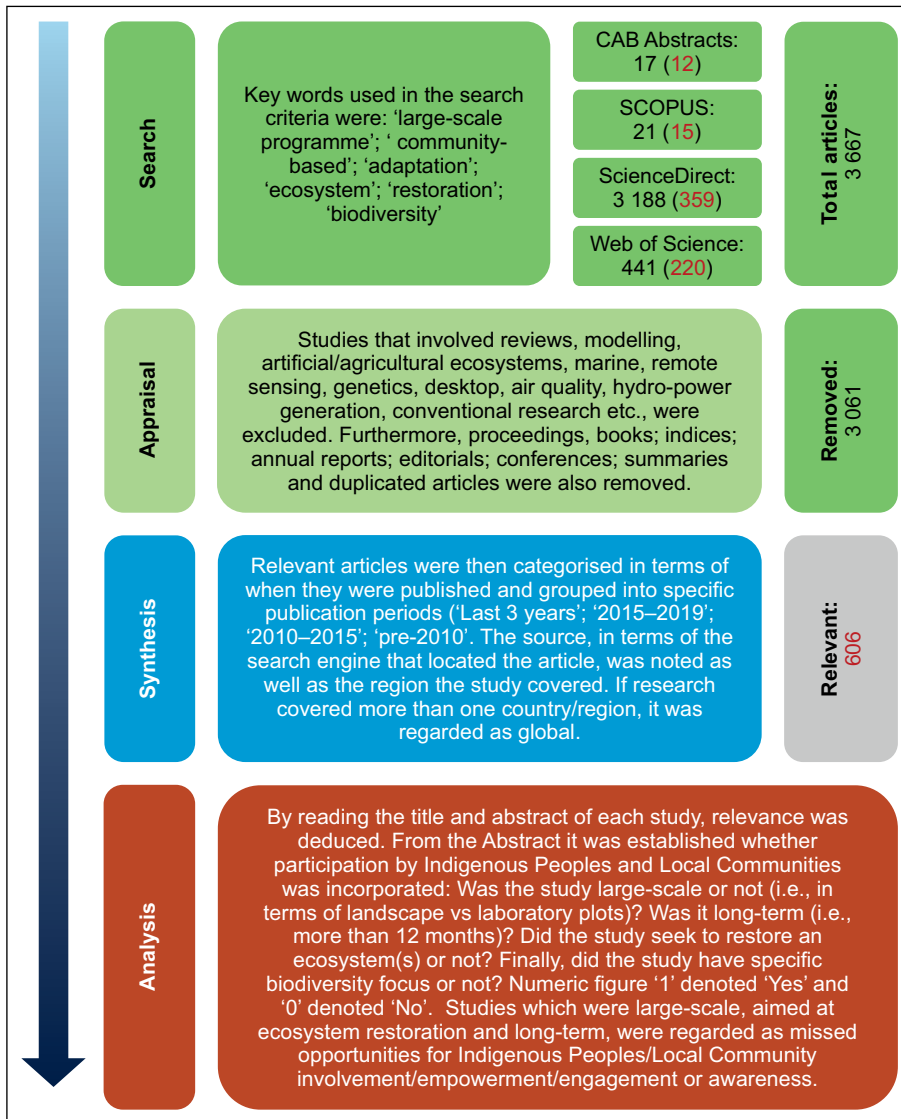


Figure 1. Diagrammatic representation of literature search, synthesis and analysis for Indigenous Peoples and Local Community (IPLC) participation in ecosystem restoration.

large-scale ecosystem restoration. To combine these terms, 'or' was used. We conducted these searches between 1 June 2021 and 22 August 2021. A total of 3 534 citations were retrieved and exported into Mendeley Reference Manager for archiving. For analysis, searched data were exported to Excel, wherein the citations were sorted by source. Book sections (648), presentations (1), summary reports (1) and proceedings (1) were removed (since we only wanted peer-reviewed literature), leaving a total of 2 882 papers in the peer-reviewed literature for analysis.

Statistical analyses

Statistical analyses were primarily descriptive and trend-based, drawing on data extracted from the systematic literature review. Frequencies and counts were used to quantify peer-reviewed publications, IPLC participation and restoration project characteristics across time, ecosystem restoration types and intervention categories. Temporal trends (1990–2022) were

visualised using time-series plots to examine changes in the prevalence of large-scale programmes, long-term projects and documented IPLC involvement. The regression was used to quantify the direction and magnitude of long-term trends, with the slope representing the average annual change in publication output. Model parameters, including the slope and intercept, were extracted and visualised alongside observed data to support interpretation of publication dynamics over time. Analyses and visualisations were conducted in R (RStudio 2026.01.0 Build 392), ensuring reproducibility and consistency in data handling, transformation and graphical presentation.

Applied evaluation methods

All the imported citations were screened for relevance by browsing through the titles and abstract. Research about anything other than the restoration of the natural environment (natural ecosystems) was excluded from the list. Duplicates were also removed from the

list. If a manuscript reported on community participation in an ecosystem restoration programme, and the programme met the descriptions of a large-scale restoration programme (made up of several projects, depending on several resources including time, budget and assets), then the programme would be included (Qui et al. 2022). Secondary citations were obtained for further applicable references by searching the literature cited in the primary manuscripts searched through the four databases mentioned earlier. All manuscripts considered relevant (and available upon request) were assessed, even though not all are explicitly cited within the body of this review. While ecosystem restoration interventions will positively impact ecosystem services, the title, abstract, keywords and objectives of a study were used to categorise the study. The categorisation thus does not undermine the lack of mutual exclusivity that exists across restoration interventions. It was broadly done to depict the participation of IPLCs in ecosystem restoration interventions.

In addition, we conducted workshops with isiZulu-speaking practitioners to identify the names of Invasive Alien Plants and conservation terminologies commonly used in ecosystem restoration (isiZulu is an indigenous language largely and dominantly spoken in the province of KwaZulu-Natal, South Africa). These workshops aimed to address the lack of equivalent terms for invasive alien plants and conservation concepts in isiZulu. Without an isiZulu lexicon around these names and terminologies, which are largely used in ecosystem restoration, engaging isiZulu IPLCs to draft framework plans and strategies for managing invasive alien species (Larson et al. 2011; Matzek et al. 2019) would have a high chance of communication challenges. Since the challenge is deep-seated within the isiZulu lexicon itself, even if someone is asked to translate, there would be no frame of reference from which to draw these names and terminologies (see Table 1). As a result, even those for whom the translation is done would still not get the message, largely because their frames of reference are not well-resourced (Van den Elzen 2024).

Results

After processing 3 667 peer-reviewed articles, only 606 were found to be relevant to this study with more than 68.3% of the consulted literature published between 2014 and 2021. These were grouped by decade to identify temporal trends in ecosystem restoration research (Figure 2). Prior to the 1990s, community-based ecosystem restoration initiatives were rarely documented. A gradual increase in related studies appeared in the early 2000s, followed by a sharp rise approaching 2010 (Figure 1). This growth reflects expanding academic attention to ecosystem restoration and related sustainability themes during that period. A steady increase in peer-reviewed articles on community participation in large-scale ecosystem restoration, occurred in the last decade.

There has been a consistent increase in peer-reviewed publications focused on ecosystem restoration over the last thirty years (Figure 1). However, the actual extent of global restoration activity is likely greater than represented in peer-reviewed literature since many community projects remain unpublished.

Data also show a steady increase in the participation of IPLCs in restoration initiatives over the same period, with a pronounced rise in the most recent decade (Figure 3). While quantitative indicators confirm the upward trajectory, qualitative aspects of participation, such as the extent of decision-making power and depth of engagement, have received limited critical, empirical analysis. IPLC participation has largely been associated with terrestrial ecosystem restoration action, with non-existent participation in cultural landscape restoration (0.99% involvement) and soil ecosystem (0% involvement) studies.

Figure 4 depicts a biased frequency participation of IPLCs in terrestrial restoration interventions, followed by ecosystem-based adaptation projects, as well as those targeted towards improving ecosystem service delivery. Limited involvement of IPLCs is noted in aquatic ecosystems, coastal zone management, governance

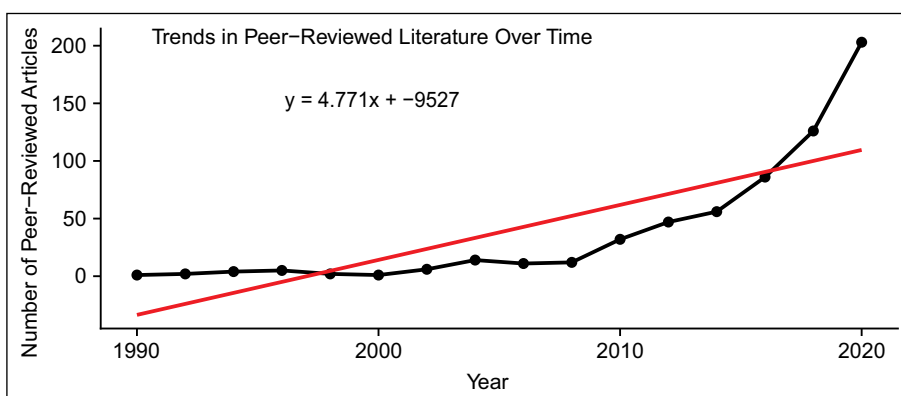


Figure 2. Trends in community-based, large-scale ecosystem restoration indicate a gradual increase in published, peer-reviewed literature over the last decade.

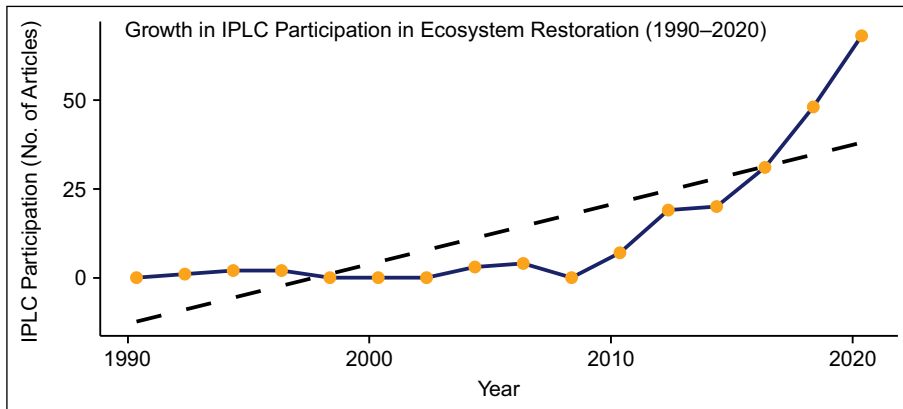


Figure 3. Trends in Indigenous Peoples and Local Community participation events in ecosystem restoration interventions between 1990 and 2022.

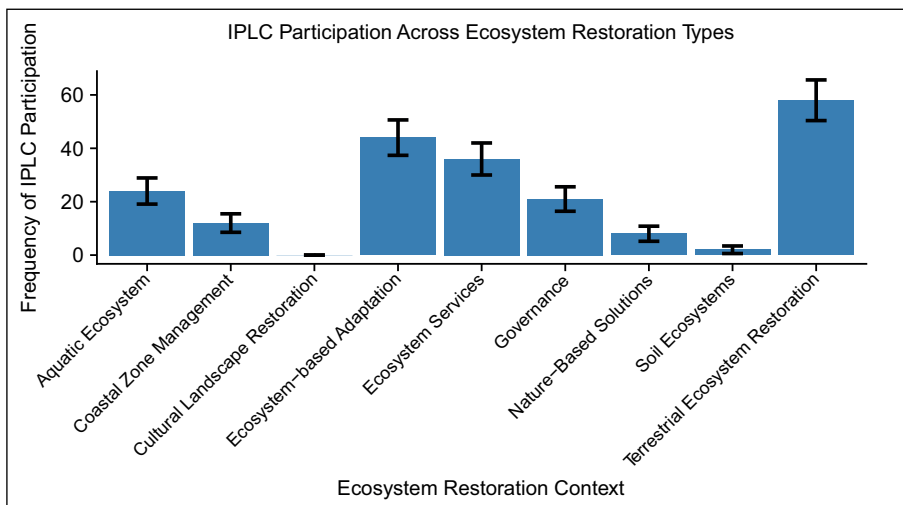


Figure 4. Frequency of IPLC participation across different ecosystem restoration intervention types. Participation was highest in terrestrial ecosystem restoration, ecosystem-based adaptation and ecosystem service projects, with lower representation in soil and nature-based solution initiatives.

practices, nature-based solutions, as well as in soil ecosystems. Note that ‘governance’, in this case, refers to research that has multiple stakeholders, including political structures like local authorities.

The analysis of project participation frequencies across nine project types revealed a mean participation of 22.8 ± 21.4 SD, indicating substantial variability in participation levels. Terrestrial restoration showed the highest participation (58), while three categories (cultural landscape restoration; nature-based solutions; and soil ecosystems) demonstrated minimal participation (< 10). Error bars, representing $\pm 10\%$ of each observation’s value, illustrate measurement uncertainty. Given the SD exceeds the mean, the data exhibits high dispersion, suggesting heterogenous participation patterns rather than consistent engagement across project types. Error margins (mean error -2.28 ± 2.14 SD) align proportionally with participation values, maintaining relative precision across the measurement range.

Figure 5 indicates that while there has been a sharp increase in the implementation of large-scale ecosystem restoration interventions in the last decade, as well as in long-term projects, the participation of IPLCs has somewhat lagged.

Figure 6 unpacks two modalities by which restoration is implemented. A top-down approach (a) originates with governments/funders and often results in IPLC engagement only taking place only during the implementation phase. The other modality (b) indicates motivation that originates from a community (bottom-up), which is very rare, and does include governments/funders to address requisite resources.

The results of this study suggest that although IPLC involvement has expanded, further research is needed to assess the nature and influence of their participation within restoration processes. Over the last three decades, ecosystem restoration has not always prioritised the participation of IPLCs since, in half the episodes of large-scale restoration, IPLCs are not involved. In the context of improving human livelihoods, empowerment, mindset change and sustainable living, when IPLCs are involved – *what* and *how much* are they benefiting beyond the mere conventional remuneration? Do their perceptions, preferences and recommendations matter in the planning and implementation of these ecosystem restoration projects, which are said to be about human livelihoods? The involvement of IPLC and the nature of their participation becomes even more relevant during the United Nations Decade on Ecosystem Restoration 2021–2030.

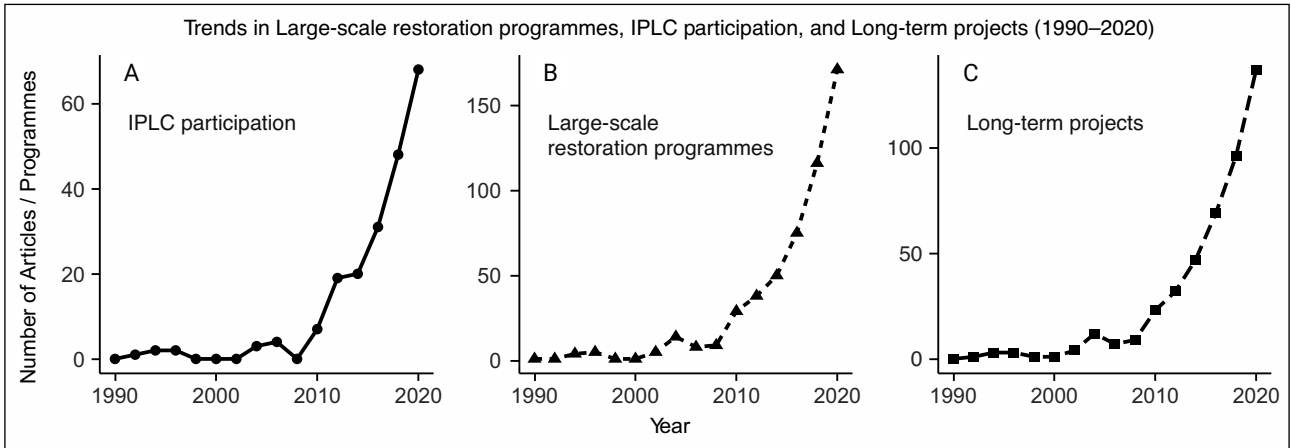


Figure 5. A, Trends in IPLC participation; B, large-scale ecosystem restoration interventions; and C, long-term projects, from 1990 to 2022. The results show a steady increase across all categories, with a pronounced increase post-2010, indicating a global growing awareness in inclusive and sustained ecosystem restoration initiatives, even though IPLC participation has somewhat lagged.

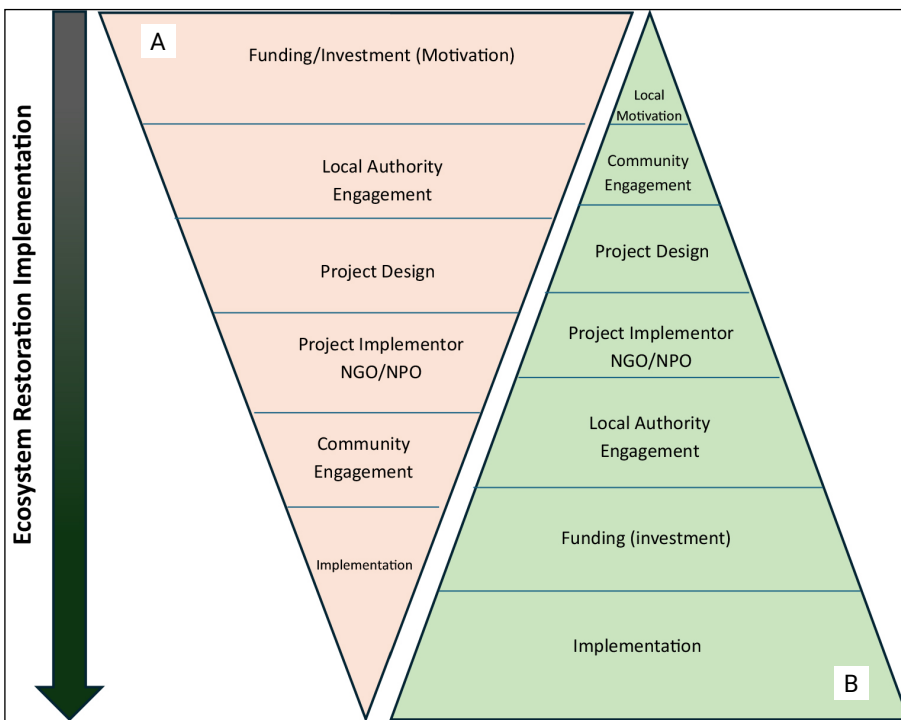


Figure 6. The implementation of ecosystem restoration work is greatly informed by (a) funding (investment) availability, which results in systems being mobilised towards project inception, planning, site selection and eventually, implementation. Community involvement is often conceptualised during the implementation phase, and awareness is created. This awareness is often project/site-specific. It is rare that a project informs funding, whereby project motivation originates with a community (b) and is escalated up to the national level for funding.

Discussion

This literature review highlights that the participation of IPLCs in ecosystem restoration has not always been prioritised. While community-based, large-scale ecosystem restoration gained traction in the 1990s – based on peer-reviewed publications – IPLC involvement began to increase around 2008 and continued to grow over the following decade (IPBES 2021). However, the literature does not indicate that IPLCs played a significant role in decision-making processes since scientists and practitioners consider Indigenous/traditional knowledge to be spiritual and governments often exclude IPLCs from decision-making processes even on matters that affect them (MacInnes et al. 2017; Andrianto et al. 2019;

Franco-Moraes et al. 2021). Instead, it suggests that IPLCs were primarily engaged in labour-related tasks, as many studies do not specify their exact contributions. Additionally, there is little discussion regarding potential language barriers when working with IPLCs or how such challenges, if present, were addressed. For example, did IPLCs have a voice in determining where and how restoration interventions were implemented? If their involvement were limited to implementation without contributing to the knowledge base of restoration efforts, this could be considered a missed opportunity for knowledge exchange and awareness-building through co-learning.

We also demonstrated that since most, if not all, restoration interventions are informed by funding, oftentimes community involvement is only considered at

the implementation phase as opposed to the planning phase. Notwithstanding, IPLCs maintain deep connections to their natural environments and possess rich understanding of seasonal patterns and ecological processes (FAO 2024). IPLC participation should be encouraged more, especially in ecosystems (including soil, estuarine and marine ecosystems) wherein they derive livelihoods since IPLCs do derive their livelihoods from these environments, and sustainable management of these environments is critical (Sandhu & Sandhu 2014; Li et al. 2025). This is not only key for alleviating ecosystem degradation by reducing societal impacts but for addressing poverty in areas where there is high reliance on ecosystem services (Sandhu & Sandhu 2014; Li et al. 2022; Wu et al. 2022).

While there is no mutual exclusivity in ecosystem restoration interventions, IPLCs are largely involved in terrestrial (above-ground) restoration interventions and with very limited involvement in below-ground interventions. The IPLCs' participation in nature-based solutions, as well as in coastal management interventions, also proved to be very limited (Mafumbu et al. 2022; SAIIA 2023; Caldeira et al. 2025). With ecosystem services defined as the benefits humans derive from their natural environments, one would expect more than 20% participation of IPLCs in coastal management interventions, which ranges from the low-tide zone to the splash zone, beyond the high intertidal zone (Figure 4).

Osborne et al. (2021) argues that ecosystem restoration efforts focusing solely on addressing the symptoms of ecosystem degradation often overlook the underlying drivers of inequity and justice that contribute to ecosystem decline. Without tackling these root causes, the United Nations Decade on Ecosystem Restoration (2021–2030) may fail to achieve its intended impact (Cecon et al. 2020; Fischer et al. 2020). Sustainable restoration necessitates meaningful involvement of IPLCs, alongside the integration of local values and perceptions (Cecon et al. 2020). Achieving the Sustainable Development Goals (SDGs) through ecosystem restoration requires direct interventions addressing the drivers of ecosystem degradation, such as ineffective awareness campaigns and poor knowledge exchange, often undermining IKS (Goncalves et al. 2021). A biocultural approach to restoration, which acknowledges both cultural and biological diversity, has been identified as an effective pathway to achieving just and sustainable restoration outcomes (Gavin et al. 2015). Since the spirit of the restoration continuum emphasises that restoration must include both ecological recovery and tackling root causes of degradation, IPLC participation then needs to be prioritised (SER 2021; FAO 2024; UNEP & FAO 2021). Challenges that lead to poor integration of Indigenous knowledge into the restoration agenda delayed inclusion of IPLCs in planning for restoration interventions; a lack of bottom-up restoration projects, as unpacked in Figure 6, need to be addressed.

Ecosystem degradation has already rendered 23% of the world's terrestrial surface unproductive (IPBES 2018, 2019). Habitat destruction and fragmentation negatively impact biodiversity, but restoration interventions – such as improving habitat extent, quality and connectivity at a landscape scale – can mitigate these effects (Abera et al. 2019; Fuentes-Montemayor et al. 2020). In response to these challenges, community-based ecological restoration programmes (ERPs) are being implemented worldwide to restore degraded ecosystems and achieve global conservation and development goals (Belmonte-Urena et al. 2021; Fekete et al. 2024). Conservation efforts prioritise the protection of pristine environments dominated by native species (Gann et al. 2019), yet where degradation has occurred, restoration serves as a complementary strategy to conservation (Kuuluvainen et al. 2002). However, sustainable restoration is contingent on community participation and buy-in, as restoration efforts cannot rely indefinitely on fluctuating budgets and political approvals (De Groot et al. 2022; Nxele et al. 2024). For restoration to be self-sustaining, it must become an integral part of people's daily lives, fostering a sense of ownership and responsibility (Noe & Stolte 2023).

Effective restoration requires long-term commitment, structured knowledge exchange and continuous resource investment (Gann et al. 2019). Several key factors contribute to the success of restoration initiatives: stakeholder engagement, strategic partnerships, comprehensive planning, skills development, risk assessment, adaptive management and rigorous monitoring and evaluation (Gann et al. 2019). However, due to inconsistent monitoring and evaluation frameworks, it remains difficult to assess the true success of restoration efforts and to determine missed opportunities for IPLC involvement (Nxele et al. 2021).

Gann et al. (2018, 2019) emphasise the necessity of established principles and standards to guide restoration practices. These frameworks provide essential guidelines for partnership-building, stakeholder engagement and socio-cultural integration (Gann et al. 2019). They also facilitate measuring and evaluating restoration efforts, ensuring ecological, social and economic sustainability. A significant component of these standards is the incorporation of diverse knowledge systems. Principle 6 explicitly states that 'ecosystem restoration incorporates all types of knowledge and promotes their exchange and integration throughout the process' (FAO, IUCN CEM & SER 2021). Since IPLCs contribute to conserving approximately 50% of the world's biodiversity (Pearce 2016), their knowledge must be integrated into restoration strategies.

Furthermore, Principle 5 asserts that 'ecosystem restoration addresses the direct and indirect causes of ecosystem degradation'. If the exclusion of IPLCs is a contributing factor to ecosystem degradation, then their inclusion

should be a fundamental component of restoration efforts. Target 3 of the Kunming-Montreal Global Biodiversity Framework seeks to protect or conserve 30% of land and sea by 2030 through 'equitably governed systems' (Dawson et al. 2024). Equitable governance involves principles such as acknowledging and respecting the knowledge, diverse values and rights of all relevant actors, including their ancestral territories and cultural practices, while also ensuring their full and meaningful participation in decision-making (Dawson et al. 2024). The ten principles proposed by Osborne et al. (2021) advocate for establishing balanced relationships between humans and nature, ensuring ecological, social and economic resilience. They emphasise prioritising local knowledge and practices, fostering equitable participation and addressing social and environmental justice issues. In this regard, it is crucial to consider who owns the land, who benefits from restoration, and who bears the costs.

Community-based, large-scale restoration initiatives have gained global traction as mechanisms for addressing ecosystem degradation, poverty alleviation and climate resilience (Costanza et al. 1997). Approximately 43% of the world's vegetated surface – equivalent to five billion hectares – has been degraded due to deforestation and soil erosion (Abera et al. 2019). While research supports the positive correlation between restoration efforts and ecosystem services, the lack of standardised evaluation frameworks raises concerns about their long-term efficacy. The unchecked expansion of restoration projects, without effective IPLC engagement, risks unintended environmental consequences that could undermine restoration investments (Abera et al. 2019). Furthermore, restoration strategies such as invasive species management and native biodiversity reintroduction must be carefully assessed for their ecological impact.

As the United Nations Decade on Ecosystem Restoration progresses, this study seeks to contribute valuable insights into the effectiveness and sustainability of restoration efforts. A systematic review of existing research, combined with empirical evidence, underscores the need for inclusive restoration practices that integrate social, ecological and economic considerations. Historical and colonial land dispossession has disproportionately marginalised IPLCs, making it imperative that they receive equitable benefits from restoration initiatives. Equitable participation should involve IPLCs in decision-making processes and empower them to effectively participate in restoration action, express their needs and expectations, as well as shape restoration strategies (Neumann 1992; Kelly 2011). As conservation efforts grow to address biodiversity loss, there is still a lack of clarity on which governance structures and actor roles lead to the most effective ecological results, and IPLCs contribute not just through participation but also through more equitable governance, which acknowledges their authority, values and institutions (Dawson et al. 2024; Sangkachai et al. 2025). However, the

connection between these governance approaches and conservation outcomes remains uncertain (Dawson et al. 2024; Sangkachai et al. 2025).

Osborne et al. (2021) stress the importance of restoration strategies that are guided by traditional ecological knowledge rather than solely by political or economic interests. A shift from conventional top-down governance to grassroots-driven decision-making is essential for effective restoration. IPLCs have historically managed over 50% of the world's landscapes, shaping ecosystems through their sociocultural practices (Pearce 2016; Reyes-Garcia 2015). Despite this, governments frequently exclude IPLCs from planning and decision-making while imposing policies that disrupt their livelihoods and biodiversity conservation efforts (Andrianto et al. 2019). Indigenous landscape management practices have been observed across the globe, from South America (Fernández-Llamazares et al. 2020) to Africa (Murove 2004), and from Asia (Anthwal et al. 2010) to Oceania (Knudsen 2004) demonstrating their significant role in ecological processes (Sun et al. 2017).

Finally, Osborne et al. (2021) advocate for cross-border collaboration in restoration efforts, a concept not explicitly outlined in Gann et al. (2019). Given that biodiversity transcends political boundaries, international cooperation is essential for achieving large-scale restoration goals. The proposed principles and standards provide a framework for standardising restoration practices and ensuring effectiveness at multiple scales (Gann et al. 2019; Fuentes-Montemayor et al. 2020; Osborne et al. 2021). However, significant gaps remain in understanding the effectiveness of restoration at landscape and global scales, particularly in terms of species recovery, ecosystem services, perceptions of IPLCs about threats to the provisioning of ecosystem services and management thereof, as well as ecological resilience (Fekete et al. 2024). With ecosystem restoration needing to be informed by all available types of knowledge, including IKS, the exclusion or ineffective participation of IPLCs in restoration interventions, could be contributory to unsustainable restoration.

Knowledge platforms with bottom-up motivations for restoration interventions need to be created in order to address disparities in frames of reference between IKS and Western science. Addressing these gaps requires interdisciplinary collaboration, improved stakeholder engagement and innovative funding mechanisms to ensure long-term sustainability. Western-trained ecologists have access to resources, tools, knowledge and training that indigenous researchers have often been excluded from (Bulmer et al. 2024). In contrast, indigenous researchers possess deep, place-based histories with the environment, encompassing governance and resource management, which foster a profound understanding, connection and sense of responsibility to ecological systems (Harcourt & Awatere 2022).

Reflections on the Study

This study strongly advocates for the integration of IKS and the meaningful participation of IPLCs in mainstream ecosystem restoration. It highlights that IPLC involvement has historically been limited to labour-based activities, with minimal influence on decision-making or knowledge-sharing processes. By aligning with the ecosystem restoration continuum (Gann et al. 2019), the study frames the exclusion of IPLCs as a driver of ecosystem degradation and calls for their inclusion in addressing both ecological and social dimensions of restoration. It argues that sustainable and equitable restoration requires co-learning platforms that bridge Indigenous and Western scientific knowledge systems, fostering bottom-up, culturally grounded interventions. Drawing on evidence that poverty heightens dependence on ecosystem services (Sandhu & Sandhu 2014; Li et al. 2022), the study positions IPLC participation as critical not only for ecological recovery but also for poverty alleviation and long-term resilience. Ultimately, the study promotes a shift from top-down governance toward inclusive, rights-based approaches that ensure IPLCs' perceptions, values and institutions shape restoration strategies at local and global scales. The study also tried to articulate a transformative vision of restoration that is inclusive, fair and epistemologically plural, and also consistent with the principles of the United Nations Decade on Ecosystem Restoration (2021–2030). Finally, the study calls for structural reform in knowledge production and governance.

Recommendations on how IKS can be integrated into mainstream scientific research

Integrating IKS from IPLCs into mainstream scientific research, requires deliberate strategies that respect the epistemology, values and governance of IPLCs, while fostering co-production of knowledge. A study by Matuk et al. (2020), highlighted the importance of knowledge co-production with IPLCs to sustain ecosystem functionality and human well-being. To achieve this, IPLCs need to be promoted from participants to partners, where their knowledge is treated as complementary rather than anecdotal, and structures need to be established to support equitable collaboration, co-learning and benefit-sharing. An analytical review by Sangha et al. (2025), revealed significant underrepresentation of cultural and spiritual services of ecosystems due to IPLC exclusion. As such, research questions especially at MSc, and PhD levels, would need to be co-developed with IPLCs, and objectives jointly defined to ensure cultural practices are respected. This will also ensure studies address locally relevant issues, acquire local buy-in, and thus facilitate dialogue between Indigenous knowledge holders and scientists (mutual learning opportunities). Most importantly, such an approach

will provide a platform for addressing language barriers through translation of terminologies, concepts and names of species, thus aligning Indigenous languages with feedback from research findings at the end of the studies. This approach will also provide institutional support for acknowledging and protecting intellectual property rights of IPLCs over traditional knowledge.

Conclusions

In conclusion, ecosystem restoration must balance environmental, social and economic considerations to enhance socio-ecological resilience and safeguard human livelihoods. Indigenous knowledge and deep connection to the local environment serve as valuable assets for sustainable environmental management and effectively integrating IKS in ecosystem restoration, which is currently largely based on the Western approach, can facilitate reconnecting people with nature and sustaining restoration interventions, going forward.

This review demonstrates that although community-based ecosystem restoration has expanded globally, Indigenous Peoples and Local Communities (IPLCs) are still largely excluded from meaningful decision-making. Language barriers play a critical but under-recognised role in limiting IPLC participation, constraining knowledge exchange and reinforcing power asymmetries between Western science and IKS. Addressing linguistic exclusion can enhance socio-ecological resilience by enabling co-learning, improving adaptive management, and aligning restoration objectives with local livelihood needs. Linguistically inclusive management also strengthens cultural identity, reconnects people with nature and fosters long-term stewardship, which is essential for sustaining restoration outcomes beyond short-term funding cycles.

The findings underscore that effective and equitable ecosystem restoration under the United Nations Decade on Ecosystem Restoration (2020–2030) requires deliberate attention to language as a governance and inclusion mechanism. Persistent language barriers limit IPLC participation to implementation roles, undermine the integration of IKS, and weaken restoration legitimacy. Addressing linguistic exclusion through multilingual engagement and culturally appropriate communication can improve ecological outcomes. For policy frameworks led by FAO, UNEP and IPBES, embedding language-inclusive approaches within restoration planning, monitoring and evaluation is essential to ensure that restoration interventions are socially just, locally owned and resilient over the long term.

Finally, addressing language barriers in ecosystem restoration directly supports the achievement of multiple global policy commitments, including the Sustainable

Development Goals (SDGs), the Kunming-Montreal Global Biodiversity Framework (GBF), and the Society for Ecological Restoration (SER) principles. Linguistically, inclusive restoration contributes to SDG 1 (No Poverty), and SDG 2 (Zero Hunger), by aligning restoration objectives with IPLC livelihood strategies, while supporting SDG 13 (Climate Action) and SDG 15 (Life on Land) through enhanced adaptive capacity and ecological resilience. It also facilitates GBF Target 3 by enabling equitably governed conservation systems that respect IPLC rights, values and knowledge. In line with SER Principle 5, addressing language barriers helps tackle indirect drivers of ecosystem degradation linked to social exclusion, while SER Principle 6 is advanced through the meaningful integration and exchange of Indigenous and Western scientific knowledge systems. Together, these linkages highlight that linguistic inclusion is not peripheral but central to achieving just, effective and sustainable restoration outcomes.

Acknowledgments

The author would like to thank the following stakeholders who participated in numerous workshops and meetings on naming invasive alien species in Indigenous languages, as well as in translating conservation terminology into isiZulu; the late Bheki Mdletshe and Bheka Memela

from the Biodiversity Management Department of eThekweni Municipality, as well as Hlobisile Sithole (former employee), Nomzamo Mncube and Sanelo Mchunu (former graduate trainees) of the same department; Menzi Nxumalo, employee of the South African National Biodiversity Institute (SANBI); Thabiso Cele, Senior Technician at SANBI and Mthobisi Hadebe, former graduate trainee at SANBI; Phakamani Mlaba and Khulekani Nhleko, employees of the KZN Department of Economic Development and Environmental Affairs (KZN EDTEA); and Zukiswa Zulu, employee of the national Department of Forestry, Fisheries & Environment (DFFE). The author would also like to thank The Biodiversity Management Department, formerly known as Environmental Planning and Climate Protection Department (EPCPD), of eThekweni Municipality, for access to its products, the 'Beautiful but Dangerous Posters and Flashcards', which provided the foundation of the species reviewed; the South African National Biodiversity Institute (SANBI) and the Wildlife Society of South Africa (WESSA) for invasive species dossiers; and Dr Sandra J. Land from the Durban University of Technology (DUT), South Africa for her guidance, when needed.

Ethical considerations

AI was used for grammar to improve readability in certain sections.

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