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How changing fire management policies affect fire seasonality and livelihoods

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Abstract There is a long history of fire management in African savannas, but knowledge of historical and current use of fire is scarce in savanna-woodland biomes. This study explores past and present fire management practices and perceptions of the Khwe (former hunter-gatherers) and Mbukushu (agropastoralists) communities as well as government and non-government stakeholders in Bwabwata National Park in north-east Namibia. Semi-structured interviews and focus groups were used in combination with satellite data (from 2000 to 2015), to investigate historical and current fire management dynamics. Results show that political dynamics in the region disrupted traditional fire practices, specifically a policy of fire suppression was initiated by colonial governments in 1888 and maintained during independence until 2005. Both the Khwe and Mbukushu communities use early season (i.e. between April and July) fires for diverse interrelated historical and current livelihood activities, and park management for managing late season fires. The Mbukushu community also use late season burns to prepare land for crops. In this study, we use a pyrogeographic framework to understand the human dimension of fires. This study reveals how today's fire management practices and policies, specifically the resurgence of early season burning are entrenched in the past. Understanding and acknowledging the social and cultural dynamics of fire, alongside participatory stakeholder engagement is critical for managing fires in the future.

Keywords Early burning · Fire management · Political history · Pyrogeography · Stakeholder engagement · Traditional fire knowledge

INTRODUCTION

Throughout world history, fire has been part of peoples' culture, and has been used as an effective tool for livelihood and land management practices (Stewart 1956; Kull 2002). For millennia, the San (otherwise known as 'Bushmen') in southern Africa have used fire extensively to attract game to grazing areas (Schapera 1930; Lee and DeVore 1976), to maintain veld food resources (i.e. edible food plants), and diverse ecosystems in the savannas of the Kalahari (Powell 1988). Thus, African savannas have likely been shaped by a long history of anthropogenic fire (Pyne 1995), with modern human (i.e. *Homo sapiens*) occupation since 100 000 to 200 000 kya. (Scott et al. 2014). Today, people still rely on fire to maintain their livelihoods and to manage vegetation and wildfires (Russell-Smith et al. 1997; Kull 2002). Knowledge of the use of fire is imperative in the Anthropocene, because natural and historical fire regimes have been over-ridden by colonial fire management strategies of fire suppression and prescribed burning (Bowman et al. 2011; Coughlan and Petty 2012).

Despite the historical importance of anthropogenic fires, controversy still prevails because of the perceived unsustainability of indigenous burning practices (Mistry et al. 2005). Consequently, local (i.e. traditional or indigenous) communities are commonly perceived by fire scientists and local and national governments as 'major agents of wild-fire' (Mbow et al. 2000), because of land use practices perceived to cause environmental degradation and

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biodiversity loss (Laris and Wardell 2006; Pausas and Keeley 2009). However, the view that local burning strategies benefits savanna systems has recently gained acceptance among some fire managers (Brockett et al. 2001; Laris 2002; Russell-Smith et al. 2013).

In fire science literature, fires are commonly described by when they occur (e.g. early, mid and late seasons), (see Laris et al. 2016 for a review). Indigenous people frequently practice early burning (i.e. fires that are set soon after the rainfall season when the grass is drying out, that are patchy in distribution due to the moisture content of the grass) in Australia (Kakadu National Park), South Africa (Pilanesberg National Park) (Trollope 2011) and in Mali (Laris 2002). In densely populated areas in southern Africa, burned area mainly consists of many small fires in the early months of the year (Scholes et al. 2011). However, fires are also extensively used later in the year prior to the rainfall and are associated with traditional cultivation practices (Eriksen 2007). Local people generally use fire according to their livelihood needs (Walters 2010).

Place-based studies have shown that indigenous communities have been instrumental in managing biodiversity by burning seasonal patch-mosaics (see Parr and Andersen 2006 for a review). These mosaics facilitate habitat heterogeneity in West Africa (Fairhead and Leach 1996; Laris 2002; Laris and Wardell 2006) and in Australia (Braithwaite 1996; Parr and Brockett 1999; Bird et al. 2005). They also prevent the damaging effects of late season fires (Russell-Smith et al. 1997; Laris 2002). Other studies of indigenous peoples' use of fire have resulted in insightful understanding of communities in relation to vegetation fires in Africa (Butz 2009 [Tanzania]; Eriksen 2007 [Zambia]; Hough 1993 [Benin]; Kull 2002 [Madagascar], Nyamadzawo et al. 2013 [Zimbabwe]; Shaffer 2010 [Mozambique]; Walters 2010 [Gabon]). Moreover, satellites that detect fires on the earth surface have been pivotal in corroborating the spatial and temporal patterns of indigenous peoples' fire use (Bowman 1998; Laris 2002).

Recent research has revealed that in Bwabwata National Park (BNP), the target area of this study, communities share many similarities with other indigenous groups in the use of fire (Delcourt and Delcourt 1997; Bowman 1998; Laris 2002; Whitehead et al. 2003; Bird et al. 2005; Eriksen 2007; Walters 2010). Trollope and Trollope (1999) found at the local level amongst the elder generation in the greater BNP region a well-developed and practical traditional understanding of the role of fire in the management of herbaceous and woody vegetation. Nonetheless, the use of fire by disparate indigenous communities inevitably varies from location to location (Walters 2010).

Today, conservation management plans use early season fires to manage biodiversity, prevent large intense late hot season burns, rehabilitate landscapes and manage bush

encroachment (Russell-Smith et al. 1997; Mistry et al. 2005). On some continents (e.g. South America, Australia), multiple perspectives of fire are recognised, and the use of 'intercultural fire governance' is deemed critical for addressing fire management for ecological reasons alongside people's needs and roles (Mistry et al. 2018). Further, new interdisciplinary perspectives of the study of fire (e.g. pyrogeography; Bowman et al. 2011) have resulted in the integration of available methodologies, and greater scope for research on fire and human dynamics across the globe. Pyrogeography integrates the socio-cultural, biological and geophysical aspects of fire regimes (i.e. characteristic patterns of fires in a defined area) and recognizes the importance of livelihoods, ecosystems and climate in making decisions for fire management.

Until recently, local burning knowledge and practices have been largely unrecognized by national government officials in southern Africa. Further, studies that compare government and indigenous ecological understanding and reasons for burning in southern Africa are rare (Eriksen 2007). Fire is a biophysical phenomenon, yet its management is a social process (Martínez-Torres et al. 2018). The integration of indigenous fire practices, with current fire management policy could improve the management of fire for ecosystem services (e.g. natural resources) in the twenty-first century (Trollope 2011) and protect fire knowledge and cultural diversity (Mistry et al. 2018). In this paper we propose that by investigating how indigenous and national government stakeholders perceive and manage fire, better consensus and understanding could strengthen collaboration between stakeholders because it acknowledges both of their experiences and could be used to improve fire management and stakeholder relations in the future.

Here, we use Bwabwata National Park (BNP) commonly known as the *western caprivi* in the north-east of Namibia to examine the historical and current social dynamics (19th–21st century) of fire management strategies of two stakeholder groups: (1) Community: Khwe (former hunter-gatherers) and Mbukushu (agropastoralists) people, and (2) government and non-government organisations. Four key questions are addressed in this study: (1) What are the stakeholders' historical and current perspectives on the use of seasonal fire?; (2) how has the historical context, and present social factors (e.g. local ecological knowledge; fire use and perceptions; changing land-use associated with rights to natural resources and traditional practices) influenced fire management and policies in BNP?; (3) does the pixel-based fire data corroborate with when people say they use fire in BNP? (4) how does the BNP case study fit within a pyrogeographic framework?

MATERIALS AND METHODS

The study area: Bwabwata National Park

Bwabwata National Park (18.1157° S, 21.6696° E; 627, 412 ha) lies within the centre of the Kavango Zambezi–Transfrontier Conservation Area (KAZA-TFCA; 440 000 km²), one of the world's largest transfrontier conservation areas (Fig. 1). It is bordered to the north by Luiana Partial Reserve in Angola, and to the south by the Okavango Delta in Botswana. The region in which BNP is situated, has the highest rainfall in the country (average of 650 mm, Tinley 1966), and thus supports a tropical ecosystem associated with major rivers, floodplains, wetland systems, dry Kalahari forests, and savanna-woodlands together with a high biodiversity (Mendelsohn et al. 2009). The park falls within a palaeo landscape characterised by grass-laden fossil drainage lines (locally known as omirmaba) that lie between degraded dune crests that are stabilised by wooded savanna (Tinley 1966). The primary drivers of the ecological patterns in BNP are the rainfall, flooding regimes,

soil types and fire (Mendelsohn and Roberts 1997). The rainfall season typically occurs between September and February, with the dry season months spanning from April to October (hottest month). The park also falls with the southern limit of the 'Miombo Eco-region' (i.e. woodlands that occur in south-central Africa from Angola to Tanzania that comprise tree species from the genus *Brachystegia*) because it is characterised by high mammal diversity and endemism and is an important vegetation type threatened by the extent of fire and human activities (Frost 1999).

Historical context

The unfolding narrative of the greater region and the study area are closely tied to political events, which have strongly influenced conservation development of the park (1963–2015) (see Lenggenhager 2015 for a review), as well as community livelihoods over the last half century. BNP is a unique setting in southern Africa, as people are permitted to live alongside wildlife in a zoned multiple use area (MUA) in the park. From the 19th century until

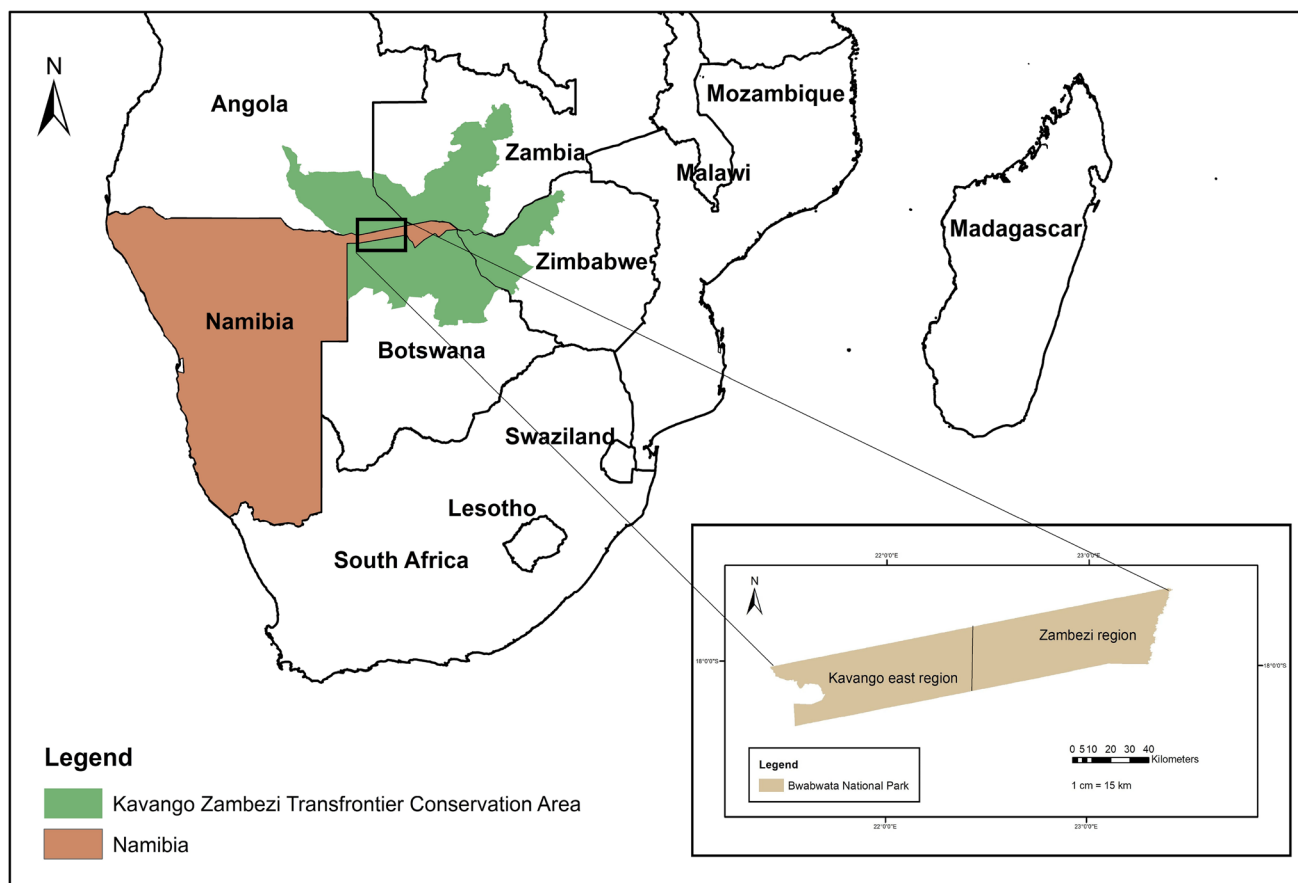


Fig. 1 Map of southern Africa showing the location of Namibia, and Bwabwata National Park centred within the Kavango Zambezi–Transfrontier Conservation Area (KAZA-TFCA). The solid black box indicates the locality of Bwabwata National Park in Namibia and the KAZA-TFCA. The boundary between the Kavango East and Zambezi Regions is shown with the vertical black line within the park in the second map in the bottom right hand corner

independence in 1990, the inhabitants within BNP, the Khwe (former hunter-gatherers), and the Mbukushu people (agropastoralists) have been subject to colonial occupation (Germany, South Africa), ensuing cross-border conflict and wars, and independence struggles, inter-ethnic conflict, social–political resettlement, political violence, emergence of livestock diseases (e.g. Tsetse fly invasion; rinderpest), changing land use and conservation plans, as well as associated varying fire management approaches. Table 1 below provides a timeline of the history of fire policy events and changes in Namibia (19th–21st century). Under the German administration period in South West Africa (SWA) (i.e. former title for modern day Namibia) (1884–1915), the South African regime (1915–1989), and after Namibia's independence (1990), indigenous rights were suppressed, and this extended to the use of fires. Thus, colonial fire suppression policies held precedence for 122 years (from 1884) and persisted after independence in 1990. However, in 2006, seasonal burning strategies (e.g. percentage of area to be burnt, season and type of burn) were implemented in the park (Ministry of Environment and Tourism [MET] 2013). The colonial period had a major impact on the Khwe's identities, which centered on their use of natural resources and tracking skills (see Taylor 2012; Hitchcock 2012, 2019 for a review). A chronology of major historical events (1795–2016) relevant to the Khwe, Mbukushu and the Government of the Republic of Namibia (GRN) in north-east Namibia are presented in Table S1.

Today, BNP is comprised of three conservation core areas designated for special protection to support key government constitutional biodiversity objectives, and controlled tourism, which comprise Kwando (134, 481 ha), Buffalo (62, 921 ha) and Mahango (24, 479 ha). A central Multiple Use Area (MUA; 405, 531 ha) is zoned for community-based tourism, trophy hunting, and human settlement where the harvesting of natural resources (e.g. veld foods), and agricultural and farming practises by the inhabitant communities are permitted. The MUA is home to an extensive village network (19), and the park also contains schools, clinics, fields, housing, and a Catholic Mission which are remnant structures from the South African Defence Force (SADF) occupation during the South African Border War, also known as the Namibian War of Independence (1964–1989).

Theoretical framework

In this study, we use a pyrogeographic framework (Bowman et al. 2013) because it acknowledges the integration of the human aspects (i.e. social and cultural factors) in combination with fire science to address immediate and long-term fire management issues that are relevant to BNP (Fig. 2).

Data collection

A combination of quantitative satellite data (Moderate Resolution Imaging Spectrometer; MODIS) and qualitative methods including stakeholder interviews, focus group meetings and seasonal calendars were used to document all stakeholder observations, knowledge and use of fire. The MODIS fire product (MCD14ML) was used as secondary data to establish the number of pixel hotspots (i.e. the number of pixels affected by fire in a spatially gridded database), and the timing (i.e. season) of fires in BNP (2000–2015). Data were collected over the course of 4 months in 2014 and 2015. Field work periods occurred within the two main dry seasons in BNP: early dry season (Apr–July) and late dry season (Aug–Nov). In total 61 interviews and 3 focus group meetings took place. Additional primary data sources consisted of informal discussions with conservation and community-based organisations in Namibia, published reports in the region by governmental departments and non-government organisations (NGOs), government policy documents (e.g. management plans and Acts), books, and archival records obtained from the Namibian Scientific Society, relevant newspaper and radio reports, and attendance of three fire management workshops held in Namibia between 2014 and 2016. These sources were critical both for providing a historical context of contemporary events in the area, for cross-checking oral accounts (Taylor 2012), and for documenting changing fire management perceptions and policies in Namibia during this study.

Community stakeholder interviews

Thirty-six in-depth semi-structured interviews were carried out with the Khwe ($n = 26$) and Mbukushu participants ($n = 10$) from 9 villages in the MUA. The Khwe people are the majority, and the Mbukushu the minority population in the park (Suzman 2001). Elderly community members (over 60 years of age) were identified as interview participants because of the research interest in the historical use of fire. Interviews were structured into 4 themes: (i) cultural practices and beliefs; (ii) fire management (how, where, why, when and how often fire is used), which included land use practices; (iii) vegetation and fire history, and (iv) livelihood resources (Table S2). Well-respected translators from the BNP community translated the interview questions from English into Khwé-dàm (Khwe language) and Thimbukushu (Mbukushu language). The interview responses were used to create a database of stakeholder perceptions of fire, and vegetation fires, and how fire practices today, differ from the past in BNP. A locality map (1: 250 000) was used as a visual aid during the interviews to assist with the identification of where small and large fires occur in BNP.

Table 1 Timeline of the development of fire events and policy in Namibia (nineteenth–twenty-first century)

Year	Event/Policy	Activities
1884	Removal of power from Traditional Authorities (TA) to control fire	The supervision and control of burning was transferred from the Traditional Authorities to government. Daily supervision ceased and large-scale uncontrolled shifting cultivation and hunting with the use of fires began in Northern Namibia
1888	Deutsche Kolonialgesellschaft Für Südwestafrika (German Colonial Society)	First official fire policy in Namibia banning all fires in the late 19th century
1960–1990	Namibian War of Independence (SADF occupy north-east Namibia)	Namibian Government restricted from the area; Khwe were banned from using fires by the South African Military (SADF); removal of the responsibility of fire management from the Traditional Authorities (TA) by South African administration officials
1996	Namibia Forestry Strategic Plan (NFSP)	Provided the foundation for fire policy and management planning; “Production, Protection, and Participation “ were considered the three imperatives of forest policy. Clearing of firebreaks, and fire awareness programmes were a priority. The Strategic Plan was based on ecological, environmental, cultural, and socio-economic considerations. The importance of community participation in fire management was recognised
1997–2001	Namibian-Finland Forestry Program (pilot project) (NFFP): Integrated Fire Management Programme (IFFP)	Assistance in National fire policy development and the elaboration of a regional fire management plan for the East Caprivi. Instigated annual prescribed burning in the East Caprivi. The IFFP component intended to enhanced the capabilities of all stakeholders on forest fire control and ecologically acceptable use of fire, and was also aimed at changing of attitudes, cultural values and habits in relation to fire and burning
1999	Namibia Round Table on Fire	Assisted with the development of National Fire Policy and Guidelines on Fire Management: Focus was on fire prevention and suppression, and implementation consisted of discouraging burning through public awareness campaigns, firebreak networks and community wildfire suppression
1999	Technical Review of the Integrated Forest Fire Management Component of the Namibia-Finland Forestry Programme	Assessed the positive and negative attributes of controlling forest fires; provided recommendations for prescribed burning based on different land use categories in the East Caprivi
2001	Directorate of Forestry (DoF)	Official regulation of fire management in Namibia
2001	Forest Act 12 of 2001	Custodian for veld and forests fires in Namibia. One of the main objectives was to ‘to provide control and management of forest fires’; emphasis was on fire suppression and prevention
2001	National Guidelines on Forest Fire Management	Focused on forest fire prevention, suppression, prescribed (controlled) burning, post fire evaluation and community education campaigns in the East Caprivi state forests
2004	<i>Draft</i> National Forest Veld Fire Management Policy	No burning’ instilling fire prevention and suppression
2009	Directorate of Forestry’s (DoF) National Remote Sensing Centre	Created remotely sensed fire scar maps and produced Burned Area reports for distribution in Namibia
2010	Southern African Development Community (SADC) Protocol on Forestry	Adherence to cross-border co-operation in fire management
2006	Bwabwata National Park Management Plan (2013–2018) implements the use of early dry season fire management	The Ministry of Environment and Tourism (MET) implements and follows a controlled fire management policy, with the aim of burning 1/3 of the park each year, with an emphasis on early cool season fires
2007–2011	Caprivi Region: Draft Integrated Fire Management Strategy	‘Implemented to support community, national parks and forestry in the East Caprivi region. A pilot community based integrated fire management (CBFiM) policy was established for fire management that complements the environment, land use, resources and the capacity of inhabitant communities in the region
2011–2015	Forest Research Strategy for Namibia (Ministry of Water, Agriculture and Forestry, MWAF)	Identified focus area to monitor fires, including seasonal variation, timing, severity and extent to understand the dominant regional fire regime; and to understand the communities’ interaction with fire, including attitudes towards fire
2013–2018	Bwabwata National Park Management Plan (Ministry of Environment and Tourism)	Key focus on fire management and early burning in the park. Objective is to use fire as a management tool for actively maintaining and rehabilitating all habitats in the park
2013	Can savanna burning projects deliver measurable greenhouse emissions reductions and sustainable livelihood opportunities in fire-prone settings?	Scientific journal article: Inclusion of CBiFM in global carbon budgets research. The communities living in Bwabwata National park were consulted during fieldwork for this paper

Table 1 continued

Year	Event/Policy	Activities
2014	International Savanna Fire Management Initiative Southern African Regional Workshop	Learning exchange between southern Africa and Australia; the main objective was to explore how sustainable livelihoods can be reinforced through integrated fire management drawing from traditional fire management and the application of emissions abatement burning methodologies from Australia
2014	Community-Based Fire Management: An integrated Trans-frontier Fire Management approach for Liuana National Park in Angola and Bwabwata National Park in Namibia	A cross-border fire management project to establish a network for the management of fires on the borders and between local communities between the two neighbouring parks in Namibia and Angola
2015	Regional Fire Co-ordination Committee Meeting–Zambezi Region	Local committee was developed to address fire management issues in the region. Identified large areas of the Kavango East and Zambezi Regions that burn every year
2015	Forest Regulations: Forest Act, 2001	Describes measures to be taken for forest protection, prevention of fires and protection of soil and water resources; permit system for controlled burning and stipulation of a rehabilitation agreement for any person who uses fire for resource utilization
2016	Fire Management Workshop and Strategy Development	The Ministry of Agriculture, Water and Forestry (MWF) in partnership with the Ministry of Environment and Tourism (MET) addressed approaches to the management of veld and forest fires. The workshop was arranged as an information exchange on fire management and involved several Namibian ministries, policy makers, practitioners, academics and non-governmental organisations (NGOs). Key causes of veld and forest fires, assessment of current fire management practises, and identification of research gaps on the management and causes of fires were discussed. Local communities were recognised as managing and controlling fires in the east of Bwabwata National Park
2019	Management Plan Bwabwata National Park, 2019–2028	Revision of fire management plans in Bwabwata National Park

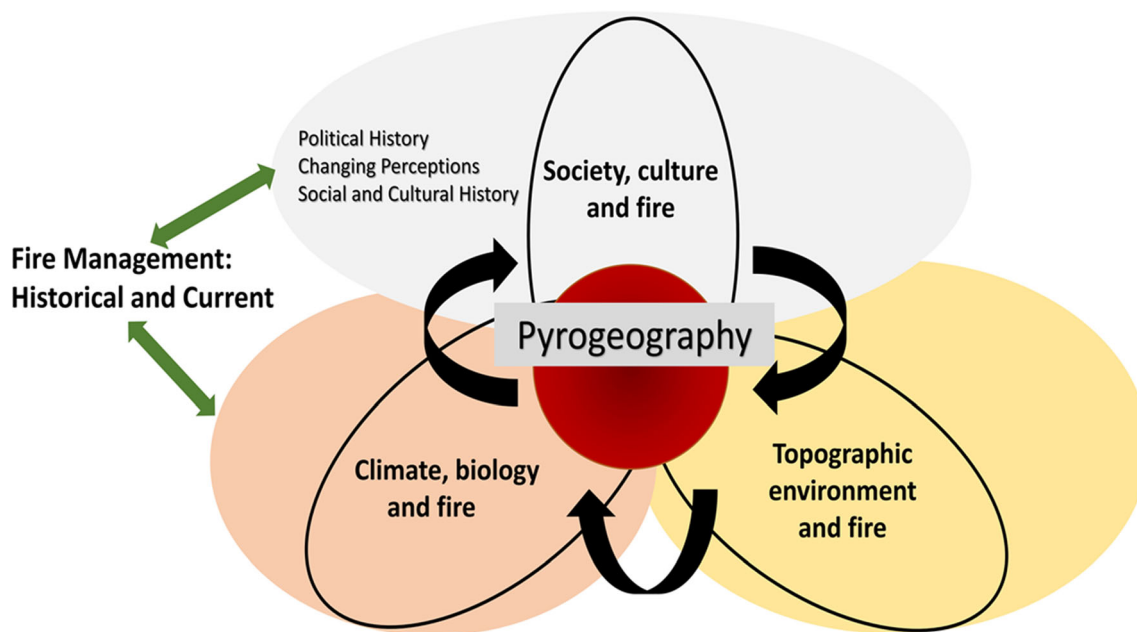


Fig. 2 A conceptual model illustrating the associations between three key pyrogeographic factors (e.g. ‘society, culture and fire’; ‘climate, biology and fire’; ‘topographic environment and fire’), and the interacting feedbacks concerned with fire management and the social dynamics identified in Bwabwata National Park (adapted from Bowman et al. 2013)



Fig. 3 Left: Topographical maps used for the identification of small and large fires amongst the community stakeholders. Right: focus group meeting held in Chetto village in Bwabwata National Park. Left photo by author Glynis Humphrey and right photo by Soner Geira

Further, seasonal calendars (Prober et al. 2011) were used to document the community's observations and historical knowledge of seasonal fire patterns and the effect of fire on natural resources (e.g. veld foods) as part of the interviews and focus group meetings (Fig. 3).

Government and non-government stakeholder interviews

Twenty-five in-depth semi-structured interviews were used to elicit stakeholder perceptions of early and late dry season burning in the BNP as a management practice, drivers of the fire regime (ecological and/or social factors), and past fire policies (Table S3). Interviews were held with representatives from the Namibian government, NGOs, park wardens and field rangers, academic staff, and other stakeholders (e.g. tourism operators, state veterinarian and ecological consultants). All interviews were conducted in English.

Data analysis

Grounded theory (Glaser 2002) was used as the core analytical framework (Fig. S1) to address the social aspects of this study. This approach provided a platform for the emergence of key concepts and relationships in the data through iterative interpretation which contributed to the conceptual understanding of the human-driven fire use patterns in the park. The data was analysed using thematic content analysis (Namey et al. 2008). Atlas.ti (Version: 7.5.10) was used for categorizing, coding and developing themes. The number of recurring themes and individual respondents who provided replies were counted. The co-occurring themes were then organised into conceptual diagrams that maintained the respondents' descriptions of cause and effect, and the number of respondents reporting each sub-theme were included (Ray et al. 2012).

Satellite data: MODIS active fires (i.e. pixel hotspots)

The MODIS Fire Information for Resource Management System¹ active fire dataset (MCD14ML) was clipped to the BNP boundary, and was used to identify the season, time of the day and the number of pixels (1 km × 1 km) affected by fire from 2000 to 2015. The geographical Information system (GIS) ESRI software ArcGIS v10.2 was used to produce a data clock graph showing the time over 24 h, the month, and the number of pixels affected by fire at satellite (Terra [AM] and Aqua [PM]) overpass. The purpose of this graph was to visually represent and determine the frequency of active fire pixels (pixel hotspots) per month in BNP (2000–2015). This data was used alongside the interview scripts, to verify and triangulate what time of day, and in what month people typically use fire in BNP.

RESULTS

Community stakeholder perspectives: Historical and current burning strategies

Seasonality

The use of fire in BNP, both historically and currently, is entrenched in the tradition and culture of the Khwe and Mbukushu (Table 2). Eighteen main themes, and 75 sub-themes (Fig. S2), interrelated with the use, motives, causes, and general factors associated with fire emerged through analyses of the community responses. All respondents

¹ FIRMS: <https://earthdata.nasa.gov/earth-observation-data/near-real-time/firms/active-fire-data>.

Table 2 Summary of the reasons for burning as identified by the Khwe and Mbukushu stakeholders (n = 36) associated with traditional–cultural fire knowledge and early burning practises (historically and present day) in Bwabwata National Park, 2014–2015

Reasons for burning	Description of activity
<i>Traditional—cultural fire knowledge</i>	
Creation of fire	Survival; traditional practise and is regarded as a symbol of manhood
Cooking, boiling water	Survival; food and nourishment
Provision of light at night	Survival; protection from dangerous animals at night
Removal of vegetation	Close to the homestead for protection from the late season fires
Protection from dangerous animals	Removal of dense vegetation whilst gathering veld food resources; and to open an area for visibility (e.g. lion, elephant); chase snakes away
Medicinal plants	Extract parts of a plant for healing properties (e.g. boiling and reducing roots)
Healing rituals/ceremonies	Promotion of a sick family member's health. Fire is transferred from the 'dwelling' of the sick to the healing ceremony
Gender: Homestead	Male of the household will make the fire, and women typically can only use the fire for cooking
Gender: Cultivation	Women typically make the fire in the cultivation fields for the purposes of burning of brush piles (i.e. vegetation debris) before planting seeds prior to the rainfall
Spiritual purposes	Communication with ancestors (e.g. where to hunt)
Communication	To signal to distant family members in the bush to notify them of their location and success of a hunt
Traditional use	Immediately light a fire as soon as the arrival at a location; fire also provided the means to move into remote areas
Removal of parasites	Tick infestations
Knowledge	Early burning was and is a planned activity; the elders of the community used to control who would burn and where; and people were taught how to burn
Cultivation	Agricultural practises (removal of dry vegetation debris); increase the land productivity (i.e. crops grow rapidly after the use of fire)
<i>Early burning: Historical and present day</i>	
Regeneration of vegetation	Burning the old grass to generate new growth
Protection of veld food resources	Protection of fruiting trees that provide vital veld food resources (particularly on dune crests); protection of the family's food resources
Protection from the late season fires	Protection of the family, and village areas from large hot dry season fires
Burning to source veld foods	Removal of the grass layer beneath trees in seed, since it's easier to locate fallen seeds on the ground
Livestock grazing	Generate new growth of grass for cattle
Hunting	Survival; generate growth of grass to attract wildlife (particularly in the grass laden Omiramba); flush smaller animals out from the grass (e.g. duikers, monitor lizards, tortoises); preparation of the meat for consumption
Tracking	Clearing of vegetation to see the tracks on the ground after the fire for the ease of locating animal tracks in the remnant ash

identified two distinct phases of savanna fire seasons: the earlier season in cooler conditions after the rainfall period when the grass is green, and the late dry season fires during dry, and hot conditions. The seasonal calendar (Table 3) illustrates the historical and current annual cycle of both early and late season fire use by park management and the community stakeholders in relation to the use of resources, food preparation and activities in the park.

During the field work seasons of 2014 and 2015, a number of early dry season fires were observed that were in proximity to the village areas in the months of May–June, and early as well as late dry season fires were evident in the satellite MODIS pixel hotspot data clock analysis (2000–2015) (Fig. 4). Thus, the period of burning extends

over 10 months of the year in the park. The MODIS data clock revealed that most fires were early season fires that took place between May and July, with the latter month experiencing the greatest number of pixels affected by fire in BNP. Further, the data clock showed that generally 50 % fewer pixels were burnt in the late dry season, of which were probably fires lit by the Mbukushu community for cultivation purposes.

Early burning

Figure 5 illustrates the interrelated reasons and activities for the historical (shaded in brown), and the current use of seasonal dry season fires (early and late) of both the *Khwe*

Table 3 Seasonal calendar showing historical and present-day activities in relation to the use of fire amongst community and government and non-government stakeholders in Bwabwata National Park (2014, 2015)

	Rainfall season			Early dry season				Late dry season				
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Season				Dry				Wet				
Food preparation	Growth period: Crops			Vegetation dries out				Crop-field preparation				
				Harvesting of crops				Clearing and burning: brush piles				
				Harvesting of veld food resources				Harvesting of veld food resources				
				Use of fire on the dune crests (May): Veld food Harvesting								
				Use of fire in the omirambas (June - July) for hunting purposes (Historical)								
Fire use	Hunting of smaller species by the communities in BNP (Present day)											
				Community: Historical early season fires				Late season fires: crop related fires				
				Community: Current use of early season fires								
				Park management: BNP early season fires (2006 - present)								

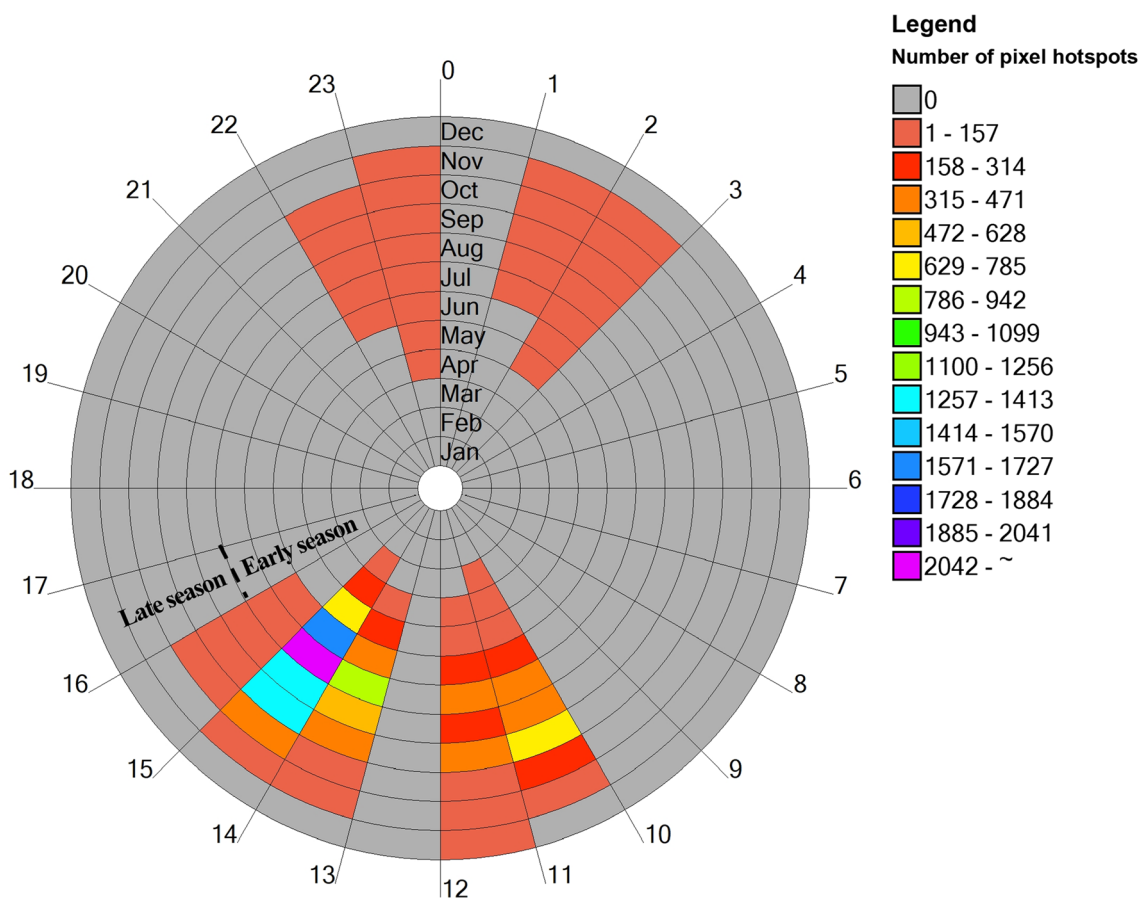


Fig. 4 Data clock showing the number of MODIS active pixel hotspots per 1 km × 1 km pixel per month and hour of the day (24 h) covering the early and late dry seasons in Bwabwata National Park, 2000–2015. Data derived from FIRMS MODIS MCD14ML. The dashed line indicates the division between the early and late dry seasons in BNP

and the Mbukushu people. Early season burning was historically used for the maintenance and protection of veld food resources, prevention of late season fires, and hunting and tracking activities, particularly by the Khwe people.

For example, the Khwe people used to burn the grass-laden omirambas so that they could detect animal tracks in the ash, which they could follow. Historically, the use of fire in the early dry season between the months of April and July

was fundamental to the Khwe's fire use and was referred to as 'early burning' and/ or 'patch burning', and locally called "tsei tsei" (Khwé-dàm). The Khwe described early season burning as a deliberate management strategy associated with their forefathers' knowledge and was considered as a traditional fire practise. "Patch burning began when the elder people tell the young people to put fire close to the village and where to burn, and to be careful, and that the fire should not go further, and that they should stop it. It's been around for many years" (Khwe respondent; see Table S4 for a list of representative quotations from the community stakeholders). The use of early burning for the management of livestock grazing areas was mainly exclusive to the Mbukushu people, as they own most of the cattle in the park.

When asked whether early burning practices were still being employed, the majority ($n = 33$) of the Khwe referred to the past, and others stated that early burning is still in use today ($n = 19$). However, people may have been afraid to talk about their current fire practices, since it is typically prohibited in the park. Twenty five out of the 36 Khwe respondents reported that during the SADF occupation, the use of fire, together with their traditional activities (e.g. hunting and gathering) were restricted. Currently, people in the BNP communities ($n = 14$) associate early burning

activities as being implemented by the community game guards on patrol in the park who are directed by the MET, and therefore they believe that the government controls fire.

Late burning

Fires are, however, also used in the late season, mainly September and October (Table 3) to clear brush piles (i.e. old branches from trees and dry grass) ($n = 28$) and to increase the productivity of the crops in cultivation plots in the MUA, which was an activity predominantly carried out by the Mbukushu people as agropastoralists. Notably, a few community stakeholders referred to the occurrence of runaway fires due to mismanagement of cultivation fires in the late season. Twenty-four of the 36 respondents preferred using early season fires versus burning later in the season, because the late season fires were reported as negatively affecting the availability and abundance of veld food resources ($n = 35$). Table S5 details a list of tree species described as being used as veld food plants by the Khwe people observed to be negatively impacted by fire in BNP.

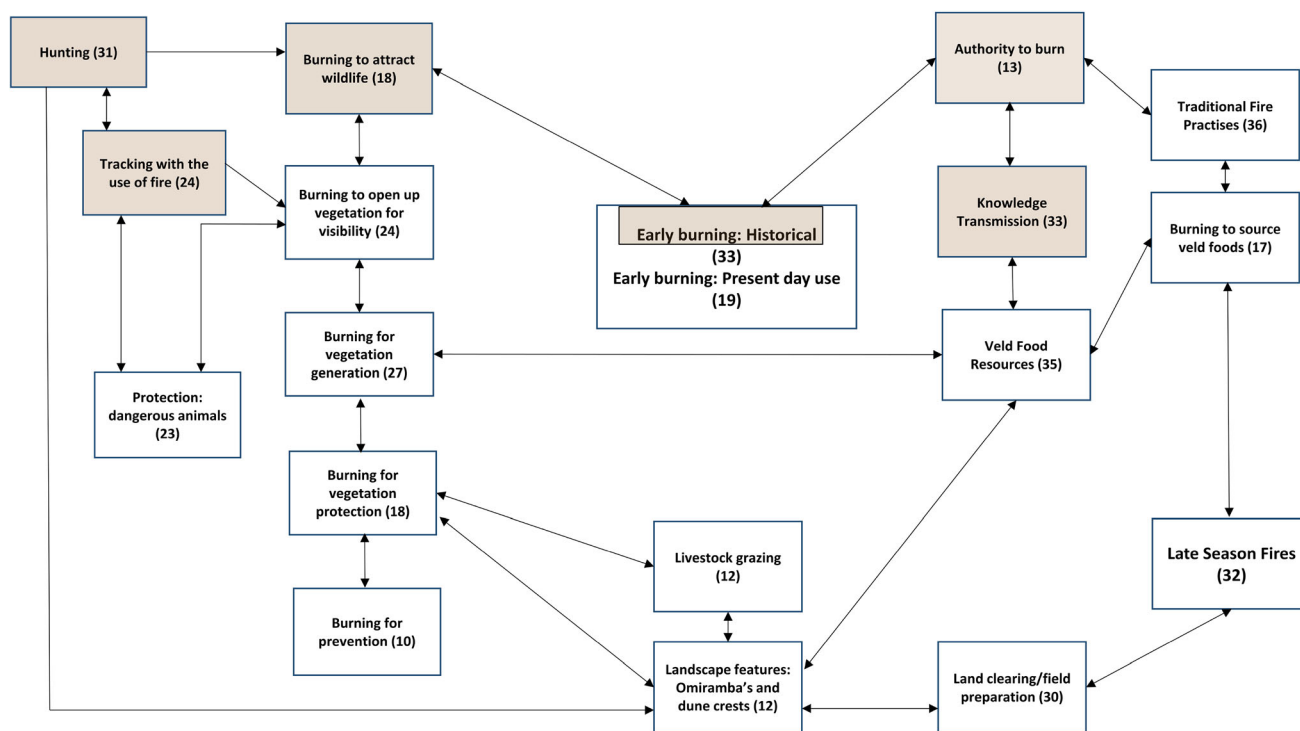


Fig. 5 A conceptual diagram showing the associations between historical and current traditional-cultural practises by the BNP communities. *The numbers in parentheses refer to the number of participants who provided a response for each theme, and the numbers between sub-themes indicate the number of times they co-occurred. The brown shaded boxes indicate the Khwe's historical practises in relation to early burning, which no longer take place today. Fire use activities that are linked by arrows indicate that there is a connection between the activities

Government and non-government stakeholder perspectives

Perspectives on early burning strategies

Currently, early burning strategies are preferred by these stakeholders as an ecological management approach in BNP, and fire was described as usually being applied early in the dry season to reduce and prevent the intensity of the late season fires in the landscape. “The game guards and the MET burn the area and communicate with each other and maintain the fire in a patch work mosaic. They burn when the grass is wet so that the fire can't spread” (Table S6 provides examples of quotations from the government and non-government stakeholders). The emphasis on early dry season burning in the last decade was described by respondents as the result of negative impact of the late season fires on vegetation structure in the region and the prevailing perception of the decline in woodland trees. Consequently, almost all (24 out of 25) of the respondents held a positive perception of early season fire. Twelve of the respondents commented on the positive influence of the Community Based integrated Fire Management (CBiFM) early burning programme (Fig. S3) initiated in the *eastern Caprivi*, which they suggested has facilitated the motivation for the implementation of early burning strategies in BNP. Nonetheless, the park management respondents ($n = 12$) described the management of early season fires in BNP as ‘*ad hoc*’, meaning that there was no planning, coordination and strategic burning strategies concerning place-based environmental observations (e.g. rainfall, grass phenology, time since last burn etc.). Twenty-one respondents believed that early burning practices in the park would improve if they were implemented and managed effectively, and if communication and collaboration with all stakeholders (communities included [$n = 10$]) was improved. Nevertheless, twelve respondents acknowledged that fire is complex and there are multiple factors that need to be addressed to understand the fire regime (e.g. the combination of elephants, fire and people in the region). Eighteen main themes, and 68 sub-themes (Fig. S4) associated with fire emerged through analyses of the government and non-government stakeholder responses.

Fire and vegetation history: Perceived changes in the fire regime

Respondents held mixed views concerning changes in the regime in the past, and some respondents thought the lack of burning associated with the long-standing former policy of fire suppression was the reason for the prevalence of late season fires in the park today. Some attributed extensive

bush encroachment in the park to the suppression policy. Respondents ($n = 16$) also thought there was an increase in fires since the past and subsequently there are less trees and more shrubs. Respondents also referred to the formation of the MUA ($n = 13$), which they associated with an increase in fire frequencies across the park because of the increase in people living in the park. Perceived changes in the fire regime in BNP were also associated with social-political circumstances prior to independence (1990). For example, reference was made to the era of the South African Border War (1964–1989), and the probability of the prevalence of fires during that time due to the use of the SADF military artillery, and the ensuing ignition of vegetation during combat. The view of the respondents was that without adequate resources to suppress fires, fires would have spread in an infrequently burnt landscape in the late dry season. Furthermore, respondents stated that cross-border fires were likely prevalent, as Angola was at the time involved in a civil war (1975–2002), and Botswana has a policy of fire suppression.

Views on past and present traditional fire knowledge and management

Fourteen of the respondents stated that communities are required to be educated in fire use in the MUA as these respondents perceived communities to be less informed in fire management matters. On the other hand, other respondents ($n = 11$) were aware of the use of the current early burning strategy used by park management as an approach that was historically used by the Khwe in the region. Nonetheless, there was an awareness amongst 20 of the 25 stakeholders about the use of traditional fire and cultural values of the resident communities in BNP (Fig. S4), though there was scepticism about the use of traditional fire strategies for the management of natural resources in a sustainable way.

DISCUSSION

This study has revealed how the Khwe and Mbukushu people historically used, and currently use, fire for both immediate and longer-term gain, by manipulating fire seasonally for interrelated beneficial purposes (Tables 2 and 3; Figs. 4 and 5). The use of early burning by the Khwe emerged as central to their historical use of fire for hunting, tracking and veld food gathering, and protection from dangerous animals, which has evidently influenced their current use of early season burning practices. Early ethnographical records (eighteenth century) found that the use of fire was central to the hunter-gatherer San people's lives for generating herbage to attract game for hunting

purposes (Schapera 1930; Lee and DeVore 1976). However, this previous research did not detail the importance of human driven fire seasonality, and the use of the early season fires as ancestral knowledge associated with a variety of livelihood activities, as revealed in this study. Moreover, the Khwe and Mbukushu people's land use options, and livelihood activities have fundamentally changed since the nineteenth century in BNP (Table S1), which indicates that cultural practices (Table 2) are not static, but are flexible, and have necessarily changed and adapted over time because of the changing socio-political circumstances in the region. Yet, significantly the historical early burning practices have been upheld even under the era of fire suppression. Specifically, the MODIS satellite data (Fig. 4) supports the community claims about the use of early as well as late season fires in the BNP landscape. However, it was largely recognised amongst the Khwe community that ancestral fire knowledge is disappearing over time (Fig. 3), as it is amongst traditional communities world-wide (Huffman 2013).

What are the stakeholders' historical and current perspectives on the use of seasonal fire?

The 'government and non-government' stakeholders viewed early burning positively as an ecological fire management tool in BNP. Both stakeholder groups (community and government/non-government) viewed the use of fire both positively and negatively for similar reasons, however the community stakeholders perceived fire negatively for an additional factor, due to the impact on veld food resources in the park, particularly during the late season (Fig. S5). Nonetheless, the use of fire in the late season for cultivation purposes is a critical component of food security in the park, as it is among many other agropoastalist groups in southern African and globally (e.g. Asia) (Eriksen 2007). With the emergence of a revised fire management policy, the 'Fire Management Strategy for Namibia's Protected Areas' for BNP (2016), the MET subsequently acknowledged there is considerable knowledge of controlled burning among the resident communities and fire management implementation, specifically in the east of the park. Thus, during the process of this research, the fire management policy changed from one of lack of recognition to acknowledgement of the community burning traditions, which is the first time in the history of the GRN.

The acknowledgement of the BNP communities' use of early season fire use and the recognition of the ecological benefits of fire by the government and non-government stakeholders represents a very recent (2016) shift in fire management perspectives in Namibia. The positive aspects are that early season burning is an area of mutual

agreement between the two stakeholders' groups and thus, provides an area of congruence for potential future management arrangements. Yet, even though the communities were recently acknowledged in the policy (MET 2016), the interview data herein showed that there is still scepticism about indigenous fire use especially by fire managers in the region, and that the community perceived the government to be in control of fire in BNP. Thus, this highlights that there is miscommunication and a resulting lack of cohesiveness among stakeholders concerned with fire in BNP, even though they have a similar understanding of the seasonal use of fire. This scenario indicates that power and uneven societal status between communities and government in the park may be factors influencing the current use of fire (Schusser 2012); although the local communities have been officially acknowledged, they perhaps do not see that reflected in their interactions with park management.

How have historical context and present social factors influenced fire management and policies in BNP?

Traditional burning practices were overshadowed by political interests on both sides (South African and Namibian) during the Namibian War of Independence (1964–1989), a time when politics was priority and not natural resource management (Kangumu 2008). These complex factors influenced communication, transparency and trust, and any possible balances of social cohesion between the GRN and BNP communities. The absence of recognition of the communities' knowledge, failure to formally recognize the Khwe as a Traditional Authority (TA) (Hitchcock and Vinding 2004), and their continual marginalisation has resulted in an absence of interest within the community to collaborate with government stakeholders on developing fire management regimes. As one government stakeholder stated, "we experience difficulty as the communities are no longer interested in meetings". Government and community collaboration, knowledge sharing, and engagement are deemed a necessity if fire management issues are to be adequately addressed in the region. For this collaboration to be possible, it would be important for the GRN to acknowledge the social-political history and past marginalisation of the Khwe, which as this study has revealed, has affected relations between the GRN and communities, and therefore the management of fire.

How does the BNP case study fit within the pyrogeographic framework?

Namibia has been subject to several external fire management initiatives since the nineteenth century (Finland,

Table 4 List of recommendations for implementing participatory fire management among stakeholders in Bwabwata National Park

Recommendations	Outcomes
- Provide an understanding of the various fire management strategies at the local scale of both the positive and negative aspects of fire management	- Lead to locally adapted and acceptable policies, thereby allowing the BNP communities to use fire in a more controlled and rational manner for livelihood purposes together with park management
- Acknowledge both early and late season traditional burning practises in fire management plans and during campaigns	- Help clarify any misunderstanding between park management and the BNP communities concerning the use of fire during the early and late dry seasons
- Grant the Khwe community to have community representatives and/or a Traditional Authority (TA) in BNP	- Improve communication and trust between stakeholders and allow for opportunities for an exchange of knowledge between the community and people who manage fire in the park
- Design a fire management communication system (e.g. fire notices) that details the use of prescribed fires in the park	- Increase information flow about monthly and annual fire management plans (e.g. scheduled burns in designated areas), including about high fire risk days and/or seasons
- Translate signage about fire management on display into the dominant local languages (e.g. Khwé-dàm; Thimbukushu; Ma-Yea-yi) in the region ^a	- Improve communication and understanding between stakeholders of the park's fire management plans, as well as of the positive and negative aspects of fires
- Train protected area managers and decision-makers in participatory social engagement methods related to fire management knowledge related events (e.g. facilitated community meetings) (Mistry et al. 2018)	- Encourage stakeholder engagement with indigenous people in the park concerning their traditional fire management perspectives and practices
- Create formal opportunities for local community fire representatives (e.g. Khwe and Mbukushu people) to work with the park community game guards for prescribed burning events in BNP	- Increase collaboration and encourage a learning exchange about adaptable fire management strategies
- Increase collaboration (e.g. joint committee fire meetings) between all environmental ministries involved in fire management and decision making	- Improve interdepartmental communication and relations and understanding about fire managements objectives and plans

^aA great proportion of the community have not had the opportunity to obtain a formal education and are non-English speaking

Germany, South Africa and more recently, Australia) (Table 1). The involvement of the Finnish and Germans in Namibia led to government policies centred on fire suppression, whereas recommendations by South Africa and Australian advisors more recently (twentieth century) led to a deeper understanding of the important role of indigenous knowledge in governing fire in the savanna-woodlands in the north-east of Namibia. Thus, differences in perceptions of fire use are highlighted between communities, cultures (Khwe versus Mbukushu), countries, and centuries (nineteenth–twenty-first centuries). This complex scenario of a multitude of international perspectives are embedded in Namibia's culture and social history. Understanding these dynamics is central to the pyrogeography framework that embraces societal and cultural fire knowledge alongside comprehending the ecological fire dynamics. Importantly, pyrogeography highlights the need to address urgent management decisions for sustainable fire management, livelihoods, ecosystems and climate change.

The understanding of fire and the management implemented in the *eastern caprivi* (2006–2011–CBiFM programme) by an Australian fire manager and a local Namibian based NGO, the Integrated Rural Development and Nature conservation (IRDNC), was based on early burning as the premise of traditional fires, and thus was

largely influenced by indigenous practices. The CBiFM programme, initiated in 2006, involved collaborations with the communities and resulted in a transformation in BNPs management approach to understanding early season fire as ecologically beneficial to the savanna-woodland system (Figs. S4 and S5), as indicated by respondents in this study. The CBiFM programme hinged on devolving the responsibility of fire management to the communities, and implementation involved creating a patch mosaic pattern of burnt and unburnt areas in the landscape early in the dry season. Importantly, it recognised the knowledge of traditional burning practices (Mbongo et al. 2011). Thus, the CBiFM programme marked a significant yet informal transition to fire management versus the GRN Forest Act No 12 (Ministry of Agriculture, Water and Forestry [MWAF], 2001), and Forest Regulations (2015) based on fire prevention, suppression, and controlled burning only under specific circumstances.

As has been demonstrated in the east Caprivi by the success of the CBiFM, involving local communities in fire management has the potential to improve fire management, and relationships between people living in the park and government. Perhaps further acknowledgement of seasonal fire knowledge and burning rights for livelihood purposes in the BNP communities by the GRN would enhance

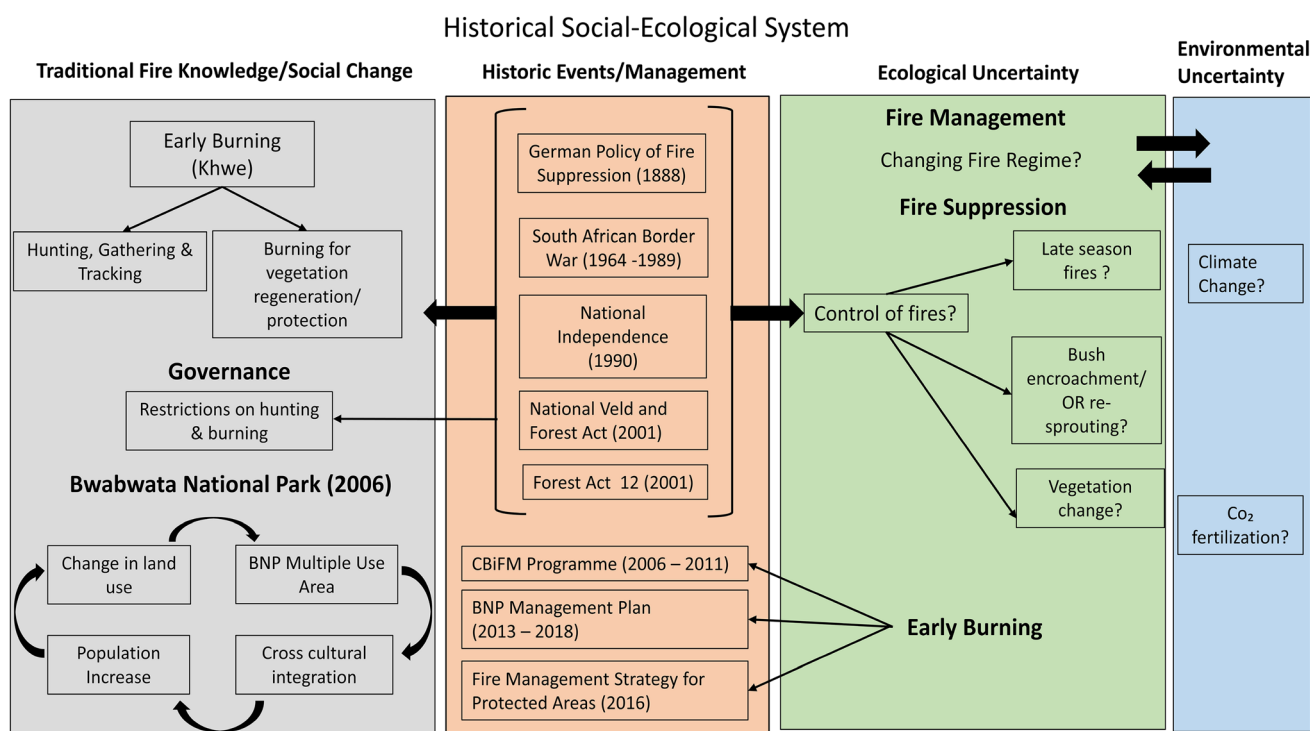


Fig. 6 A conceptual model showing the interactions and feedbacks within the social-political ecological system in relation to the use of fire in Bwabwata National Park (nineteenth Century—present). The figure illustrates the Khwe’s traditional fire knowledge as restricted in relation to the social—political context (i.e. chronological historical and management events) of the region, inclusive of changing government fire management Acts and policies in combination with the South African Border War/Namibian War of Independence (1964–1989), and the interaction of these factors alongside ecological uncertainty with questions pertaining to current fire management in BNP in association with environmental uncertainty

relations and create a platform for future management and cooperation. Table 4 provides a list of recommendations that could be considered by the GRN and the MET together with the BNP community that could assist in the transition towards more participatory fire management and governance in the future (Humphrey 2018).

Emerging questions on historical fire management and ecology

Figure 6 illustrates how complex historical factors, which disrupted traditional fire management interact with ecological uncertainty to produce a state of environmental uncertainty in BNP, where the likely extent and ecological consequences of fire are unpredictable. This complexity highlights the need to investigate the ecological uncertainty identified during this study (e.g. bush encroachment; and long-term vegetation change dynamics due to early and late season fires) in relation to changes in the fire regime in BNP (MET 2016). Palaeoecological work is currently underway to develop an understanding of vegetation and fire dynamics in BNP over the past 1000 years, alongside inter-decadal studies of woody cover and bush encroachment. Stakeholder scenario planning could be used to

explore different futures that might emerge under various combinations of environmental, social and ecological drivers using a combination of tree cover estimates, fire management practices [early/late], climate and CO₂ states. By combining the social and ecological (recent past and present) in combination with palaeoecological (deep past) aspects, a fuller understanding of fire dynamics in their historical and societal contexts in BNP will emerge.

CONCLUSION

This study has presented a historical and contemporary understanding of why, where, how and when people use fire in BNP. The study integrates two stakeholder groups’ (i.e. community and government and non-government) perceptions of fire management and explains the current fire management status in BNP, and its roots in the region’s socio-historical and political past. Indigenous practices of preventative and regenerative early season burning practices have until recently received little attention in policy making circles (Butz 2009; see Laris 2002 for exceptions). Recently, the BNP fire management policy changed and is now centred on early burning as a result of the influence of

the CBiFM project incorporating indigenous knowledge in north-east Namibia, as well as due to several fire management interventions that have occurred in the recent past (Table 1). Nevertheless, the absence of cultural understanding, knowledge and communication flow, combined with mixed land use (cultivation fires/national park) and interactions with environmental factors have contributed to the social complexity of fire management between community and governmental/non-governmental stakeholder groups in the rest of BNP.

This study has shown that it is useful to position fire ecology within the social-historical context, which allows for the understanding of causal interactions between changes in policies, social systems and fire regimes. Furthermore, the comparisons of the different viewpoints of the stakeholders has shown that both groups value and understand the benefits of early burning, which indicates that there is common ground for understanding the use of fire in the future in BNP. The implications of these findings are clear in terms of recommendations for the advancement of fire management policy: understanding the social and cultural dynamics embedded in fire management is critical for managing fires in the future. Thus, communities can and should be extensively involved in the development of early burning management techniques used in park management, and their traditional knowledge should be acknowledged and respected, as it is on other continents where the integration of multiple perspectives of fire are critical to developing participatory 'intercultural governance' (Mistry et al. 2018). The pyrogeographic perspective provides a useful framework for integrating social, environmental and ecological perspectives. This study presents results which reveal the implications for understanding human-driven fire regimes in southern Africa savannas, and how the complex social dynamics reflected in the past are affecting current fire management in north-east Namibia.

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REFERENCES

- Bird, D.W., R.B. Bird, and C.H. Parker. 2005. Aboriginal burning regimes and hunting strategies in Australia's Western Desert. *Human Ecology*. 33: 443–464.
- Bowman, D.M. 1998. The impact of Aboriginal landscape burning on the Australian biota. *New Phytologist* 140: 385–410.
- Bowman, D.M., J. Balch, P. Artaxo, W.J. Bond, M.A. Cochrane, C.M. D'antonio, R. DeFries, F.H. Johnston, et al. 2011. The human dimension of fire regimes on Earth. *Journal of Biogeography*. 38: 2223–2236.
- Bowman, D.M., J.A. O'Brien, and J.G. Goldammer. 2013. Pyrogeography and the global quest for sustainable fire management. *Annual Review of Environment and Resources* 38: 57–80.
- Braithwaite, R.W. 1996. Biodiversity and fire in the savanna landscape. *Biodiversity and savanna ecosystem processes*, 121–140. Berlin, Heidelberg: Springer.
- Brockett, B.H., H.C. Biggs, and B.W. van Wilgen. 2001. A patch mosaic burning system for conservation areas in southern African savannas. *International Journal of Wildland Fire* 10: 169–183.
- Butz, R.J. 2009. Traditional fire management: Historical fire regimes and land use change in pastoral East Africa. *International Journal of Wildland Fire*. 18: 442–450.
- Coughlan, M.R., and A.M. Petty. 2012. Linking humans and fire: A proposal for a transdisciplinary fire ecology. *International Journal of Wildland fire*. 21: 477–847.
- Delcourt, H.R., and P.A. Delcourt. 1997. Pre-Columbian native American use of fire on southern Appalachian landscapes. *Conservation Biology*. 11: 1010–1014.
- Eriksen, C. 2007. Why do they burn the 'bush'? Fire, rural livelihoods, and conservation in Zambia. *The Geographical Journal*. 173: 242–256.
- Fairhead, J., and M. Leach. 1996. *Misreading the African landscape: Society and ecology in a forest-savanna mosaic (Vol 90)*. Cambridge: Cambridge University Press.
- Frost, P.G. 1999. Fire in southern African woodlands: origins, impacts, effects and control. In: *Proceedings of an FAO Meeting on Public Policies Affecting Forest Fires*. FAO Forestry Paper 138, FAO, Rome, pp 191–205.
- Glaser, B. 2002. Conceptualization: On theory and theorizing using grounded theory. *International journal of qualitative methods*. 1: 23–38.
- Hitchcock, R.K. 2012. Refugees, resettlement, and land and resource conflicts: the politics of identity among! Xun and Khwe San in North-eastern Namibia. *African Study Monographs*. 33: 73–132.
- Hitchcock, R.K. 2019. The impacts of conservation and militarization on indigenous peoples. *Human Nature*. 30: 217–241.
- Hitchcock, R.K. and D. Vinding, eds., 2004. *Indigenous peoples' rights in Southern Africa* (No. 110). Copenhagen. International Work Group for Indigenous Affairs (IWGIA).
- Hough, J.L. 1993. Why burn the bush? Social approaches to bush-fire management in West African National Parks. *Biological conservation* 65: 23–28.
- Huffman, M. 2013. The many elements of traditional fire knowledge: Synthesis, classification, and aids to cross-cultural problem solving in fire-dependent systems around the world. *Ecology and Society*. 18: 3.
- Humphrey, G.J. 2018. The role of humans, climate and vegetation in the complex fire regimes of north-east Namibia. PhD Thesis. University of Cape Town. South Africa.
- Kull, C.A. 2002. Empowering pyromaniacs in Madagascar: Ideology and legitimacy in community-based resource management. *Development and Change*. 33: 57–78.

- Kangumu, B. 2008. Contestations over Caprivi identities: from pre-colonial times to the present. Ph. D. Thesis. University of Cape Town.
- Laris, P. 2002. Burning the seasonal mosaic: Preventative burning strategies in the wooded savanna of southern Mali. *Human Ecology*. 30: 155–186.
- Laris, P. 2011. Humanizing savanna biogeography: Linking human practices with ecological patterns in a frequently burned Savanna of southern Mali. *Annals of the Association of American Geographers*. 101: 1067–1088.
- Laris, P., and D.A. Wardell. 2006. Good, bad or 'necessary evil'? Reinterpreting the colonial burning experiments in the savanna landscapes of West Africa. *The Geographical Journal*. 172: 271–290.
- Laris, P., M. Koné, S. Dadashi, and F. Dembele. 2016. The early/late fire dichotomy. *Progress in Physical Geography: Earth and Environment* 41: 68–94.
- Lee, R.B., and I. DeVore. 1976. *Kalahari hunter-gatherers: Studies of the! Kung San and their neighbours*. Cambridge, MA: Harvard University Press.
- Lenggenhager, L. 2015. Nature, war and development: South Africa's Caprivi strip, 1960–1980. *Journal of Southern African Studies*. 41: 467–483.
- Martínez-Torres, H.L., D.R. Pérez-Salicrup, A. Castillo, and M.I. Ramírez. 2018. Fire management in a natural protected area: What do key local actors say? *Human ecology* 46: 515–528.
- Mbongo, W., R. Beatty, and P. Ries. 2011. *Caprivi region: Draft integrated fire management strategy. 2007–2011*. Integrated Rural Development & Nature Conservation & Directorate of Forestry Report. Windhoek, Namibia.
- Mbow, C., T.T. Nielsen, and K. Rasmussen. 2000. Savanna fires in East-Central Senegal: Distribution patterns. Resource management and perceptions. *Human Ecology* 28: 561–583.
- Mendelsohn, J., and R. Roberts. 1997. *Environmental profile of the caprivi strip*. Windhoek, Namibia: RAISON.
- Mendelsohn, J., A. Jarvis, C. Roberts, and T. Robertson. 2009. *Atlas of Namibia*, 3rd ed. South Africa: Sunbird Publishers.
- Ministry of Environment and Tourism [MET]. 2013. *Management Plan for Bwabwata National Park 2013/2014 to 2017/2018*. Windhoek: Government of the Republic of Namibia.
- Ministry of Agriculture, Water and Forestry (MWAf). 2001. Forest Act No. 12. Windhoek, Namibia.
- Ministry of Agriculture, Water and Forestry (MWAf). 2015. Forest Regulations. 2015. Republic of the Government of Namibia. Windhoek.
- Ministry of Environment and Tourism. 2016. *Fire management strategy for Namibia's protected areas*. Namibia: Government of the Republic of Namibia, Directorate of Wildlife and National Parks Windhoek.
- Mistry, J., A.V. Berardi, T. Andrade, P. Kraho, and O. Leonardos. 2005. Indigenous fire management in the cerrado of Brazil: The case of the Kraho of Tocantins. *Human Ecology*. 33: 365–386.
- Mistry, J., L.B. Schmidt, L. Eloy, and B. Bilbao. 2018. New perspectives in fire management in South American savannas: The importance of intercultural governance. *Ambio*. 48: 172–179.
- Namey, E., G. Guest, L. Thairu, and L. Johnson. 2008. Data reduction techniques for large qualitative data sets. *Handbook for team-based qualitative research*.
- Nyamadzawo, G., W. Gwenzi, A. Kanda, A. Kundhlande, and C. Masona. 2013. Understanding the causes, socio-economic and environmental impacts, and management of veld fires in tropical Zimbabwe. *Fire Science Reviews*. 2: 1–13.
- Parr, C.L., and B.H. Brockett. 1999. Patch mosaic burning: A new paradigm for savanna fire management in protected areas? *Koedoe Research Journal*. 42: 117–130.
- Parr, C.L., and A.N. Andersen. 2006. Patch mosaic burning for biodiversity conservation: a critique of the pyrodiversity paradigm. *Conservation Biology* 20: 1610–1619.
- Pausas, J.G., and J. Keeley. 2009. A burning story: The role of fire in the history of life. *BioScience*. 59: 593–601.
- Powell, N. 1988. Co-management in non-equilibrium systems. PhD thesis. Swedish University of Agricultural Sciences, Uppsala.
- Prober, S., M. O'Connor, and F. Walsh. 2011. Australian Aboriginal peoples' seasonal knowledge: a potential basis for shared understanding in environmental management. *Ecology and Society*. <https://doi.org/10.5751/ES-04023-160212>.
- Pyne, S. 1995. *World Fire. The culture of fire on Earth*. Washington: University of Washington Press.
- Ray, L., C. Kolden, and F. Chapin. 2012. A case for developing place-based fire management strategies from traditional ecological knowledge. *Ecology and Society*. 17: 37.
- Russell-Smith, J., P.G. Ryan, and R. Durieu. 1997. A LANDSAT MSS-derived fire history of Kakadu National Park, monsoonal northern Australia, 1980–94: Seasonal extent, frequency and patchiness. *Journal of Applied Ecology*. 34: 748–766.
- Russell-Smith, J., G.D. Cook, P.M. Cooke, A.C. Edwards, M. Lendrum, C.P. Meyer, and P.J. Whitehead. 2013. Managing fire regimes in north Australian savannas: Applying aboriginal approaches to contemporary global problems. *Frontiers in Ecology and the Environment*. 11: 55–63.
- Schapera, I. 1930. *The Khoisan peoples of southern Africa*. London: Routledge and Keagan Paul.
- Scholes, R.J., S. Archibald, and G. von Maltitz. 2011. Emissions from fire in Sub-Saharan Africa: The magnitude of sources, their variability and uncertainty. *Global Environmental Research*. 15: 53–63.
- Scott, A.C., D.J.M.S. Bowman, W.J. Bond, S.J. Pyne, and M. Alexander. 2014. *Fire on Earth: An introduction*. Chichester, U.K.: Wiley.
- Shaffer, L.J. 2010. Indigenous fire use to manage savanna landscapes in southern Mozambique. *Fire Ecology* 6: 43–57.
- Stewart, O.C. 1956. Fire as the first great force employed by man. In *Man's role in changing the face of the Earth*, ed. W.L.J. Thomas, 115–133. Chicago: University of Chicago Press.
- Suzman, J. 2001. *An assessment of the status of the San in Namibia*. Report Series, Report No. 4 of 5. Legal Assistance Centre (LAC), Windhoek.
- Taylor, J. 2012. Naming the Land: San Identity and community conservation in Namibia's West Kavango. PhD Thesis. Oxford University.
- Tinley, K.L. 1966. *Western caprivi conservation area, South West Africa: A proposal of natural resource land use*. Windhoek, Namibia: Department of Nature Conservation.
- Trollope, W.S.W., and L.A. Trollope. 1999. *Technical review of the integrated forest fire management component of the Namibia-Finland Forestry Programme*. Alice: Department of Livestock and Pasture Science, Faculty of Agriculture, University of Fort Hare, Republic of South Africa.
- Trollope, W.S. 2011. Personal perspectives on commercial versus communal African fire paradigms when using fire to manage rangelands for domestic livestock and wildlife in southern and East African ecosystems. *Fire Ecology*. 7: 57–73.
- Walters, G. 2010. *The Land Chief's Embers: Ethnobotany of Bateke fire Regimes, Savanna Vegetation and Resource Use in Gabon*. Ph.D. Thesis. University College of London.
- Whitehead, P.J., D.M. Bowman, N. Preece, F. Fraser, and P. Cooke. 2003. Customary use of fire by indigenous peoples in northern Australia: Its contemporary role in savanna management. *International Journal of Wildland Fire*. 12: 415–425.

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