CHAPTER 14

Future directions of palaeoecological research in the hyper-diverse Cape Floristic Region: The role of palynological studies

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ABSTRACT: The Cape Floristic Region (CFR) is a key focus area within southern Africa due to its botanical importance in terms of high levels of biodiversity as well as its rich cultural and archaeological heritage. The area is sensitive to cycles of regional and global environmental change, and palynological records obtained from the region can potentially provide valuable information regarding past vegetation dynamics and climate variability. Prior to the last decade, few high resolution palaeoenvironmental records were recovered from the CFR, and therefore its Late Quaternary environmental history was previously poorly understood. Significant progress was made over recent years and a considerable body of new palynological (as well as palaeoclimatological) evidence emerged. These new records provide greater insight into the nature and timing of past vegetation shifts and improve our understanding of how different subregions of the CFR have responded to past climate changes. They also highlight that there is a much higher degree of complexity, in terms of both vegetation and climate change, than previously thought. This paper provides a perspective on the progress made towards elucidating the palaeoecological history of the CFR, it highlights the importance of continuing and expanding upon the existing body of work and outlines current and future directions for palynological research in this hyper-diverse southwestern corner of southern Africa.

14.1 INTRODUCTION

The southwestern Cape of South Africa has long been recognized as a unique region particularly in terms of the distinctiveness of its flora. Due to the extraordinarily high levels of biodiversity and plant endemism found within the region it has previously been recognized as one of the six global floral kingdoms (Marloth 1908; Takhtajan *et al.* 1986) and is currently world-renowned as a key biodiversity hotspot (Mittermeier *et al.* 2004; Myers *et al.* 2000). The Fynbos Biome (Figure 1) and Cape Floristic Region (CFR) are considered by many to be synonymous, however the 'biome' refers only to the two dominant vegetation groups (Fynbos and Renosterveld), whereas the 'region' refers to the general geographical area and includes other vegetation types in the Afrotropical Forest, Nama Karoo, Succulent Karoo and Albany Thicket Biomes. The CFR has been the subject of decades of intensive botanical research due to its unique floristic, evolutionary and ecological characteristics as well as its conservation appeal (e.g. Allsopp *et al.* 2014; Bond and Goldblatt 1984; Campbell 1985; Cowling 1992; Cowling *et al.* 1995; Goldblatt and Manning 2000; Rebelo *et al.* 2006).

Figure 1. The distribution of fossil pollen records for the Cape Floristic Region (as demarcated by the Fynbos Biome) (A) and in relation to seasonality of rainfall (defined in terms of percentage of winter rainfall) (B). Records are grouped according to subregion and the type of archive is demarcated in brackets after the site name (w = wetland deposit; h = hyrax midden and c = cave deposit, hc = hyena coprolites). 1 – Groenkloof (w) (MacPherson *et al.* 2018), 2 – Pakhuis Pass (h) (Scott and Woodborne 2007b, a), 3 – De Rif (h) (Quick *et al.* 2011; Valsecchi *et al.* 2013), 4 – Driehoek and Sneeuwberg vleis (w) (Meadows and Sugden 1991), 5 – Truitjes Kraal 4 (h) (Chase *et al.* 2015b; Meadows *et al.* 2010), 6 – Katbakkies 1 (h) (Chase *et al.* 2015b; Meadows *et al.* 2010), 7 – Vankraal Spring (w) (Forbes *et al.* 2018), 8 – Elands Bay Cave (c) (Meadows and Baxter 1999), 9 – Grootdrift (w) (Meadows *et al.* 1996), 10 – Klaarfontein Springs (w) (Meadows and Baxter 2001), 11 – Rietvlei (w) (Schalke 1973), 12 – Cecilia Cave (c) (Meadows and Baxter 1999), 13 – Princessvlei (w) (Cordova *et al.* 2019; Neumann *et al.* 2011), 14 – Cape Flats (w) (Meadows *et al.* 2010), 15 – Cape Hangklip (w) (Schalke 1973), 16 – Voelvlei (w) (Carr *et al.* 2006), 17 – Soetendalsvlei (w) (Carr *et al.* 2006), 18 – Rietvlei Still Bay (w) (Quick *et al.* 2015), 19 – Boomplass (c) (Deacon *et al.* 1984), 20 – Norga (w) (Scholtz 1986), 21 – Eilandvlei (w) (Quick *et al.* 2018), 22 – Bo Langvlei (w) (du Plessis *et al.* 2020), 23 – Groenvlei (w) (Martin 1968), 24 – Vankervelsvlei (w) (Irving and Meadows 1997; Quick *et al.* 2016), 25 – Platbos 1 (w) (MacPherson *et al.* 2019), 26 – Oyster Bay (hc) (Carrion *et al.* 2000) [Data: South African National Biodiversity Institute (2006–). The Vegetation Map of South Africa, Lesotho and Swaziland, Mucina, L., Rutherford, M.C. and Powrie, L.W. (Editors), Online, <http://bgis.sanbi.org/SpatialDataset/Detail/18>, Version 2018].

The southwestern Cape is also important from a climatic perspective as it is a particularly dynamic region in terms of long-term climate change. Unlike most of South Africa which receives summer rainfall, the CFR mainly falls within the winter rainfall zone (WRZ) (*sensu* Chase and Meadows 2006), presently receiving most of its rainfall during the austral winter when the southern westerly storm track migrates northward (Taljaard 1996; Tyson 1986; Tyson and Preston-Whyte 2000). Whereas during the austral summer, the westerlies and the South Atlantic Anticyclone shift southward limiting the influence of both frontal systems and tropical moisture sources (Reason *et al.* 2006; Tyson and Preston-Whyte 2000), resulting in warm, dry summer conditions. This Mediterranean-type climatic setting has played an important part in the development of the CFR and is thought to have helped foster the region's botanical diversity (Bradshaw and Cowling 2014; Cowling and Lombard 2002; Cowling *et al.* 2015; Goldblatt 1978; Linder 2005; Linder *et al.* 1992). While long-term climatic stability during the Pliocene and Pleistocene is hypothesized to be one of the key factors for the diversification of the Cape flora (Verboom *et al.* 2014; Cowling and Lombard 2002; Cowling *et al.* 2015; Cowling *et al.* 1997; Linder 2005), little direct evidence is available. Furthermore, species diversity within the CFR is not homogeneous and at finer spatial and temporal scales the concept of climatic stability driving diversity and species richness becomes more complex (Cowling 1992; Cowling and Lombard 2002; Cowling *et al.* 1997).

Palaeoecological studies within the CFR have the potential to contribute important insight into biodiversity patterns and processes, providing long-term perspectives of climatic and ecosystem changes. The CFR has a rich archaeological history as it is the locality for speciation events that culminated in the evolution of anatomically and behaviourally modern humans (Brown *et al.* 2009; Brown *et al.* 2012; Henshilwood *et al.* 2001; Henshilwood *et al.* 2002; Marean 2010; Marean *et al.* 2007). Determining the environmental context for these events represents an essential tool to understand human evolution, behaviour, and dispersal patterns. Not only can palaeoecology provide important insights into long-term human evolutionary trends but palaeoecological studies within the CFR can also help contextualize more recent archaeological trends such as migration patterns of indigenous pastoralists (e.g. Deacon 1992; Sadr 1998, 2008)) and their possible impact on late Holocene environments and ecosystems (e.g. Meadows and Baxter 2001; Neumann *et al.* 2011).

In terms of palaeoecological data, palynology represents the principal method available to determine the responses of vegetation to environmental change over various spatial and temporal scales (Bennett and Willis 2001; Birks *et al.* 2016; Faegri and Iversen 1989). Despite being a key focus area within southern Africa (as outlined above) no systematic study of the palynology of the Cape Flora has been conducted, considerable efforts have however been made towards the generation of individual fossil pollen records.

This paper presents a brief synopsis of the current state of the palaeoecological record of the CFR, with a focus on the pollen records that have been produced over the last decade. The role that palynology can play in advancing palaeoecological research is further explored by outlining current initiatives and future directions for palynological research within the CFR.

14.2 THE LATE QUATERNARY PALAEOECOLOGICAL HISTORY OF THE CAPE FLORISTIC REGION

As this is a short perspective piece, this section is not an exhaustive review of all the palynological records that fall within the CFR (although all pollen records are presented in Figure 1), but rather focuses on several of the most recently established records.

In general, the significant advances that were made in palaeoenvironmental/palaeoecological research could not have been achieved without the generation and evaluation of multiple lines of proxy evidence as well as the use of unique environmental archives. This is particularly the

case for the CFR as organic sediments (which are traditionally the main source of fossil pollen) are relatively rare, given the semi-arid nature of the region. Records from rock hyrax (*Procapra capensis*) middens represent the single most significant contribution to a more nuanced and detailed understanding of the palaeoclimates of the CFR as they are remarkably sensitive to environmental changes and contain a great diversity of proxies (e.g. fossil pollen, stable isotopes, plant biomarkers) (Chase *et al.* 2012; Scott 1990). Hyrax middens are however largely preserved only within the more arid inland mountainous regions of the CFR (i.e. within mountain ranges associated with the Cape Fold Belt) while more conventional palaeoecological archives, such as coastal lakes and wetlands, are found along the west and southern Cape coasts. Records derived from these sites helped to provide a more balanced coverage across the CFR (Figure 1). While inherent differences exist between pollen assemblages derived from hyrax middens and those from wetland deposits (i.e. pollen spectra from wetland deposits often include high proportions of local hydrophilic taxa whereas pollen found in hyrax middens is likely a more direct representation of the terrestrial vegetation), each record is carefully considered in the context of its unique environmental, ecological, hydrological and geomorphological setting – all of which can influence pollen production, dispersal and representation. These factors are also taken into account when comparing records across the CFR.

That the existing spatial heterogeneity within the CFR is a key determining factor for the nature of any identified palaeoenvironmental changes is not a new observation (Chase and Meadows 2007; Cowling 1992; Cowling and Holmes 1992; Meadows and Baxter 1999), however, with more records generated, and the increasing availability of high-resolution data, we are now able to explore this theory to a fuller extent. To best illustrate how distinct subregions of the CFR have responded differently to palaeoenvironmental changes and to highlight the contribution of the most recent published pollen records, two key subregions – the southern Cape coast and the Cederberg mountains – are briefly considered.

14.2.1 Palaeoecology of the southern Cape: The significance of coastal environments

The southern Cape coastal plain forms the eastern lowland subregion of the CFR (Figure 1) and is influenced by atmospheric dynamics associated with both the winter and summer rainfall zones (the aseasonal or year-round rainfall zone; *sensu* Chase and Meadows 2007).

While several sediment cores have been extracted from the Vankervelsvlei wetland site (Irving 1998; Irving and Meadows 1997), limited reliable palaeoenvironmental evidence has emanated from these studies due to poor chronological control and inconsistent pollen preservation. However, with the addition of optically stimulated luminescence (OSL) as a dating technique, Quick *et al.* (2016) established a chronology for a sediment sequence spanning the last 140,000 years. The variability within the pollen assemblage from this record indicates a complex response to the transition from interglacial to glacial conditions. In general, the dominance of afrotemperate forest pollen from Marine Isotope Stage (MIS) 5d (c. 108–96 ka) alludes to enhanced summer rainfall under warmer conditions allowing for the development of more extensive forests in the area (Quick *et al.* 2016). In contrast, the pollen from the last glacial period was dominated by fynbos types indicating cooler temperatures and a more seasonal winter-dominated rainfall regime (Quick *et al.* 2016).

Due to the virtual absence of palaeoenvironmental data from the southern Cape covering MIS 5 to MIS 3, the Vankervelsvlei pollen data represents an important contribution, however as no pollen was preserved from c. 27–8.7 ka, the record is incomplete. This highlights a particularly frustrating trend of the Last Glacial Maximum (LGM; 26.5–19 cal ky BP (Clark *et al.* 2009)) period being absent from pollen sequences from the southern Cape coast. Either the pollen records recovered from the subregion do not extend as far back as the LGM (e.g. du Plessis *et al.* 2020; Martin 1968; Scholtz 1986) or as is the case of Vankervelsvlei and Rietvlei–Still Bay (Quick *et al.* 2015), there is limited to no pollen preserved. Supplementary proxy data from Vankervelsvlei

and Rietvlei-Still Bay suggest that conditions were likely quite arid during the LGM (Quick *et al.* 2015; Quick *et al.* 2016), which could explain the lack of pollen preservation, and is supported by evidence of decreased moisture availability from other studies from the subregion (Chase and Meadows 2007, and references therein). Other factors that could potentially have contributed to decreased wetland productivity and a lack of pollen preservation within these coastal or near-coastal wetlands during the LGM are lower sea-levels (affecting groundwater recharge and regional hydrology) and enhanced aeolian activity. As pollen is found within the LGM sections of records from the western interior (e.g. the Pakhuis Pass and De Rif hyrax midden records (Quick *et al.* 2011; Scott and Woodborne 2007a, b; Valsecchi *et al.* 2013)) and the southwestern Cape coast within the modern WRZ (Pearly Beach record (Quick *et al.*, 2021), the lack of preservation seems to be confined to the year-round rainfall portion of the southern Cape (Southern Cape subregion, Figure 1) and therefore likely to be tied to subregion-scale changes in moisture availability. This theory can be tested with the acquisition of new sites from both the coast and the interior.

With an average sample resolution of 57 years, the pollen record from the coastal lake of Eilandvlei (Quick *et al.* 2018; Figure 1) represents the most continuous and highest resolution record of Holocene vegetation change for the southern Cape subregion. Similar to the Vankervelsvlei record, the Eilandvlei pollen assemblage primarily reflects shifts in the abundance of afrotemperate forest and fynbos taxa. For example, fynbos dominates the assemblage during the early Holocene, indicating generally cool, seasonal conditions, whereas increasing percentages of afrotemperate forest taxa from 3.5 cal ky BP to present day suggest that the late Holocene was characterized by a long-term trend of steadily increasing moisture availability (Quick *et al.* 2018). Comparisons of this high-resolution record with regional and extra-regional palaeoclimatic data highlight the complex nature of southern Cape climate dynamics (Quick *et al.* 2018). The similarities between the Eilandvlei record and records from more tropical regions of South Africa led to the proposal that summer rainfall is of great importance in terms of maintaining high moisture availability and that the Agulhas Current could be responsible for transmitting this signal of tropical variability along the coast (Chase and Quick 2018; Quick *et al.* 2018). These insights emphasize the importance of considering proxy evidence, including fossil pollen, from sites on the coast separately from those from the interior and caution against extrapolating results beyond the subregion scale.

14.2.2 Cederberg palaeoenvironments: Environmental stability vs. extreme palaeoclimatic changes

The Cederberg mountains represent the core of the western interior CFR subregion (Figure 1) and while free from the direct, localized influence of coastal dynamics, the palaeoenvironmental history of the Cederberg is no less complex than that of the southern Cape coast.

Several fossil pollen records from this subregion infer that extremely muted changes in vegetation composition took place during the last glacial and Holocene (Meadows *et al.* 2010; Meadows and Sugden 1991; Meadows and Sugden 1993; Quick *et al.* 2011). It has been suggested that mountain fynbos (the dominant vegetation type in the area) is highly resilient to changes in moisture availability, which could account for the low-amplitude variability within these palaeoecological records (Quick *et al.* 2011). However, this is contrasted by a growing body of data that indicates more dynamic patterns in vegetation and, especially, climate change (Chase *et al.* 2019; Chase *et al.* 2015a; Chase *et al.* 2011; Scott and Woodborne 2007a, b; Valsecchi *et al.* 2013). This evidence mainly consists of stable isotope records derived from hyrax middens situated within the central (Chase *et al.* 2011; Chase *et al.* 2015), northern (Chase *et al.* 2019) and eastern (Chase *et al.* 2015) sections of the Cederberg. These records indicate that substantial, rapid changes in hydroclimatic conditions occurred since the LGM, and that while the drivers

of climate dynamics appear to be shared across the subregion, there are distinct local responses, resulting in a great degree of variability across short spatial gradients (Chase *et al.* 2019).

The discrepancies between the older pollen records and the more recent stable isotope records could be related to differences in the nature of the information obtained from these two proxies. Stable carbon and nitrogen isotope data from hyrax middens are excellent recorders of changes in moisture availability (Chase *et al.* 2012) whereas palynological data is more nuanced and it can be difficult to disentangle ecological and climatic drivers of vegetation change. A further possibility is that while species turnover may be high, because it is generally only possible to identify pollen to genus or family level, this variability is not captured within the pollen assemblages.

It is clear from the emerging complexity of the palaeoenvironmental dynamics within these two subregions that substantial variability can occur across relatively short distances and interpolations beyond site level cannot always be reliably applied to regional syntheses.

14.3 CURRENT AND FUTURE DIRECTIONS FOR PALAEOECOLOGICAL RESEARCH IN THE CAPE FLORISTIC REGION

We now have a more nuanced understanding of palaeoenvironmental change within the CFR, however new high-resolution data are still required to fully explore subregional variability and to provide a more comprehensive understanding of the climate dynamics, drivers and the impact of climate change on CFR environments. There is great potential for fossil pollen data to contribute to this research agenda and to provide long-term perspectives of ecological dynamics within the CFR. The following sections outline current and potential future research directions that align to these goals.

14.3.1 The influence of the Agulhas Current on coastal palaeoenvironments

To expand on the theory outlined in Chase and Quick (2018) that a strong dipole in hydroclimatic conditions exist between the coast and interior during the Holocene, and that the Agulhas Current acts as a vector for the propagation of tropical southeast African climate signals to the southern Cape, more data is required. For a clearer understanding of the spatiotemporal dynamics of this hypothesized relationship additional high-resolution records extending into the last glacial period are needed from both the interior and coastal subregions of the southern Cape as well as from offshore (i.e. sea-surface temperature records). To begin to address this gap, a new project (by the author and collaborators) is currently underway (2020–2023) that focuses on the generation of palaeoenvironmental data, particularly fossil pollen, from wetland sites situated on a west-east transect along the southern Cape coastline.

14.3.2 Exploring steep palaeoenvironmental gradients in the Cederberg mountains

As previously outlined, the findings from the high-resolution stable isotope data from the Cederberg suggest that considerable palaeoclimatic change occurred across the subregion during the last glacial and Holocene (Chase *et al.* 2019). To fully evaluate and contextualize these findings, more sites from transects across the subregion are required. A range of proxies (such as stable isotopes, pollen, plant biomarkers, phytoliths and microcharcoal) will be analysed. New pollen data would be especially useful as it is still unclear as to whether vegetation change was in fact relatively muted or if the pollen records currently in existence are not of high enough spatial or temporal resolution to adequately capture the variability evident in the stable isotope records.

14.3.3 Palaeoenvironments of the eastern Cape: The final frontier?

Encompassing the transition from fynbos to Albany/subtropical thicket as well as from fynbos to Succulent Karoo, the eastern Cape represents an important, understudied eastern boundary of the CFR. Palaeoecological data for the eastern Cape is extremely limited and no palynological research has been conducted within the Albany Thicket biome. Only one pollen record exists for the region and this record, derived from hyena coprolite samples from a Middle Stone Age archaeological site, has no chronology and the pollen content was not sufficient for a detailed palaeoenvironmental reconstruction to be performed (Carrion *et al.* 2000; Figure 1). There are two additional publications that include pollen data from sites situated within the Eastern Cape Province, however both of these sites fall outside the CFR: the Dunedin and Salisbury vlei pollen records from the Winterberg escarpment (Meadows and Meadows 1988) and the more recently published preliminary pollen results from ongoing archaeological research at Waterfall Bluff, eastern Pondoland (Esteban *et al.* 2020; Fisher *et al.* 2020).

There is great scope for the generation of new pollen records from both the montane (e.g. the Baviaanskloof mountains) and the coastal regions (e.g. between Tsitsikamma and Port Elizabeth). Stable isotope data from a hyrax midden site within the Baviaanskloof provide new evidence for a high degree of spatiotemporal climatic variability during the Holocene (Chase *et al.* 2020). The generation of pollen data from this midden is currently underway, this data will be able to shed light on how vegetation within this ecotonal subregion of the CFR may have responded to the documented changes in hydroclimatic variability.

14.3.4 Bridging the gap between palaeoecology and ecology

Despite the similarities in their names, ecology and palaeoecology have historically been almost entirely distinct fields of research. Both fields have contributed to this disassociation: While ecologists generally recognize the need for long-term perspectives of vegetation change, they have been sceptical of the robustness of palaeoecological research methods and the inferences that are drawn from proxy records. Consequently, they have had reservations about the usefulness and reliability of palaeoecological data for addressing ecological questions. While this may once have been a legitimate concern, there have been vast methodological improvements to the generation of palaeoecological data which have resulted in much higher resolution, more accurately dated, proxy sequences (Birks *et al.* 2016). Conversely, due to the different spatial and temporal scales, palaeoecologists have often assumed that contemporary ecology is too far removed methodologically and theoretically from their field to be truly applicable. They have tended to focus on directly answering climate-related questions and in doing so have often overlooked the ecological associations of the data which has significant implications for palaeoclimatic reconstructions.

While several studies integrating ecological theory and palynological research have been conducted elsewhere in South Africa (e.g. Gillson and Duffin 2007; Gillson and Ekblom 2020; Gillson and Marchant 2014) until recently, this approach had not been attempted for the CFR. Drawing from the relatively muted changes within two late Holocene pollen records derived from sediment cores from biome boundaries (MacPherson *et al.* 2018; MacPherson *et al.* 2019), Gillson *et al.* (2020) present new hypotheses exploring possible ecological mechanisms to explain the apparent resilience of fynbos to environmental change. An assessment of how the ecosystem resilience and resistance hypotheses outlined in Gillson *et al.* (2020) align to the greater shifts in fynbos-forest dynamics documented in other palaeoecological records from ecotonal regions of the CFR (e.g. du Plessis *et al.* 2020; Quick *et al.* 2018; 2016) remains to be undertaken. However these studies as well as Forbes *et al.* (2018) highlight the potential for applying a more analytical ecological lens to CFR palynological records.

Fire is a major driving force in most Mediterranean-type ecosystems including fynbos (Cowling 1992). Without fire, fynbos communities become senescent and other plant types can

invade into the biome (Cowling *et al.* 1992; Mucina and Rutherford 2006). Information on past fire regimes is therefore particularly important in order to understand changes at the plant community level as well as shifts in biome boundaries, especially boundaries shared with fire-intolerant communities such as forest and thicket (Mucina and Rutherford 2006). Microcharcoal abundances (which are routinely counted simultaneously with pollen) can be used to reconstruct local and regional fire regimes (Cowling *et al.* 1997). Determining fire intensities from charcoal found in sedimentary sequences is now possible as a result of the development of a new method (Gosling *et al.* 2019), this method should be explored within the context of the CFR.

By providing a better understanding of ecological responses to natural and anthropogenic impacts, palaeoecological data can directly contribute to conservation management and restoration practices, however this will rely on the establishment of effective multidisciplinary working groups (Gillson, this volume; Manzano *et al.* 2020).

14.3.5 New methods and resources

The CREST (Climate REconstruction SoftWare) method developed by Chevalier *et al.* (2014) has been very successful in producing quantitative climate reconstructions for southern Africa using contemporary climate data, modern plant distributions and fossil pollen records (Chase *et al.* 2015a; Chase *et al.* 2015b; Chevalier and Chase 2015; Chase *et al.* 2017; Chevalier *et al.* 2021; Cordova *et al.* 2017; Lim *et al.* 2016). A major advantage of this method is that a large modern pollen database (which does not currently exist for the CFR) is not required. The steep environmental gradients and coastal settings of many of the CFR pollen records have proven to introduce a great degree of complexity to the application of CREST within this region. However, there certainly still is scope for its application particularly with the addition of a new resource:

A ‘by-product’ of the CREST method has given rise to the ‘Atlas of southern African pollen taxa: Distributions and Climatic Affinities’ (Chevalier *et al.* this volume) which will greatly improve, refine and standardize qualitative interpretations of fossil pollen data as well as quantitative reconstructions (such as CREST). This reference atlas includes a series of diagnostic tools and results based on statistical analyses of modern distributions of common southern African pollen taxa in relation to key climate variables. This new resource reduces the subjectivity often inherent in more qualitative interpretations and presents more accurate determination of absolute and relative climate sensitivities of southern African pollen types, including a large proportion of CFR taxa.

The recent digitization of CFR pollen reference material (originally from the Palaeoecological Laboratory in the Department of Environmental and Geographical Science, University of Cape Town) and the establishment of a new open access, searchable electronic database (<http://pollen.mandela.ac.za>) represents a new primary palynological resource. While the resurrection of the African Pollen Database (APD, Vincens *et al.* 2007) and its integration into the Neotoma Palaeoecology Database (Goring *et al.* 2015), will ensure that previously published and new pollen datasets are archived within an open access online platform (Ivory *et al.* 2020). If the majority of fossil pollen records for the CFR were included in the new APD - Neotoma database, new forms of spatiotemporal analyses could be conducted which would provide greater insight into ecosystem-climate linkages across the region.

14.4 CONCLUSIONS

While our understanding of paleoenvironmental change within the CFR has been greatly improved by the establishment of recent high-resolution palaeoclimatic and palaeoecological records, fundamental questions still remain relating to the full extent of the subregional variability of both climate and vegetation change, and how these subregions are associated/disassociated with each

other. Further insight into the long-term environmental dynamics within the CRF will be possible if the spatial and temporal coverage of sites are expanded and by employing the new methods and resources now available.

In the face of global climate change and ever-increasing ecological uncertainty as a result of unprecedented climatic and societal changes, there has never been a more urgent need for scientific collaboration and the establishment of multidisciplinary studies. The wide sphere of applicability of pollen analysis to a multitude of fields (e.g. vegetation modelling, restoration ecology, conservation biology, aerobiology and archaeology) highlights the incredible potential, both current and future, of palaeoecology's role within multidisciplinary studies. Hopefully in the coming years palaeoecological research within the CFR will continue to advance and contribute to a greater understanding of the region's unique biodiversity and climatic history.

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