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Links between poverty, climate-induced migration and deforestation in western Madagascar

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ABSTRACT

Recently, people from arid regions in Madagascar have migrated to greener and wetter areas, creating socioeconomic and environmental challenges from increased demand for natural resources. This paper examines the relationship between human migration and land use change in five communes in and around the Menabe Antimena protected area, a critical biodiversity hotspot in western Madagascar. We analysed poverty and climate differences between migrants' origins and destinations by conducting 92 semi-structured interviews, 46 with migrants in Menabe and 46 with residents of Androy, a region contributing to migration flow. We also investigated population dynamics and ecological indicators, including forest cover and number of VIIRS active fires detected weighted with precipitations between 2017 and 2022. Results show that migrants moved to areas with more rainfall and less poverty, with 89.1 % leaving their home villages due to famine and poor lifestyle. The number of migrants entering the protected area has increased 3.2 times with 63.0 % of them directly involved in illegal agricultural practices. The forest cover in areas of communes inside the protected area declined by 22.1 % though 36.4 % outside, while weighted active fires rose by 24.7 % inside and 55.9 % outside, with higher fire occurrences in communes with larger forest. Among migrants, 45.7 % plan to return home once they have saved sufficient funds, 28.3 % intend to settle permanently, and 13.0 % aim to relocate to more productive areas after clearing local forest. These findings can guide authorities and conservation managers in making policies to support migrants in adopting sustainable farming practices, addressing links to deforestation.

1. Introduction

Human migration, often triggered by climate-related shocks, contributes to forest degradation and biodiversity loss in tropical

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regions, although its drivers remain highly context-specific (Barbieri and Carr, 2005; Cattaneo et al., 2019; Ruf et al., 2015; Zommers and MacDonald, 2012). Climate change influences migration in complex ways, with many young people in Sub-Saharan Africa expressing intentions to migrate because of growing climate-related issues (Ofori et al., 2023). Due to climate variability, some regions may no longer sustain agriculture and become too dangerous to live in (Vinke and Hoffman, 2020), forcing people to migrate. In those areas, remote, less-favoured agricultural lands are home to over 130 million people living in poverty due to limited market access and challenging farming conditions (Barbier and Hochard, 2019). Although the links between environmental change and migration has been studied since the 18th century (Piguet, 2013), they remain overlooked by most scientists (Carr, 2009). Migration, often from poorer to wealthier areas, could be a cause and consequence of deforestation, driven more by travel costs and perceived frontier opportunities than destination characteristics (Amacher et al., 1998; Britta et al., 2021). This is a concern because deforestation harms biodiversity which plays a crucial role in maintaining productive ecosystems (Duffy et al., 2017). Even though migrants have been shown not to be exceptional resource degraders in certain protected areas (Codjoe and Bilsborrow, 2012; Jones et al., 2018), they risk to significantly change the land-use, posing a major threat to primary tropical forests (Amacher et al., 2009; Phillips et al., 2017). Some cases have already shown that migration contributes to deforestation, e.g. the Rohingya influx into Bangladesh (Ahmed et al., 2019), palm oil expansion in Indonesia (Darmawan et al., 2016), and cocoa farming in Côte d'Ivoire (Ruf et al., 2015). Development projects can also drive migration and forest loss, such as road construction in the western Amazon, opening new frontiers and incited illegal coca cultivation (Dávalos et al., 2016).

In least developed countries, internal migration is often driven by population growth, land scarcity, and declining soil fertility, as tropical soils are rapidly exhausted, pushing settlers into forest area (Poston and Micklin, 2005). However, the roles of climate, poverty, and migrants' long-term intentions after forest depletion in those areas remain poorly understood. Further research is needed to explore these links, particularly in African countries like Madagascar, a biodiversity hotspot (Myers et al., 2000; Raik, 2009; Ralimanana et al., 2022; Weber, 2021) where complex human-nature interactions (Antonelli et al., 2022) intersect with environmental, socio-demographic, economic, and political changes (Borderon et al., 2019).

With 143 protected areas, including 7.52 million hectares (ha) of terrestrial coverage (UNEP-WCMC, 2025), Madagascar's biodiversity remains threatened, having lost 44 % of its natural forest between 1953 and 2014, largely due to slash-and-burn agriculture (Vieilledent et al., 2018). Fire use was widespread across Madagascar, with an average of 356,189 fires detected each year

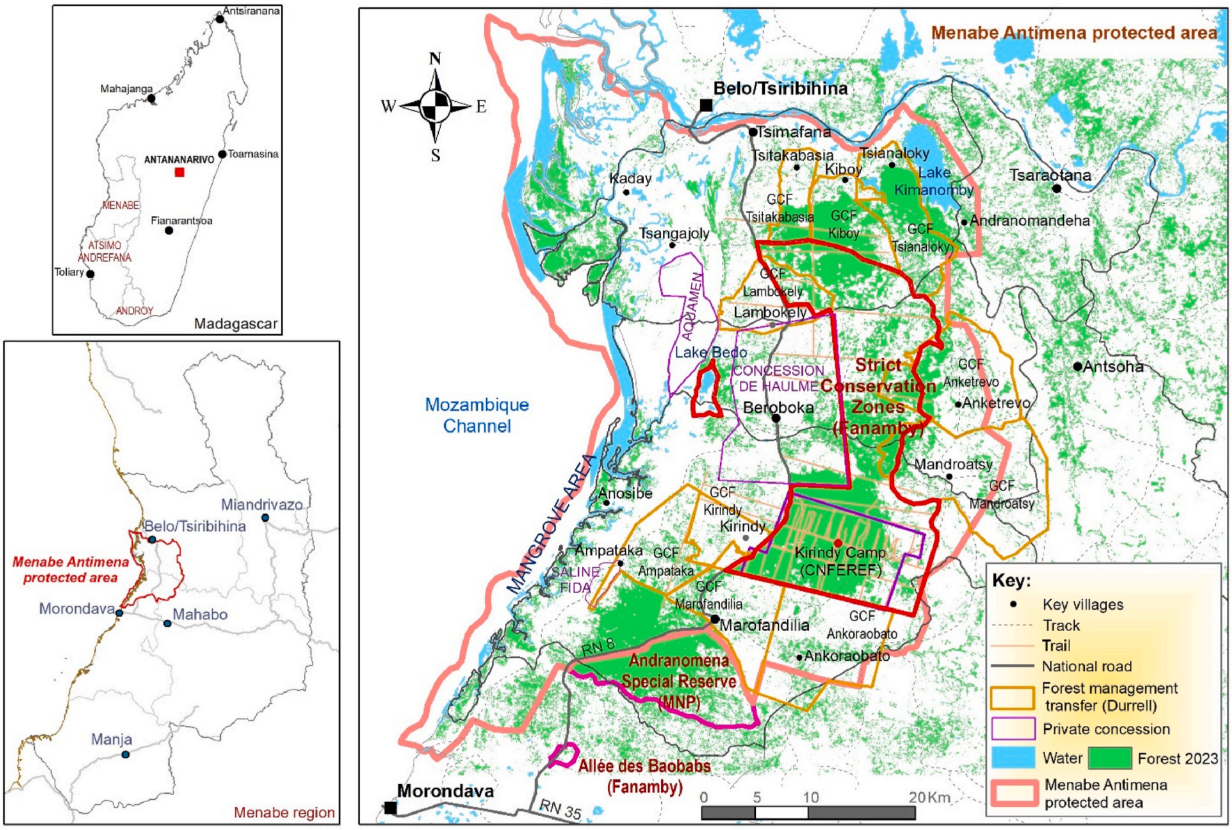

Fig. 1. Map of study areas: Upper left: Madagascar showing the Androy and Atsimo andrefana regions. Bottom left: Menabe region highlighting the Menabe Antimena protected area between the Morondava and Belo/Tsiribihina districts. Right: Menabe Antimena protected area with management zones and the five municipalities receiving migrants.

(0.604 fires/km^2) from 2012 to 2019, mostly in the western dry forests and succulent woodlands (Frappier-Brinton and Lehman, 2022). This is worsened by drought, which can increase deforestation rates by 7.6 %, and up to 17 % in dry and semi-arid areas (Desbureaux and Damania, 2018). Deforestation in Madagascar stems from poverty-driven itinerant agriculture, causing continual environmental degradation (Scales, 2014). In 2023 alone, the country lost 303,000 ha of natural forest, equivalent to 160 million tonnes of CO_2 emissions (Global Forest Watch, 2024), and without effective conservation strategies, up to 93 % of its natural forest present in 2000 could disappear by 2050 (Vieilledent et al., 2020). Madagascar is ranked as the third most vulnerable region to the impacts of climate change (WMO, 2018); it risks facing reduced agricultural production, more frequent natural disasters, and a rise in climate-related diseases (Nematchoua et al., 2018). With a population of 25.7 million, 74.2 % multidimensionally poor (84.4 % in rural area) and 77.9 % engaged in agriculture (INSTAT, 2020), the country is unlikely to achieve the first Sustainable Development Goal of poverty eradication by 2030 (Pettersson et al., 2023).

In Madagascar, internal migration linked to deforestation has occurred since the 19th century (Razanaka et al., 1999), mainly as rural-to-rural movement driven by regional disparities in livelihoods, poverty, natural resources and infrastructure (Burnod et al., 2017; Casse et al., 2004). Protected areas in north-western and western Madagascar, including Menabe Antimena (IUCN Category V 'protected landscape'), have faced migration-driven challenges from illegal farming prompted by the 2014 maize and 2015 peanut booms (IOM & Region Menabe, 2021). This has been amplified by climate change, environmental degradation, and the COVID-19 pandemic, changing the migration patterns (Burnod et al., 2017). For Madagascar, the warning is clear, there is a vital need for more effective natural resources management including environmental regulation (Kull, 2002; Scales, 2014) and now is the last chance to address these conservation challenges (Jones et al., 2019a). The presence of migrants in Menabe Antimena protected area raises concern as Madagascar's biodiversity is already facing serious threats (Jones et al., 2019b). It is believed that a flow of people has fled from hard living conditions in southern Madagascar mainly Androy region (Fig. 1), to squat in the forest or settle in villages near this protected area to grow maize *Zea mays* and peanut *Arachis hypogaea*.

Menabe Antimena has unique biodiversity e.g. the giant jumping rat *Hypogeomys antimena* (CR) - largest extant endemic rodent of the country (Sommer et al., 2002; Wilmet et al., 2022), the flat-tailed tortoise *Pyxis planicauda* (VU) (Young et al., 2008), the Madame Berthe's mouse lemur *Microcebus berthae* (CR) - the world's smallest primate (Markolf et al., 2019; Schäffler and Kappeler, 2014), and a very suitable habitat for baobab trees *Adansonia* spp. (Wan et al., 2021). The management of Menabe Antimena protected area is led by Fanamby, which focuses on the core area, in collaboration with the Durrell Wildlife Programme (dry forest management transfers), the Chances for Nature, the German Primate Center (DPZ), and the National Research and Training Centre in Environment and Forestry (CNFEREF) (Kirindy camp), World Wide Fund for Nature (WWF) (mangroves), and local environmental associations. The area receives support from partners including USAID Mikajy, A2DM (Association d'Appui au Développement de Madagascar), Louvain Development, the civil society coalition FIVE, all contributing to the management of the protected area. However, since 2008 Menabe Antimena has experienced increased annual deforestation rates from 0.42 % over 1973–1992 to 2.55 % over 2008–2010 (Zinner et al., 2014), with average losses estimated at 4.27 % per year between 2018 and 2022 and down to 2.50 % in 2022 and 2023 (Andrianambinina et al., 2025).

This study examines the origins, travel patterns, and motivations of migrants and explores the links between poverty, climate-induced migration, and deforestation across five communes in and around the Menabe Antimena protected area targeted by migrants. This analysis is vital, as i) protected areas are important to mitigate fire, forest loss and improve social wellbeing (Eklund et al., 2016; Gorenflo et al., 2011; Jones et al., 2023; Sommerville et al., 2010; Wright et al., 2007); ii) the forest is key to save the region's exceptional biodiversity; iii) it will generate knowledge to help inform forest conservation and rural development policies (Carr, 2009).

It is hypothesised that communes with higher numbers of migrants experience more frequent fires and greater forest loss both inside and outside the protected area, with migration primarily driven by the search for better living conditions and access to agricultural land under more favourable climatic conditions.

Our research questions include:

- What are the differences and similarities in migrants' origins, activities, and perceptions? How do poverty and climate conditions vary between their home and destination areas?
- How have forest cover and fire patterns changed over time?
- To what extent are changes in forest cover and fire incidence associated with the number of migrants?

Answering these questions will ultimately enhance protected area management and inform broader strategies for addressing environmental challenges in Madagascar and beyond. It is a scientific contribution to understanding socioecological complexity in support of both human well-being and environmental sustainability.

2. Materials and methods

2.1. Study areas

2.1.1. Menabe Antimena protected area

Situated in western Madagascar, the Menabe region (Fig. 1) covers 46,121 km^2, with its capital in Morondava. Home to the Sakalava ethnic group, the region had a population of 692,463, 14.2 inhabitants per km^2 in 2018 (INSTAT, 2020). The region is renowned for its Allée des baobabs, mangroves, and dry forests, including the Menabe Antimena protected area, 210,312 ha (decree n° 2015-762 on 28 April 2015; 201,927 ha if referring to the shapefiles). Formerly called Menabe Central protected area, 125,000 ha (temporary decree of protection n° 4532/2006 - MINENVEF on 28 March 2006), this protected area represents the first implementation of the '2003 Durban Vision' which aimed at expanding the country's protected areas from 1.7 million to 6 million ha to cover 10 % of the territory. In 2024, Menabe Antimena protected area had 57,689 ha of forests (Andrianambinina et al., 2025), as well as 2960 ha of lakes, and private concessions such as AQUAMEN (3868 ha), Grand Saline de Menabe (357 ha), Saline FIDA (663 ha), and De Heaulme (16,000 ha) (Fig. 1). Since its designation, Menabe Antimena has lost approximately 30 % of its dry forests, putting endemic species at high risk of extinction within 30 years if deforestation and illegal logging persist (Kappeler et al., 2022; Markolf et al., 2019; Wilmet et al., 2022). Adjacent to Andranomena Special Reserve (6620 ha) and the Allée des baobabs protected area (320 ha), Menabe Antimena, including Kirindy forest (12,500 ha), has eight conservation targets: four species *Hypogeomys antimena*, *Pyxis planicauda*, lemur communities, and *Adansonia* spp, and four habitats: dry forests, mangroves, Lake Bedo (1062 ha), and Lake Kimanaomby (1898 ha). The Menabe Antimena dry forest is among the top-priority conservation areas (Ganzhorn et al., 2001; Waeber et al., 2015); it has 11 active forest management transfers under the decree 2001-22 related to Contractual Management of government Forests '*Gestion Contractualisée des Forêts de l'État*' (GCF) on 14 February 2001. Since 2004, the core conservation area of the dry forest was monitored by 72 trained local patrollers who collected weekly data on biodiversity and resource use (Andrianandrasana et al., 2022). Now monitoring is done by 370 local monitors including 270 KMMFA (protected area comittee) and 100 fire patrollers. The initiative was tied to an intervillage competition and payment for ecosystem services scheme but faced challenges due to limited benefits offered to communities (Sommerville et al., 2010).

2.1.2. *Androy region*

The Androy region, located in southern Madagascar covers 19,317 km^2, with its capital in Ambovombe. In 2018, its population was 900,235, 47.5 inhabitants per km^2 (INSTAT, 2020). Androy is the driest region in Madagascar, receiving 350–700 mm of annual rainfall, unevenly distributed throughout the year. Most riverbeds, except the Mandrare River, remain dry, and the region endures frequent droughts every 8–10 years, often linked to El Niño (Healy, 2017). These droughts lead to famines *kere*, a chronic food insecurity in Southern Madagascar, such as the 2021 crisis, which affected 1.35 million people, forcing 30,000 to survive on cactus (*Opuntia dillenii*) and locusts (*Locusta migratoria capito*) (United Nations, 2021). Local names for famines reflect their severity and social impact, such as 'Ceinture vy' (iron belt in 1980), 'tsimitolike' (eating without looking at children in 1989–1992), and 'gegy mirovaly' (parents frustrated over feeding children). Strong winds and sandstorm like 'tiokatimo' and 'tiomena' further damage crops and livelihoods in coastal areas (International Monetary Fund, 2023).

2.2. *Data collection and description of variables*

2.2.1. *Units of analysis*

The unit of analysis is commune, the second-smallest administrative division in Madagascar, each represented as a polygon, based on FTM records (Foiben-Taosarintanin'i Madagasikara - National Geographical and Hydrographical Institute) to extract annual environmental and social variables (2017–2022) using ArcGIS 10.8.2 (ESRI Inc, 2021). Data used in this study included forest cover, precipitation data (quantity of rainfall, number of rainy days), VIIRS detected fires (Visible Infrared Imaging Radiometer Suite) including the ratio of fires to rainy days, Multidimensional Poverty Index (MPI) from Oxford Poverty and Human Development Initiatives (OPHI), migrant characteristics and perceptions, and population dynamics (Table 1). All GIS layers were projected to Tananarive 1925 Laborde Grid projections, specific to Madagascar (Roggero, 2009). Data collection happened between May and August 2023, involving researchers from the University of Warwick, regional universities of Menabe and Androy, Madagascar's Ministry of Environment and Sustainable Development, and journalists. Methods included personal interviews, workshops, remote sensing, GIS, and meetings with local authorities. Data from areas of communes located inside and outside the Menabe Antimena protected area were separated using the Extract tool in Arc GIS 10.8.2 (ESRI Inc, 2021) to understand the impacts of migration on protected and unprotected zones.

2.2.2. *Workshops and personal interviews*

Before conducting the interviews, we reviewed reports and published papers and organised two regional workshops in Morondava (Menabe) and Ambovombe (Androy), each attended by 50 participants representing regional authorities, NGOs, and local

Table 1
List of variables used in statistical analysis.

Variables	Source	Unit	Type
Forest size	Global Hansen Tree cover	ha	Continuous
MPI/Proportion of MPI poor	OPHI	Index (0–1)	Continuous
Mean temperatures	General Directorate of Meteorology, Madagascar	°C	Continuous
Mean precipitation (monthly)	General Directorate of Meteorology, Madagascar	mm	Continuous
No. of migrants/non-migrants	Communes/Districts	Number	Continuous
No. of VIIRS active fires detected	NOAA, NASA	Number	Continuous
No. of rainy days	CHIRPS 2.0 by USGS (EROS) General Directorate of Meteorology, Madagascar	Number	Continuous
Proportion of MPI poor	OPHI	Proportion	Continuous
Size of municipality	FTM	km^2	Continuous

communities. These workshops mapped environmental threats, located migrants, and examined the migration-deforestation nexus. Using semi-structured interviews with questionnaires (S1-2), we gathered data from 92 participants: 46 migrants in Menabe and 46 local residents in South Madagascar. Thirteen trained university students who speak local dialects conducted interviews across five communes in Menabe and four in Androy, guided by local authorities who helped identify key villages, spending 3–5 days in each village. Potential participants were stratified by gender, origin, and age within the sampling frame before interviewees were randomly selected.

Conducted in Malagasy and lasting about 45 min, interviews were audio-recorded; they were anonymised and questions covered social and environmental challenges, motivations, activities, and migrants' plans, incorporating life satisfaction methods from Diener et al. (2013). Personal data collected included age, gender, marital status, activities, and origin, while sensitive financial and health information was excluded to protect participant privacy. Participants provided informed consent after receiving written information leaflet or oral information, and interviews were conducted at a location of their choice, typically in their homes. Ethical approval (#HSSREC 132.22-23) was granted by the University of Warwick, with data stored securely in compliance with the UK Data Protection Act of 2018 and General Data Protection Regulation (GDPR) (2016/679).

2.2.3. Population dynamics data

In RGPH-3 2018, migration is defined as moving between districts for at least six months or with intent to stay that long (INSTAT, 2020). However, in this study, migrant and non-migrant numbers also include inter-communal movements, as these may influence patterns of fire and deforestation. According to Article 12 of the Constitution of Madagascar, internal migration is legal, provided it respects the rights of others and complies with the national law (Government of Madagascar, 2010). Migrants are required to notify local authorities and register at their destination, stating the reason for their relocation. We used the population data from INSTAT (2020) to assess migration trends in 2018. To extend the analysis, we reviewed official records from the four districts in Androy and the five target communes in and around the Menabe Antimena protected area to estimate migrant and non-migrant populations from 2018 to 2022 (communes were unable to provide data for 2017). To improve data reliability, we consulted local administrative and traditional authorities to identify unregistered migrants. Many migrants settled in illegal forest camps to avoid enforcement, as squatting and farming in the protected area are prohibited. While some agreed to interviews, these conditions limited our Menabe sample size to 46 participants.

2.2.4. Time series multidimensional poverty data

The Multidimensional Poverty Index (MPI) is appropriate for Madagascar, capturing deprivations beyond income in key aspects of well-being. Data on annual MPI and the proportion of MPI-poor people from 2017 to 2022 were obtained from OPHI (2024) to assess poverty trends, as official figures from (INSTAT, 2020) only cover 2018. The MPI ranges from 0 to 1 (0: no poverty; 1: all people deprived in all indicators). It includes three dimensions Health (nutrition, child mortality), Education (schooling years, attendance), Living standards (cooking fuel, sanitation, drinking water, electricity, housing) with a total of 10 indicators. Often calculated from Demographic and Health Surveys (DHS) or Multiple Indicator Cluster Surveys (MICS), the MPI is the product of the headcount ratio (H) and the average deprivation score among the poor (A), expressed as $M_0 = H \times A$ (Alkire and Santos, 2010). People are identified as multidimensionally poor if they are deprived in at least 33.33 % of the weighted indicators (poor: MPI$\geq$0.33; non-poor: MPI$<$0.33) (Alkire and Foster, 2011).

2.2.5. Precipitation and temperature data

The quantity of rainfall and average temperatures of the study areas over 2017–2022 were calculated from the monthly climatic data from the General Directorate of Meteorology in Madagascar based in Antananarivo. Additionally, we downloaded the raster of daily precipitation data (0.05° resolution, ~5.5 km) from Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS 2.0) to count the number of rainy days per year per commune inside and outside the protected area. CHIRPS is a widely used data in environmental research especially in regions with sparse meteorological station coverage (Funk et al., 2015). We used *Zonal Statistics* function in Spatial Analysis tools in Arc GIS 10.8.2 (ESRI Inc, 2021) to calculate the mean precipitations for each commune outside and inside the protected area. The number of rainy days indicate the number of days with at least 1 mm precipitation (typical threshold). Given that drought can enhance flammability of drier vegetation, increasing the probability of anthropogenic fires (Desbureaux and Damania, 2018), we weighted the number of VIIRS fires detected with the number of rainy days and quantity of rainfall (see equation in section 2.2.7).

2.2.6. Extraction of forest data

We downloaded raster files of historical Hansen global tree cover presenting percent tree canopy density per 30m pixel (from 0 to 100), tree gain, and loss year data (2017–2023) corresponding to tiles 10S 040E and 20S 040E, 10 × 10° granules covering the study areas (Hansen et al., 2013). Forest cover data for 2023 were excluded from the analyses, as they fall outside our study period, and were used only to display current forest conditions. We used a specific tree canopy density threshold of 29 %, classifying areas with <29 % non-forest and ≥29 % forest as recommended by (Andrianambinina et al., 2024; Rafanoharana et al., 2023) for detecting forest in Menabe Antimena protected area with highest accuracy. Using ArcGIS 10.8.2 geoprocessing tools (ESRI Inc, 2021), raster files were mosaiced and clipped to the study area. Using spatial analysis tools, we reclassified the 2000 tree cover layer based on the threshold mentioned above to develop a baseline forest cover for that year. The tree loss year layer was reclassified, annual true persistence was derived, and the tree gain layer (2000–2012) was added to the 2013 forest cover to estimate forest cover in subsequent years, using the equation below.

$$\text{Forest cover (Year n + 1)} = \text{True persistence (Year n + 1)} \times \text{Forest cover (Year n)}$$

The annual forest area within each commune, both inside and outside the Menabe Antimena protected area, was then assessed using the *Zonal Statistics* function in the Spatial Analyst toolbox.

2.2.7. Extraction of active fire data

VIIRS data are widely used by the Malagasy Ministry of the Environment and Sustainable Development and conservation managers, to monitor fires and deliver warnings to local emergency teams. So far, they are the most accurate records available for assessing the impacts of fires (Elvidge et al., 2021). VIIRS fire data (2017–2022) at 0.375 km resolution provide near-real-time detection of active fires. VIIRS is a key sensor aboard the NASA/NOAA Suomi National Polar-orbiting Partnership (Suomi NPP) and NOAA-20 satellites. The number of active fires per commune per year was extracted using ArcGIS 10.8.2 (ESRI Inc, 2021). We used *Spatial Join* function in Analysis tools of Arc GIS 10.8.2 to extract the number of VIIRS detected fires in each commune both inside and outside protected area. Given the potential association between fire, precipitation, and habitat in Madagascar (Joseph et al., 2024), we considered a fire-precipitation ratio as an explanatory variable to examine the relationship between migration and fire. This ratio combines VIIRS fire density with rainfall metrics, as shown in the equation below.

$$\text{Weighted VIIRS fire} = \text{Number of VIIRS fires}/\text{km}^2 \times \text{Proportion of rainy days in a year} \times \text{Average monthly rainfall}$$

2.3. Data analysis

Interview recordings were transcribed, translated in English, coded, then converted into csv spreadsheets. Descriptive statistics, content analysis, and *t*-test comparisons following methods by Fink (1995) were carried out to understand the origin of migrants, reasons for migration, age, level of life satisfaction, the problems they encountered and their future plans. *Spatial join* and *zonal statistics* functions in Arc GIS 10.8.2 were used to carry out spatial analysis evaluating changes in forest cover and number of detected VIIRS fires in the five communes. We performed unpaired *t*-tests using R Studio v4.2.3 (R Core Team, 2025) to compare climatic variables and MPI across regions. To reduce bias from small sample sizes, we also applied a repeated measures correlation model using *rmcorr* package (100 replicates, 95 % confidence interval) which accounts for variability between communes and estimates the overall correlation between the number of migrants and forest cover or fire incidence. The number of migrants was used as the predictor variable, while the density of weighted VIIRS active fires and forest cover were used as response variables (Table 1).

3. Results

3.1. Origins and motivations of migrants in Menabe: similarities and differences

According to district and commune-level data, an estimated 71,292 people may have left the Androy region between 2018 and 2022, while 23,872 migrants were registered during the same period in five key communes in and around the Menabe Antimena protected area. Overall, the personal interviews conducted in Menabe revealed that 27 out of the 46 migrants interviewed (58.7 %) had come from the Androy region while 19 of them, 41.3 %, were from the Atsimo andrefana region. However, of the 46 migrants we interviewed, 39.1 % (n = 18) including 15 from Androy and 3 from Atsimo andrefana, arrived between 1975 and 2017, while 60.9 % (n = 28) (12 from Androy and 16 from Atsimo andrefana) arrived between 2018 and 2022, meaning an increasing number of migrants from Atsimo andrefana in later years (Fig. 2). Of all migrants from Androy, 66.7 % (n = 18) were from the Ambovombe district, 22.2 % (n = 6) from Beloha district, and 11.1 % (n = 3) from Bekily district. Among those from Atsimo andrefana, 79.0 % (n = 15) were from Ampanihy district, 15.8 % (n = 3) from the Betioky sud district, and 5.3 % (n = 1) from Tulear II district (S3 and S32).

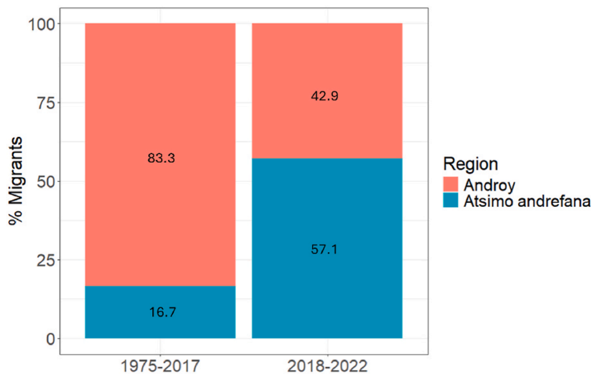

Fig. 2. Changes in origin of migrants in Menabe Antimena protected area between 1975–2017 and 2018–2022 (personal interviews in Menabe).

3.2. Age structure and household size of migrants

Of migrants interviewed in Menabe, 80.4 % (n = 37) were married, while 19.6 % (n = 9) were single, widowed or divorced, with an average age of 40.88 years. Migrants from Atsimo andrefana tend to be younger, on average 33 years old, compared to those from the Androy region, 47 years old, p = 0.002 (S4). The youngest migrant, 16 years old was from Ampanihy district, arriving in Menabe in 2021. The 19.6 % of migrants were over 60 years old; the oldest moved in 1975. According to our interview data, the mean size of migrant households was 4.4; this is close to the national average 4.3 in rural area (INSTAT, 2020). Unpaired *t*-tests analysing the interview data suggest that the average length of stay for migrants from Atsimo andrefana is shorter, 5.7 years, compared to those from Androy 16.2 years, with a statistically significant difference (p = 0.005).

3.3. Social and environmental factors driving migration

The 56.5 % of migrants (n = 26) in Menabe were forced to leave the south due to the *kere* famine; 32.6 % (n = 15) admit they left because they suffered a poor lifestyle; while 10.9 % (n = 5) left to replenish funds spent on relatives' funerals. Everyone experienced severe drought, lack of rain, and pest in the south, making agriculture impossible; they migrated for work, willing to accept any job available. These responses match the perception of interviewees in Androy where 77.1 % (n = 35) admitted that people leave the region due to drought, windstorm 8.7 % (n = 4), or deforestation 4.4 % (n = 2). Some 52.2 % of migrants (n = 24) working in Menabe chose their migrating communes because of opportunities in farming, while 30.4 % (n = 14) were influenced by family members who had already settled there or informed of their successful activity. The 6.5 % (n = 3) of migrants remained after being discharged from a local sugar factory which ceased operating in 2013, while 6.5 % (n = 3) stated that they arrived in Menabe by chance following colleagues' advice and available transport.

3.4. Migrants' main activities and social integration while in Menabe

Peanut farming was the main activity for the 63.0 % of migrants (n = 29). Only 8.7 % of migrants (n = 4) reported engaging in maize farming, with most also cultivating cassava, sweet potato, or rice as secondary activities to support their families (S5). The 82.6 % (n = 38) of migrants indicated no sign of any social discrimination in their villages - this supports (IOM and Region Menabe, 2021) stating that 91.1 % of migrant women report having a "good relationship" with non-migrant women in local communities. Most challenges faced by migrants are about their agriculture activities; 21.7 % (n = 10) of them complained about insecurity (theft of cattle and agricultural products) while the same proportion complained about the lack of seed available for crop planting. Other challenges include the lack of agriculture investment funding, scarcity of agricultural land, lack of agricultural materials, and proliferation of pests ravaging their plantations (Table 2). Some migrants were found working in the 15 warehouses recorded in Morondava town which can process up to 40,000 tonnes of maize and peanuts every year.

3.5. Migrants' perceived value of ecosystem services

The 63.0 % of migrants (n = 29) asserted that the potential of the ecosystem making land suitable for agriculture was the most crucial ecosystem service offered by the Menabe Antimena protected area, a clear indication that converting forest into fertile farmland soil is a priority for migrants. Other valued resources provided by the forest are fuelwood 13.0 % (n = 6), Non-timber forest products 8.7 % (n = 4), timber for construction and furniture 8.7 % (n = 4), and water source 4.4 % (n = 2). None of the interviewed migrants identified cultural services as a benefit provided by the forest.

3.6. Level of migrants' prospects and life satisfaction

Some 63.0 % of migrants (n = 29) expressed satisfaction with their current life, including 6.5 % (n = 3) 'highly satisfied' (S6). The

Table 2
Key issues encountered by migrants in Menabe (personal interviews).

Key issue encountered by migrants	Frequency	%
Insecurity (bandits)	10	21.7
Lack of crop seeds	10	21.7
Lack of agriculture investment funds	6	13.0
Too much rain for peanut crop	4	8.7
Lack of agricultural land	4	8.7
Lack of agricultural materials	2	4.3
Insect pest damage to crop	1	2.2
Lack of rain for rice growing	1	2.2
No problems experienced	1	2.2
Rental of agricultural land too expensive	1	2.2
Tuberculosis	1	2.2
No response	6	10.9
	46	100.0

level of life satisfaction was higher for migrants from Androy (74.1 %) compared to those from the Atsimo andrefana (47.4 %), and higher for migrants who have spent more time in Menabe: 75.0 % for migrants who arrived in Menabe before 2018 and 53.8 % for those who arrived after 2018. Overall, 45.7 % of migrants (n = 21) have a firm plan to return home when they have saved enough money, 17.4 % (n = 8) will visit home village but return in Menabe whilst 10.9 % (n = 5) had decided to definitively stay in Menabe, and 13.0 % (n = 6) intended to move to more productive areas when the local forest was cleared (S7).

3.7. *Differences in climate conditions and multidimensional poverty between areas of origin and destination*

There are significant differences in both climate and poverty levels between Menabe (destination) and the regions of origin, Androy and Atsimo andrefana. In terms of climate, Menabe received an average of 67 mm of precipitation per month between 2017 and 2022 (maximum: 368 mm), compared to only 42 mm in Androy (maximum: 171 mm), a 37.0 % reduction ($p = 0.004$). Despite being drier, Androy is also cooler, with an average temperature of 29.5 °C, while Menabe is hotter at 32.9 °C ($p < 0.001$). However, this temperature difference did not deter migration (S8-12).

MPI data from OPHI (2018–2022) show that all three regions were multidimensionally poor (MPI >0.33), though the severity varied. Menabe has the lower MPI (mean 0.481, 0.495 in 2018, 0.472 in 2022), compared to Androy (mean 0.586, 0.625 in 2018, 0.560 in 2022) with $p = 0.002$, and Atsimo andrefana (mean 0.54, 0.516 in 2018, 0.552 in 2022) with $p = 0.001$. On average, 82.0 % of people in Menabe were multidimensionally poor during the study period (85.3 % in 2018, 79.7 % in 2022); this was significantly lower than in Androy (mean 94.2 %, 96.2 % in 2018, 92.9 % in 2022) with $p < 0.001$, but not different from Atsimo andrefana (mean 85.9 %, 82.9 % in 2018, 87.9 % in 2022). Although Menabe faces environmental challenges, it offers a relatively better quality of life than the areas of origin (S13-17).

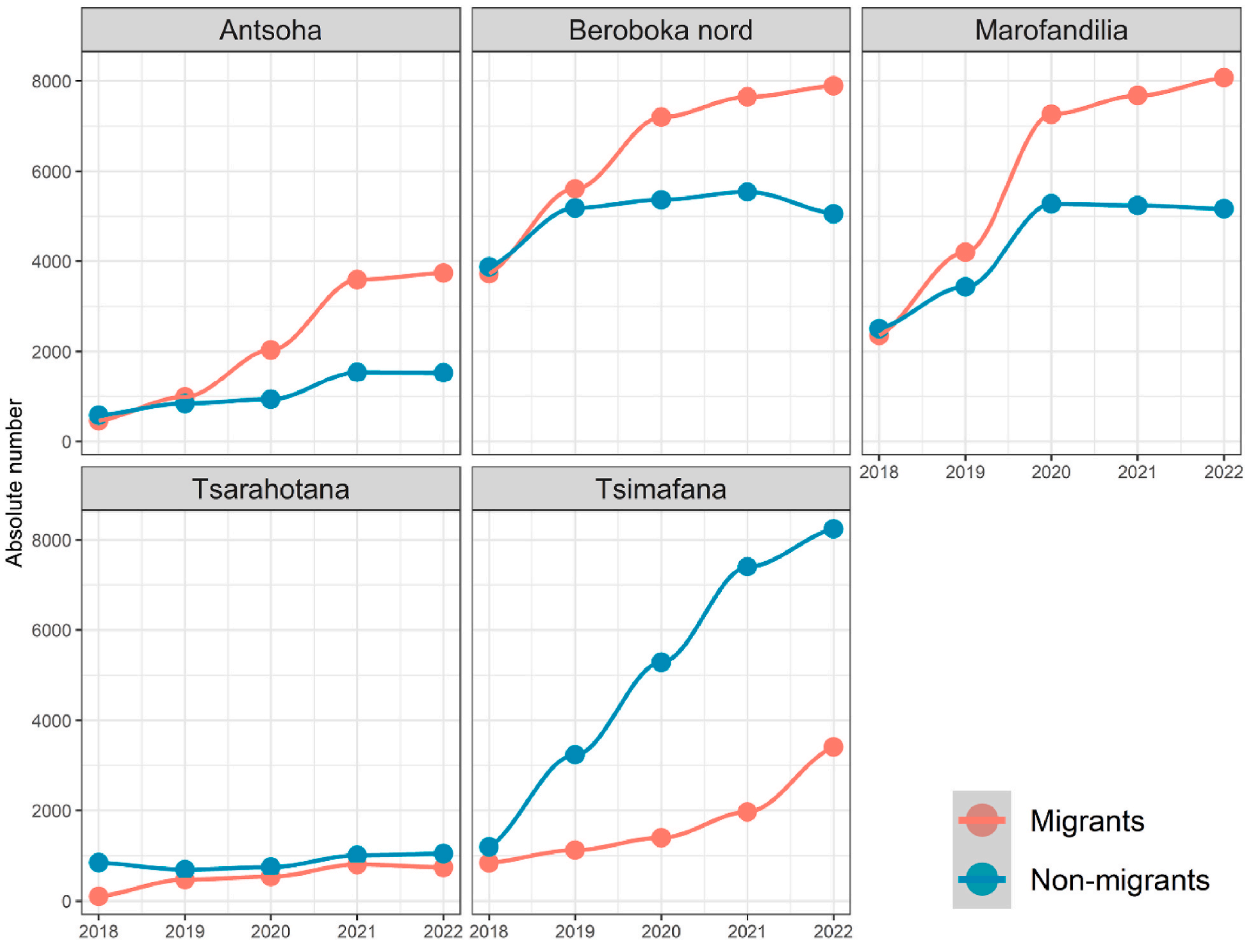

Fig. 3. Changes in population dynamics in the five communes considering area inside and outside the Menabe Antimena protected area over the period 2018–2022.

3.8. Changes in number of migrants around the protected area

The number of migrants who arrived in the five communes covering Menabe Antimena protected area increased 3.2-fold between 2018 and 2022, from 7490 to 23,872. According to district and commune records, between 2018 and 2022, 71,292 people may have left the Androy region to migrate to any region while 23,872 migrants were registered in the five communes in Menabe. In general, the number of migrants who arrived in the five communes in Menabe increased from 7490 (45.4 % of total inhabitants) in 2018 to 23,872 in 2022 (53.2 %), with the highest proportion recorded in Antsoha 61.5 %, Marofandilia 56.4 %, and Beroboka nord 55.5 % (S20-23). Since 2020, there have been more migrants than local residents in these five communes (Fig. 3) (S18-21).

3.9. Changes in forest cover in areas of communes inside and outside the Menabe Antimena protected area

Forest cover in the parts of communes located within the protected area decreased from 75,686.77 ha to 58,911.74 ha between 2017 and 2022, representing a 22.2 % decline. During the same period, areas of the communes outside the protected area also experienced a reduction in forest cover, from 18,678.20 ha to 11,888.35 ha (36.4 % decline). Among the commune areas within the protected area, the commune of Beroboka nord, which includes the village of Lambokely, shows the fastest forest decline: from 15,396.77 ha in 2018 to 10,567.81 ha, a reduction of 31.4 % (Figs. 4 and 5, S22-27).

3.10. Changes in density of detected active fires in areas of communes inside and outside the Menabe Antimena protected area

The weighted VIIRS fire showed an overall increase from 0.625/km^2 in 2017 to 0.829/km^2 in 2022 (24.7 %) inside the areas of commune inside the protected area with a peak of 1.388/km^2 in Beroboka nord in 2021 (Figs. 6 and 7) (see Fig. 5). The parts of commune located outside the protected areas also presented an increase of weighted VIIRS fires from 2.159/km^2 to 4.900/km^2 (55.9 %) between 2017 and 2022, with highest values detected in Marofandilia (1.435/km^2) and Tsarahotana (1.219/km^2) in 2019 (S28-31).

3.11. Interaction between number of migrants, fire frequency and forest size

Repeated measures correlation analysis between the number of migrants and VIIRS fire density (per km^2) from 2018 to 2022 showed a moderate, non-significant positive correlation for parts of communes inside the Menabe Antimena protected area ($r = 0.421$, 95 % CI: 0.018 to 0.721, $p = 0.092$), and a significant positive correlation for parts of communes outside the protected area ($r = 0.518$, 95 % CI: 0.130 to 0.833, $p = 0.016$) (Fig. 8a). The overall trend (red line in Fig. 8a–b) confirms that fire activity increases with the number of migrants, particularly outside the protected area. Similarly, the number of migrants was strongly negatively correlated with forest size for parts of communes inside ($r = -0.788$, 95 % CI: 0.917 to -0.644, $p < 0.001$) and outside ($r = -0.732$, 95 % CI: 0.833 to -0.650, $p < 0.001$) the protected area (Fig. 8c–d). This suggests migrants tend to move to communes with larger forest areas, and forest cover declines as migrant numbers rise, both inside and outside the protected area.

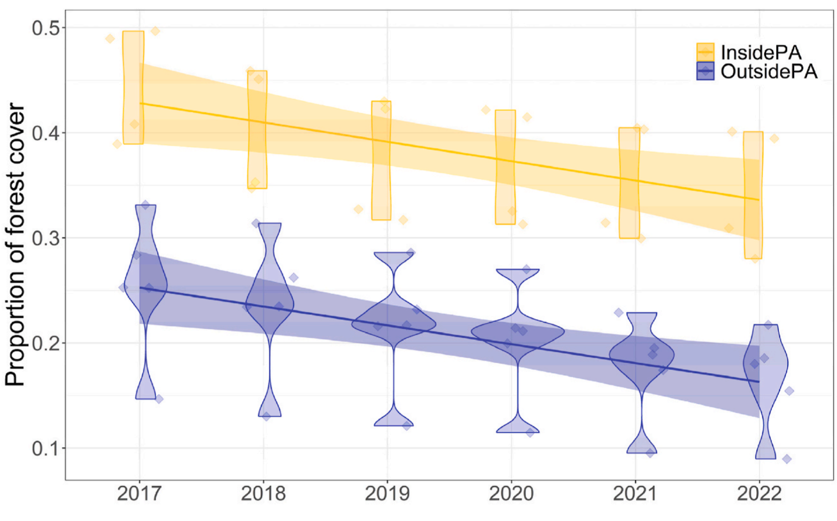

Fig. 4. Overall changes in forest cover in areas of the five communes inside and outside the Menabe Antimena protected area (PA) between 2017 and 2022.

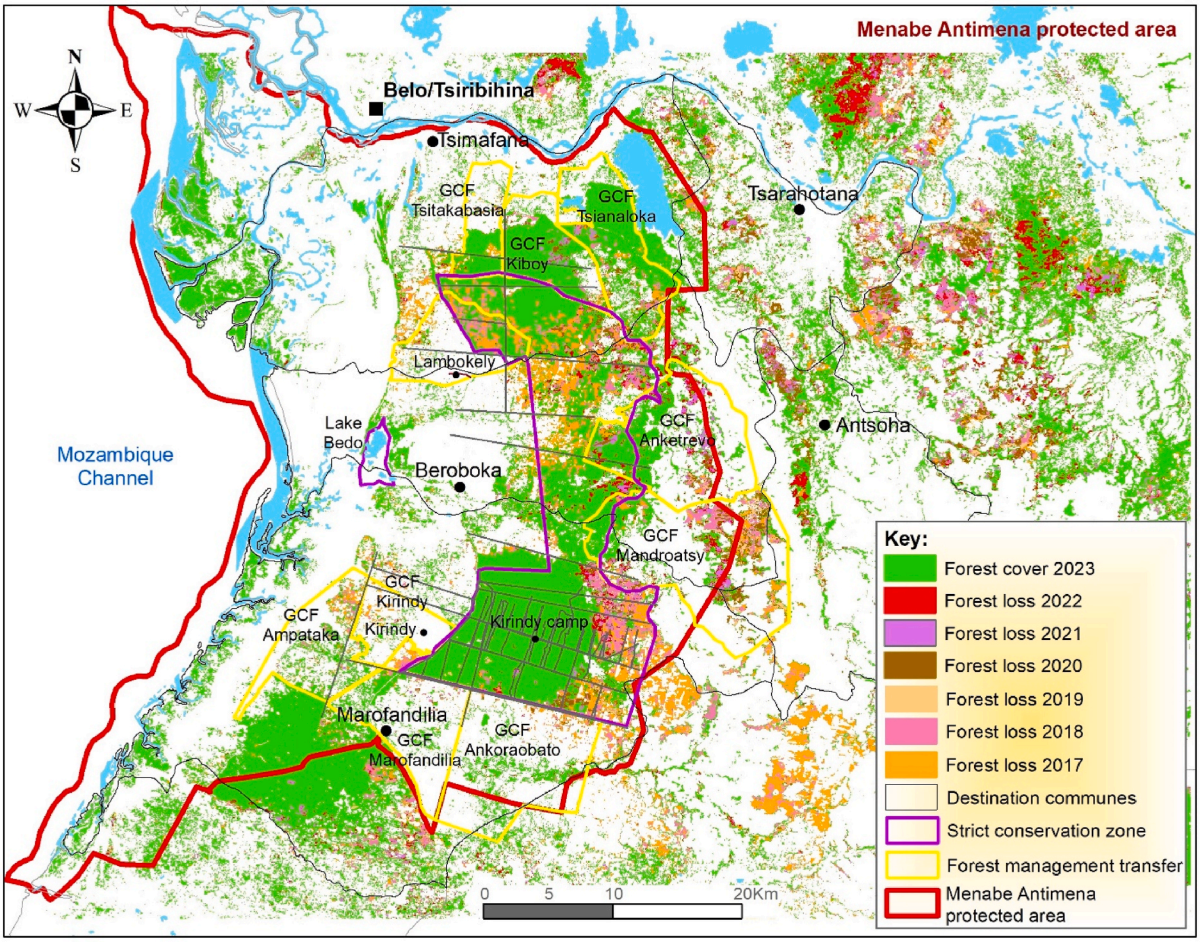

Fig. 5. Hansen forest cover 2023 and forest loss 2017–2022 (30 m resolution) in and around Menabe Antimena protected area.

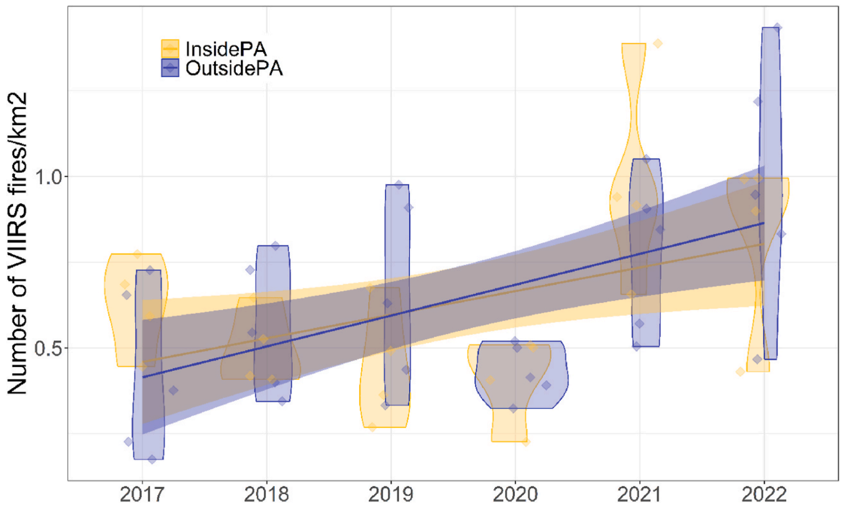

Fig. 6. Overall changes in density of weighted VIIRS fires/km^2 in areas of the five communes inside and outside the Menabe Antimena protected area (PA) between 2017 and 2022.

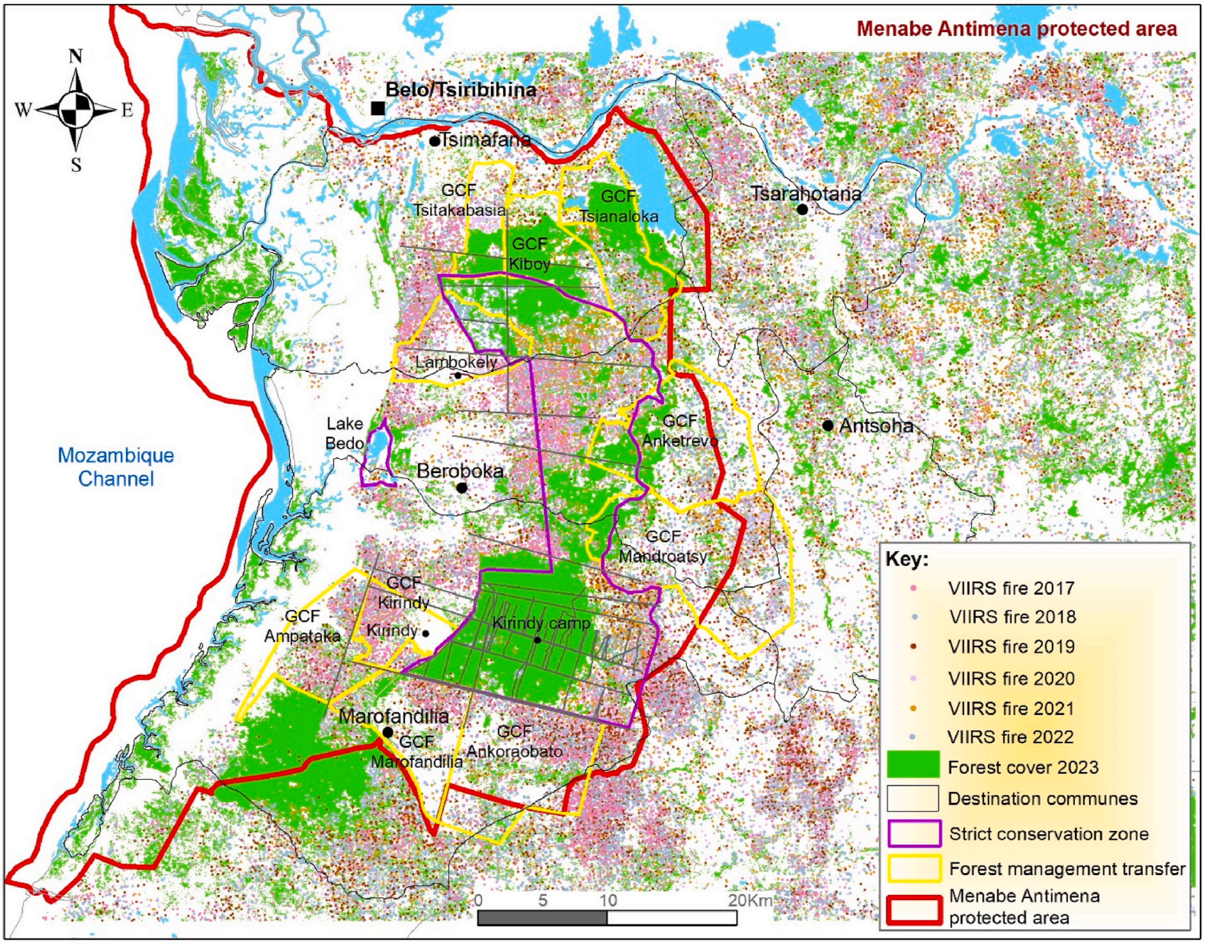

Fig. 7. Hansen forest cover 2023 and VIIRS active fires detected between 2017 and 2022 (375 m resolution) in and around Menabe Antimena protected area.

4. Discussion

4.1. A vicious circle linking migration, poverty and deforestation

This study's results indicate that deforestation increased from 2017 to 2022 in areas of five communes both inside and outside Menabe Antimena protected area, linked to a rise in number of migrants. This study highlighted four key points linking migration with deforestation. First, migration is a result of hard environmental and socio-economic conditions such as drought, famine and sandstorms in the arid areas, forcing people to move to wetter and greener areas, including protected areas. Second, desperate for improved quality of life, migrants would accept any paid work such as illegal agriculture labour inside protected areas even if that presents a high risk of going to jail. Third, more migrants lead to more fires, which is a proxy for slash and burn agriculture often exacerbating deforestation (Thurston, 1997). Fourth, amplified by the increase in local and global demand, social inequality and incentives to corruption, the maize and peanut businesses thrive and motivate those who benefit from the system. This requires more effective control of strict conservation zones in the protected area, transport of goods, and of warehouses (Fig. 9).

4.2. Climate-induced migration

Southern Madagascar has always been drier than other regions and droughts were more intense between 2017 and 2022 (Rigden et al., 2024). Between 2018 and 2022, the area of origin (Southern Madagascar) had a lower level of precipitation than the area of destination (Menabe) (S8-9). Results show that 89.1 % of migrants left their home villages due to drought making agriculture impossible. Interviewees in Androy reported that direct public transport, sometimes prepaid, often departs from rural communes like Bekitro, Bevitiky or Belindo (Bekily District) (S32) to carry migrants. Land and rainfall are vital for agriculture, with insufficient rainfall reducing yields and driving deforestation (Desbureaux and Damania, 2018); temperature and rainfall are key parameters for

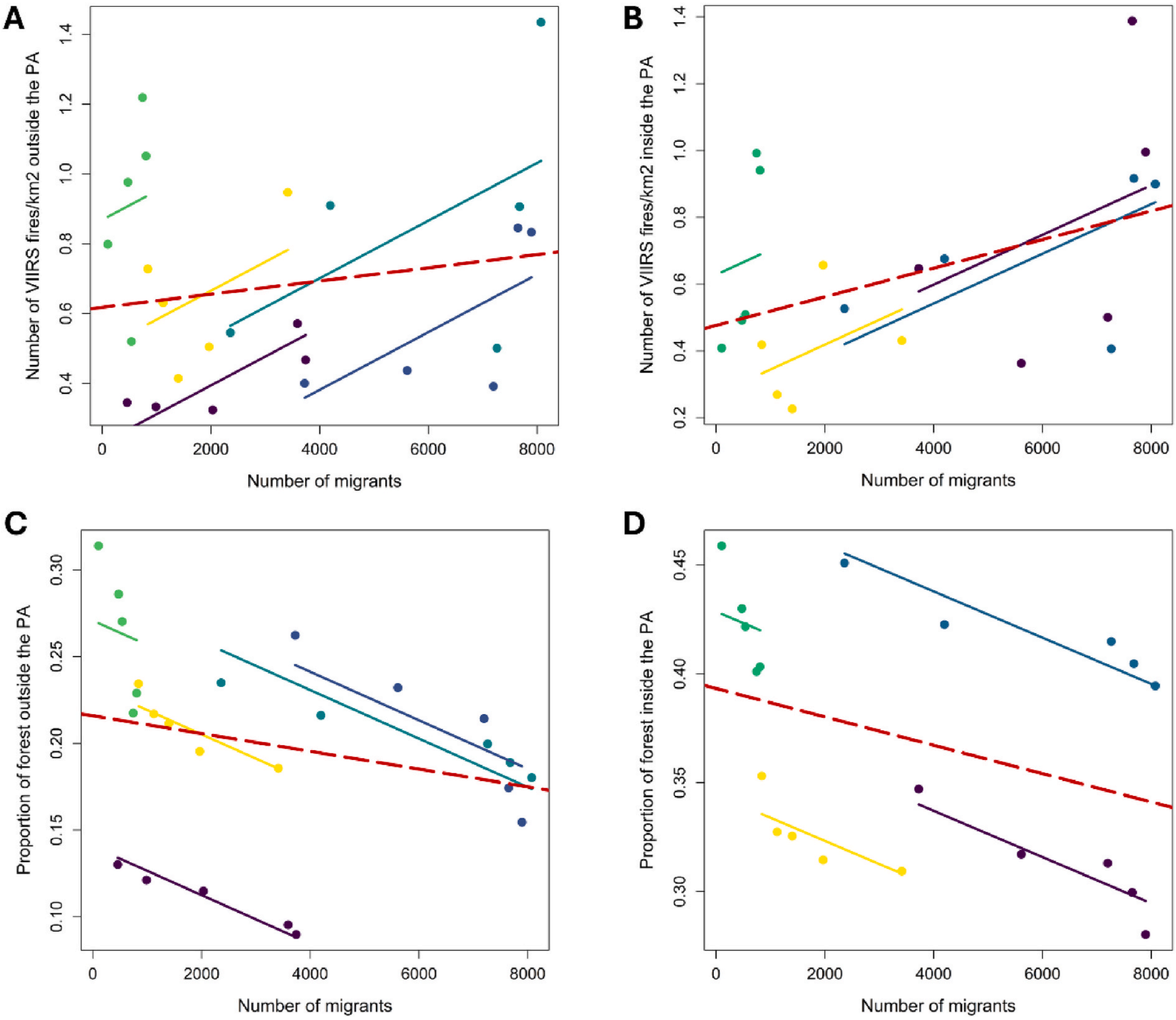

Fig. 8. (a, b) Repeated measures correlation between the number of migrants and weighted VIIRS active fires inside and outside Menabe Antimena protected area over the period 2018–2022 (c, d) Repeated measures correlation between number of migrants and forest size inside and outside Menabe Antimena over the period 2018–2022. Different colours indicate different communes, dashed red lines indicate the overall correlation. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

understanding climate variability (Van Der Wiel and Bintanja, 2021). Understanding crop responses to temperature shifts is important for effective adaptation (Lobell and Burke, 2008). Excessive rainfall hindering peanut farming was reported by 8.7 % of migrants (Table 2), likely linked to heavy rains from Tropical Cyclone Batsirai, which severely impacted southwestern Madagascar in February 2022. Climate change projections suggest that in many regions especially Southern Africa, drought is likely to increase (Rigden et al., 2024) and more yield losses will occur (Cairns et al., 2012). Maize requires more fertile land than peanuts and is less tolerant of heat (Zaidi et al., 2023). Stalker (1997) stated that peanut yield is often harmed when it faces water irregularities during reproductive phase.

4.3. Migrants' priorities and perceptions of ecosystem services

That 63.0 % of migrants value Menabe Antimena forest for its fertile soil (section 3.5) shows farming is their main motivation. Interviewed migrants see the forest less for medicinal plants, honey, biodiversity, or construction wood, and more as cultivable land for agriculture. Only 13.0 % consider timber important, likely because it requires greater knowledge and specific experience in the area. Cultural services are highly valued by local communities in southwestern Madagascar, where forests are homes to ancestral spirits (Randrianarivony et al., 2016). However, migrants never mentioned this, suggesting their presence may threaten local culture. Enforcing traditional agreements like the *dina* will be challenging and necessitates dialogue among elders from different ethnic groups.

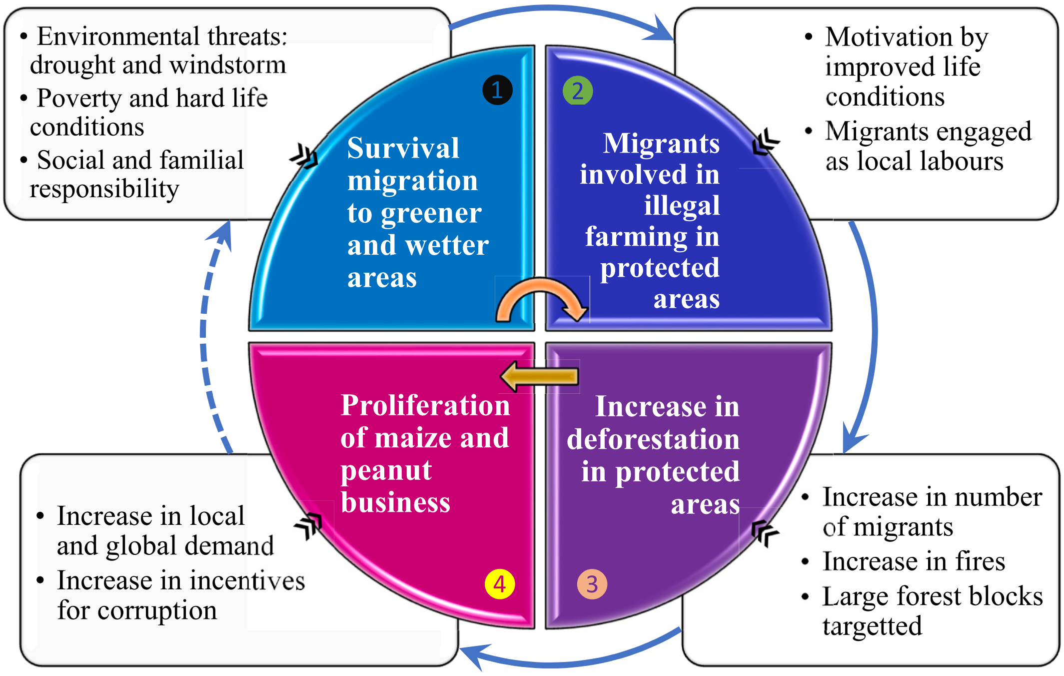

Fig. 9. Framework describing the links between human migration and deforestation in western Madagascar. This causal relationship between 4 and 1 (dashed arrow) is speculative: we believe that the more businesses open in Menabe the more migrants to come, however, we do not have evidence to support this finding.

4.4. *Involvement of migrants in illegal agriculture within the protected area*

Interviews and workshops revealed that migrants first clear forest to grow maize for two years, then peanuts for two to three years, before abandoning the land and clearing new forest areas. Some early-arriving migrants reportedly became wealthier through successful farming, advancing from laborers to “bosses” who can employ other migrants or locals. They reportedly rent cleared land to new ‘employers’ for 2–3 years at $240–$400 per ha per year, before moving on to clear additional forest. The maize and peanut trade generates jobs in forest clearing, planting, harvesting, and transport. Some migrants admitted working at night or on weekends to avoid arrest. Interviewers observed families living in harsh forest conditions, relying on minimal supplies and digging wells for drinking water. More experienced migrants operated small workshops in the forest to process and store maize, which was transported by zebu cart to local collectors, who then delivered the products to town warehouses by lorry. For this reason, employers can cover transport and meals in advance, with the costs later deducted from the workers’ earnings. An interviewee confirmed he had access to 62 ha of land inside the protected area; producing 65 tonnes of peanuts, but his family remained poor due to the low price at village level (peanut 0.4 US dollars per kilogramme, maize 0.6 US dollars per kilogramme). An ongoing government project, which was supported by USAID Mikajy in partnership with stakeholders including the IOM (International Organisation for Migration), aims to relocate migrants to areas suitable for sustainable agriculture.

4.5. *Continual increase in fire and deforestation*

The link between fire and migrant presence inside the protected area was only trending towards significance (Fig. 8a), possibly because some migrants clear forest without fire. These findings highlight the need for additional monitoring methods e.g. GLAD forest loss alerts through Global Forest Watch (Hansen et al., 2016) or artificial intelligence for tracking agriculture inside the protected area. Migration has a complex link to the environment, calling for policies that both improve migrant livelihoods and protect natural resources (Maystadt et al., 2024). The increase in deforestation endangers frugivorous species, which will disrupt the vegetation and ecosystem dynamics (Albert-Daviaud et al., 2018). The forest-agriculture interface is complex, with farmers clearing more forest as a strategy against impacts of drought (Desbureaux and Damania, 2018; Keleman et al., 2010). Slash-and-burn farming, though unsustainable, persists due to few alternatives, low income, and limited technology access (Bezerra et al., 2022; Catarino et al., 2020; Daniel Tang and Yap, 2020; Laurance et al., 1999; Sudhakar Reddy et al., 2009). However, fire alone does not explain tree cover loss anomalies in Madagascar; understanding regional human-driven deforestation patterns is essential (Phelps et al., 2022).

4.6. *Increasing demand and social inequality*

In Madagascar, resource-rich areas are generally less poor, with migrants often having more natural and human capital than non-migrants (Nawrotzki et al., 2012). For example, migrant-dominated villages like Lambokely appear to thrive economically, with more shops, solar panels, and improved public transport access. Maize, a major global staple with 1.2 billion tonnes produced annually (García-Lara and Serna-Saldivar, 2019), is projected to become the most traded crop in the next decade (Erenstein et al., 2022). Global demand for peanuts has grown mainly due to rising peanut butter consumption Sithole et al. (2022); Over 2017–2021, the global peanut butter market grew by 6.1 % (3.4 billion US dollars), expected to rise by 10 % until 2026 (Expert Market Research, 2023; IMARC Group Impactful Insights, 2023; Market Data Forecast, 2023). While rice is Madagascar's main staple, maize and peanuts play important roles, e.g. livestock feed (chicken, ducks), nutrition and income. Since 2013, Madagascar's peanut production has increased, with more than 50 % exported to Asia (Vieilledent et al., 2020). In 2020, the country produced 58,500 tonnes of peanut (0.12 % of global production), 0.71 tonne per ha (Atlas Big, 2023) and 215,000 tonnes of maize (0.02 % of global production), 1 tonne per ha (Knoema, 2023). Illegal agriculture in protected areas is often financed by wealthier actors; poorer households engage in it to meet urgent needs as benefits of conservation are indirect and long term (Mbanze et al., 2021).

4.7. Poverty as a potential predictor of migration

Results showed that the vast majority of migrants left southern Madagascar due to *kere* and poor living conditions. OPHI's multidimensional poverty data align with INSTAT (2020), showing Menabe (MPI = 0.509) as less poor than Androy (0.596) and Atsimo-Andrefana (0.539) in 2018, offering migrants greater livelihood opportunities. Poverty is measured in terms of income and deprivation, with the latter capturing persistent lack of access to goods and services, and the social exclusion it entails (Halleröd and Larsson, 2008). In southern Africa, wealth is measured by factors such as the number of wives, children, farms, cattle, and cash; despite its complexity, poverty often drives migration as a survival strategy (Oucho, 2002). Among the six types of poverty: human, income, extreme, overall, relative, and absolute (UNDP, 1998), "extreme poverty" is unusual because extremely poor people never migrate (Oucho, 2002).

4.8. Need for a government-led conservation strategy

Local motivation for conservation may decline when migrants undermine efforts, especially if patrollers receive little response to reports of illegal activity or if enforcement against illegal agriculture in protected areas is weak. Community-based conservation in Madagascar often assigns minimal roles to local communities, leading to their eventual failure (Duffy, 2006). In Madagascar and other developing countries, political instability and corruption threaten conservation, with deforestation often surging after political disruptions, especially in community-managed forests (Carr et al., 2005; Neudert et al., 2018; Rasolofoson et al., 2015). Gardner (2011) argued that the IUCN Category V adopted for protected areas in Madagascar is unsuitable for achieving conservation success due to adverse human-nature interactions. Indeed, Category V and VI areas have shown higher deforestation rates than Category I and IV (Andrianambinina et al., 2025). While protected area managers in Madagascar lack power to enforce laws (Vieilledent et al., 2020), it is also proven that protected areas are severely understaffed (one agent per 37.3 km^2), hindering effective conservation (Rakotobe and Stevens, 2024). This is an issue as some migrants have shown aggression toward patrollers, including injuring a forest officer in 2021. Reporting can be risky for whistle-blowers when laws are not enforced. In Menabe Antimena, stronger law enforcement is needed as current efforts disproportionately target smallholder farmers rather than the private sector actors driving maize and peanut trades (Rasoamanana et al., 2023). As in other countries, enforcement alone cannot save protected areas without viable alternative livelihoods beyond their boundaries (Tumusiime et al., 2011).

4.9. Limitations of this study

Commune-level migrant data in Menabe may be biased due to inter-communal moves and reliance on authorities' personal knowledge to estimate unregistered migrants, such as forest squatters. Our study period also overlapped with the COVID-19 pandemic, during which fire incidents in Madagascar's protected areas rose due to suspended on-site management (Eklund et al., 2022), but see (Andrianambinina et al., 2023, 2024). The El Niño events of 1997–1998 and 2016–2017 which intensified acute poverty in southern Africa may also have influenced migration patterns in Madagascar (Healy, 2017; Thomson et al., 2003). Other covariates that might influence migration are meteorological inputs (e.g. humidity, solar radiation) hydro-climate conditions (e.g. soil moisture, evapotranspiration, runoff) and Famine Early Warning Systems (McNally et al., 2017; Zhang et al., 2017). Social factors e.g. conflict, access to infrastructure may also shape migration patterns.

5. Conclusion

This study brings evidence about the complexity of the nexus between migration, poverty, and deforestation. It contributes to a greater understanding of the real threats faced by protected areas in developing countries where people are dependent on natural resources for their survival. Protected areas are increasingly targeted by migrants to meet their needs associated with environmental degradation and poverty which in turn can be exacerbated by the climate change. The issue must be solved at its source by improving living conditions in migrants' areas of origin, and at destination sites by promoting alternatives to illegal agriculture and strengthening protected area governance. Responses to migration need to be carefully co-ordinated and monitored at local level to sustainably benefit both the human population and the environment. Long-term research should be conducted on the causality of the internal migration-deforestation nexus focussing on socioecological impacts and monitoring of climate change in Madagascar. Strategies must be identified carefully, as frequent poor decision-making underscores the need for evidence-based conservation, where synthesised evidence informs policy, practice, and long-term impact (Sutherland, 2022). Agriculture-driven deforestation requires integrated policies that align agricultural development with conservation goals (Desbureaux and Damania, 2018). A well-informed, government-led approach built on strong collaboration between the Ministry of Agriculture and Livestock and the Ministry of the Environment and Sustainable Development can enhance both conservation and development outcomes.

CRediT authorship contribution statement

Herizo T. Andrianandrasana: Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Nikoleta Jones:** Writing – review & editing, Validation, Supervision, Resources, Methodology. **Fabiola F. Viraina:** Writing – review & editing, Visualization, Validation, Investigation, Data curation. **Chrysovalantis Malesios:** Writing – review & editing, Visualization, Validation, Methodology, Investigation, Data curation. **Marco Campera:** Writing – review & editing, Visualization, Validation, Software, Formal analysis. **Sama Zefania:** Writing – review & editing, Visualization, Validation, Project administration, Data curation. **Peter R. Long:** Writing – review & editing, Validation, Supervision, Resources. **Stéphanie Panichelli-Batalla:** Writing – review & editing, Validation, Supervision, Resources, Methodology. **Nigel M. Richardson:** Writing – review & editing, Visualization, Investigation, Data curation. **Jessica Savage:** Writing – review & editing, Visualization, Validation, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envdev.2025.101284.

Data availability

Data will be made available on request.

References

Ahmed, N., Islam, M.N., Hasan, M.F., Motahar, T., Sujauddin, M., 2019. Understanding the political ecology of forced migration and deforestation through a multi-algorithm classification approach: the case of Rohingya displacement in the southeastern border region of Bangladesh. Geology, Ecology, and Landscapes 3 (4), 282–294. https://doi.org/10.1080/24749508.2018.1558025.

Albert-Daviaud, A., Perillo, S., Stuppy, W., 2018. Seed dispersal syndromes in the Madagascan flora: the unusual importance of primates. Oryx 52 (3), 418–426. https://doi.org/10.1017/S0030605317001600.

Alkire, S., Foster, J., 2011. Counting and multidimensional poverty measurement. J. Publ. Econ. 95 (7–8), 476–487. https://doi.org/10.1016/j.jpubeco.2010.11.006.

Alkire, S., Santos, M.E., 2010. Acute Multidimensional Poverty: a New Index for Developing Countries. University of Oxford, Poverty and Human Development Initiative.

Amacher, G.S., Cruz, W., Grebner, D., Hyde, W.F., 1998. Environmental motivations for migration: population pressure, poverty, and deforestation in the Philippines. Land Econ. 74 (1), 92. https://doi.org/10.2307/3147215.

Amacher, G.S., Koskela, E., Ollikainen, M., 2009. Deforestation and land use under insecure property rights. Environ. Dev. Econ. 14 (3), 281–303. https://doi.org/10.1017/S1355770X0800483X.

Andrianambinina, F.O.D., Ganzhorn, J.U., Waeber, P.O., Wilmé, L., 2025. Complex deforestation patterns in and around the protected areas of Madagascar from 2015 to 2023. Land 14 (4), 698. https://doi.org/10.3390/land14040698.

Andrianambinina, F.O.D., Rafanoharana, S.C., Rasamuel, H.A.T., Waeber, P.O., Ganzhorn, J.U., Wilmé, L., 2024. Decrease of deforestation in protected areas of Madagascar during the Covid-19 years. Madagascar Conservation & Development 18 (1), 15–21. https://doi.org/10.4314/mcd.v18i1.2.

Andrianambinina, F.O.D., Waeber, P.O., Schuurman, D., Lowry, P.P., Wilmé, L., 2023. Clarification on protected area management efforts in Madagascar during periods of heightened uncertainty and instability. Madagascar Conservation & Development 17 (1), 25–28. https://doi.org/10.4314/mcd.v17i1.7.

Andrianandrasana, H.T., Savage, J., Volahy, A.T., Long, P.R., Jones, N., 2022. Participatory ecological monitoring (PEM): participatory research methods for sustainability - toolkit #4. GAIA - Ecological Perspectives for Science and Society 31 (4), 231–233. https://doi.org/10.14512/gaia.31.4.7.

Antonelli, A., Smith, R.J., Perrigo, A.L., Crottini, A., Hackel, J., Testo, W., Farooq, H., Torres Jiménez, M.F., Andela, N., Andermann, T., Andriamanohera, A.M., Andriambololonera, S., Bachman, S.P., Bacon, C.D., Baker, W.J., Belluardo, F., Birkinshaw, C., Borrell, J.S., Cable, S., et al., 2022. Madagascar's extraordinary biodiversity: evolution, distribution, and use. Science 378 (6623), eabf0869. https://doi.org/10.1126/science.abf0869.

Atlas Big, 2023. World Peanut Production by Country. https://www.atlasbig.com/en-us/countries-peanut-production.

Barbier, E.B., Hochard, J.P., 2019. Poverty-environment traps. Environ. Resour. Econ. 74 (3), 1239–1271. https://doi.org/10.1007/s10640-019-00366-3.

Barbieri, A.F., Carr, D.L., 2005. Gender-specific out-migration, deforestation and urbanization in the Ecuadorian amazon. Global Planet. Change 47 (2–4), 99–110. https://doi.org/10.1016/j.gloplacha.2004.10.005.

Bezerra, J.S., Arroyo-Rodríguez, V., Tavares, J.M., Leal, A., Leal, I.R., Tabarelli, M., 2022. Drastic impoverishment of the soil seed bank in a tropical dry forest exposed to slash-and-burn agriculture. For. Ecol. Manag. 513, 120185. https://doi.org/10.1016/j.foreco.2022.120185.

Borderon, M., Sakdapolrak, P., Muttarak, R., Kebede, E., Pagogna, R., Sporer, E., 2019. Migration influenced by environmental change in Africa: a systematic review of empirical evidence. Demogr. Res. 41, 491–544. https://doi.org/10.4054/DemRes.2019.41.18.

Britta, R., Niederhöfer, B., Ferrara, F., 2021. *Deforestation and migration* (Publikationen von Forscherinnen und Forschern des ifo Instituts – leibniz-institut für Wirtschaftsforschung an der Universität München. EconPol Forum, CESifo GmbH) 22, 49–57. http://hdl.handle.net/10419/232387.

Burnod, P., Rakotomalala, H., Bélières, J.-F., 2017. Madagascar: Land and jobs as main drivers of rural migration. In: Mercandalli, Sara, Losch, Bruno (Eds.), Rural Africa in motion. Dynamics and drivers of migration South of the Sahara. FAO-CIRAD, pp. 38–39. http://www.fao.org/policy-support/tools-and-publications/resources-details/fr/c/1106688/.

Cairns, J.E., Sonder, K., Zaidi, P.H., Verhulst, N., Mahuku, G., Babu, R., Nair, S.K., Das, B., Govaerts, B., Vinayan, M.T., Rashid, Z., Noor, J.J., Devi, P., San Vicente, F., Prasanna, B.M., 2012. Maize production in a changing climate. In: Advances in Agronomy, vol.114. Elsevier, pp. 1–58. https://doi.org/10.1016/B978-0-12-394275-3.00006-7.

Carr, D., 2009. Population and deforestation: why rural migration matters. Prog. Hum. Geogr. 33 (3), 355–378. https://doi.org/10.1177/0309132508096031.

Carr, D.L., Suter, L., Barbieri, A., 2005. Population dynamics and tropical deforestation: state of the debate and conceptual challenges. Popul. Environ. 27 (1), 89–113. https://doi.org/10.1007/s11111-005-0014-x.

Casse, T., Milhøj, A., Ranaivoson, S., Romuald Randriamanarivo, J., 2004. Causes of deforestation in southwestern Madagascar: what do we know? For. Pol. Econ. 6 (1), 33–48. https://doi.org/10.1016/S1389-9341(02)00084-9.

Catarino, S., Romeiras, M.M., Figueira, R., Aubard, V., Silva, J.M.N., Pereira, J.M.C., 2020. Spatial and temporal trends of burnt area in Angola: implications for natural vegetation and protected area management. Diversity 12 (8), 307. https://doi.org/10.3390/d12080307.

Cattaneo, C., Beine, M., Fröhlich, C.J., Kniveton, D., Martinez-Zarzoso, I., Mastrorillo, M., Millock, K., Piguet, E., Schraven, B., 2019. Human migration in the era of climate change. Rev. Environ. Econ. Pol. 13 (2), 189–206. https://doi.org/10.1093/reep/rez008.

Codjoe, S.N.A., Bilsborrow, R.E., 2012. Are migrants exceptional resource degraders? A study of agricultural households in Ghana. Geojournal 77 (5), 681–694. https://doi.org/10.1007/s10708-011-9417-7.

Daniel Tang, K.H., Yap, P.-S., 2020. A Systematic Review of Slash-and-Burn Agriculture as an Obstacle to Future-Proofing Climate Change 01–19. https://doi.org/10.17501/2513258X.2020.4101.

Darmawan, R., Klasen, S., Nuryartono, N., 2016. *Migration and deforestation in Indonesia*. EFForTS discussion paper series. No. 19, GOEDOC, Dokumenten- und Publikationsserver der Georg-August-Universität, Göttingen. http://hdl.handle.net/10419/130249.

Dávalos, L.M., Sanchez, K.M., Armenteras, D., 2016. Deforestation and coca cultivation rooted in twentieth-century development projects. Bioscience 66 (11), 974–982. https://doi.org/10.1093/biosci/biw118.

Desbureaux, S., Damania, R., 2018. Rain, forests and farmers: evidence of drought induced deforestation in Madagascar and its consequences for biodiversity conservation. Biol. Conserv. 221, 357–364. https://doi.org/10.1016/j.biocon.2018.03.005.

Diener, E., Inglehart, R., Tay, L., 2013. Theory and validity of life satisfaction scales. Soc. Indic. Res. 112 (3), 497–527. https://doi.org/10.1007/s11205-012-0076-y.

Duffy, J.E., Godwin, C.M., Cardinale, B.J., 2017. Biodiversity effects in the wild are common and as strong as key drivers of productivity. Nature 549 (7671), 261–264. https://doi.org/10.1038/nature23886.

Duffy, R., 2006. Non-governmental organisations and governance states: the impact of transnational environmental management networks in Madagascar. Environ. Polit. 15 (5), 731–749. https://doi.org/10.1080/09644010600937173.

Eklund, J., Blanchet, F.G., Nyman, J., Rocha, R., Virtanen, T., Cabeza, M., 2016. Contrasting spatial and temporal trends of protected area effectiveness in mitigating deforestation in Madagascar. Biol. Conserv. 203, 290–297. https://doi.org/10.1016/j.biocon.2016.09.033.

Eklund, J., Jones, J.P.G., Räsänen, M., Geldmann, J., Jokinen, A.-P., Pellegrini, A., Rakotobe, D., Rakotonarivo, O.S., Toivonen, T., Balmford, A., 2022. Elevated fires during COVID-19 lockdown and the vulnerability of protected areas. Nat. Sustain. 5 (7), 603–609. https://doi.org/10.1038/s41893-022-00884-x.

Elvidge, C.D., Zhizhin, M., Ghosh, T., Hsu, F.-C., Taneja, J., 2021. Annual time series of global VIIRS nighttime lights derived from monthly averages: 2012 to 2019. Remote Sens. 13 (5), 922. https://doi.org/10.3390/rs13050922.

Erenstein, O., Jaleta, M., Sonder, K., Mottaleb, K., Prasanna, B.M., 2022. Global maize production, consumption and trade: trends and R&D implications. Food Secur. 14 (5), 1295–1319. https://doi.org/10.1007/s12571-022-01288-7.

ESRI Inc, 2021. Arcgis Desktop Version 10.8.2. Environmental Systems Research Institute, Redlands, CA (Version 10.8.2) [Computer software].

Expert Market Research, 2023. Global Peanut Butter Market by Spread Type: Regional Analysis; Historical Market and Forecast Market Dynamics (2018-2028). Market Data Forecast. https://www.expertmarketresearch.com/reports/peanut-butter-market.

Fink, A., 1995. How to Analyze Survey Data, vols. 1–8. Sage.

Frappier-Brinton, T., Lehman, S.M., 2022. The burning island: spatiotemporal patterns of fire occurrence in Madagascar. PLoS One 17 (3), e0263313. https://doi.org/10.1371/journal.pone.0263313.

Funk, C., Peterson, P., Landsfeld, M., Pedreros, D., Verdin, J., Shukla, S., Husak, G., Rowland, J., Harrison, L., Hoell, A., Michaelsen, J., 2015. The climate hazards infrared precipitation with stations—A new environmental record for monitoring extremes. Sci. Data 2 (1), 150066. https://doi.org/10.1038/sdata.2015.66.

Ganzhorn, J.U., Lowry, P.P., Schatz, G.E., Sommer, S., 2001. The biodiversity of Madagascar: one of the world's hottest hotspots on its way out. Oryx 35 (4), 346–348. https://doi.org/10.1046/j.1365-3008.2001.00201.x.

García-Lara, S., Serna-Saldivar, S.O., 2019. Corn history and culture. In Corn. Elsevier, pp. 1–18. https://doi.org/10.1016/B978-0-12-811971-6.00001-2.

Gardner, C.J., 2011. IUCN management categories fail to represent new, multiple-use protected areas in Madagascar. Oryx 45 (3), 336–346. https://doi.org/10.1017/S0030605310001808.

Global Forest Watch, 2024. *Global forest watch open data portal: primary forest loss between 2002 and 2023 in Madagascar* [computer software]. Global Forest Watch. A partnership convened by World Resources Institute. http://www.globalforestwatch.org/country/MDG.

Gorenflo, L.J., Corson, C., Chomitz, K.M., Harper, G., Honzák, M., Özler, B., 2011. Exploring the association between people and deforestation in Madagascar. In: Cincotta, R.P., Gorenflo, L.J. (Eds.), Human Population, vol.214. Springer Berlin Heidelberg, pp. 197–221. https://doi.org/10.1007/978-3-642-16707-2_11.

Government of Madagascar, 2010. Constitution de la IVe République, décret n°2010-822 du 30 septembre 2010—Extrait du Journal Officiel n°3350 du 20 janvier 2011. Journal officiel de la République de Madagascar. https://mjp.univ-perp.fr/constit/mg2010.htm#1.

Halleröd, B., Larsson, D., 2008. Poverty, welfare problems and social exclusion. Int. J. Soc. Welfare 17 (1), 15–25. https://doi.org/10.1111/j.1468-2397.2007.00503.x.

Hansen, M.C., Krylov, A., Tyukavina, A., Potapov, P.V., Turubanova, S., Zutta, B., Ifo, S., Margono, B., Stolle, F., Moore, R., 2016. Humid tropical forest disturbance alerts using landsat data. Environ. Res. Lett. 11 (3), 034008. https://doi.org/10.1088/1748-9326/11/3/034008.

Hansen, M.C., Potapov, P.V., Moore, R., Hancher, M., Turubanova, S.A., Tyukavina, A., Thau, D., Stehman, S.V., Goetz, S.J., Loveland, T.R., Kommareddy, A., Egorov, A., Chini, L., Justice, C.O., Townshend, J.R.G., 2013. High-resolution global maps of 21st-Century forest cover change. Science 342 (6160), 850–853. https://doi.org/10.1126/science.1244693.

Healy, T., 2017. The Deep South: Constraints and Opportunities for the Population of Southern Madagascar Towards a Sustainable Policy of Effective Responses to Recurring droughts/emergencies. The World Bank.

IMARC Group Impactful Insights, 2023. Global Industry Trends, Share, Size, Growth, Opportunity and Forecast 2023-2028. IMARC. https://www.imarcgroup.com/peanut-butter-manufacturing-plant.

INSTAT, C., 2020. Résultats Globaux du Troisième Recensement Général de la Population et de l'Habitation de 2018 de Madagascar (RGPH-3)—Tome I. Institut National de la Statistique, Ministère de l'Economie et des Finances de Madagascar. https://madagascar.unfpa.org/sites/default/files/pub-pdf/resultat_globaux_rgph3_tome_01.pdf.

International Monetary Fund, 2023. Food Insecurity and Climate Shocks in Madagascar (IMF Country Report No. 23/37). International Monetary Fund. https://www.elibrary.imf.org/view/journals/018/2023/037/article-A001-en.xml.

IOM, Region Menabe, 2021. Stratégie régionale de gestion des migrations 2022-2026. Région Menabe. International Organisation for Migration.

Jones, J.P.G., Mandimbiniaina, R., Kelly, R., Ranjatson, P., Rakotojoelina, B., Schreckenberg, K., Poudyal, M., 2018. Human migration to the forest frontier: implications for land use change and conservation management. Geo: Geography and Environment 5 (1), e00050. https://doi.org/10.1002/geo2.50.

Jones, J.P.G., Ratsimbazafy, J., Ratsifandrihamanana, A.N., Watson, J.E.M., Andrianandrasana, H.T., Cabeza, M., Cinner, J.E., Goodman, S.M., Hawkins, F., Mittermeier, R.A., Rabearisoa, A.L., Rakotonarivo, O.S., Razafimanahaka, J.H., Razafimpahanana, A.R., Wilmé, L., Wright, P.C., 2019a. Last chance for Madagascar's biodiversity. Nat. Sustain. 2 (5), 350–352. https://doi.org/10.1038/s41893-019-0288-0.

Jones, J.P.G., Ratsimbazafy, J., Ratsifandrihamanana, A.N., Watson, J.E.M., Andrianandrasana, H.T., Cabeza, M., Cinner, J.E., Goodman, S.M., Hawkins, F., Mittermeier, R.A., Rabearisoa, A.L., Rakotonarivo, O.S., Razafimanahaka, J.H., Razafimpahanana, A.R., Wilmé, L., Wright, P.C., 2019b. Madagascar: crime threatens biodiversity. Science 363 (6429), 825.1–82825. https://doi.org/10.1126/science.aaw6402.

Jones, N., Malesios, C., McGinlay, J., Villasante, S., Svajda, J., Kontoleon, A., Begley, A., Gkoumas, V., Cadoret, A., Dimitrakopoulos, P.G., Maguire-Rajpaul, V., Sepp, K., 2023. Using perceived impacts, governance and social indicators to explain support for protected areas. Environ. Res. Lett. 18 (5), 054011. https://doi.org/10.1088/1748-9326/acc95b.

Joseph, G.S., Seymour, C.L., Rakotoarivelo, A.R., 2024. Fire incongruities can explain widespread landscape degradation in Madagascar's forests and grasslands. PLANTS, PEOPLE, PLANET 6 (3), 656–669. https://doi.org/10.1002/ppp3.10471.

Kappeler, P.M., Markolf, M., Rasoloarison, R.M., Fichtel, C., Durbin, J., 2022. Complex social and political factors threaten the world's smallest primate with extinction. Conservation Science and Practice 4 (9). https://doi.org/10.1111/csp2.12776.

Keleman, A., Goodale, U.M., Dooley, K., 2010. Conservation and the agricultural frontier: collapsing conceptual boundaries. J. Sustain. For. 29 (6–8), 539–559. https://doi.org/10.1080/10549811.2010.485676.

Knoema, 2023. World data atlas. Madagascar. https://knoema.com/atlas/Madagascar/topics.

Kull, C.A., 2002. Madagascar's burning issue: the persistent conflict over fire. Environment 44 (3), 8–19. https://doi.org/10.1080/00139150209605604.

Laurance, W.F., Fearnside, P.M., Laurance, S.G., Delamonica, P., Lovejoy, T.E., Rankin-de Merona, J.M., Chambers, J.Q., Gascon, C., 1999. Relationship between soils and amazon forest biomass: a landscape-scale study. For. Ecol. Manag. 118 (1–3), 127–138. https://doi.org/10.1016/S0378-1127(98)00494-0.

Lobell, D.B., Burke, M.B., 2008. Why are agricultural impacts of climate change so uncertain? The importance of temperature relative to precipitation. Environ. Res. Lett. 3 (3), 034007. https://doi.org/10.1088/1748-9326/3/3/034007.

Market Data Forecast, 2023. Global Peanut Butter Market by Product Type, by Distribution Channel and by Regional Analysis, Trends, and Forecast, pp. 2023–2028. https://www.marketdataforecast.com/market-reports/peanut-butter-market.

Markolf, M., Schäffler, L., Kappeler, P.M., 2019. *Microcebus Berthae: the IUCN Red List of Threatened Species* (E. T41573A115579496). International Union for Conservation of Nature. https://doi.org/10.2305/IUCN.UK.2020-2.RLTS.T41573A115579496.en.

Maystadt, J.-F., Mishra, A.K., Mueller, V., Smoldt, M., 2024. The causes and policy responses to forced migration and environmental degradation in Africa. Annual Review of Resource Economics 16 (1), 301–322. https://doi.org/10.1146/annurev-resource-101123-100528.

Mbanze, A.A., Vieira Da Silva, C., Ribeiro, N.S., Santos, J.L., 2021. Participation in illegal harvesting of natural resources and the perceived costs and benefits of living within a protected area. Ecol. Econ. 179, 106825. https://doi.org/10.1016/j.ecolecon.2020.106825.

McNally, A., Arsenault, K., Kumar, S., Shukla, S., Peterson, P., Wang, S., Funk, C., Peters-Lidard, C.D., Verdin, J.P., 2017. A land data assimilation system for Sub-Saharan Africa food and water security applications. Sci. Data 4 (1), 170012. https://doi.org/10.1038/sdata.2017.12.

Myers, N., Mittermeier, R.A., Mittermeier, C.G.A.B., da Fonseca, G., Kent, J., 2000. Biodiversity hotspots for conservation priorities. Nature 403. Macmillan Magazines Ltd 2000).

Nawrotzki, R., Hunter, L., Dickinson, T.W., 2012. Natural resources and rural livelihoods: differences between migrants and non-migrants in Madagascar. Demogr. Res. 26, 661–700. https://doi.org/10.4054/DemRes.2012.26.24.

Nematchoua, M.K., Ricciardi, P., Orosa, J.A., Buratti, C., 2018. A detailed study of climate change and some vulnerabilities in Indian Ocean: a case of Madagascar island. Sustain. Cities Soc. 41, 886–898. https://doi.org/10.1016/j.scs.2018.05.040.

Neudert, R., Olschofsky, K., Kübler, D., Prill, L., Köhl, M., Wätzold, F., 2018. Opportunity costs of conserving a dry tropical forest under REDD+: the case of the spiny dry forest in Southwestern Madagascar. For. Pol. Econ. 95, 102–114. https://doi.org/10.1016/j.forpol.2018.07.013.

Ofori, D.O., Bandauko, E., Kutor, S.K., Odoi, A., Asare, A.B., Akyea, T., Arku, G., 2023. A systematic review of international and internal climate-induced migration in Africa. Sustainability 15 (22), 16105. https://doi.org/10.3390/su152216105.

OPHI, 2024. Global Multidimensional Poverty Index (GMPI) Archive (Oxford Poverty and Human Development Initiatives). https://ophi.org.uk/global-mpi-archive.

Oucho, J.O., 2002. *The Relationship Between Migration and Poverty in Southern Africa* (Seminar on Regional Integration, Migration and Poverty, vol. 25, p. 11. https://www.sarpn.org/documents/d0001212/oucho/oucho.pdf.

Pettersson, M.B., Kakooel, M., Ortheden, J., Johansson, F.D., 2023. Time series of satellite imagery improve deep learning estimates of neighborhood-level poverty in Africa. Proceedings of the Thirty-Second International Joint Conference on Artificial Intelligence (IJCAI-23).

Phelps, L.N., Andela, N., Gravey, M., Davis, D.S., Kull, C.A., Douglass, K., Lehmann, C.E.R., 2022. Madagascar's fire regimes challenge global assumptions about landscape degradation. Glob. Change Biol. 28 (23), 6944–6960. https://doi.org/10.1111/gcb.16206.

Phillips, H.R.P., Newbold, T., Purvis, A., 2017. Land-use effects on local biodiversity in tropical forests vary between continents. Biodivers. Conserv. 26 (9), 2251–2270. https://doi.org/10.1007/s10531-017-1356-2.

Piguet, E., 2013. From "Primitive Migration" to "Climate refugees": the curious fate of the natural environment in migration studies. Ann. Assoc. Am. Geogr. 103 (1), 148–162. https://doi.org/10.1080/00045608.2012.696233.

Poston, D.L., Micklin, M., 2005. Handbook of Population. Springer US. https://doi.org/10.1007/b100598.

R Core Team,, 2025. Rstudio 2025.05.0 Build 496: Integrated Development for R. R Foundation for Statistical Computing, Boston MA. http://www.rstudio.com/.

Rafanoharana, S.C., Andrianambinina, F.O.D., Rasamuel, H.A., Waeber, P.O., Ganzhorn, J.U., Wilmé, L., 2023. Tree canopy density thresholds for improved forests cover estimation in protected areas of Madagascar. Environ. Res. Commun. 5 (7), 071003. https://doi.org/10.1088/2515-7620/ace87f.

Raik, D., 2009. Forest management in Madagascar: an historical overview. Madagascar Conservation & Development 2 (1). https://doi.org/10.4314/mcd.v2i1.44123.

Rakotobe, D.J., Stevens, N.J., 2024. Closing staffing gaps in Madagascar's protected areas to achieve the 30 by 30 conservation target. Conservation Science and Practice 6 (5), e13118. https://doi.org/10.1111/csp2.13118.

Ralimanana, H., Perrigo, A.L., Smith, R.J., Borrell, J.S., Faurby, S., Rajaonah, M.T., Randriamboavonjy, T., Vorontsova, M.S., Cooke, R.S.C., Phelps, L.N., Sayol, F., Andela, N., Andermann, T., Andriamanohera, A.M., Andriambololonera, S., Bachman, S.P., Bacon, C.D., Baker, W.J., Belluardo, F., et al., 2022. Madagascar's extraordinary biodiversity: threats and opportunities. Science 378 (6623), eadf1466. https://doi.org/10.1126/science.adf1466.

Randrianarivony, T.N., Andriamihajarivo, T.H., Ramarosandratana, A.V., Rakotoarivony, F., Jeannoda, V.H., Kuhlman, A., Randrianasolo, A., Bussmann, R., 2016. Value of useful goods and ecosystem services from agnalavelo sacred forest and their relationships with forest conservation. Madagascar Conservation & Development 11 (2), 44. https://doi.org/10.4314/mcd.v11i2.1.

Rasoamanana, A., Tahina, R.F., Gardner, C.J., 2023. Linking institutional weaknesses to deforestation drivers in the governance of protected areas in Madagascar. In: Ongolo, S., Krott, M. (Eds.), Power Dynamics in African Forests, 1st ed. Routledge, pp. 188–209 https://doi.org/10.4324/9781003363101-10.

Rasolofoson, R.A., Ferraro, P.J., Jenkins, C.N., Jones, J.P.G., 2015. Effectiveness of community forest management at reducing deforestation in Madagascar. Biol. Conserv. 184, 271–277. https://doi.org/10.1016/j.biocon.2015.01.027.

Razanaka, S., Grouzis, M., Milleville, P., Moizo, B., Aubry, C., 1999. *Sociétés paysannes, transitions agraires et dynamiques écologiques dans le sud-ouest de Madagascar* (CNRE, IRD). Centre National De Recherches Sur L'Environnement, Institut National De Recherche Pour le Développement Madagascar.

Rigden, A., Golden, C., Chan, D., Huybers, P., 2024. Climate change linked to drought in southern Madagascar. Npj Climate and Atmospheric Science 7 (1), 41. https://doi.org/10.1038/s41612-024-00583-8.

Roggero, M., 2009. Laborde projection in Madagascar cartography and its recovery in WGS84 datum. Applied Geomatics 1 (4), 131–140. https://doi.org/10.1007/s12518-009-0010-4.

Ruf, F., Schroth, G., Doffangui, K., 2015. Climate change, cocoa migrations and deforestation in West Africa: what does the past tell us about the future? Sustain. Sci. 10 (1), 101–111. https://doi.org/10.1007/s11625-014-0282-4.

Scales, I.R., 2014. The drivers of deforestation and the complexity of land use in Madagascar. In: Conservation and Environmental Management in Madagascar, first ed. Tailor & Francis Group, p. 22 https://www.taylorfrancis.com/chapters/edit/10.4324/9780203118313-7/drivers-deforestation-complexity-land-use-madagascar-ivan-scales.

Schäffler, L., Kappeler, P.M., 2014. Distribution and abundance of the world's smallest primate, Microcebus berthae, in central Western Madagascar. Int. J. Primatol. 35 (2), 557–572. https://doi.org/10.1007/s10764-014-9768-2.

Sithole, T.R., Ma, Y.-X., Qin, Z., Wang, X.-D., Liu, H.-M., 2022. Peanut butter food safety concerns—prevalence, mitigation and control of salmonella spp., and aflatoxins in peanut butter. Foods 11 (13), 1874. https://doi.org/10.3390/foods11131874.

Sommer, S., Toto Volahy, A., Seal, U.S., 2002. A population and habitat viability assessment for the highly endangered giant jumping rat (hypogeomys antimena), the largest extant endemic rodent of Madagascar. Anim. Conserv. 5 (4), 263–273. https://doi.org/10.1017/S1367943002004018.

Sommerville, M., Jones, J.P.G., Rahajaharison, M., Milner-Gulland, E.J., 2010. The role of fairness and benefit distribution in community-based payment for environmental services interventions: a case study from Menabe, Madagascar. Ecol. Econ. 69 (6), 1262–1271. https://doi.org/10.1016/j.ecolecon.2009.11.005.

Stalker, H.T., 1997. Peanut (Arachis hypogaea L.). Field Crops Res. 53 (1–3), 205–217. https://doi.org/10.1016/S0378-4290(97)00032-4.

Sudhakar Reddy, C., Ram Mohan Rao, K., Pattanaik, C., Joshi, P.K., 2009. Assessment of large-scale deforestation of nawarangpur district, Orissa, India: a remote sensing based study. Environ. Monit. Assess. 154 (1–4), 325–335. https://doi.org/10.1007/s10661-008-0400-9.

Sutherland, W.J. (Ed.), 2022. Transforming Conservation: a Practical Guide to Evidence and Decision Making, first ed. Open Book Publishers. https://doi.org/10.11647/OBP.0321.

Thomson, M., Abayomi, K., Barnston, A., Levy, M., Dilley, M., 2003. El Niño and drought in southern Africa. Lancet 361 (9355), 437–438. https://doi.org/10.1016/S0140-6736(03)12421-X.

Thurston, H.D., 1997. Slash/mulch Systems: Sustainable Agriculture in the Tropics (Department of Plant Pathology, Cornell University, USA). Westview Press, Inc.

Tumusiime, D.M., Vedeld, P., Gombya-Ssembajjwe, W., 2011. Breaking the law? Illegal livelihoods from a Protected Area in Uganda. For. Pol. Econ. 13 (4), 273–283. https://doi.org/10.1016/j.forpol.2011.02.001.

UNDP, 1998. *Overcoming Human Poverty* (UNDP Staff). United Nations Development, Programme.

UNEP-WCMC, 2025. Protected Area profile for Madagascar from the world database on protected areas. UN Environment Programme, World Conservation Monitoring Centre. www.protectedplanet.net.

United Nations, 2021. Madagascar: 'world cannot look away' as 1.3 million face severe hunger. UN News. https://news.un.org/en/story/2021/11/1106132.

Van Der Wiel, K., Bintanja, R., 2021. Contribution of climatic changes in mean and variability to monthly temperature and precipitation extremes. Commun. Earth Environ. 2 (1), 1. https://doi.org/10.1038/s43247-020-00077-4.

Vieilledent, G., Grinand, C., Rakotomalala, F.A., Ranaivosoa, R., Rakotoarijaona, J.-R., Allnutt, T.F., Achard, F., 2018. Combining global tree cover loss data with historical national forest cover maps to look at six decades of deforestation and forest fragmentation in Madagascar. Biol. Conserv. 222, 189–197. https://doi.org/10.1016/j.biocon.2018.04.008.

Vieilledent, G., Nourtier, M., Grinand, C., Pedrono, M., Clausen, A., Rabetrano, T., Rakotoarijaona, J.-R., Rakotoarivelo, B., Rakotomalala, F.A., Rakotomalala, L., Razafimpahanana, A., Ralison, J.M., Achard, F., 2020. It's not just poverty: unregulated global market and bad governance explain unceasing deforestation in Western Madagascar. Ecology. https://doi.org/10.1101/2020.07.30.229104 [Preprint].

Vinke, K., Hoffman, R., 2020. Data for a difficult subject: climate change and human migration. Migration Policy and Practice 10 (1), 17–22.

Waeber, P.O., Wilm, L., Ramamonjisoa, B., Garcia, C., Rakotomalala, D., Rabemananjara, Z.H., Kull, C.A., Ganzhorn, J.U., Sorg, J.-P., 2015. Dry forests in Madagascar: neglected and under pressure. Int. For. Rev. 17 (2), 127–148. https://doi.org/10.1505/146554815815834822.

Wan, J.-N., Mbari, N.J., Wang, S.-W., Liu, B., Mwangi, B.N., Rasoarahona, J.R.E., Xin, H.-P., Zhou, Y.-D., Wang, Q.-F., 2021. Modeling impacts of climate change on the potential distribution of six endemic baobab species in Madagascar. Plant Diversity 43 (2), 117–124. https://doi.org/10.1016/j.pld.2020.07.001.

Weber, M., 2021. A puzzle: the environment/development constellation in Madagascar. Globalizations 18 (6), 947–965. https://doi.org/10.1080/14747731.2020.1859762.

Wilmet, L., Toto Volahy, A., Hudson, M., 2022. Hypogeomys antimena: The IUCN Red List of Threatened Species (e. T10714A216087357). https://doi.org/10.2305/IUCN.UK.2022-1.RLTS.T10714A216087357.en.

WMO, 2018. World Meteorological Organization: Region I Africa. World Meteorological Organization. https://wmo.int/about-us/regions/africa.

Wright, S.J., Sanchez-Azofeifa, G.A., Portillo-Quintero, C., Davies, D., 2007. Poverty and corruption compromise tropical forest reserves. Ecol. Appl. 17 (5), 1259–1266. https://doi.org/10.1890/06-1330.1.

Young, R.P., Volahy, A.T., Bourou, R., Lewis, R., Durbin, J., Fa, J.E., 2008. Estimating the population of the endangered flat-tailed tortoise Pyxis planicauda in the deciduous, dry forest of western Madagascar: a monitoring baseline. Oryx 42 (2). https://doi.org/10.1017/S0030605308006844.

Zaidi, P.H., Thayil Vinayan, M., Nair, S.K., Kuchanur, P.H., Kumar, R., Bir Singh, S., Prasad Tripathi, M., Patil, A., Ahmed, S., Hussain, A., Prabhakar Kulkarni, A., Wangmo, P., Tuinstra, M.R., Prasanna, B.M., 2023. Heat-tolerant maize for rainfed hot, dry environments in the lowland tropics: from breeding to improved seed delivery. The Crop Journal S2214514123000922. https://doi.org/10.1016/j.cj.2023.06.008.

Zhang, P., Zhang, J., Chen, M., 2017. Economic impacts of climate change on agriculture: the importance of additional climatic variables other than temperature and precipitation. J. Environ. Econ. Manag. 83, 8–31. https://doi.org/10.1016/j.jeem.2016.12.001.

Zinner, D., Wygoda, C., Razafimanantsoa, L., Rasoloarison, R., Andrianandrasana, H.T., Ganzhorn, J.U., Torkler, F., 2014. Analysis of deforestation patterns in the central Menabe, Madagascar, between 1973 and 2010. Reg. Environ. Change 14 (1), 157–166. https://doi.org/10.1007/s10113-013-0475-x.

Zommers, Z., MacDonald, D.W., 2012. Protected areas as frontiers for human migration. Conserv. Biol. 26 (3), 547–556. https://doi.org/10.1111/j.1523-1739.2012.01846.x.