Adaptation of subsistence strategies of the southwestern Malagasy in the face of climate change

Estelle Razanatsoa[1], Malika Virah-Sawmy[2], Stephan Woodborne[3], Caitlyn Callanan[4] & Lindsey Gillson[1]

[1] Plant Conservation Unit, Department of Biological Sciences, University of Cape Town, University Avenue, Rondebosch, South Africa 7700
E-mail: estelle.razanatsoa@uct.ac.za, lindsey.gillson@uct.ac.za

[2] Biogeography Lab, Humboldt-Universitat zu Berlin, Geography, Rudower Chaussee 16, 12489 Berlin, Germany
E-mail: malikavs@gmail.com

[3] iThemba LABS, PO Box 722, Somerset West 7129, South Africa
E-mail: swoodborne@tlabs.ac.za

[4] Department of Biological Sciences, University of Cape Town, University Avenue, Rondebosch, South Africa 7700
E-mail: caitlyncallanan@gmail.com

Abstract

Indigenous communities depend on natural capital and adapt their livelihoods to changing environmental conditions and ecosystem services. This paper aims to understand how southwestern Malagasy living around the Mikea National Park and the Mangoky River, have adapted their subsistence strategies to decreasing rainfall over time. We analyzed charcoal and dung spores in a sediment core to infer fire use and herbivory activities during two periods with contrasting rainfall regimes: a wet period during the 14th century, and a period of aridification during the 20th century. The low abundance of charcoal and spores around AD 1300, suggests that southwestern Malagasy practiced exclusively foraging activities. Reduced rainfall in the 20th century is associated with an increase in macroscopic charcoal and high spore concentrations. This could be related to i) the practice of seasonal agriculture by Mikea forager communities*;* ii) the arrival of agriculturalists in the region; and iii) activities conducted by pastoralists. The evidence can be associated with both agriculture and pastoralism. The results suggest that southwestern Malagasy subsistence practices have shifted from foraging to the inclusion of agropastoralism over time in response to climate change. Particularly, the Mikea demonstrated an adaptation to the drying in their region over time by reinforcing their traditional practices and including seasonal agriculture as a new coping strategy. However, future environmental changes are likely to force further diversification or a larger shift in their livelihoods, if no adaptation strategies are developed. A shift in subsistence to agropastoralism would make these foragers vulnerable to food insecurity and increase threats to biodiversity. The inclusion of Mikea in decision-making would facilitate the maintenance of their indigenous knowledge, while encouraging biodiversity-friendly approaches to livelihoods.

Key words: subsistence adaptation, climate change, conservation, southwest, hunter-gatherers, Madagascar

Résumé détaillé

Les communautés indigènes dépendent du capital naturel et adaptent leurs moyens de subsistance à l'évolution des conditions environnementales et des services écosystémiques. Cet article vise à comprendre comment les communautés du Sud-ouest de Madagascar habitant autour du Fleuve Mangoky et du Parc National de Mikea, ont adapté leurs stratégies de subsistance à la diminution des précipitations au fil du temps. Nous avons analysé les particules de charbon (macro >150 µm et micro <150 µm) et les spores coprophiles d'une carotte sédimentaire collectée dans le Lac Tsizavatsy situé au nord du fleuve et du Parc National de Mikea. Ces éléments ont été analysés pour en déduire respectivement l'utilisation du feu et les activités d'herbivorie, pendant deux périodes où les régimes de précipitations étaient différents : Le 14ème siècle, période humide, et une période d'aridification au cours du 20ème siècle. La faible abondance des particules de charbon et de spores vers l'an 1300, suggère que ces communautés pratiquaient exclusivement des activités de chasse et de cueillette. La réduction des précipitations au 20ème siècle est associée à une augmentation du charbon macroscopique et à une forte concentration de spores. Cela pourrait être lié à i) la pratique de l'agriculture saisonnière par les Mikea occupant actuellement la forêt de Mikea ou *Alamikea* au sud du site d'étude ; ii) l'arrivée

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d'agriculteurs dans la région ; et iii) les activités menées par les pasteurs. Les preuves peuvent être associées à la fois à l'agriculture et au pastoralisme. Les résultats suggèrent que les populations du Sud-ouest de Madagascar auraient développé une économie mixte comprenant l'agropastoralisme lorsque le climat est devenu de plus en plus sec. Particulièrement pour la communauté chasseur-cueilleur, les Mikea, les résultats ont démontré une adaptation à la réduction de la précipitation dans la région au fil du temps en renforçant leurs pratiques traditionnelles et en incluant l'agriculture saisonnière comme nouvelle stratégie d'adaptation. Cependant, les changements environnementaux futurs risquent de forcer la diversification ou le changement de leurs moyens de subsistance si aucune stratégie d'adaptation n'est mise en place. Un changement de mode de subsistance vers l'agropastoralisme rendrait ces exploitants vulnérables à l'insécurité alimentaire et augmenterait les menaces sur la biodiversité. L'inclusion des Mikea dans le processus décisionnel garantirait le maintien de leurs connaissances indigènes tout en encourageant des approches de moyens de subsistance respectueuses de la biodiversité.

Mots clés : subsistances, adaptation, changement climatique, conservation, Sud-ouest, chasseurs-cueilleurs, Madagascar

Introduction

The role of indigenous communities in the conservation of biodiversity is increasingly being recognized (Alcorn, 1993; Gadgil *et al.,* 1993; Mehta, 2017), and full recognition of the knowledge, practices, and beliefs of indigenous peoples relating to conservation of biodiversity is required if ecosystems and biodiversity are to be managed sustainably (Gadgil *et al.,* 1993; Schwartzman & Zimmerman, 2005; Andrade & Rhodes, 2012; Coria & Calficura, 2012). This approach is encouraged especially in developing countries that must combine biodiversity conservation with poverty alleviation. Many protected areas around the world are home to indigenous communities, including about 85% of those in South America and 70% of those in the Central African region (Mombeshora & Le Bel, 2009). The protected areas categories V and VI of the International Union for the Conservation of Nature (IUCN) combine biodiversity conservation and livelihoods (Dudley, 2013). However, failure to understand the history of human subsistence and land-use in these areas could potentially jeopardize conservation efforts and lead to negative impacts on these communities. It is crucial to understand how human subsistence has evolved in relation to changing climate, if we are to understand and predict human adaptation.

Foraging is the oldest form of subsistence, originating at least 100,000 years ago (Kelly, 2013). Foragers often shift their territories seasonally, annually, or on some longer time scale, a strategy that may promote resource conservation (Johnson, 1989; Gadgil *et al.,* 1993; Coria & Calficura, 2012). Many foraging communities have adapted to climatic, environmental, and demographic factors that impose constraints on forager lifeways. Adaptive strategies include mixed economies, where, for example, foraging is supplemented by other activities like farming (Kelly, 2013). Although the ancestors of people in western Madagascar were suggested to be hunter-gatherers, many of them have shifted to agriculture and pastoralism in recent times. However, there is still a community of foragers called "Mikea", living in the southwest of the island. These communities are considered indigenous and are provided the rights to practice their customs and continue their way of life (Repoblikan'i Madagasikara, 2010). Mikea communities collect and dry food resources for the coming season and cultivate maize and cassava (Stiles, 1998; Tucker, 2020; Figure 1). Today, some Mikea who occupy the forests are primarily hunter-gatherers, while others use mixed livelihoods including keeping cattle and goats, a tradition dating back to the 19^{th} century and early 20^{th} century (Bram Tucker, personal communication, October 2020).

Although it can be difficult to reconstruct foraging activities due to the ephemeral nature of forager sites in the archaeological record (Douglass & Zinke, 2015), most southwestern Malagasy, including Mikea, currently use fire in a swidden farming method called *hatsake* for agriculture during the transitional seasons and conduct zebu pastoralism. Although Mikea communities have been described as the only Malagasy people officially recognized by the World Bank as an "indigenous" community (Ferguson, 2009; Repoblikan'i Madagasikara, 2010; Huff, 2012), some have mixed with neighboring agropastoral ethnicities through marriage or other forms of exchange and practice resource partitioning in symbiosis with farmers (Stiles, 1998; Yount *et al*., 2001; Tucker, 2003). The subsistence practices that persist reflect these cultural exchanges. Since the establishment of the Mikea National Park in 2012, southwestern communities have experienced subsistence difficulties (Tucker, 2020). One of the main motives that has framed the decisions around the protected area was to mitigate forest destruction caused by fire from swidden farming (Kull, 2000; Scales, 2012; Tucker, 2020). Since the Mikea occupied the area, they were given the choice to stay in the park, living mostly by foraging without practicing any agricultural activities or moving to the park's buffer zone, where other activities can take place (Tucker, 2020). Those who stayed in the park have experienced conflicts with the forest guards causing most of the Mikea to move outside the park with their pastoralist neighbors, the Masikoro, a choice that has increased their food insecurity (Tucker *et al.,* 2010).

Human-induced fire on Madagascar is associated with deforestation, which has increased since the late 1980s (Blanc-Pamard *et al.,* 2005; Scales, 2012). Fire is associated with the destruction of vegetation from activities such as forest clearing linked to pastoralism and agriculture (Bloesch, 1999; Kull, 2000; Waeber *et al.,* 2015). To complement emerging archaeological work documenting Holocene subsistence strategies in coastal southwest Madagascar (Douglass, 2016; Douglass *et al.,* 2018), microscopic charcoal in sediments provides a good proxy of fire resulting from human activities in an area where 95% of fires today are considered anthropogenic (Bloesch, 1999; Waeber *et al*., 2015), particularly when combined with other proxies indicative of human activity, such as dung fungal spores. Charcoal preserved in lake sediments, peat, and soils provides a record of past fire occurrence. Coprophilous fungal spores have been widely used to reconstruct pastoral activity, as they are an indicator of high densities of large herbivores, like cattle, near lakes (Van Geel *et al.,* 2003; López-Sáez & López-Merino, 2007; Cugny *et al.,* 2010; Gelorini *et al.,* 2012; Guillemot *et al.,* 2015; Doyen & Etienne, 2017). The combination of fire and pastoral proxies provides the opportunity to evaluate change in human subsistence practices in southwest Madagascar during two periods with contrasting climate histories, a wet period during the 14th century AD and a dry period of the 20th century AD (Razanatsoa, 2019). This would enable further evaluation of interactions between vegetation, climate, and human disturbances through the last several millennia (Patterson *et al.,* 1987; Tinner & Hu, 2003; Mooney *et al.,* 2011). Wet periods encourage human settlement due to greater availability of fresh water and increased biological productivity, and are associated with high fire occurrence. On the other hand, during dry periods, evidence of abundant fires associated with low dung fungal spores is likely related to climate. Teasing apart these interactions between vegetation, climate and human disturbances will improve our understanding of how communities in southwest Madagascar such as Mikea foragers have adapted in the face of climatic and anthropogenic pressure. This will also facilitate the integration of traditional knowledge with management decisions.

In this study, we assess the evolution of activities involving fire and pastoralism, conducted by southwestern Malagasy living around the current *Alamikea* (Mikea Forest) and Mangoky River through

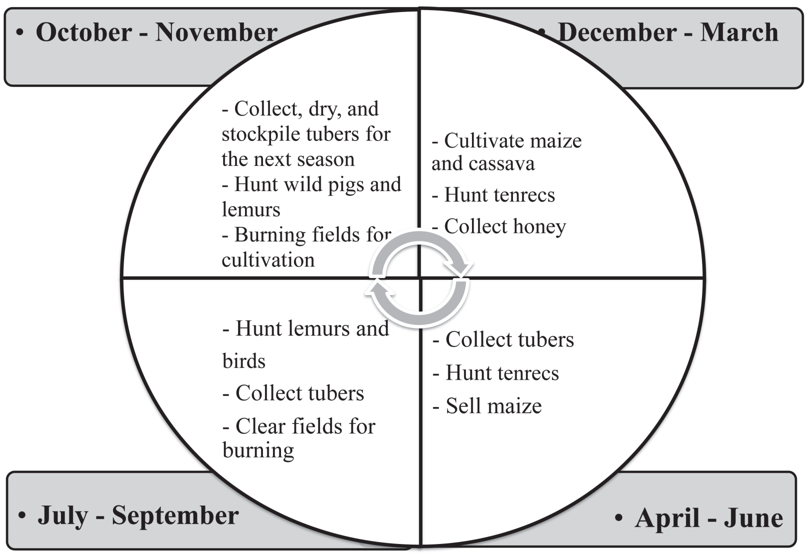

Figure 1. Annual cycle of subsistence strategies by the Mikea, a forager community in southwest Madagascar in the 1990s. Adapted from Stiles (1998).

paleoecological proxies. We report microscopic charcoal and coprophilous spore records from the region and explore evidence of changes in fire and herbivory, in terms of subsistence strategies of southwestern Malagasy. The research is framed around the following questions: i) what was the fire history around the *Alamikea* and Mangoky River in the 14th century and 20th century?; ii) what was the history of herbivory in these periods?; iii) what do the data suggest in terms of how the southwestern Malagasy living around the area responded to the climatic changes during these periods?; and iv) what can be inferred about past changes in subsistence for vulnerable Mikea forager communities and their neighbors relative to future environmental and economic changes? And finally, v) what effects could these changes have on biodiversity conservation?

Materials and methods

Study area

This research was conducted in the southwest of Madagascar near the Mangoky River and the Mikea National Park established in 2011 (Goodman *et al.,* 2018). The region has an unconsolidated sand substrate (Du Puy & Moat, 1996; Stiles, 1998; Seddon *et al.*, 2000) and a semi-arid climate with pronounced seasonality (Donque, 1972). The region experiences a dry season between May to October with annual precipitation ranging from 600 mm and declines to 400 mm per year near the coast (Stiles, 1998). The mean annual temperature varies between 23°C and 26°C with high humidity during the wet season (Du Puy & Moat, 1996; Elmqvist *et al.,* 2007). It has been suggested that the climate has been getting drier especially in the last 1000 years (Virah-Sawmy *et al.,* 2010; Goodman *et al.,* 2018; Razanatsoa, 2019). The area is home to diverse human communities. It is currently occupied by foragers and maize horticulturalists (Mikea), agropastoralists known as Masikoro, and fishers known as Vezo. Mikea, Masikoro, and Vezo share the same history but differ in their lifestyles today (Tucker *et al.,* 2010; Tucker, 2020). The Mikea and Vezo identities only emerged in the 17th century, in response to the rise of the Andrevola kings (Ottino, 1974; Yount *et al.,* 2001; Tucker, 2003). Despite sharing an agropastoral lineage with their Masikoro neighbors, Mikea define themselves as hunter-gatherers (*mpitindroke*) because they depend heavily on wild tubers, honey, and small game and have a close relationship with their forest refuge (Tucker, 2020). It has been suggested that when Mikea took up residence near water sources, they grew manioc and other crops in lake bed gardens, kept livestock (Tucker, 2020), and had an annually structured system of living in the forest as summarized in Figure 1 (Stiles, 1991; Tucker & Taylor, 2007).

Sediment coring

A 48 cm sediment core was collected from Lake Tsizavatsy in September 2015 (Figure 2) using a Russian corer (Aaby & Digerfeldt, 1986). Lake Tsizavatsy is a shallow lake, approximately 500 m in diameter, located near the Mangoky River in the southwest of Madagascar (21.77977778ºS, 43.89797222ºE). Much of the Mangoky floodplain is today devoted to rice agriculture, and home to Masikoro and migrants from different areas of Madagascar. The Mikea National Park (Figure 2), currently occupied by Mikea communities, is located south of the river. The coring site is a permanent wetland situated at the north end of the Mikea National Park. During our fieldwork the average depth of the lake was less than 0.5 m allowing us to retrieve a core from the center of the lake. According to the local community, Lake Tsizavatsy recedes to half its area during the dry season. In addition to the lake being permanent and to its location, the core from this lake had good preservation of our proxy of interest. This coring site is surrounded by Cyperaceae at the lake's edge and is encompassed by a wider landscape of wooded grasslands and a mix of degraded and intact dry deciduous forest.

Microscopic charcoal and coprophilous spore analysis

Micro and macrocharcoal pieces recorded in sediment cores indicate past fire events whether climate or human-driven (Tinner & Hu, 2003; Mooney *et al.,* 2011). Microcharcoal (<150 µm) and macrocharcoal (>150 µm) were used for the study of Quaternary fire history and provide data on contemporary fire regimes (Blackford, 2000; Scott, 2000). Macrocharcoal gives a strong signal of local fire history (Carcaillet *et al.*, 2001), which can often be interpreted as a signal of anthropogenic burning (Virah-Sawmy *et al.,* 2016). Macrocharcoal was recovered by sieve before the hydrofluoric acid (HF) step. Charcoal samples of >150 µm were recovered to count the macrocharcoal content of the sediments. The counting was done using a dissecting microscope at x10 magnification.

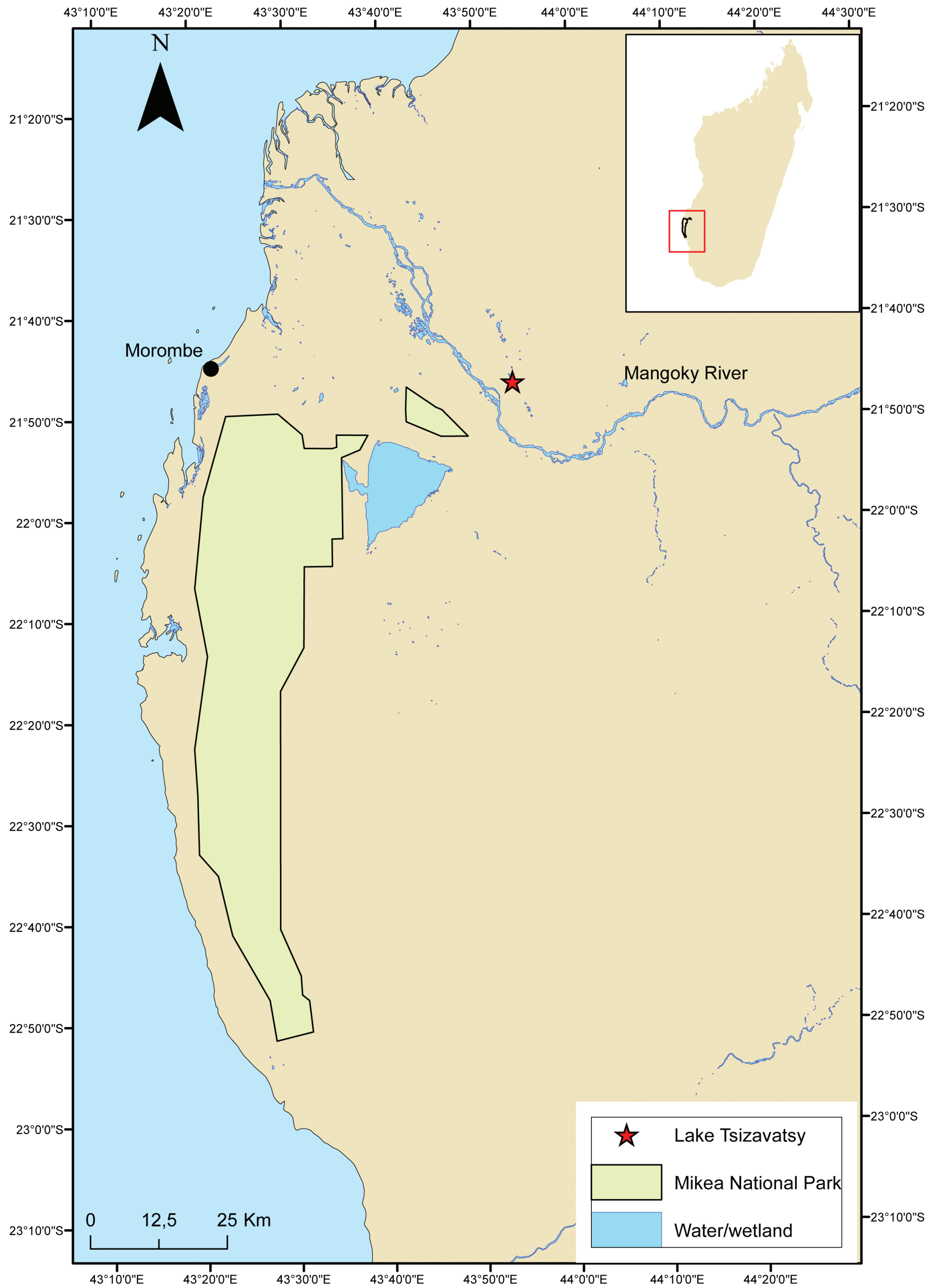

Figure 2. Location of the study area, the coring site at Lake Tsizavatsy, and the Mikea National Park in southwest Madagascar.

Microcharcoal analysis follows the extraction procedure described and reviewed in Bennett and Willis (2001). Microcharcoal analysis was conducted following the point count method (Clark, 1982). This method has been reported to be one of the most efficient in analysing microcharcoal in sediment samples (Finsinger & Tinner, 2005). A minimum of 200 counts of *Lycopodium* and charcoal were recorded (Finsinger & Tinner, 2005) excluding any ambiguous particles. The identification of spores and *Lycopodium* was completed under 1000x magnification with the addition of immersion oil. For each level, spores were counted until a combined total of 300 spores and *Lycopodium* was reached (Etienne & Jouffroy-Bapicot, 2014). The spores counted were *Sporormiella*, *Gelasinospora*, *Coniochaeta*, *Podospora*, and *Sordaria* (Ekblom & Gillson, 2010; Baker *et al.,* 2013; Figure 3).

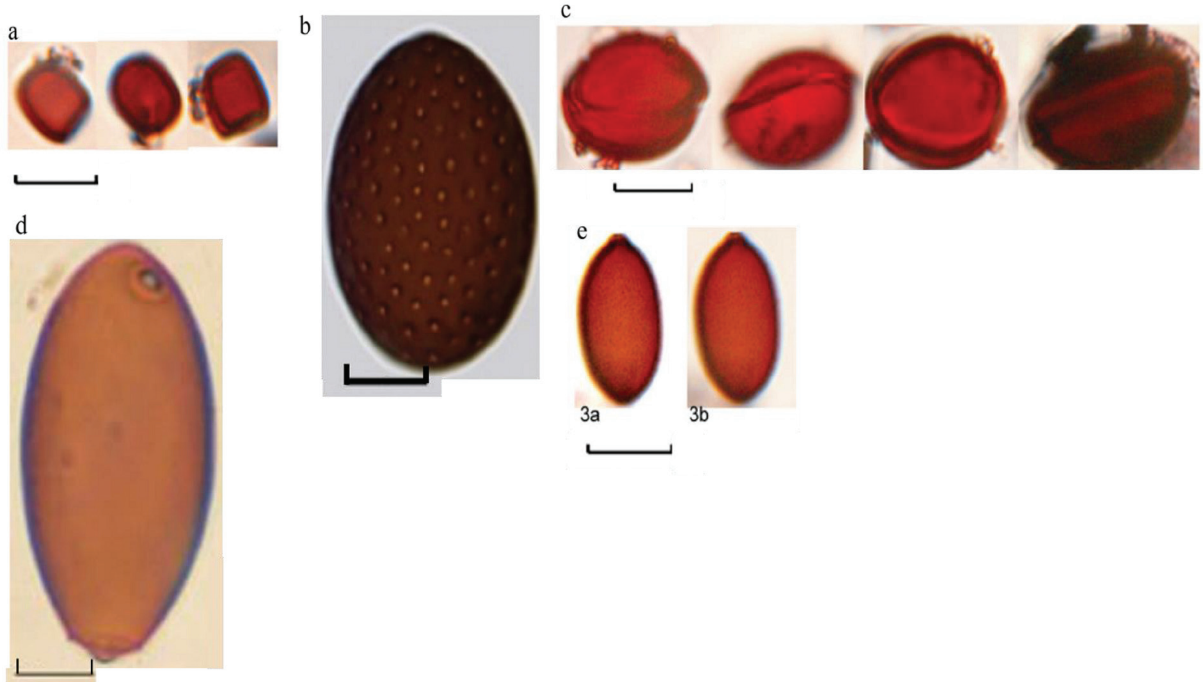

Figure 3. The spores counted. Each bar represents 10 μm. Key: a = *Sporormiella*, b = *Gelasinospora*, c = *Coniochaeta*, d = *Podospora*, and e = *Sordaria*. Images a, c, and e are from Ekblom & Gillson (2010), image b is from Baker *et al*. (2013), and image d is from Cugny *et al*. (2010).

Sediment chronology

The chronology of the core is based on four AMS radiocarbon dates (Gasse & Van Campo, 2001; Colombaroli *et al*., 2010). The radiocarbon dates were measured at iThemba LABS facility in Johannesburg (South Africa); Beta Analytic Inc, Laboratory in Florida (USA), and 14CHRONO labs in Belfast (UK). Age-depth models were built using Clam 2.3.1 based on the SHCal04 southern hemisphere calibration curve (Blaauw, 2010; Blaauw & Christen, 2011) using linear interpolations of the dates based on age point estimates for depths on weighted means of the dated levels. All calibrated ages were expressed in BC/AD in reference to BCE/CE.

Data analysis

Charcoal influx was calculated to reflect the abundance based on the sediment accumulation rate obtained from the age-depth model. The spore concentration was calculated and plotted against the modelled age (Figure 4). A Non-metric Multidimensional Scaling (NMDS) was applied to the spore and charcoal data to identify the main variation and trends during the two major periods. The numbers of dimensions included in the ordinations was determined by calculating "stress" which is an inverse measure of fit between rank orders of the original dissimilarity matrix and the NMDS ordination space data (MacPherson, 2017) ranging between 0 and 1 (Kruskal, 1964; Clarke & Warwick, 2001; McCune *et al.,* 2002).

Results

Age model of the sediment core

The four radiocarbon dates run on this 48 cm core show the presence of a hiatus related to sediment accumulation around 24 cm (Figure 4). The basal date at 43 cm depth yields a calibrated age of AD 1301-1365 followed by three other dates respectively at 35 cm, 29 cm, and 24 cm. The dates associated with these depths are AD 1289-1396, AD 1378-1406, and AD 1804-1935, respectively. The linear interpolation of the calibrated dates was based on the best probability density for the upper section of the core while maximum intercepts were assigned for the lower section of the core. The age model suggested the presence of a hiatus at about 24 cm dividing the core into two parts covering the 14th and the 20th century. The section of the core from 0 to 24 cm represented the period from AD 1910 to 2010 with sediment accumulation of 2.5 mm yr^{-1}, and the section from 25 to 48 cm with an accumulation rate of 2 mm yr^{-1} represented the period from AD 1300 to 1420. These periods will be from now referred to as the 14th and 20th centuries.

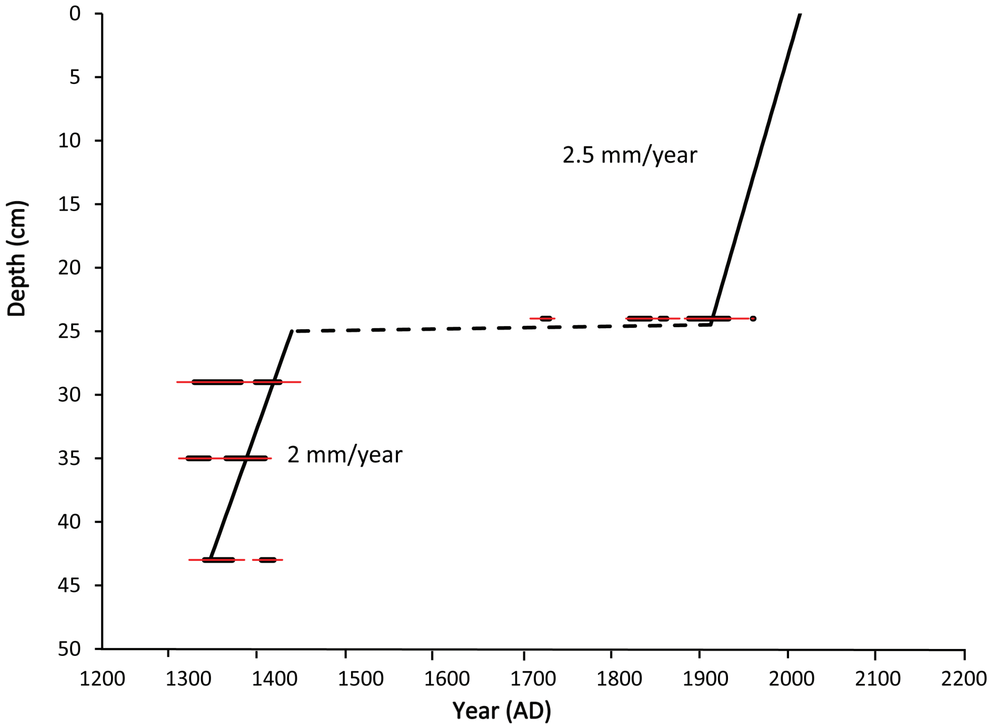

Figure 4. Age depth model of the core from Lake Tsizavatsy. Red horizontal lines indicate the 1-sigma calibration intervals for the radiocarbon dates done at the depth indicated in the y-axis. Dotted lines indicate the 500-year hiatus period from AD 1420 to 1910.

Charcoal records during the 14th and 20th century

The analysis of microcharcoal and macrocharcoal allowed for the reconstruction of fire history of the area in the 14th and 20th centuries. A total abundance of 1228 particles.cm^{-3} of microcharcoal was recorded with the lowest value recorded at AD 1420 with 28 particles.cm^{-3}. Macrocharcoal abundance remained relatively low during the period AD 1300 to 1420. For the microcharcoal, the abundance in the whole core was about 3719 cm^2.cm^{-3}. The lowest abundance of charcoal is recorded at the bottom of the core around AD 1300 with the value of approximately 51 cm^2.cm^{-3}. The correlation between microcharcoal and macrocharcoal abundance was not significant ($r = 0.02$, $P = 0.92$; Figure 5). The influx of charcoal differs between the two periods identified from the age model. The 14th century was marked by very low but dynamic charcoal records. The lowest charcoal abundance was at AD 1300 after which the charcoal influx increased and reached the highest microcharcoal value of about 107.7 cm^2 yr^{-1} at AD 1360, although macrocharcoal remained relatively low (16.8 particles yr^{-1}). Low charcoal influx was recorded at the end of the period around AD 1380 to 1420 reaching as low as 33.47 cm^2 yr^{-1} for microcharcoal and eight particles. yr^{-1} for macrocharcoal. During the 20th century, there was a more stable charcoal influx with a mean of 52.2 ± 16 cm^2 yr^{-1} and 26.8 ± 2.2 particles yr^{-1} for microcharcoal and macrocharcoal, respectively. During this period, macrocharcoal was high while microcharcoal remained relatively low compared to the previous period.

Coprophilous spore record during the 14th and 20th century

During the 14th century there was a low concentration of all spore types with a gradual increase over time (Figure 5). The minimum concentration was 64.66 cm^{-3} in AD 1350 and the maximum concentration was 597.90 cm^{-3} in AD 1360. This zone ends at a concentration of 529.64 cm^{-3} in 1400 before the hiatus. The 20th century has a much higher concentration of spores than the 14th century. This period exhibited high variability, with three major peaks that occur in AD 1930 with a concentration of 2636.18 cm^{-3} (the maximum), AD 1960 with a concentration of 1990.06 cm^{-3} and in AD 2000 with a concentration of 1757.45 cm^{-3}. The minimum of 733.28 cm^{-3} occurs in 1925, which is similar to around 2010 (735.82 cm^{-3}). During these two periods, *Sordaria* had the highest concentration followed by *Coniochaeta* and *Podospora*. *Gelasinospora* and

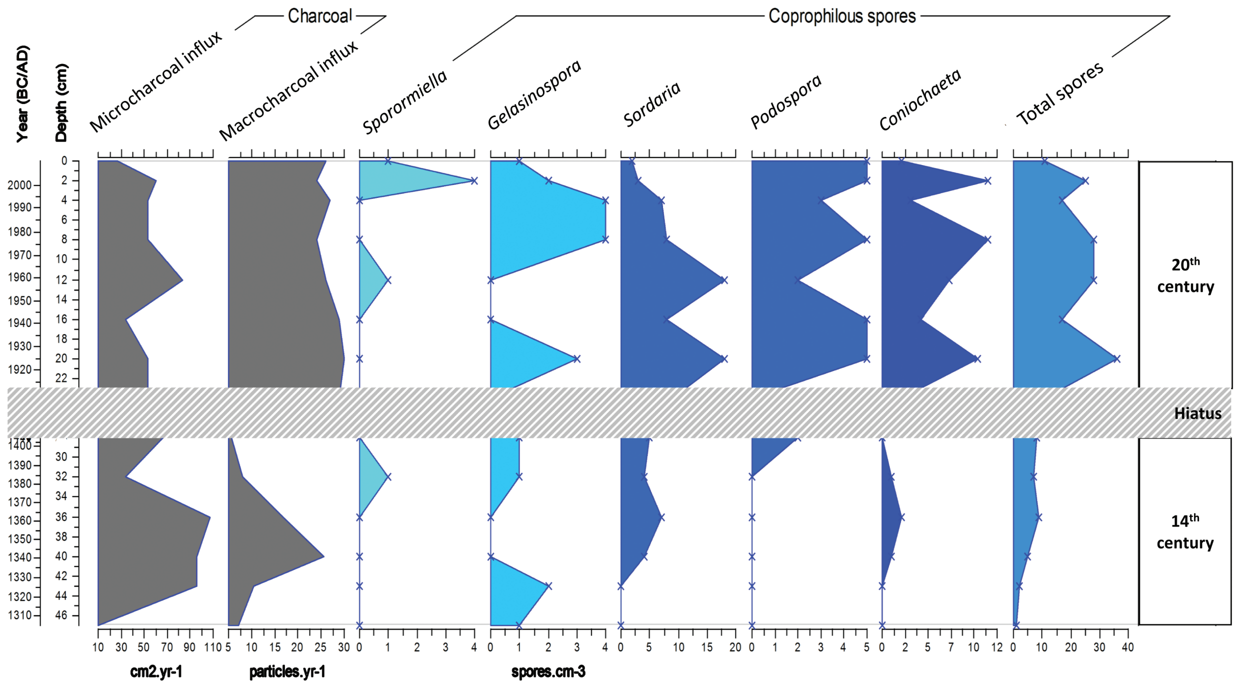

Figure 5. Charcoal and coprophilous spores records from the core during the 14th century and the 20th century.

Sporormiella remained relatively low during the investigated period.

Multidimensional analysis of charcoal and spores

The multidimensional analysis of the charcoal and spore data represented the two periods in two different clusters based on a stress value of 0.12 and a linear fit r^2 of 0.9 (Figure 6). The 14th century cluster was associated with microcharcoal over time while the 20th century cluster is marked by the association of all the samples with the coprophilous spores including *Coniochaeta*, *Podospora, Gelasinospora, Sporormiella,* and *Sordaria* in addition to macrocharcoal.

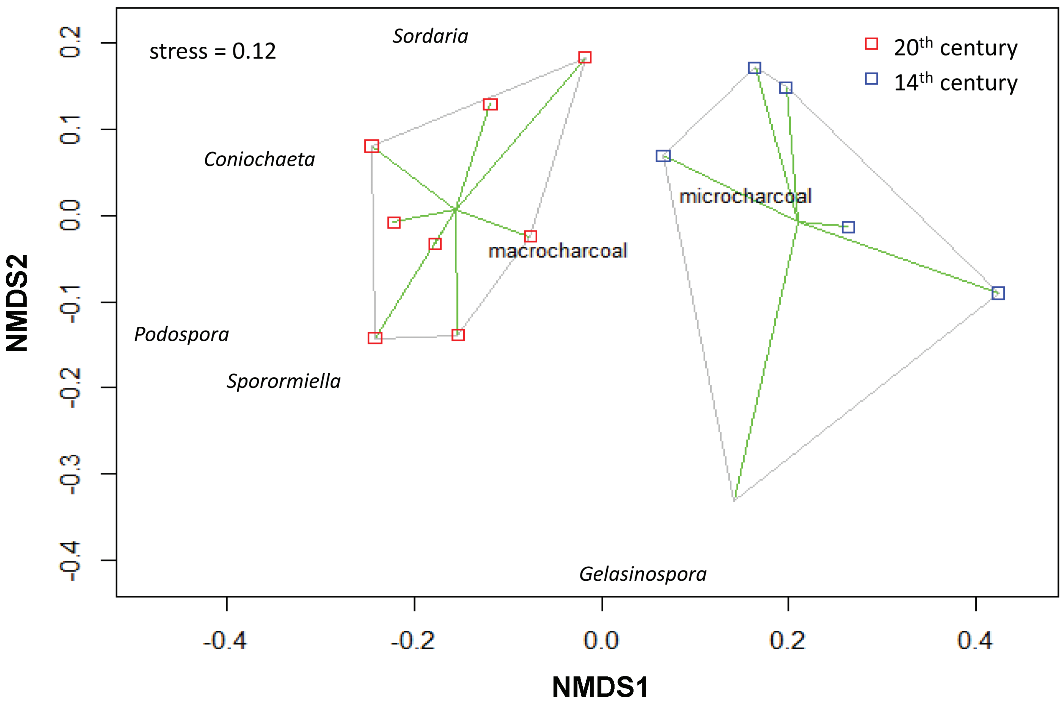

Figure 6. Non-metric Multidimensional Scaling (NMDS) of the charcoal and spore data showing the trends of changes in subsistence during the 14th and 20th century.

Discussion

Changes in fire and herbivory activities

In this study, we analyzed charcoal and dung fungal spores from Lake Tsizavatsy in southwest Madagascar, in order to reconstruct fire history and herbivory activities, which are used as a basis to infer human activities during the 14th and 20th centuries. Charcoal records reflect fire events that probably resulted from agricultural practices and coprophilous spore concentration is inferred to be evidence of herbivory activity by domesticates (López-Sáez & López-Merino, 2007; Guillemot *et al.,* 2015; Doyen & Etienne*,* 2017) and thus pastoralism. The record from this study should therefore serve as a proxy of pastoralist activities conducted around Lake Tsizavatsy in southwest Madagascar in the 14th and 20th centuries.

The 14th century was marked by a low but dynamic fire record with an increasing rate of microcharcoal at the beginning but decreasing over time, while macrocharcoal remained low throughout. The low macrocharcoal abundance indicates a low frequency of fire events surrounding the site, while at a more regional scale there were increasing fire events, as recorded by the microcharcoal. This period appears to be the wettest in the last 700 years (Razanatsoa, 2019). Increased regional fire could indicate the presence of humans across southwest Madagascar (Anderson *et al.,* 2018) although herbivory activities, as reflected in the concentration of coprophilous spores remained quite low during this period. There may also have been increasing natural fires despite the wetter conditions due to enhanced grass biomass production.

In the 20th century there was an overall stable rate of charcoal accumulation with lower microcharcoal compared to the previous period but an increased rate of macrocharcoal. In addition, there was a variable but high concentration of coprophilous spores with three massive peaks around AD 1930, AD 1960, and AD 2000. These peaks in herbivory activities corresponded to the increase in fire events, which could be the result of human activities, despite increasing aridity. This possibility is supported by estimates that 95% of fire events on Madagascar are human-induced (Bloesch, 1999; Waeber *et al.,* 2015).

Changes in human subsistence

The two periods investigated are the wettest and the driest period recorded in the region over the last 700 years (Razanatsoa*,* 2019). Increasing influx of microcharcoal during much of the 14th century (until AD 1370) and similar increases at other sites in southwest Madagascar since AD 950 (Virah-Sawmy *et al.,* 2016; Razanatsoa, 2019) are linked to the expansion of agropastoralism across the region (Virah-Sawmy *et al.,* 2016; Anderson *et al.,* 2018). Archaeological evidence suggests that by the end of the 1st millennium AD or the beginning of the 2nd millennium, the growth in maritime trade along the Swahili coast coincided with the introduction of livestock to the island (Dewar & Wright, 1993; Blench, 2010; Beaujard, 2012; Douglass *et al.,* 2019). By the end of the 14th century, the influx in microcharcoal became very low, possibly reflecting the stasis of pastoralist activity around the site occupied by the ancestors of today's southwestern Malagasy. Despite these records of livestock introduction and the expansion of pastoralism starting from 950 AD, spore concentrations and local fire events remain relatively low in the 14th century record (AD 1310 to 1400), which could suggest that most human activities around Lake Tsizavatsy during this period were based on foraging (Figure 7).

During the 20th century, microcharcoal remained relatively low compared to the previous period while the influx of macrocharcoal increased over time. The increase in macrocharcoal as a proxy for increase in local fires suggests increased agricultural activity compared with the 14th century. However, the accumulation of microcharcoal at Lake Tsizavatsy is much lower than what has been recorded at a site occupied by agropastoralist communities further to the north at Lake Longiza (see Razanatsoa *et al.*, 2021a). This finding is consistent with lower population density and less intensive land-use (Razanatsoa, 2019). First, this could suggest that agropastoral communities surrounding Lake Tsizavatsy could have started to use fires for swidden farming. Second, it might suggest that foragers started to practice mixed economies, including cultivating maize from December to March (Stiles, 1998; Figure 1) and maintained this practice during the 20th century. Third, in addition to the increase in local fire use, a massive increase in coprophilous spores indicates an augmentation in herbivory activity during the 20th century. This suggests an increase in pastoralism in the region despite reductions in rainfall (Razanatsoa, 2019). Overall, the results indicate the presence of subsistence associated with agriculture and pastoralism in the southwest region during the 20th century (Figure 7).

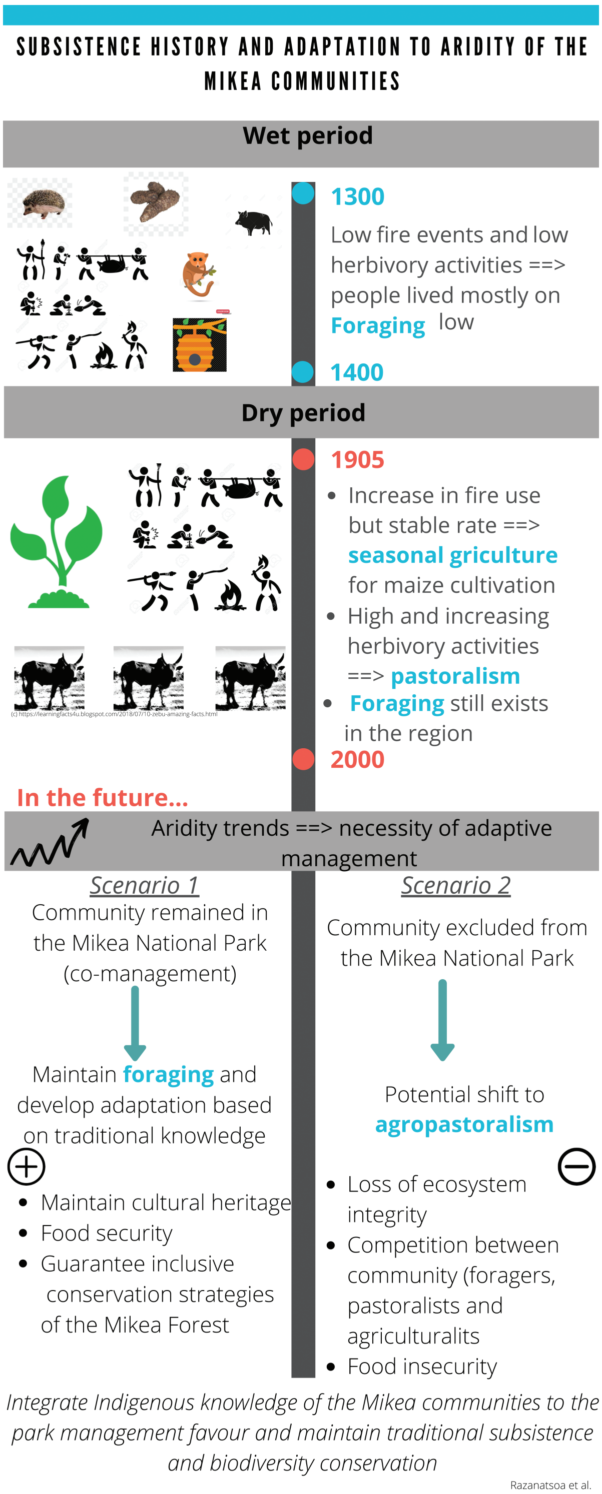

Figure 7. Summary of subsistence change and adaptation of Mikea communities in southwest Madagascar.

Of the diverse communities living in southwest Madagascar (Tucker *et al.,* 2010; Tucker, 2020), Mikea communities living south of the study site are considered among the poorest populations in the country (Healey, 2018; Tucker, 2020). They have kept foraging as their main subsistence strategy despite the expansion of pastoralism, a practice that most communities in southwest Madagascar have adopted (Healey, 2018). Although they have limited financial means, foragers are thought to be less food insecure than their agropastoral counterparts (Tucker *et al.,* 2010). Greater food security may be linked to their seasonal subsistence strategies that include maize cultivation from December to March (Figure 1) combined with gathering in the forest throughout the year (Kelly, 2010; Tucker *et al.,* 2010). The area occupied by the Mikea is known to have very low water availability and low soil fertility (Du Puy & Moat, 1996; Stiles, 1998; Seddon *et al.*, 2000), but diversification of the subsistence economy likely allowed these communities to survive harsh conditions over time.

Subsistence trends in the near future

Anticipated future environmental change is likely to lead to reduced food resources due to biodiversity loss (Tucker, 2020), demographic pressure caused by immigration (Blanc-Pamard, 2009), and predicted drying trends linked to climate change (Razanatsoa, 2019). These present significant challenges for Mikea forager communities. Based on the results of this study, foraging and agropastoral economies have co-existed in the region in the past. With governmental support, Mikea could possibly re-establish a mixed economy of farming and foraging that might stabilize their food security, despite the future environmental changes noted above. At present, some Mikea are experiencing difficulties in accessing their territory and foraging grounds (Mikea National Park), constraining their access to food and resources (Huff, 2012; Tucker, 2020). Access to the park is dependent upon official designation of a person's Mikea and, hence, indigenous status which is problematic as it is based on criteria such as primitivism, traditionalism, and vulnerability (Poyer & Kelly, 2000; Huff, 2012). Such distinction and criteria have increased the vulnerability and fear in the Mikea due to the perception of them being poor leading them to experience abuse from state representatives and others. Therefore, they are reluctant to get involved in management decisions and were not represented during the establishment of the protected area (Huff, 2012). Improving their access to the designated zone within the park and establishing policies that foster respect for Mikea dignity could motivate them to be involved in the management of the park (Huff, 2012; Tucker, 2020).

Return to a more mixed economy might also allow for the renewal of overexploited resources, as people have alternated the use of different resources available within the area at least since the early 20th century (Poyer & Kelly, 2000; Tucker, 2020; this study). Land use regulations could focus on how much, how often and where burning is done, to ensure that the zone of conservation remains intact, and that forest within the buffer zone can be maintained for continued community use. Quotas of areas for burning could be created for all communities to ensure the sustainability of common pool land use and reduce risks of land conflicts that are already recorded in some areas (Blanc-Pamard, 2009). This approach should further involve indigenous Mikea knowledge to supplement prospective management policies. Involving Mikea in decision-making and park management could also positively impact biodiversity. A mixed approach of protected areas and indigenous-managed lands has been implemented, for example, in Brazil, Australia, and Canada and ameliorated land protection for biodiversity conservation (Weir *et al.,* 2011; Schuster *et al.,* 2019).

Failure to provide appropriate support and collaborate with these communities in the future will further erode Mikea cultural practices and may result in a complete shift to agropastoralism as natural resources and water become depleted (Figure 7). Such a shift might lead to permanent food insecurity and rural poverty for these communities in southwest Madagascar, due to competition with other groups living in the area (Tucker *et al.,* 2010; Tucker, 2020). Increased reliance on land clearing for crops and grazing would exacerbate the effects of climate change on forest and shrub land loss, which in turn pose challenges to rain-fed agriculture and livelihood sustainability (Morton, 2007). Ultimately, a complete shift to agriculture would potentially cause further destruction of the Mikea Forest within and surrounding the Mikea National Park, due to the search for arable lands.

Forest destruction through clearing appears to accentuate biodiversity loss in the Mikea Forest (Kull, 2000; Blanc-Pamard, 2009). A complete subsistence shift for Mikea would not be beneficial for these communities or the unique biodiversity of the region. It is therefore important to establish land-use strategies that ensure food security while maintaining local ecological processes. An ecosystem-based management approach that integrates indigenous knowledge of the landscape would help identify areas of concern and negotiate a compromise. Authorities can build a community-based management scheme that utilizes the direct involvement of native people in the maintenance and management of the land. This could be done by allowing people to remain in their territories and facilitating community education regarding the changing landscape. Adaptive management is particularly important since the park is experiencing increased aridity which threatens the food security of forager communities. Only their inclusion in decision-making and their reintegration within their forest will benefit a biodiversity-friendly livelihood that could adapt to a long-term change of climate (Figure 7). However, further investigation is needed to understand the extent to which their fire use and their neighbors' pastoral activities have affected the recorded reduction of forest cover from satellite images in the last 40 years (Blanc-Pamard *et al.,* 2005) and the decrease in the tree component of the pollen record from this site since AD 1950 (Razanatsoa *et al.,* 2021b). It is important to increase the resolution of paleo-research to show historical and contemporary landscape processes and patterns that can be used to appropriately manage the park.

Conclusion

In this study, we reconstructed the fire history and herbivory activity in the Lake Tsizavatsy area reflecting how human subsistence near the Mikea Forest and Mangoky River has changed during the wettest period around the 14th century and the driest period of the 20th century. These periods were differentiated in terms of fire and herbivory, which we interpret in terms of changes in human activities and livelihoods. The first period was dominated by foraging, as indicated by the low macrocharcoal influx and spore concentrations. Then, in the 20th century, an influx of charcoal and increase in coprophilous spore concentrations reflect a change in human activities, including agriculture and pastoralism. The results suggest that the southwestern Malagasy subsistence transitioned from an exclusive foraging activity to a mixed economy including agropastoralism as climate became increasingly dry. Particularly, during these two time periods, the data are consistent with the continuous presence of foragers. Today, foraging communities have started diversifying their activities by adopting seasonal practices of agriculture. This diversification may be an adaptive response to the harsh conditions of their territories, especially in recent decades of aridifying climate. In the near future with the possible drying trends in the area, Mikea communities could adapt to climate change through their traditional practices, if included in management decisions by the park administration. Their current exclusion from the protected area might lead them to shift completely to agropastoralism, which may increase resource competition with surrounding communities and ultimately be more harmful to biodiversity and food security. We recommend that park managers and conservationists consider the inclusion of Mikea peoples' knowledge and traditional practices to improve social and ecological outcomes in a changing climate.

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