The Application of Paleoenvironmental Research in Supporting Land Management Approaches and Conservation in South Africa

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Abstract

Research into past environments and climates of South Africa has significantly grown in recent decades, owing to its rich archeological heritage and high biodiversity. The paleoscience community has worked toward an improved understanding of long-term climate and environmental dynamics, yet the application and dissemination of such information into the realm of conservation and land-use management have remained limited. In this chapter, we briefly explore the current state of paleoenvironmental research in South Africa, recent methodological advancements and potential applications of paleoresearch for natural resource management and conservation. We advocate for a more integrated research approach, bringing together the fields of ecology, ecosystem restoration, conservation biology and paleoecology, as an avenue toward tackling

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uncertainties in conservation and land-use management practices. We use a case study from the Kruger National Park, to demonstrate the benefits of incorporating a long-term perspective in understanding the natural variability and thresholds of an ecological system, and thereby inform more sound natural resource management strategies and conservation planning.

12.1 Introduction

The state of a landscape is the product of current and past environmental factors, including climatic, biotic and anthropogenic factors. Growing anthropogenic impacts on the climate and the biosphere has brought into focus the dynamic nature of our planet and highlighted the need to understand long-term climate and ecological processes, both retrospectively in terms of historical patterns and processes, and as a basis for informing future projections (Willis et al. 2010). Under current climate change scenarios, environmental systems are expected to undergo adaptive responses leading to novel ecosystems with no modern analogue (Lovejoy 2007; Williams and Jackson 2007). Long-term ecological observatories, monitoring programs and advancements in remote sensing techniques have allowed for ecosystem dynamics to be mapped and monitored at a large spatial scale; however, these are temporally restricted to the last few decades. Among other applications, long-term datasets form the basis for model building and validation for future climate projections. For more recently established observatories, it is impractical to wait for decades to generate long-term monitoring data (Rull 2014). Given the limited temporal range of historical data, alternative approaches are required to gain insight as to how climates and ecosystems operate over ecologically meaningful timescales.

To provide a deeper understanding of environmental variability over longer timescales, researchers have turned to natural archives of environmental change, such as marine, lake and wetland sediments. These archives offer an indirect record of ecological variability, and the underlying mechanisms influencing ecosystem change (Jackson and Hobbs 2009). For instance, through the identification of fossil pollen preserved in sedimentary archives, paleoresearch attempts to reconstruct past vegetation composition. This is achieved by transferring a species, environmental envelope from the extant ecosystem processes within which it occurs to the fossilized occurrences within the paleorecord (Williams and Jackson 2007; Willis et al. 2010). This approach offers a window into environmental change over the course of deposition and contributes to understanding environmental factors such as climate and hydrology, and biological factors such as species niche parameters and geographical range (Seddon et al. 2014). In many cases, baseline conditions are perceived to be those which occurred prior to intensive human involvement and modification. Yet, ecosystems are anything but static in nature, but rather dynamic with a range of natural variability (Froyd and Willis 2008). Fundamentally, systems are in continual flux, responding to external forces within a defined boundary range and baselines can shift depending on the timescale of observation. This is a key consideration when developing a management strategy and identifying ecologically realistic management targets (Forbes et al. 2018). Here, paleoenvironmental research can present unique insights in determining a system's threshold and resilience to change by revealing former multiple interacting processes (Willis et al. 2010; Gillson and Marchant 2014; Gillson 2015).

Paleoecology as a discipline has progressed from a largely qualitative base typified by the descriptive reconstruction of past environments to a considerably more quantitative science. This is mainly due to statistical innovations that have allowed for cross-validation of sites and proxies and the detection of regime shifts and tipping points (e.g., Line et al. 1994; Birks et al. 2012; Seddon et al. 2014; Blaauw et al. 2020). This, coupled with the development of more robust chronologies (see Blaauw et al. 2007; Bronk Ramsey 2008; Aquino-López et al. 2018) has provided direct correlations between sites, ultimately creating a regional perspective. The application and perceived relevance of the research outputs from quantitative, temporally constrained environmental reconstructions has increased. For example, paleoclimatic data now forms a critical component of the Intergovernmental Panel on Climate Change (IPCC) Physical Science basis (IPCC 2021), and the reassessment of the Ramsar Convention on Wetlands, on an individual site basis, to include paleoenvironmental insights into the natural ecological character of wetland systems for better management practices (Finlayson et al. 2016; Gell et al. 2016; Gell 2017). Paleoenvironmental perspectives also increase our understanding of climate versus human-driven fire regimes, through charcoal-based paleofire records, assisting in fire management, conservation and restoration efforts (McWethy et al. 2013; Iglesias et al. 2015; Maezumi et al. 2021).

There have been numerous calls for the closer integration of ecology, ecosystem restoration, conservation biology and paleoecology (e.g., Willis and Birks 2006; Dearing 2008; Froyd and Willis 2008; Willis and Bhagwat 2010; Birks 2012; Gillson and Marchant 2014; Gillson 2015; Davidson et al. 2018) leading to a greater application of paleoenvironmental and paleoecological datasets to answer questions of conservation and management relevance. Yet, concrete applications of paleoecology in conservation and management remain scarce. Rull (2014, p. 2) criticizes this lack of synergy and warns of "delaying the advancement of ecological knowledge and the potential impact of its applications on ... nature conservation and the sustainable use of ecological services." High resolution, multiproxy paleoenvironmental studies reveal the importance of long-term data in broadening our comprehension of alterations in ecosystem services (ES), ecosystem resilience and variability and incorporating knowledge into ecosystem assessments and management (Dearing et al. 2012b; Gillson 2015; Jeffers et al. 2015). In the South African context, there are numerous Holocene-age paleoecological studies (Table S12.1); however, few adequately demonstrate the impactful application of paleoecological data for land management (Fig. 12.1). Such applied paleoecology is a major development in the field, which is beginning to gain traction in South Africa, working to address the "fundamental disconnect" between the disciplines of ecology and paleoecology (Gillson and Duffin 2007; Forbes et al. 2018).

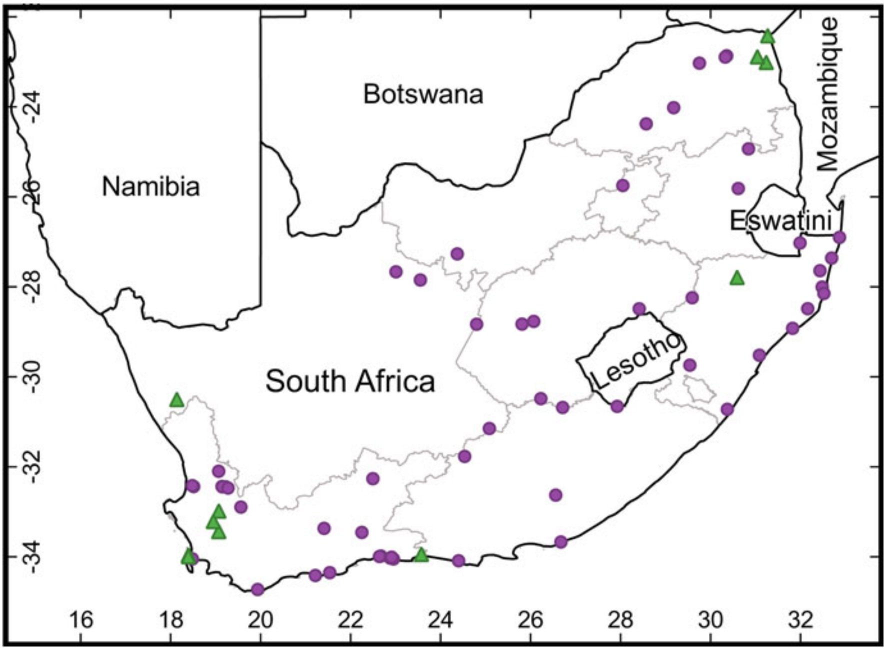

Fig. 12.1 Spatial distribution of selected Holocene-age paleosites across South Africa, noting those which included applied paleoecological aspects (triangles) (Full details and associated references for these sites are in the Supplementary Material)

12.2 Evolution of South African Paleoenvironmental Research

The paleoresearch community in South Africa has emerged from relatively slow beginnings, compounded by a range of region-specific limitations. These include the often cited lack of organic sedimentary archives due to the arid and semiarid climatic setting (Chase and Meadows 2007), and, more generally, a lack of capacity, funding and isolated research environment, at least up until the mid-1990s. There are now several active research groups and organizations across the country, with strong evidence of ongoing international collaboration (e.g., Haberzettl et al. 2014). In recent years, growing interest, and investment, in the story of human evolution has propelled the paleosciences forward, as a means of providing climate and environmental context to the development of early modern humans (Meadows 2015). Through this inherent geographical advantage, South Africa is broadly recognized as a priority research area for the paleosciences and has benefitted from a dedicated national funding instrument, the National Research Foundation African Origins Platform.

Paleoenvironmental research in South Africa has traditionally focused on pollen-based vegetation reconstructions, using wetland sediments, as a means to infer past climatic conditions (e.g., Martin 1956; Coetzee 1967). Innovative strides were taken to combat the effects of dry and strongly seasonal climate, which hampers accumulation of long, continuous sedimentary deposits. Thus, an expansion into a broader range of unconventional archives began (Meadows 2015), including pan sediments (e.g., Scott 1988), cave sediments (e.g., Thackeray 1992), rock hyrax middens (e.g., Scott et al. 2004) and coprolites (e.g., Carrion et al. 2000). Fitchett et al. (2017) noted a rapid increase in both the number of studies published and the number of proxies used in recent years, as researchers moved from a pollen-dominated narrative to include additional physical, chemical and biological proxies (Meadows 2014). In particular, studies employing isotopes (e.g., Smith et al. 2002; Esterhuysen and Smith 2003), geochemistry (e.g., Wündsch et al. 2016, 2018; Strobel et al. 2019) and diatoms (e.g., Kirsten et al. 2018, 2020) have become more prevalent (Fitchett et al. 2017). This shift toward a more multiproxy approach follows international trends, with the use of multiple independent lines of evidence as a means to strengthen interpretations and identify inconsistencies.

Although local paleoenvironmental research has remained largely qualitative, recent shifts toward a more quantitative analytical science have begun. The advent of transfer functions and various modeling approaches to paleodata have provided measurable comparisons to modern ecosystems (Anderson 1995; Birks et al. 2012). The incorporation of paleodata for use in probability density functions (PDF), such as that employed by the software CREST (Chevalier 2021), has assisted in reconstructing several climatic variables, including winter and summer temperature and precipitation, mean annual aridity and rainfall seasonality, by assigning modern climatic envelopes to fossil pollen assemblages across southern Africa (e.g., Chevalier and Chase 2016). Additionally, a transfer function was developed to quantitatively reconstruct relative sea level along the east coast of South Africa through the analysis of the modern elevation preferences of intertidal salt-marsh foraminifera (Strachan et al. 2014, 2015). Such quantitative approaches are underpinned by their modern data coverage, following which a recent move to address this modern data deficit is apparent (see, for example, Sobol et al. 2019; Strobel et al. 2020), still more work is needed in this area. These quantitative applications can deliver a direct source of information to support climate projections, with a scope to further develop southern African training databases to better constrain local predictions.

Nevertheless, the application of paleoenvironmental data implicitly relies on robust and well-constrained chronologies. Early studies developed age models based on linear interpolation of often uncalibrated radiocarbon age determinations; however, age-depth modeling of sediment sequences has developed into a complex, multisample, statistical approach. This transition has assisted in cross-validating environmental trends on a local, regional and global scale. For greater refinement, extensive work was undertaken in determining regional marine reservoir effects for the eastern to southeastern coast (Maboya et al. 2018) and the west coast (Dewar et al. 2012) of South Africa, where previously the marine carbon component was overlooked. Beyond the accelerator mass spectrometry (AMS) radiocarbon and optically stimulated luminescence dating methods, the incorporation of chronological markers (Neumann et al. 2011), lead-210 (see Forbes et al. 2018) and even paleomagnetic secular variations (see Haberzettl et al. 2019) have assisted in refining age-depth models. These analytical developments have greatly benefitted the interpretation of data and temporally constrained environmental events from sites across South Africa.

Despite the paleocommunity being active in advancing the field, there are several gaps in the knowledge of the role and application of paleoecology in informing sustainable land-use management, restoration and conservation. By focusing on the last 5000 years, key reference conditions for restoration and conservation efforts can be ascertained due to notable climatic deviations, including the mid-Holocene Altithermal, arrival of pastoralism in southern Africa, Medieval Climate Anomaly, Little Ice Age, European settlement and twentieth century global change drivers. However, even with global efforts heeding the call to put applied paleoecology into practice, there is limited implementation, bar a few studies (e.g., Forbes et al. 2018; Cramer et al. 2019; MacPherson et al. 2019; Dirk and Gillson 2020; Gillson et al. 2020; Dabengwa et al. 2021) (Fig. 12.1).

12.3 Shifting Mindsets: The Combination of Paleoecology and Restoration Ecology

Defining restoration and management targets requires a nuanced understanding of landscape history and an acknowledgement that variability and disturbance are normal. For example, an increase in tree cover in savannas might be considered undesirable if it is caused by the unprecedented disruptions of the twentieth century, including CO_2 enrichment and fire suppression, but might be considered tolerable or advantageous, if representing a return to former tree cover following land abandonment (Fig. 12.2). Furthermore, in the late twentieth century, ecological paradigms shifted, with the recognition that change rather than balance was the norm for most ecosystems (Pickett et al. 1997). Early conservation tactics aimed at preventing change, such as fire suppression and culling of animals, largely failed to stabilize ecosystems and ecologists realized that a new ecology of flux was needed (Gillson 2015).

In restoration ecology, managers aim to restore a degraded ecosystem whose structure, composition and function has been compromised, usually as a result of anthropogenic factors, for example deforestation, agriculture, urbanization, pollution or the invasion of nonnative species (Falk 2017). To define restoration goals, a reference condition is needed. In the case of a once-off disturbance event, the reference condition can be the state of the ecosystem prior to the disturbance, or the state of a neighboring ecosystem that has not experienced the disturbance. However, in most cases, defining reference conditions is much more complicated. Disturbance and variability are normal in most ecosystems; climate and fire regime changes over time can be an integral process in system functionality and many landscapes have been managed by people for centuries or even millennia. These factors leave a lasting legacy on landscapes that must be considered in restoration plans (Higgs et al. 2014; Johnstone et al. 2016; Manzano et al. 2020). What then should be the reference conditions that inform restoration management?

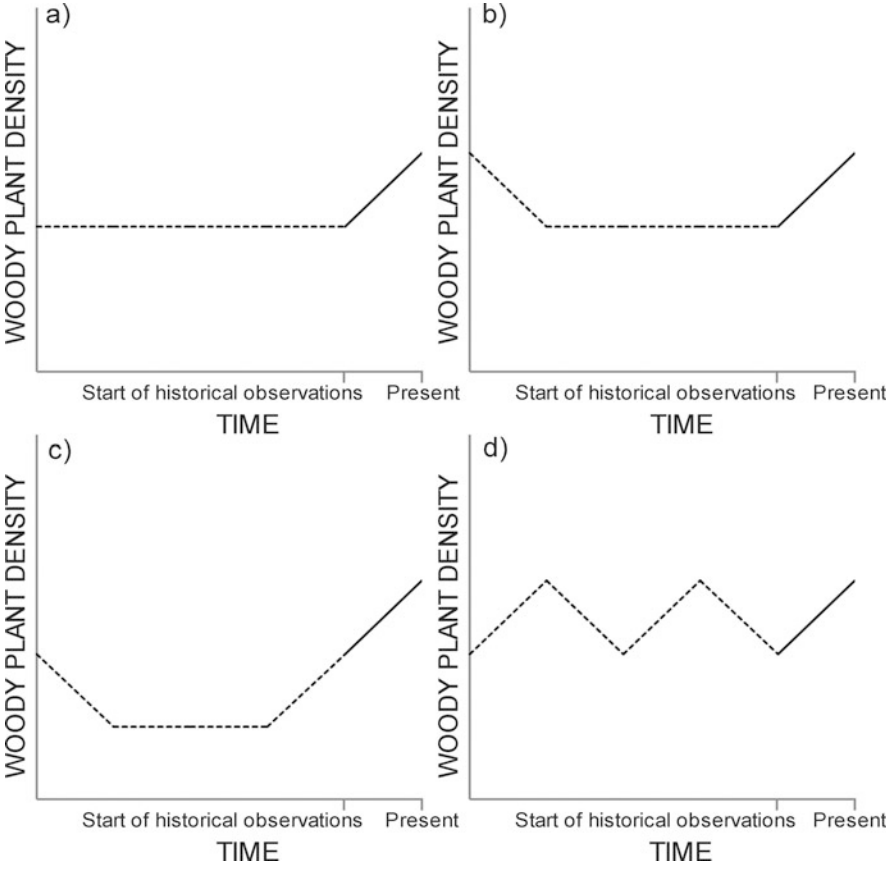

Fig. 12.2 Hypothetical graphs indicating observed increase in woody vegetation cover in the recent past (solid line) and different possible late Holocene landscape histories (dotted lines) (**a**) the recent increase in tree cover is unprecedented within the timeframe examined (**b**) the recent increase represents an recovery from past woody vegetation clearance (**c**) the recent increase represents an recovery from past woody vegetation clearance, but woody cover is now higher than it was before clearance (**d**) woody vegetation cover varies cyclically over time

In Sub-Saharan Africa, there is a case to be made that at least 500 years of paleoecological data are needed to define an appropriate range of variability, this captures the status of ecosystems and social-ecological systems prior to European settlement, and well before the onset of postindustrial anthropogenic climate change (Gillson and Marchant 2014; Gillson 2015). Data from fossil pollen, together with historical documents and archeological records, can be used to reconstruct the influence of anthropogenic and environmental change on vegetation cover and form a basis for informing restoration of degraded landscapes. These data can also be useful in restoring traditional management techniques, such as patch mosaic burning

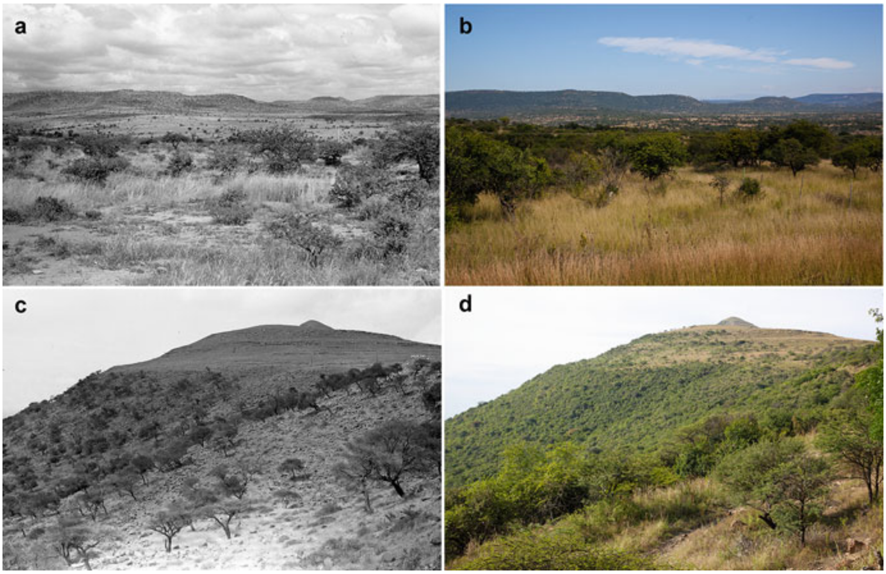

Fig. 12.3 Repeat photographs showing increases in woody vegetation in the savanna biome of KwaZulu-Natal, South Africa in recent decades. Weenen Nature Reserve in (**a**) 1955 and (**b**) 2011. Weenen Middlerest in (**c**) 1955 and (**d**) 2011. Original photos: D. Edwards (1955) © South African National Biodiversity Institute. *Repeat photos*: J. Puttick (2011) © Plant Conservation Unit, UCT. CC BY-NC 4.0. Photos courtesy of Timm Hoffman and rePhotoSA [http://ibali.uct.ac.za/s/rephotosa/] (Hoffman and O'Connor 1999)

and transhumant grazing, that are well-adapted to the variable environments that are typical of African rangelands (Laris 2002).

Here, savannas are used as an example case study to illustrate the importance of long-term data in defining reference conditions and informing restoration targets. In recent decades, woody vegetation has increased in many savannas (Wigley et al. 2010; O'Connor et al. 2014; Hoffman et al. 2019) (Fig. 12.3), with several factors interacting to determine tree density. Tree abundance varies in response to climate (especially rainfall), fire, herbivory, soil nutrients and CO_2 (Bond and Midgley 2012). Furthermore, savannas are important rangelands and humans have manipulated both fire and herbivory to sustain grazing for domestic animals and retain a diverse array of ES. This manipulation of savannas through fire and herbivory was disrupted due to the eighteenth-century European colonization and settlement. Hunting of elephants for ivory and extermination of predators, for example, would have affected herbivory and therefore tree recruitment and vegetation structure (Hempson et al. 2015; Venter et al. 2017). In the late nineteenth century, Rinderpest wiped out significant proportions of herbivores, probably driving pulses of tree and shrub recruitment and leading to unusually high tree densities (Ofcansky 1981; Holdo et al. 2009). In addition, many colonial governments instigated policies of fire suppression and later prescribed burning that disrupted natural fire regimes and traditional patterns of fire management, again facilitating tree growth (van Wilgen et al. 2014; Humphrey et al. 2020).

Such fire management policies were often continued beyond independence and in many cases are only recently being reviewed. At the same time, rising levels of CO_2 further enhanced tree recruitment (Scheiter and Higgins 2012), while land-use and settlement patterns changed, with increasing sedentarization of previously transhumant populations. With increasing urbanization and government grants, destocking of formerly heavily grazed areas has occurred in recent decades (Blair et al. 2018). Many savannas were unusually heavily wooded by the opening of the twentieth century, due to the unusual and rapidly changing conditions of the past two centuries. Therefore, when many national parks were founded in the early decades of the twentieth century, they were likely in a state of atypically high tree density compared with preceding centuries and millennia. Using protected areas as reference conditions for other, more heavily degraded areas is therefore often inappropriate and highlights the potential role of paleoecology in establishing reference conditions for savanna restoration.

Where paleoecology shows that tree abundance is unprecedented or outside of the historical range of variability (Fig. 12.3a and c), appropriate restoration might include attempts to reduce tree cover, for example through larger herbivore populations or more intense burns. Such interventions might be deemed unnecessary, where tree cover is recovering from past clearance or undergoing cyclical change (Fig. 12.3b and d). With so many variables at play, it is not surprising that the structure of savannas is highly variable over both space and time. Therefore, the appropriate response to increasing woody cover depends on understanding the history of the landscape, requiring long-term data that extends beyond the timescale of intensive human impact in the past few centuries (Gillson and Marchant 2014; Gillson 2015).

Sediment cores retrieved from the Kruger National Park, and spanning the last 5000 years, assisted in identifying a series of alternate stable states in savanna vegetation, from studying interactions between local hydrology, climate, fire and herbivory (Gillson and Ekblom 2009, 2020; Ekblom and Gillson 2010). These states are largely determined by the interplay between rainfall and fire, but transitions between states can be facilitated or discouraged by management actions that alter herbivory and fire. In this way, the impacts of global change, can be ameliorated at least to some extent by management actions at landscape scales (Midgley and Bond 2015). Fossil pollen data assisted managers and ecologists in the Kruger National Park in developing suites of monitoring endpoints, known as Thresholds of Potential Concern (TPCs) (Rogers 2003; Gillson and Duffin 2007). These thresholds define upper and lower limits of acceptable change in key environmental parameters, for example tree cover. When the measured parameters approach the thresholds, management interventions are triggered that bring the variable back into the accepted range of variability, or alternatively the TPC is re-evaluated. Managers chose limits of variability to tree cover, which if crossed would trigger management responses such as relocation of elephants or changes in fire management (Gillson and Duffin 2007; van Wilgen and Biggs 2011; Gillson 2015). Thus, long-term records can assist in defining the historical range of variability and identifying ecological thresholds, which are significant in restoration and ecosystem management due to their impacts on ecological process and biodiversity. The application of these insights into past variability can assist in the management and restoration of terrestrial ecosystems by determining whether to control increases in woody plants (scenarios a and b in Fig. 12.2) or where paleoecology shows ancient open grassland or heathland systems.

Paleoecology can similarly be used to describe the "natural ecological character" of ecosystems (Finlayson et al. 2005; Gell et al. 2013, 2018; Davidson 2016; Gell 2017), a requirement under the Ramsar Convention which was ratified in 1971. An example from the Murray-Darling Basin (MDB), Australia, shows how a lack of long-term data can lead to incorrect assumptions about "baselines" leading to the perpetuation of degraded states (Finlayson et al. 2017). Decadal–centennial timescales allowed the previous centuries of human impact to be understood, providing a more realistic target for wetland restoration and management of the surrounding landscape policies. Long-term data contextualizing recent vegetation changes and insight into the history of landscapes, environmental change and land use is particularly vital at the current time, an example would be management pressure to afforest open landscapes that are perceived as degraded or denuded forests (Bond et al. 2019). In fact, many open landscapes such as savannas, grasslands and heathlands are valuable in terms of biodiversity and ES. Therefore, it is essential that ancient ecosystems are distinguished from degraded systems if misguided restoration plans on ancient open and biodiverse ecosystems are to be avoided. As shown in the examples of the Kruger National Park and Murray-Darling Basin, this can only be achieved if the history of landscapes is properly understood.

12.4 A Look into the Future: Applied Paleoecology

With the increase and advancements of paleostudies within South Africa, much can be done to operationalize and mainstream paleoecology for sustainable development in the region. Recent applied paleoecological studies seek to combine methodologies and promote interdisciplinary and transdisciplinary (TD) research, thus encouraging a past-present-future continuum (Dawson et al. 2011; Birks 2012; Gillson and Marchant 2014; Marchant and Lane 2014; Gillson 2015) to frame methodological approaches. This continuum is multifaceted, encompassing a wide variety of methodologies that must be taken into account at a past, present and future level to ensure a comprehensive research approach (Table 12.1).

Table 12.1 Examples of mixed methods that can be used to explore the past–present–future continuum in interdisciplinary and TD research

Past	Paleoecology and paleoclimate science, analysis of orthorectified historical aerial photographs, repeat terrestrial photographs, GIS mapping, remote sensing, documentation analysis of historical records and long-term monitoring
Present	Stakeholder engagement via interviews and workshops, vegetation surveys, analysis of modern pollen trap data and experiments
Future	Scenario planning and various modeling techniques such as adaptive cycle, Bayesian network, systems- and agent-based simulation models

12.4.1 What Operational Approaches Are Needed to Implement Ecosystem-Based Management Actions Based on Applied Paleoecology?

Paleoecology is in a unique position to offer insights into historical variability, thereby providing clues regarding climatic and anthropogenic-induced impacts over time. Policymakers and land managers can use the paleoresults in a strategic way within existing systemic structures at multiple governance scales (Monat and Gannon 2015). Coherence and coordination with governance strategies that focus on ES and human well-being values, stewardship, environment-friendly technology, innovation and investment would therefore be an ideal leverage point for mainstreaming paleoecology into the sustainability development dialogue, which contains both environmental and social dimensions (Dearing 2008; Bond and Morrison-Saunders 2011; Grace 2015; Morrison-Saunders et al. 2015; Díaz et al. 2018; Folke et al. 2021). In this regard, the analysis of multiple paleoproxies can contribute to understanding environmental change at global to local scales, from the interaction between regional biophysical drivers such as climate and fire to changes in vegetation and grazing patterns. However, it is of utmost importance that the (applied) paleoecological community coordinates research efforts to align with governance mechanisms at multiple governance scales.

South Africa's climate change and biodiversity policy supports and promotes coordinated and cross-sectoral implementation of Ecosystem-based Adaptation (EbA) (DEA and SANBI 2016; DEFF 2019). EbA is a globally-recognized approach that advocates for a climate change response that also has socio-economic and biodiversity/ecological cobenefits, thus contributing to sustainable development (Secretariat of the Convention on Biological Diversity 2009; Vignola et al. 2009; Pasquini and Cowling 2015; Aronson et al. 2019). Therefore, ecosystem-based approaches are a potential leverage point to incorporate applied paleoecology into land management and decision-making. Paleoresearch should be mainstreamed into governance structures and planning processes (including adaptive management and policy frameworks, e.g., Dearing et al. 2012a, b; Gillson and Marchant 2014), bearing in mind possible contextual factors that would either constrain or enable environmental mainstreaming efforts (Dalal-Clayton and Bass 2009; Bass et al. 2011; Pasquini and Cowling 2015; Food and Agriculture Organization (FAO) of the

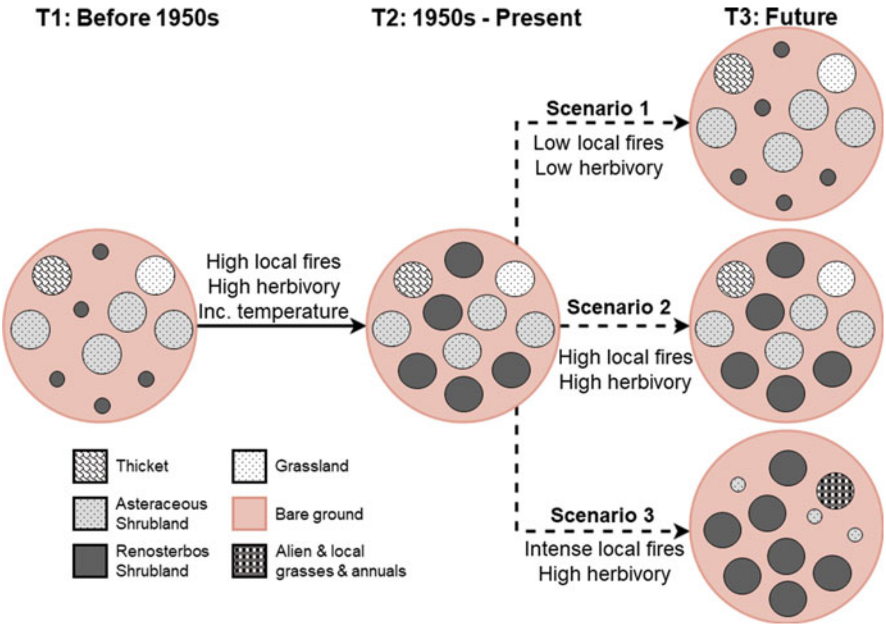

Fig. 12.4 Conceptual model showing a transition from T1 which is ca. AD 750–1950s to T2 which is ca. AD 1950s to present, and then to a potential future state (T3). Scenarios 1–3 represent potential transitions and the drivers of change associated with them. Herbivory is by livestock between ca. AD 1705–1973 and by reintroduced large indigenous herbivores since AD 1973–present. Scenario 1 shows a reversal to a pre-1950s state. Scenario 2 shows if the current state remains as is. It is hypothesized that, should an environmental threshold be crossed in the future, an alternative stable state of degraded Renosterveld may be attained (Scenario 3). This occurs as the intensity of local fires continues to increase, and the grazing of reintroduced large indigenous herbivores persists

United Nations 2016), and therefore impact the likelihood of sustained resilience and social dynamics on South African landscapes.

An interesting interface exists between paleoecology and modeling which further develops the holistic past-present-future continuum and could also improve the utilization of end-products. Despite the scarcity of research that combines long-term paleoecological data with system dynamics (e.g., United Kingdom agro-ecosystem study by McKay et al. 2019), a recent study at a lowland conservation site (Elandsberg Private Nature Reserve) in the Cape Floristic Region of South Africa showed that this can be achieved (Dirk 2021). The study noted the development of the site pre- and post-1950s to present and proposed potential future shifts to one of three alternative stable states (Fig. 12.4). It is indeterminate as to when a forthcoming regime shift will occur and the shift could be due to inappropriate levels of land-use disturbance (fire and overgrazing) and/or climate change. It has been observed that Degraded Renosterveld would consist of more than 60% bare ground, and would be homogenous at the landscape level, with Elytropappus rhinocerotis and alien plant species dominating the area (Forbes et al. 2018). The TD study utilized high temporal resolution, multiproxy paleodata (fossil pollen, spores and charcoal) to infer the alterations of a provisioning Ecosystem Service (plant biodiversity) and two land-use drivers of change (fire and herbivory) to define the historical range of variability. Participatory system dynamics—including a multistakeholder engagement workshop and semistructured interviews with commercial farmers, conservation practitioners and government officials—was used to unravel the temporal complexity of the area. This approach was used to identify feedbacks in the dynamic SES structure and analyze potential scenarios in response to grazing and fire policy, management practices and climate change. The end-product included a simulation model interface (Story Interface in Stella ® Architect, 2019. Isee Systems Inc.), which facilitates engagement with interactive paleodata visualizations enabled by the system dynamics model. The end-product could then be used as a participatory tool or boundary object (Star and Griesemer 1989; Fischer and Riechers 2019) to encourage dialogue regarding unexpected simulation results and future scenarios to provide information to aid in land-use management and the promotion of resilience in the region.

When amalgamating techniques from a variety of disciplines, it is imperative to prioritize the politics and social dynamics associated with not only the formation of knowledge, but also its application outside of academia (Roux et al. 2017; Biermann et al. 2020). To achieve sustainable ecosystem management, the manner in which data is obtained and utilized should incorporate stakeholder participation and mutual learning (Knight et al. 2008). Moreover, the applied paleoecological Community of Practice (CoP) needs to consider the benefits of reflection, and the compilation and dissemination of insights on how and why we engage with stakeholders. A common practice in climate change development programs is a process of monitoring and evaluation (M&E) to assess desired outcomes and impacts, and capturing lessons learned during project implementation (Spearman 2011; Bours et al. 2014). Such principles of transparency and replicability are equally important in applied research. Applied paleoecology is "reflexive" by nature because it uses techniques to gather data that describes the past and develops insights for the present and future. By harnessing best practices from the reflexive nature of paleoecology, the applied paleoecology CoP should be reflecting and reporting on the operational research processes they employ as innovative approaches and methodologies emerge. Documenting and sharing the novel process steps and methodological adaptations are essential for case-specific, multisector and geographically diverse contexts in southern African is an essential knowledge management practice for advancing this field (e.g., Dirk 2021).

Community buy-in and stakeholder ownership is essential for addressing knowledge gaps, integrating diverse knowledge streams and bringing about meaningful change. Therefore, novel approaches whereby researchers and stakeholders iteratively and collaboratively formulate research questions based on real-world problems, use mixed methods and reflect on the applicable evidence and end-products is the fundamental nature of sustainability science (Kates et al. 2009). In addition to using participatory approaches for multistakeholder collaboration at research conception and implementation, long-term data needs to be relevant and effective for communities that require the information. Thus, (applied) paleoecologists need to assume the duty of disseminating paleooutputs which are converted and presented in accessible formats for all relevant stakeholder groups (be they are from the public, private, or civil society sector). Applied paleoecological outputs packaged into useful management decision-support tools will hopefully empower and motivate land-users to practice biodiversity conservation and use natural resources judiciously (Gelderblom et al. 2003; Jackson et al. 2009).

12.5 Conclusions

The South African paleocommunity, in collaboration with international partners and funders, has actively sought to understand and decipher past environmental change. Historically, this has often taken on the form of relatively low temporal resolution studies emphasizing environmental reconstruction over a variety of timescales (decadal–centennial–millennial timescales), with the presentation of the generated data often being inaccessible to other disciplines and end-users, due to the specialist format or the lack of dissemination.

However, over the last decade or so, the development of the science has been recognized as a valuable instrument in informing on the natural variability and thresholds of an ecological system. Globally, paleoenvironmental research has transitioned to encompass quantitative approaches including modeling, experimentation and observation to directly inform natural resource management practices.

Thus, to take timely action in a world that is facing global problems (such as climate change, poverty and pandemics such as COVID-19), the paleocommunity together with other stakeholders (as multiactor levers) should consider using a past-present-future continuum. Through this lens, innovation and advancement is propelled with an emphasis on recognizing and initiating points of leverage to incorporate paleoecological understandings of long-term change into numerous institutionalized governance levels.

The inclusion of applied paleoecology by the South African paleocommunity, by actively incorporating reflexivity into their research outcomes and providing opportunities for knowledge sharing, will enable them to tailor their work for effective context-based interventions by other researchers and practitioners. It is recommended that reflexive outputs such as lessons learnt, conceptual frameworks, historical range of variability and limits of acceptable change could be compiled and disseminated in the format of policy briefs, grey literature and shared with other knowledge holders (e.g., restoration ecology) Gillson et al. 2021.

Lastly, the next iteration of paleoecological outputs must take into account the end-user and the practicality of the data to effectively guide sustainable land management through the incorporation of policy-relevant concepts such as ES, ecosystem function and social-ecological systems resilience (Dirk 2021).

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References

Anderson NJ (1995) Using the past to predict the future: lake sediments and the modelling of limnological disturbance. Ecol Model 78:149–172. https://doi.org/10.1016/0304-3800(94)00124-Z

Aquino-López MA, Blaauw M, Christen JA, Sanderson NK (2018) Bayesian analysis of 210 Pb dating. J Agric Biol Environ Stat 23:317–333. https://doi.org/10.1007/s13253-018-0328-7

Aronson J, Shackleton S, Sikutshwa L (2019) Joining the puzzle pieces: reconceptualising ecosystem- based adaptation in South Africa within the current natural resource management and adaptation context. Cape Town, South Africa

Bass S, Banda JLL, Chiotha S, et al. (2011) Mainstreaming the environment in Malawi's development: Experience and next steps.

Biermann C, Kelley LC, Lave R (2020) Putting the anthropocene into practice: methodological implications. Ann Assoc Am Geogr 111:808–818

Birks HJB (2012) Ecological palaeoecology and conservation biology: Controversies, challenges, and compromises. Int J Biodivers Sci Ecosyst Serv Manag 8:292–304. https://doi.org/10.1080/21513732.2012.701667

Birks HJB, Lotter AF, Juggins S, Smol JP (2012) Tracking environmental Change using lakes sediment: volume 5 data handling and numerical techniques. Springer, London

Blaauw M, Bakker R, Christen JA et al (2007) A Bayesian framework for age modeling of radiocarbon-dated peat deposits: case studies from the Netherlands. Radiocarbon 49:357–367

Blaauw M, Christen JA, Aquino-López MA (2020) A Review of Statistics in Palaeoenvironmental Research. J Agric Biol Environ Stat 25:17–31. https://doi.org/10.1007/s13253-019-00374-2

Blair D, Shackleton CM, Mograbi PJ (2018) Cropland abandonment in South African smallholder communal lands: Land cover change (1950–2010) and farmer perceptions of contributing factors. Land 7:1–20. https://doi.org/10.3390/land7040121

Bond WJ, Midgley GF (2012) Carbon dioxide and the uneasy interactions of trees and savannah grasses. Philos Trans R Soc Lond Ser B Biol Sci 367:601–612. https://doi.org/10.1098/rstb.2011.0182

Bond AJ, Morrison-Saunders A (2011) Re-evaluating sustainability assessment: aligning the vision and the practice. Environmental Impact Assessment 31:1–7. https://doi.org/10.1016/j.eiar.2010.01.007

Bond WJ, Stevens N, Midgley GF, Lehmann CER (2019) The Trouble with Trees: Afforestation Plans for Africa. Trends Ecol Evol 34:963–965. https://doi.org/10.1016/j.tree.2019.08.003

Bours D, McGinn C, Pringle P (2014) Guidance note 3: Theory of Change approach to climate change adaptation programming

Bronk Ramsey C (2008) Deposition models for chronological records. Quat Sci Rev 27:42–60

Carrion JS, Brink JS, Scott L, Binneman JNF (2000) Palynology and palaeo-environment of Pleistocene hyaena coprolites from an open-air site at Oyster Bay, Eastern Cape coast, South Africa. S Afr J Sci 96:449–453

Chase BM, Meadows ME (2007) Late Quaternary dynamics of southern Africa's winter rainfall zone. Earth Sci Rev 84:103–138. https://doi.org/10.1016/j.earscirev.2007.06.002

Chevalier M (2021) crestr an R package to perform probabilistic climate reconstructions using fossil proxies. Clim Past Discuss 18:1–35. https://doi.org/10.5194/cp-2021-153

Chevalier M, Chase BM (2016) Determining the drivers of long-term aridity variability: a southern African case study. J Quat Sci 31:143–151. https://doi.org/10.1002/jqs.2850

Coetzee JA (1967) Pollen analytical studies in East and Southern Africa. Palaeoecology of Africa 3:125–147

Cramer MD, Power SC, Belev A et al (2019) Are forest-shrubland mosaics of the Cape Floristic Region an example of alternate stable states? Ecography 42:717–729. https://doi.org/10.1111/ecog.03860

Dabengwa AN, Gillson L, Bond WJ (2021) Resilience modes of an ancient valley grassland in South Africa indicated by palaeoenvironmental methods. Environ Res Lett 16(5):1–31. https://doi.org/10.1080/14484846.2018.1432089

Dalal-Clayton B, Bass S (2009) The challenges of environmental mainstreaming: experience of integrating environment into development institutions and decisions. IIED, London

Davidson NC (2016) Editorial: understanding change in the ecological character of internationally important wetlands. Mar Freshw Res 67:685–686. https://doi.org/10.1071/MF16081

Davidson TA, Bennion H, Reid M et al (2018) Towards better integration of ecology in palaeoecology: from proxies to indicators, from inference to understanding. J Paleolimnol 60:109–116. https://doi.org/10.1007/s10933-018-0032-1

Dawson TP, Jackson ST, House JI et al (2011) Beyond predictions: biodiversity conservation in a changing climate. Science 332:53–58

DEA, SANBI (2016) Strategic framework and overarching implementation plan for ecosystem-based adaptation (EbA) in South Africa: 2016–2021. DEA, SANBI, Pretoria

Dearing JA (2008) Landscape change and resilience theory: A palaeoenvironmental assessment from Yunnan, SW China. The Holocene 18:117–127. https://doi.org/10.1177/0959683607085601

Dearing JA, Bullock S, Costanza R et al (2012a) Navigating the perfect storm: research strategies for social ecological systems in a rapidly evolving world. Environ Manag 49:767–775

Dearing JA, Yang X, Dong X et al (2012b) Extending the timescale and range of ecosystem services through paleoenvironmental analyses, exemplified in the lower Yangtze basin. Proc Natl Acad Sci 109:E1111–E1120. https://doi.org/10.1073/pnas.1118263109

DEFF (2019) Ecosystem based adaptation Action Plan and Priority Areas Mapping report. DEFF, Pretoria

Dewar G, Reimer PJ, Sealy J, Woodborne S (2012) Late-Holocene marine radiocarbon reservoir correction (ΔR) for the west coast of South Africa. The Holocene 22:1481–1489. https://doi.org/10.1177/0959683612449755

Díaz S, Pascual U, Stenseke M et al (2018) Assessing nature's contributions to people. Science 359:270–272

Dirk CJ (2021) Using applied palaeoecology and participatory system dynamics modelling to investigate changes in ecosystem services in response to climate and social-ecological drivers within the Middle Berg River Catchment. University of Cape Town, Cape Town

Dirk CJ, Gillson L (2020) Using paleoecology to inform restoration and conservation of endangered heathlands. Past Global Changes Magazine 28:20–21. https://doi.org/10.22498/pages.28.1.3

Ekblom A, Gillson L (2010) Hierarchy and scale: Testing the long term role of water, grazing and nitrogen in the savanna landscape of Limpopo National Park (Mozambique). Landsc Ecol 25:1529–1546. https://doi.org/10.1007/s10980-010-9522-x

Esterhuysen AB, Smith JM (2003) A comparison of charcoal and stable carbon isotope results for the Caledon River Valley, Southern Africa, for the period 13,500–5000 yr BP. South African Archaeol Bull 58:1–5. https://doi.org/10.2307/3889151

Falk DA (2017) Restoration ecology, resilience, and the axes of change. Ann Mo Bot Gard 102:201–216. https://doi.org/10.3417/2017006

Finlayson CM, Bellio MG, Lowry JB (2005) A conceptual basis for the wise use of wetlands in northern Australia - linking information needs, integrated analyses, drivers of change and human well-being. Mar Freshw Res 56:269–277. https://doi.org/10.1071/MF04077

Finlayson CM, Clarke SJ, Davidson NC, Gell P (2016) Role of palaeoecology in describing the ecological character of wetlands. Mar Freshw Res 67:687–694. https://doi.org/10.1071/MF15293

Finlayson C, Baumgartner LJ, Gell P (2017) We need more than just extra water to save the Murray-Darling Basin. In: The Conversation. http://theconversation.com/we-need-more-than-just-extra-water-to-save-the-murray-darling-basin-80188

Fischer J, Riechers M (2019) A leverage points perspective on sustainability. People and Nature 1:115–120

Fitchett JM, Grab SW, Bamford MK, Mackay AW (2017) Late quaternary research in southern Africa: progress, challenges and future trajectories. Trans R Soc S Afr 72:280–293

Folke C, Polasky S, Rockstrom J et al (2021) Our future in the Anthropocene biosphere. Ambio 50:834–869. https://doi.org/10.1007/s13280-021-01544-8

Food and Agriculture Organization (FAO) of the United Nations (2016) Mainstreaming ecosystem services and biodiversity into agricultural production and management in East Africa

Forbes CJ, Gillson L, Hoffman MT (2018) Shifting baselines in a changing world: Identifying management targets in endangered heathlands of the Cape Floristic Region, South Africa. Anthropocene 22:81–93. https://doi.org/10.1016/j.ancene.2018.05.001

Froyd CA, Willis KJ (2008) Emerging issues in biodiversity & conservation management: The need for a palaeoecological perspective. Quat Sci Rev 27:1723–1732. https://doi.org/10.1016/j.quascirev.2008.06.006

Gelderblom CM, van Wilgen BW, Nel JL et al (2003) Turning strategy into action: Implementing a conservation action plan in the Cape Floristic Region. Biol Conserv 112:291–297

Gell PA (2017) Using paleoecology to understand natural ecological character in Ramsar wetlands. Past Global Changes Magazine 25:86–87. https://doi.org/10.22498/pages.25.2.86

Gell P, Mills K, Grundell R (2013) A legacy of climate and catchment change: The real challenge for wetland management. Hydrobiologia 708:133–144. https://doi.org/10.1007/s10750-012-1163-4

Gell PA, Finlayson CM, Davidson NC (2016) Understanding change in the ecological character of Ramsar wetlands: Perspectives from a deeper time - Synthesis. Mar Freshw Res 67:869–879. https://doi.org/10.1071/MF16075

Gell PA, Perga M-E, Finlayson CM (2018) Changes over time. In: Hughes J (ed) Freshwater ecology and conservation: approaches and techniques. Oxford University Press, Oxford, pp 283–305

Gillson L (2015) Biodiversity conservation and environmental change: using palaeoecology to manage dynamic landscapes in the Anthropocene. Oxford University Press, Oxford

Gillson L, Duffin KI (2007) Thresholds of potential concern as benchmarks in the management of African savannahs. Philos Trans R Soc B Biol Sci 362:309–319. https://doi.org/10.1098/rstb.2006.1988

Gillson L, Ekblom A (2009) Resilience and thresholds in Savannas: Nitrogen and fire as drivers and responders of vegetation transition. Ecosystems 12:1189–1203. https://doi.org/10.1007/s10021-009-9284-y

Gillson L, Ekblom A (2020) Using palaeoecology to explore the resilience of southern African savannas. Koedoe 62:1–12. https://doi.org/10.4102/koedoe.v62i1.1576

Gillson L, Dirk C, Gell P (2021) Using long-term data to inform a decision pathway for restoration of ecosystem resilience. *Anthropocene, 36*, p.100315

Gillson L, Marchant R (2014) From myopia to clarity: Sharpening the focus of ecosystem management through the lens of palaeoecology. Trends Ecol Evol 29:317–325. https://doi.org/10.1016/j.tree.2014.03.010

Gillson L, MacPherson AJ, Hoffman MT (2020) Contrasting mechanisms of resilience at mesic and semi-arid boundaries of fynbos, a mega-diverse heathland of South Africa. Ecol Complex 42:100827. https://doi.org/10.1016/j.ecocom.2020.100827

Grace WR (2015) Sustainability and the SDGs: a systems perspective. University of Queensland, St Lucia

Haberzettl T, Baade J, Compton J et al (2014) Paleoenvironmental investigations using a combination of terrestrial and marine sediments from South Africa - The RAIN (Regional Archives for Integrated iNvestigations) approach. Zentralblatt für Geologie und Paläontologie, Teil I:55–73. https://doi.org/10.1127/zgpI/2014/0055-0073

Haberzettl T, Kirsten KL, Kasper T et al (2019) Using 210 Pb-data and paleomagnetic secular variations to date anthropogenic impact on a lake system in the Western Cape, South Africa. Quat Geochronol 51:53–63. https://doi.org/10.1016/j.quageo.2018.12.004

Hempson GP, Archibald S, Bond WJ (2015) A continent-wide assessment of the form and intensity of large mammal herbivory in Africa. Science 350:1056–1061

Higgs E, Falk DA, Guerrini A et al (2014) The changing role of history in restoration ecology. Front Ecol Environ 12:499–506. https://doi.org/10.1890/110267

Hoffman MT, O'Connor TG (1999) Vegetation change over 40 years in the Weenen/ Muden area, KwaZulu-Natal: evidence from photo-panoramas. Afr J Range Forage Sci 16:71–88

Hoffman MT, Rohde RF, Gillson L (2019) Rethinking catastrophe? Anthropocene 25:100189

Holdo RM, Sinclair ARE, Dobson AP et al (2009) A Disease-Mediated Trophic Cascade in the Serengeti and its Implications for Ecosystem C. PLoS Biol 7:e1000210. https://doi.org/10.1371/journal.pbio.1000210

Humphrey GJ, Gillson L, Ziervogel G (2020) How changing fire management policies affect fire seasonality and livelihoods. Ambio 50:475–491. https://doi.org/10.1007/s13280-020-01351-7

Iglesias V, Yospin GI, Whitlock C (2015) Reconstruction of fire regimes through integrated paleoecological proxy data and ecological modeling. Front Plant Sci 5:1–12. https://doi.org/10.3389/fpls.2014.00785

IPCC (2021) Climate change 2021: the physical science basis. Contribution of working group I to the sixth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge

Jackson ST, Hobbs RJ (2009) Ecological restoration in the light of ecological history. Science 325:567–569. https://doi.org/10.1126/science.1172977

Jackson ST, Gray ST, Shuman B (2009) Paleoecology and resource management in a dynamic landscape: case studies from the Rocky Mountain headwaters. Conserv Paleobiol Sci Pract 15:61–80

Jeffers ES, Nogué S, Willis KJ (2015) The role of palaeoecological records in assessing ecosystem services. Quat Sci Rev 112:17–32. https://doi.org/10.1016/j.quascirev.2014.12.018

Johnstone JF, Allen CD, Franklin JF et al (2016) Changing disturbance regimes, ecological memory, and forest resilience. Front Ecol Evol 14:369–378. https://doi.org/10.1002/fee.1311

Kates RW, Clark WC, Corell R et al (2009) Sustainability science. Science 292:641–642

Kirsten KL, Haberzettl T, Wündsch M et al (2018) A multiproxy study of the ocean-atmospheric forcing and the impact of sea-level changes on the southern Cape coast, South Africa during the Holocene. Palaeogeogr Palaeoclimatol Palaeoecol 496:282–291. https://doi.org/10.1016/j.palaeo.2018.01.045

Kirsten KL, Kasper T, Cawthra HC et al (2020) Holocene variability in climate and oceanic conditions in the winter rainfall zone of South Africa—inferred from a high resolution diatom record from Verlorenvlei. J Quat Sci 35:572–581. https://doi.org/10.1002/jqs.3200

Knight AT, Cowling RM, Rouget M, Balmford A, Lombard AT, Campbell BM (2008) Knowing but not doing: Selecting priority conservation areas and the research-implementation gap. Conserv Biol 22:610–617

Laris P (2002) Burning the seasonal Mosaic: preventative burning strategies in the wooded Savanna of Southern Mali. Hum Ecol 30:155–186

Line JM, ter Braak CJF, Birks HJB (1994) WACALIB version 3.3 - a computer program to reconstruct environmental variables from fossil assemblages by weighted averaging and to derive sample-specific errors of prediction. J Paleolimnol 10:147–152. https://doi.org/10.1007/BF00682511

Lovejoy TE (2007) Paleoecology and the path ahead. Front Ecol Environ 5:456. https://doi.org/10.1890/1540-9295(2007)5[456:PATPA]2.0.CO;2

Maboya ML, Meadows ME, Reimer PJ et al (2018) Late Holocene marine radiocarbon reservoir correction for the south and east coast of South Africa. Radiocarbon 60:571–582

MacPherson AJ, Gillson L, Hoffman MT (2019) Between- and within-biome resistance and resilience at the fynbos-forest ecotone, South Africa. The Holocene 29:1801–1816. https://doi.org/10.1177/0959683619862046

Maezumi SY, Gosling WD, Kirschner J et al (2021) A modern analogue matching approach to characterize fire temperatures and plant species from charcoal. Palaeogeogr Palaeoclimatol Palaeoecol 578:110580. https://doi.org/10.1016/j.palaeo.2021.110580

Manzano S, Julier ACM, Dirk CJ et al (2020) Using the past to manage the future: the role of palaeoecological and long-term data in ecological restoration. Restor Ecol 28:1335–1342. https://doi.org/10.1111/rec.13285

Marchant R, Lane P (2014) Past perspectives for the future: foundations for sustainable development in East Africa. J Archaeol Sci 51:12–21

Martin ARH (1956) The ecology and history of Groenvlei. S Afr J Sci 52:187–192

McKay DIA, Dearing JA, Dyke JG et al (2019) To what extent has sustainable intensification in England been achieved? Sci Total Environ 648:1560–1569

McWethy DB, Higuera PE, Whitlock C et al (2013) A conceptual framework for predicting temperate ecosystem sensitivity to human impacts on fire regimes. Glob Ecol Biogeogr 22:900–912. https://doi.org/10.1111/geb.12038

Meadows ME (2014) Recent methodological advances in Quaternary palaeoecological proxies. Prog Phys Geogr 38:807. https://doi.org/10.1177/0309133314540690

Meadows ME (2015) Seven decades of Quaternary palynological studies in southern Africa: A historical perspective. Trans R Soc S Afr 70:103–108. https://doi.org/10.1080/0035919X.2015.1004139

Midgley GF, Bond WJ (2015) Future of African terrestrial biodiversity and ecosystems under anthropogenic climate change. Nat Clim Chang 5:823–829. https://doi.org/10.1038/nclimate2753

Monat JP, Gannon TF (2015) What is systems thinking? A review of selected literature plus recommendations. Am J Syst Sci 4:11–26. https://doi.org/10.5923/j.ajss.20150401.02

Morrison-Saunders A, Pope J, Bond A (eds) (2015) Handbook of sustainability assessment. Edward Elgar Publishing, Cheltenham

Neumann FH, Scott L, Bamford MK (2011) Climate change and human disturbance of fynbos vegetation during the late Holocene at Princess Vlei, Western Cape, South Africa. The Holocene 21:1137–1149. https://doi.org/10.1177/0959683611400461

O'Connor TG, Puttick JR, Hoffman MT (2014) Bush encroachment in southern Africa: changes and causes. Afr J Range Forage Sci 31:67–88. https://doi.org/10.2989/10220119.2014.939996

Ofcansky TP (1981) The 1889–1897 Rinderpest epidemic and the rise of British and German Colonialism in Eastern and Southern Africa. J Afr Stud 8:31–38

Pasquini L, Cowling RM (2015) Opportunities and challenges for mainstreaming ecosystem-based adaptation in local government: evidence from the Western Cape, South Africa. Environ Dev Sustain 17:1121–1140

Pickett STA, Ostfeld RS, Shacha M, Likens GE (eds) (1997) The ecological basis of conservation; heterogeneity, ecosystems, and biodiversity. Springer Science & Business Media, New York

Rogers KH (2003) Adopting a heterogeneity paradigm: implications for management of protected savannas. In: du Toit JT, Rogers KH, Biggs HC (eds) The Kruger experience: ecology and management of Savanna heterogeneity. Island Press, Washington, DC, pp 41–58

Roux DJ, Nel JL, Cundill G, O'farrell P, Fabricius C (2017) Transdisciplinary research for systemic change: who to learn with, what to learn about and how to learn. Sustainability Science 12:711–726

Rull V (2014) Time continuum and true long-term ecology: from theory to practice. Front Ecol Evol 2:1–7. https://doi.org/10.3389/fevo.2014.00075

Scheiter S, Higgins SI (2012) How many elephants can you fit into a conservation area. Conserv Lett 5:176–185. https://doi.org/10.1111/j.1755-263X.2012.00225.x

Scott L (1988) Holocene environmental change at western Orange Free State pans, South Africa, inferred from pollen analysis. Palaeoecol Afr 19:109–119

Scott L, Marais E, Brook GA (2004) Fossil hyrax dung and evidence of Late Pleistocene and Holocene vegetation types in the Namib Desert. J Quat Sci 19:829–832. https://doi.org/10.1002/jqs.870

Secretariat of the Convention on Biological Diversity (2009) Connecting biodiversity and climate change mitigation and adaptation: report of the second ad hoc technical expert group on biodiversity and climate change. Secretariat of the Convention on Biological Diversity, Montreal

Seddon AWR, Mackay AW, Baker AG et al (2014) Looking forward through the past: identification of 50 priority research questions in palaeoecology. J Ecol 102:256–267. https://doi.org/10.1111/1365-2745.12195

Smith JM, Lee-Thorp JA, Sealy JC (2002) Stable carbon and oxygen isotopic evidence for late Pleistocene to middle Holocene climatic fluctuations in the interior of Southern Africa. J Quat Sci 17:683–695. https://doi.org/10.1002/jqs.687

Sobol MK, Scott L, Finkelstein SA (2019) Reconstructing past biomes states using machine learning and modern pollen assemblages: a case study from Southern Africa. Quat Sci Rev 212:1–17. https://doi.org/10.1016/j.quascirev.2019.03.027

Spearman M (2011) Making Adaptation Count: Concepts and options for monitoring and evaluation of climate change adaptation. World Resources Institute: Washington, D.C.

Star SL, Griesemer JR (1989) Institutional ecology, translations' and boundary objects: Amateurs and professionals in Berkeley's Museum of Vertebrate Zoology, 1907–39. Soc Stud Sci 19:387–420

Strachan K, Hinch JM, Hill T, Barnett RL (2014) A late Holocene sea-level curve for the east coast of South Africa. S Afr J Sci 110:1–9

Strachan KL, Hill TR, Finch JM, Barnett RL (2015) Vertical zonation of foraminifera assemblages in Galpins salt marsh, South Africa. J Foraminifer Res 45:29–41

Strobel P, Kasper T, Frenzel P et al (2019) Late Quaternary palaeoenvironmental change in the year-round rainfall zone of South Africa derived from peat sediments from Vankervelsvlei. Quat Sci Rev 218:200–214. https://doi.org/10.1016/j.quascirev.2019.06.014

Strobel P, Haberzettl T, Bliedtner M et al (2020) The potential of δ2Hn-alkanes and δ18Osugar for paleoclimate reconstruction – a regional calibration study for South Africa. Sci Total Environ 716:137045. https://doi.org/10.1016/j.scitotenv.2020.137045

Thackeray AI (1992) The Middle Stone Age south of the Limpopo River. J World Prehist 6:385–440. https://doi.org/10.1007/BF00975633

van Wilgen BW, Biggs HC (2011) A critical assessment of adaptive ecosystem management in a large savanna protected area in South Africa. Biol Conserv 144:1179–1187. https://doi.org/10.1016/j.biocon.2010.05.006

van Wilgen BW, Govender N, Smit IPJ, Macfadyen S (2014) The ongoing development of a pragmatic and adaptive fire management policy in a large African savanna protected area. J Environ Manag 132:358–368. https://doi.org/10.1016/j.jenvman.2013.11.003

Venter ZS, Hawkins H-J, Cramer MD (2017) Implications of historical interactions between herbivory and fire for rangeland management in African savannas. Ecosphere 8:e01946. https://doi.org/10.1002/ecs2.1946

Vignola R, Locatelli B, Martinez C, Imbach P (2009) Ecosystem-based adaptation to climate change: what role for policy-makers, society and scientists? Mitig Adapt Strateg Glob Chang 14:691–696

Wigley BJ, Bond WJ, Hoffman MT (2010) Thicket expansion in a South African savanna under divergent land use: Local vs. global drivers? Glob Chang Biol 16:964–976. https://doi.org/10.1111/j.1365-2486.2009.02030.x

Williams JW, Jackson ST (2007) Novel climates, no-analog communities, and ecological surprises. Front Ecol Environ 5:475–482. https://doi.org/10.1890/070037

Willis KJ, Bhagwat SA (2010) Questions of importance to the conservation of biological diversity: Answers from the past. Clim Past 6:759–769. https://doi.org/10.5194/cp-6-759-2010

Willis KJ, Birks HJB (2006) What is natural? The importance of a long-term perspective in biodiversity conservation and management. Science 314:1261–1265

Willis KJ, Bailey RM, Bhagwat SA, Birks HJB (2010) Biodiversity baselines, thresholds and resilience: Testing predictions and assumptions using palaeoecological data. Trends Ecol Evol 25:583–591. https://doi.org/10.1016/j.tree.2010.07.006

Wündsch M, Haberzettl T, Kirsten KL et al (2016) Sea level and climate change at the southern Cape coast, South Africa, during the past 4.2 kyr. Palaeogeogr Palaeoclimatol Palaeoecol 446:295–307. https://doi.org/10.1016/j.palaeo.2016.01.027

Wündsch M, Haberzettl T, Cawthra HC et al (2018) Holocene environmental change along the southern Cape coast of South Africa – insights from the Eilandvlei sediment record spanning the last 8.9 kyr. Glob Planet Chang 163:51–66. https://doi.org/10.1016/j.gloplacha.2018.02.002