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REVIEW **Open Access**

Changing fire regimes in East and Southern Africa's savanna-protected areas: opportunities and challenges for indigenous-led savanna burning emissions abatement schemes

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Abstract

Background Late dry-season wildfires in sub-Saharan Africa's savanna-protected areas are intensifying, increasing carbon emissions, and threatening ecosystem functioning. Addressing these challenges requires active local community engagement and support for wildfire policy. Savanna burning emissions abatement schemes first implemented in Northern Australia have been proposed as a community-based fire management strategy for East and Southern Africa's protected areas to deliver win–win-win climate, social, and biodiversity benefits. Here, we review and critically examine the literature exploring the design and application of savanna burning emissions abatement schemes in this region, characterizing their contextual and implementation challenges.

Results We show that the application of Northern Australian savanna burning methodologies in East and Southern Africa tends to adopt centrally determined objectives and market-based approaches that prioritize carbon revenue generation at the national level. The exclusive prescription of early-dry season burns in African mesic savannas prone to woody thickening can compromise savanna burning objectives to mitigate late-dry season wildfires and their greenhouse gas emissions in the long-term, as well as present multiple biodiversity trade-offs in the absence of formal metrics monitoring species' responses to changes in fire regime. These features restrict indigenous participation and leadership in fire management, creating uncertainties over the opportunities for local income generation through carbon trading. Findings suggest that future savanna burning applications will need to address asymmetries between formal institutions and local land governance systems, explicitly acknowledging colonial legacies in institutional arrangements across protected areas and hierarchies in agrarian politics that threaten processes of equitable decentralization in natural resource management.

Conclusion We argue that the effective transfer of the Northern Australian fire management model is limited by a lack of long-term ecological and emissions data and political and institutional barriers, and is hindered by the region's recent colonial history, population growth, and consequences of rapid climatic change. To provide a community-based strategy, savanna burning schemes need to establish context-specific legal frameworks and implement Free, Prior, and Informed Consent to safeguard the roles and responsibilities of indigenous and local people and their distribution of carbon benefits.

Keywords Fire management, Savanna burning, Prescribed burning, Carbon market, Community-based fire management, Kyoto Protocol, Indigenous knowledge, Woody thickening

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Resumen

Antecedentes Los incendios en la temporada tardía en áreas protegidas de la sabana Sub-Sahariana se están intensificando, aumentando las emisiones de carbono y amenazando el funcionamiento de los ecosistemas. El enfrentar esos desafíos requiere del involucramiento activo de las comunidades locales y el apoyo a las políticas de incendios. Los esquemas de disminución de las emisiones implementados previamente en el norte de Australia han sido propuestos como una estrategia de manejo comunitaria del fuego en áreas protegidas del este y sur de África, para desarrollar beneficios de ganancia (win–win-win) tanto en lo social, climático y de diversidad. En este trabajo revisamos y examinamos críticamente la literatura que explora el diseño y la aplicación de esquemas de disminución de las emisiones de la región, caracterizando sus desafíos contextuales y de implementación.

Resultados Mostramos que la aplicación de las metodologías de quemas de las sabanas del norte de Australia en el este y sur de África tienden a adoptar objetivos determinados centralmente y aproximaciones basadas en el mercado, que priorizan la generación de ganancias a nivel nacional. La prescripción exclusiva de realizar quemas durante la estación de crecimiento temprana en sabanas proclives al crecimiento de renovales leñosos puede comprometer los objetivos de mitigar los incendios de fines de la temporada seca y sus emisiones de gases de efecto invernadero a largo plazo, así como presentan múltiples compensaciones en biodiversidad en ausencia de medidas formales de monitoreo de respuestas de las especies a cambios en los regímenes de fuego. Estos hechos restringen la participación de los indígenas y el liderazgo en el manejo del fuego, creando incertidumbres sobre las oportunidades para la generación de ingresos locales a través de transacciones de carbono. Los resultados sugieren que la aplicación de quemas en el futuro necesita determinar las asimetrías entre las instituciones formales y los sistemas locales del gobierno de tierras, los que explícitamente acuerdan legados coloniales de arreglos entre áreas protegidas y jerarquías en políticas agrarias que amenazan los procesos de descentralización equitativa en el manejo de los recursos naturales.

Conclusiones Argüimos finalmente que la transferencia efectiva del modelo de manejo del fuego de norte de Australia está limitado por la falta de datos ecológicos y de emisiones a largo plazo, por barreras políticas e institucionales, y obstaculizada por la reciente historia colonial de la región, el crecimiento de la población, y las consecuencias del rápido cambio climático. Para proveer de una estrategia basada en la comunidad, los esquemas de quemas en la sabana necesitan establecer un contexto específico de marco legal, e implementar consensos Libres, Previos, e Informativos para salvaguardar los roles y responsabilidades de los indígenas y de la gente local, y la distribución de los beneficios del carbono.

Introduction

African savanna fires account for over 60% of global fire extent and are responsible for approximately 71% of global savanna CO_2 emissions (UNU-IAS 2015; Maraseni et al. 2016). These fires are concentrated in sparsely populated protected areas across Eastern and Southern Africa, where more than 80% of annual large fire extent and emissions occur during the late-dry season (Russell-Smith et al. 2021). Humans historically altered fire regimes to achieve diverse land management objectives, contributing to the evolution of pyro- and bio-diverse savanna ecosystems (Archibald 2012). However, the regular fire disturbances required for maintaining open grass and woodland vegetational structures (Bond and Keeley 2005) have been disrupted due to population, settlement, and agricultural expansion across communal rangelands (Knorr et al. 2014).

To mitigate challenges posed by wildfires and offset associated greenhouse gas emissions, Kyoto Protocol-compliant savanna burning emissions abatement (SBEA) schemes established in Northern Australia have been proposed as an alternative community-based fire management (CBFiM) approach in semi-arid and mesic African savannas (Lipsett-Moore et al. 2018). SBEA projects are promoted indigenous-led "win–win-win" solutions to curb biodiversity loss (Tear et al. 2021), meet climate change mitigation targets, and build resilient communities through the improvement of local and national economic conditions (Russell-Smith et al. 2017; Moura et al. 2019). They are often considered as community-based strategies, or decolonizing experiments (Neale et al. 2019), where the interest of pastoralists and indigenous landholders is a pre-requisites for project development (Lipsett-Moore et al. 2018). Institutional legitimacy and the empowerment of local populations are critical components of indigenous fire stewardship, supporting long-term sustainable resource management and avoiding uncontrolled fire use centered on individualistic short-term objectives (Bloesch 1999; Lake and Christianson 2019). Nevertheless, the implementation of exclusive early-dry season burns in SBEA projects can raise trade-offs between wildfire and emissions mitigation objectives and local biodiversity adapted to diverse fire regimes (Corey et al. 2019; Laris 2021). Additionally, research into the socio-cultural dimensions of SBEA schemes in local contexts is limited, and the active involvement of indigenous and local people in project design and governance has mostly been assumed, consistent with broader challenges in defining and ascribing participation in natural resource management (Arnstein, 2007).

The demarcation of new African states in the twentieth century cut across ecosystems and ethnic and cultural boundaries, disrupting population distributions and local burning practices (Moura et al. 2019). The establishment of exclusionary protected areas for conservation and introduction of fire suppression operations under colonial governments was reinforced by anti-fire wisdom condemning local burning practices as a leading cause of deforestation and environmental degradation (Kull 2002; Alvarado et al. 2015). The reorganization of people, burning practices, biomass, and fuel connectivity have altered the spatiotemporal distribution of fires across African savannas. High-intensity wildfires are mostly concentrated in protected areas, while increasing human pressures outside their boundaries have accelerated the conversion of savanna ecosystems to shrub and bare ground, driven by the replacement of fire and wild herbivores with livestock as the dominant fuel consumer (Archibald 2016; Li et al. 2020). Contrasting fire regimes inside and outside protected areas can be referred to as the “wildfire paradox” (Tendim et al. 2020), increasingly recognized as symptomatic of historical inequalities and the failures of colonial and post-independence resource management policies (Otero and Nielsen 2017). This is forcing governments to redress reactive fire measures and consider alternative anticipative approaches (Cassidy et al. 2022).

CBFiM is increasingly recognized as a bottom-up framework within community-based natural resource management, defined as “a type of land and forest management in which a locally resident community has substantial involvement in deciding the objectives and practices involved in preventing, controlling, or utilising fires” (Ganz et al. 2003; FAO 2011). CBFiM acknowledges the dual role of fire as regenerative and destructive in savanna ecosystems, and the need to transcend formal organizations to include traditional knowledge and practices in fire management to address the wildfire paradox across conservation landscapes and achieve long-term sustainable outcomes (Huffman 2013; Tendim et al. 2020).

Traditional fire practices have been applied in several types of wildfire management strategies (Smith and Mistry 2021), including state-mandated or voluntary projects that aim to revitalize cultural burning by local people (Petty et al. 2015; Neale et al. 2019), the establishment of community fire brigades to support local wildfire prevention operations (Dube 2013; Denny 2015), and payment for ecosystem services schemes for conducting prescribed burns to offset late-dry season fires and protect forests (McKemey et al. 2020), or to limit burning to reduce emissions and increase carbon sequestration (Khatun et al. 2016; van Wilgen et al. 2022).

In this paper, we outline the evolution of CBFiM and its expansion to encompass indigenous-led SBEA projects. We systematically review the literature on SBEA to explore how the integration of Aboriginal fire practices with modern emissions accounting methodologies in Northern Australia has influenced proposed fire management strategies in East and Southern African savanna-protected areas. We then apply a pyro-geographic framework to assess the assumptions informing the transfer of Australian SBEA methodologies to East and Southern African savanna-protected areas, drawing on the broader literature on the interactions between fire and regional climatic and biological, environmental, and societal and cultural dynamics. We identify and discuss several implementation challenges in the context of East and Southern Africa’s recent history, population growth, and climatic changes, to highlight the barriers for bottom-up CBFiM from being realized in SBEA projects implemented in this region, providing recommendations for future research on the development of community-based SBEA schemes outside of Northern Australia. This paper adds to the literature on the role of indigenous fire stewardship in climate change mitigation and sustainable development projects in protected areas by characterizing the conditions for equitable local governance in fire management, as well as highlighting the need for extensive biogeophysical and ecological monitoring in local contexts to avoid negligible outcomes.

Background

Community-based fire management (CBFiM)

The 1971 Tall Timbers Fire Ecology Conference on “Fires in Africa” highlighted the importance of both social and physical characteristics of savanna fire regimes (Trollope 2011). In the 1990s, interdisciplinary research began documenting complex human-fire relationships in East and Southern Africa, acknowledging opportunities for CBFiM in local contexts (FAO 2011; Pooley 2021). However, most of the literature examines the biophysical properties of fire to develop guidelines for wildlife conservation, omitting the social dimension of fire management (Shaffer 2010; Moura et al. 2019; Nieman et al. 2021). At the same time, the lack of a common definition for community participation, the embeddedness of CBFiM policies in top-down integrated fire management and community-based natural resource management frameworks, and its exclusive implementation in communal rangelands, restricts CBFiM success in savanna-protected areas (Croker et al. 2023). Recent CBFiM proposals seek to incorporate traditional fire knowledge into contemporary management frameworks through the adoption of prescribed early-dry season burns (Humphrey et al. 2021). However, without legislation recognizing local fire rules, institutions, and inter-annual burning practices, the role of indigenous and local people in rule-making organizations and property-rights systems is uncertain.

Savanna burning emissions abatement (SBEA)

SBEA schemes aim to reduce the frequency, intensity, and extent of savanna fires through a seasonal shift in burning from the late-dry to the early-dry season (Corey et al. 2019). Late-dry season savanna wildfires are typically of high intensity,[1] driven by higher temperatures and lower relative humidity, and are associated with higher greenhouse emissions due to the accumulation of dry biomass (Russell-Smith et al. 2021). Prescribed early-dry season burns formalized through Northern Australia's indigenous-led SBEA schemes to mitigate the negative effects of late-dry season wildfires and to diversify landholder income from carbon offsets are increasingly gaining attention in other fire-prone settings globally (Russell-Smith et al. 2017). Lipsett-Moore et al. (2018) identified 29 African states that could benefit from SBEA to reduce greenhouse emissions, 17 of which are least developed countries and account for 37% of total savanna burning emissions. SBEA pilot sites have been identified across the Kavango-Zambezi Transfrontier Conservation Area, Luangwa Valley sub-region in Zambia, and Central Kalahari in Botswana (UNU-IAS 2015).

Australian model

Northern Australia's eucalyptus-dominated savannas extend over approximately 1,900,000 km^2, of which an average of 20% is burned annually by late-dry season wildfires (Russell-Smith et al. 2013), contributing up to 50% of Australia's Northern Territory's annual total greenhouse gas emissions (Whitehead et al. 2008). The Australian government was the first to recognize savanna burning as an emissions reduction activity in its National Greenhouse Gas Inventory, integrating Aboriginal fire management with Kyoto Protocol-compliant emissions reductions methodologies (Maraseni et al. 2016; Russell-Smith et al. 2017). By 2019, more than 70 SBEA projects had been established across Northern Australia, and Aboriginal-owned companies were created to register and operate fire projects (Ansell et al. 2019; McKemey et al. 2020).

Methods

We followed the Collaboration for Environmental Evidence's Version 5.0 review and synthesis protocol to carry out a scoping review of the relevant literature on the development of indigenous-led or community-based SBEA schemes in East and Southern African savanna-protected areas (CEE 2022). We defined CBFiM as a type of management structure with (i) significant community authority in decision-making that transcends consultation, (ii) proactive community participation in management tasks, (iii) community interest and support in project establishment, and (iv) a sponsorship program which encourages long-term self-governance once external support is withdrawn (Ganz et al. 2003; FAO 2011).

We conducted the search on Scopus online database, applying no restrictions on document type or publication date. A qualitative Population, Interest, Context (PICo) framework was used to structure the search strategy, including the development of a search string syntax and inclusion and exclusion criteria. Specifically, the population of concern was indigenous and local people, interest was SBEA schemes in savanna-protected areas, and the context was restricted to East and Southern Africa. The search strategy and eligibility screening process applied in this review are summarized in Fig. 1 and further information can be found in the Supporting Information.

We established a test-list of 10 articles prior to carrying out this review, consisting of studies identified as relevant to the synthesis question through conversations with researchers working in this field (Table S1). This test-list was used to develop and assess the performance of the search strategy, such as the number of studies returned and retrieval performance of each search string syntax (i.e., percentage of test-list retrieved in each search) (Fig. S1). The search string was developed over three iterations using terms from the test-list, referenced papers, and grey literature sources (e.g., workshop reports and policy documents) until all 10 articles were retrieved in Scopus (Table S2).

The final search string was structured on PICo components Interest (e.g., "savanna ecosystem" and "savanna burning emissions abatement scheme") and Context (e.g., "East and Southern Africa"): *[("savanna*" OR "fire-prone")] AND [("burn*") AND ("emissions" OR "carbon") AND ("abate*" OR "offset*" OR "reduction" OR "mitigation") AND ("project" OR "scheme" OR "plan" OR "policy" OR "model")] AND [("Africa*" OR "Angola" OR "Botswana" OR "Burundi" OR "Ethiopia" OR "Kenya" OR "Lesotho" OR "Madagascar" OR "Malawi" OR "Mozambique" OR "Namibia" OR "Rwanda" OR "Somalia" OR*

[1] High intensity refers to high radiant energy release from the flaming front (Keeley, 2009).

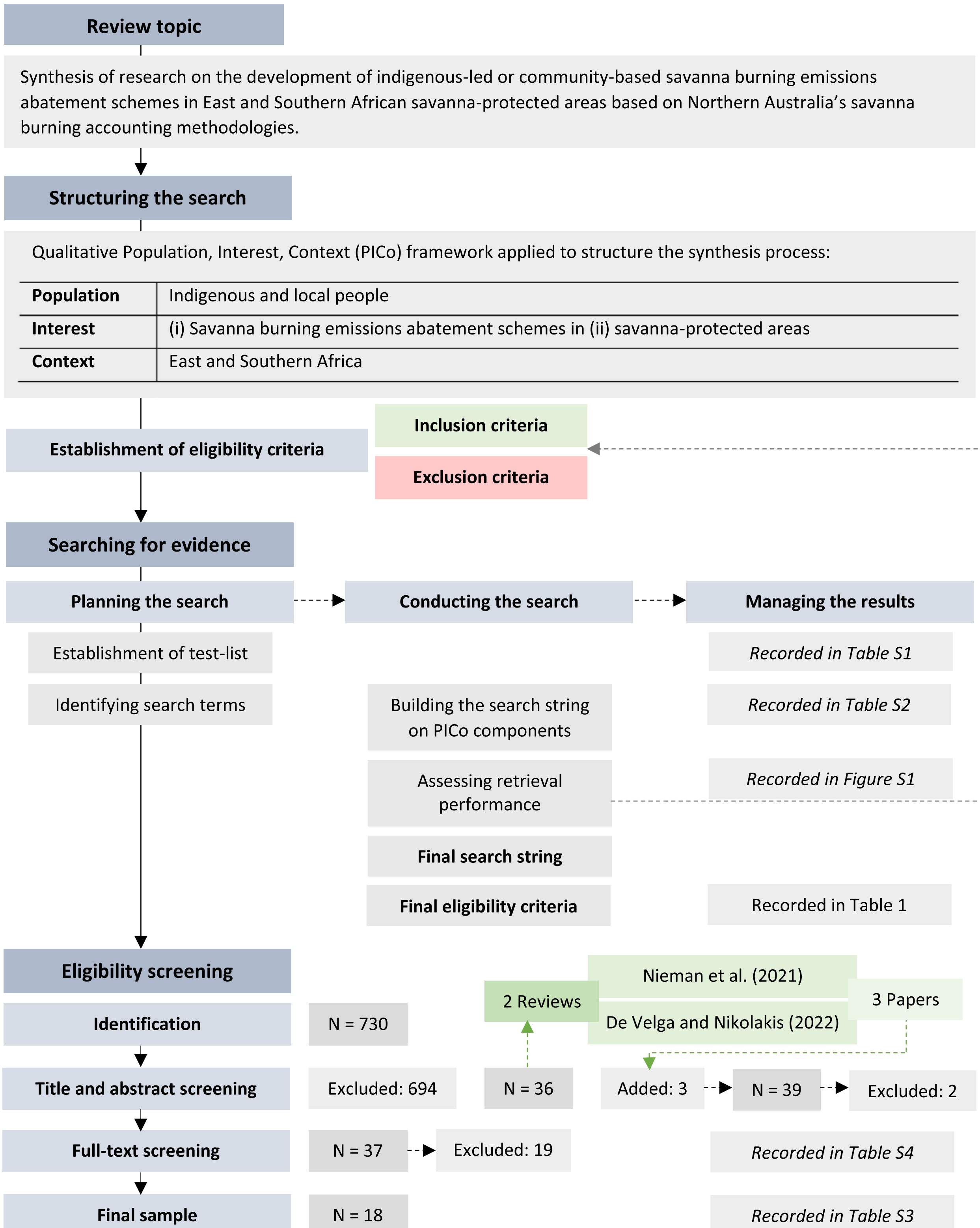

Fig. 1 Search strategy and eligibility screening process for systematic review on savanna burning emissions abatement schemes in East and Southern African savanna-protected areas

"Somaliland" OR "South Africa" OR "Swaziland" OR "Eswatini" OR "Tanzania" OR "Uganda" OR "Zambia" OR "Zimbabwe")].

Population component "indigenous and local people" and Interest component "protected areas" were not included in this syntax given the diversity and specificity of terms used to define heterogenous communities in Africa and Australia and the range of protected area types included in this review (Table 1). Terms used to determine "savanna ecosystem" (e.g., "savanna*" OR "fire-prone") were applied under field code Title, Abstract, and Key words to identify studies that specifically focus on savannas while providing some flexibility regarding their fire-induced bimodality with forests (Michele and Accatino 2014). Terms used to determine "savanna burning emissions abatement" and "East and Southern Africa" were applied under field code ALL to avoid omitting studies where SBEA was mentioned within a broader fire management or emissions mitigation context, and in recognition of the challenges associated with searching for geographic location such as range, name, and absence from publication title, abstract, and keywords (CEE 2022).

We screened the title, abstract, and full text of papers under the application of a pre-established eligibility criteria consisting of inclusion and exclusion categories described in Table 1. The eligibility criterion was designed to reduce reviewer bias and inconsistencies in the screening process, as well as extract and include papers in the evidence synthesis that are directly relevant to the review topic. Several papers detailing Northern Australia's Emissions Reduction Fund and carbon accounting methodologies, but without reference to their development in other tropical fire-prone savanna contexts, informed the analysis of included literature but were excluded in the screening process (Whitehead et al. 2008; Murphy et al. 2014; Parr et al. 2014; Ansell et al. 2019; McKemey et al. 2020).

Results

The search identified 730 published papers. We removed 694 of those during title and abstract screening stages as they did not examine the application of Kyoto Protocol-compliant savanna burning schemes in fire-prone settings. We screened the abstracts of three additional papers (Ryan and Williams 2011; Trollope and Trollope 2010; Khatun et al. 2016) identified in previous reviews on fire management retrieved in this search (Nieman et al. 2021; da Veiga and Nikolakis 2022), two of which were excluded for focusing on the physical drivers and effects of fire regime components on savanna vegetation without reference to local fire management for carbon credit generation (Ryan and Williams 2011; Trollope and Trollope 2010). Nineteen papers were removed at full-text screening for not meeting most of the inclusion criteria. These papers and the reason for their exclusion are recorded in Table S4. The final sample of 18 papers included in this review is recorded in Table S3. These studies exhibited large variation in research aims, focus, and the level of detail describing the opportunities and challenges for SBEA schemes in East and Southern African savanna-protected areas.

All papers were published after 2013. The expansion of literature exploring opportunities for SBEA development corresponds with the publication of two key reviews: the

Table 1 Inclusion and exclusion criteria applied to review the evidence on savanna-burning emissions abatement schemes in East and Southern African savanna-protected areas

PICo category	Inclusion	Exclusion
General	Peer-reviewed	
	Published/translated in English	
Indigenous and local people	Focus on socio-cultural aspects of savanna burning schemes, e.g., "indigenous," "traditional," or "community-based" fire management	Focus on biogeophysical properties of fire with no or limited reference to social aspects, e.g., experiment reports, vegetation assessments, satellite and remote sensing analyses, medical studies, paleo-ecological accounts
Savanna burning emissions abatement schemes	Prescribed early dry season fires for carbon credit generation based on Northern Australian model	Other fire management strategies where fire is not actively prescribed for carbon credit generation (e.g., prescribed early dry season fires for fuel reduction, but without carbon credit aims)
Savanna-protected areas	Savanna ecosystems: grass- and wood-dominated savannas, inclusive of Miombo Woodlands	Non-savanna ecosystem, including forests
	Protected areas as defined by IUCN I-VI (may be locally recognized) and buffer areas	Outside protected areas (IUCN I–VI) and buffer areas (including surrounding communal rangelands)
East and Southern Africa	Angola; Botswana; Burundi; Ethiopia; Kenya; Lesotho; Madagascar; Malawi; Mozambique; Namibia; Rwanda; Somalia; South Africa; Swaziland/Eswatini; Tanzania; Uganda; Zambia; Zimbabwe	

International Savanna Fire Management Initiative's (ISFMI) flagship report highlighting the global potential for indigenous fire management through early-dry season savanna burning (UNU-IAS 2015), and an analysis of fire emissions mitigation and revenue generation opportunities for SBEA projects in African least developed countries by Lipsett-Moore et al. (2018). Members of the ISFMI and researchers at the Darwin Centre for Bushfire Research were authors of eight papers included in this review. Five of those papers did not include authors affiliated with institutions outside Australia. Only seven papers included authors affiliated with institutions in East and Southern Africa.

Most papers focus on the success of commercial SBEA schemes and carbon accounting methodologies in Northern Australia. They provide useful insights on the development of SBEA in fire-prone environments beyond this region, but do not focus on the potential for their effective and equitable transfer to East and Southern Africa. While the broader literature records contextual challenges and variation in the human and natural environments between Australian and African savannas (Lehmann et al. 2014), this information is not widely incorporated into discussions over the development and application of community-based SBEA projects.

Recommendations for project implementation highlight opportunities for prescribed early-dry season burning to mitigate carbon emissions and deliver socioeconomic, cultural, and biodiversity co-benefits in tropical savannas. However, subsidiary benefits are mostly assumed in SBEA feasibility assessments rather than being actively researched and measured in relation to project implementation in African savanna-protected areas. The challenges preventing these benefits from being realized are recognized within the wider context of local fire-based emissions projects worldwide. This includes difficulties in quantifying the direct and indirect effects of changes in fire management on poverty alleviation, community resilience, biological diversity, and ecosystem restoration, as well as a lack of metrics and data analyzing potential benefits and trade-offs (Corey et al. 2019; Edwards et al. 2021). These challenges are summarized in Table 2.

The assumed benefits of local SBEA projects and challenges to their development highlight a critical need to analyze how inter-regional variations and nuances in the human and physical environment might impact their implementation in East and Southern African savanna-protected areas.

Discussion

The transferability of Australian SBEA methodologies to Africa's savanna-protected areas is based on three main assumptions: (i) perceived similarities between nutrient-poor mesic savannas marked by distinct wet and dry seasons; (ii) presence of extensive protected area networks (each > 1000 km^2) which emulate Northern Australia's savanna rangelands, characterized by low human and livestock population densities and frequent intense wildfires; and (iii) accruement of similar fire management strategies practiced by indigenous landholders and pastoralists across the two regions and their interest in diversifying income through carbon benefits. We draw upon the review evidence-base and broader studies on indigenous fire stewardship and savanna ecosystem dynamics to critically examine these assumptions, highlighting the challenges that contextualize East and Southern Africa's wildfire paradox and hinder the implementation of SBEA in savanna-protected areas.

Contextual challenges

To understand the opportunities and costs associated with the transfer of Australian SBEA methodologies to East and Southern Africa, it is first important to consider the region's complex history, population growth, and climatic changes, and how these processes interact to create a highly challenging domain for the effective implementation of indigenous-led SBEA in protected areas.

Complex history

East and Southern Africa's recent colonial history and neocolonial influences set it apart from the rest of the world. The prioritization of resource extraction in colonial policy in Africa has established lasting power hierarchies between former colonizers and colonies in the global economy, reinforced by the international aid regime and processes of public–private re-territorialization across communal lands (Catley et al. 2012; Lind et al. 2020a, b). These challenges are pronounced in areas where weak governance, corruption, and lack of accountability or transparency have removed local monitoring and regulatory barriers, lowering the transaction costs of extractive activities (Koenig-Archibugi 2004; Scoones 2015; Ford et al. 2020).

The dependent position of resource-rich African states in the global economy constrains their ability to utilize natural resource exports for generating national wealth (Besada et al. 2015; Taylor 2016). At the same time, green conditionalities in the disbursement of aid from the Global North determine the rules for the implementation of conservation and development projects (Bryant and Bailey 1997; Eriksen 2007). Western institutions and donors hold strong political influence over local community-based projects, raising the possibility that the distribution of climate mitigation finance and the development of accredited carbon projects are influenced by colonial ties and contingent on the willingness of beneficiary countries to facilitate donor interests (Halimanjaya 2014). In this respect, external governance

Table 2 Implementation challenges for Northern Australia's savanna burning emissions abatement methodologies in East and Southern African savanna-protected areas. This information was extracted from the review evidence-base and criteria adapted from Russell-Smith et al. (2017), Nieman et al. (2021), and da Veiga and Nikolakis (2022)

Criteria for savanna burning projects	Implementation challenge
Enabling policy and legislation	■ Institutional resistance towards including savanna burning as a mitigation strategy in Nationally Determined Contributions ■ Negative perceptions towards traditional fire use and lack of policy support for local participation in decision-making ■ No supporting policies and carbon abatement contracts to safeguard local distribution and access to carbon benefits ■ No legal requirements to include social-cultural aspirations and non-ecological goals in fire management
Kyoto Protocol-compliant Methodologies	■ Spatiotemporal discordance between aerial-based Kyoto Protocol compliant methodologies and walking-based adaptive local burning practices ■ Requirement for secure land tenure and legal access to manage savanna burning projects for ≥ 7 years ■ Historical dominance of mid-dry season and future wet season burning overlooked by determination of fire seasons as early- and late-dry
Evidence and baseline data	■ No formal guidelines to determine appropriate pre-project emissions baseline ■ Lack of long-term scientific evidence and monitoring for robust baseline data underpinning project development (e.g., fire mapping, fuel accumulation, combustion efficiency, site emissions factors, bio-sequestration, and biodiversity responses)
Emissions reductions objectives	■ Reporting and funding conditions contingent on annual fire performance (burned area and seasonality) rather than multiple fire and ecological dynamics ■ No accounting for the effects of inter- and intra-annual biogeophysical variability on fire type, occurrence, and associated emissions ■ No temporal correlation between weather and seasonal cut-off dates for emissions in semi-arid savannas ■ Increase in CH_4 emissions factors associated with combustion of uncured fuels in early-dry season burning ■ Uncertain relationship between N_2O emissions factors and combustion efficiency and fuel type
Conservation of carbon stocks objectives	■ Uncertain relationship between fire and grazing on future carbon sequestration potential of grass and woody species ■ Misapplication of voluntary carbon market mechanisms that define forests as having 10–30% woody cover ■ Expansion of unpalatable and fire-resistant increaser II and invader species not included as applicable vegetation types in savanna burning ■ Increased long-term wildfire risk and associated emissions ■ Permanency obligation challenges (i.e., maintaining carbon offsets for 25 or 100 years) in bio-sequestration projects in protected areas
Equity and rights of local people	■ Limited application of FPIC and income diversification opportunities due to the absence of local property rights in protected areas ■ Commodification of traditional burning practices in state-mandated indigenous ranger programs to meet donor demands and market objectives ■ Acceleration of power inequities between carbon credit purchasing and producing countries through "accumulation by decarbonisation" ■ Revocation of dry season grazing and resource harvesting rights due to competition with savanna burning for fuel biomass
Co-benefits	■ Limited assignment of monetary values to additional direct and off-site ecosystem services due to stakeholder diversity and variation in purchasing power ■ "Bio-perverse" outcomes due to implementation of low-cost extensive burns to maximize annual carbon revenue rather than fine-scale patch-mosaic burning ■ No legislation and allied market incentives to develop an adaptive biodiversity monitoring framework and incorporate biodiversity credits into savanna burning ■ Wildlife conservation trade-offs due to herbivore-fire competition for grass biomass and prevention of intense fires necessary to prevent woody thickening
Capacity	■ Limited community capacity to address conflicting land-use objectives and fire management due to weak local governance ■ Requirement for international support and sustained national political will-power to develop and scale-up projects ■ Limited public support and transparent financial systems for the establishment of taxpayer-funded Emissions Reduction Fund (equiv.) for fire management ■ Requirement for large attitudinal change of public and private investors to realize sustainability of carbon revenue over short-term development aid

arrangements in local projects risk reproducing colonial "divide and rule" policies through the employment of local administrations, adopting "inclusion through exclusion" strategies to mitigate conflicts and promote congruence among the interests of multiple actors (Croker et al. 2023). The transfer of exclusion rights to local elites can introduce or reinforce hierarchies in local agrarian politics, resulting in greater autocracy and the accumulation of carbon benefits among select individuals (Olowu and Wunsch 2004).

Population growth

Sub-Saharan Africa is experiencing the world's highest population growth rate, with a projected increase from 1.1 billion people in 2020 to 3.8–5.7 billion in 2100 (UN DESA 2019). Compounding challenges including high rates of migration and urbanization,[2] insecure settlement-governance arrangements (Guneralp et al. 2017), inter- and intra-state conflict and land disputes, declining food security (FAO et al. 2021), and income inequality (Sulemana et al. 2019), exacerbate pressures on economic and infrastructural development in low-income countries (Peterson 2017). In recent years, large-scale land use change has reorganized and privatized access to critical resources, intensifying the impact of population growth on subsistence-based economies, particularly agro-pastoralist communities (Lind et al. 2020a, b).

Climate change

Current and projected rises in surface temperatures and mean annual temperature over Africa exceed the global average, driving increased variability in annual wet and dry season conditions (WMO 2021). The IPCC (2021) identified Southern Africa as the continent's "hottest spot," warming at a rate four-times faster than the global average and experiencing a 220% increase in flash droughts (1961–2016) (Kruger and Sekele 2012). East African countries are also experiencing an increase in extreme pluvial floods interspersed with prolonged agricultural and ecological droughts,[3] resulting in severe savanna degradation (Funk et al. 2018; Kew et al. 2021). Fire-prone weather has intensified across the region, and the fire season has lengthened by more than a month relative to the 1980s (Jolly et al. 2015). However, climate extremes and uncertainty over feedbacks between fire, rainfall, soil, vegetation, and herbivory complicate predictions over long-term fire occurrence (Young et al. 2022), increasingly questioning binary seasonal boundaries between early-dry and late-dry seasons in prescribed fire regimes (Laris 2021).

Implementation challenges

Variation between Northern Australia's and East and Southern Africa's human and physical environment limits opportunities for prescribed early-dry season burning to achieve primary emissions reductions and carbon sequestration objectives, as well as address equity and rights concerns, and deliver socioeconomic, cultural, and biodiversity co-benefits (Table 2). We apply a pyro-geographic framework, illustrating the interconnectedness of fire with climate and biology, topographic environment, and society and culture (Bowman et al. 2013; Humphrey et al. 2021), to critically analyze the challenges presented by inter-regional variation on the main assumptions informing the implementation of indigenous-led SBEA projects in Africa (Fig. 2).

Climate, biology, and fire

Comparative analyses of the factors governing the distribution of tropical savannas worldwide show divergences between the evolutionary histories and distributive limits of Australian and Southern African savannas, their faunal and floristic assemblages, tree-to-grass ratios, species' functional traits, biogeophysical dynamics, and future vegetation and fire feedbacks under climate change (Bond et al. 2004; Lehmann et al. 2011, 2014). However, this information has not been translated into SBEA project design due to the prevailing assumption that climatic and biological processes and their relationship with fire are similar across nutrient-poor mesic savannas with marked wet and dry seasons.

Inter-regional variation in the functional role of fire in savanna ecosystems and its influence over local soil and vegetational structure impact the compatibility of savannas to SBEA development and opportunities for emissions reductions. For example, fire has significantly different impacts on savanna limits across the arid and mesic transition zones in both regions. African savannas persist in the absence of fire at the arid end of the continuum (<100 mm MAP), and there are pronounced disparities between savanna extent and fire occurrence until MAP >1000 mm (Lehmann et al.

[2] Sub-Saharan Africa is the fastest urbanising region in the world, with urban areas currently inhabited by 472 million people expected to double over the next 25 years. By 2050, Africa's share of the global urban population is projected to exceed 20% (Saghir and Santoro 2018).

[3] Agricultural and ecological droughts refer specifically to the impacts of rainfall deficits on joint agricultural-ecological systems, rather than on hydrological (i.e., water supply such as stream flow, lake levels, and ground water table) and socioeconomic (i.e., supply and demand of economic goods) systems. They link variables of meteorological (i.e., rainfall deficit and dry period) and hydrological droughts to the impacts experienced in the agricultural sector due to changing ecological conditions, such as the physical and biological properties of vegetation and soil and moisture content, actual and potential rate of evapotranspiration, ground water and reservoir levels required for irrigation, and shifting seasonality. Agricultural and ecological droughts are closely connected to socioeconomic droughts due to declines in agricultural commodities (Wilhite and Glantz 1985).

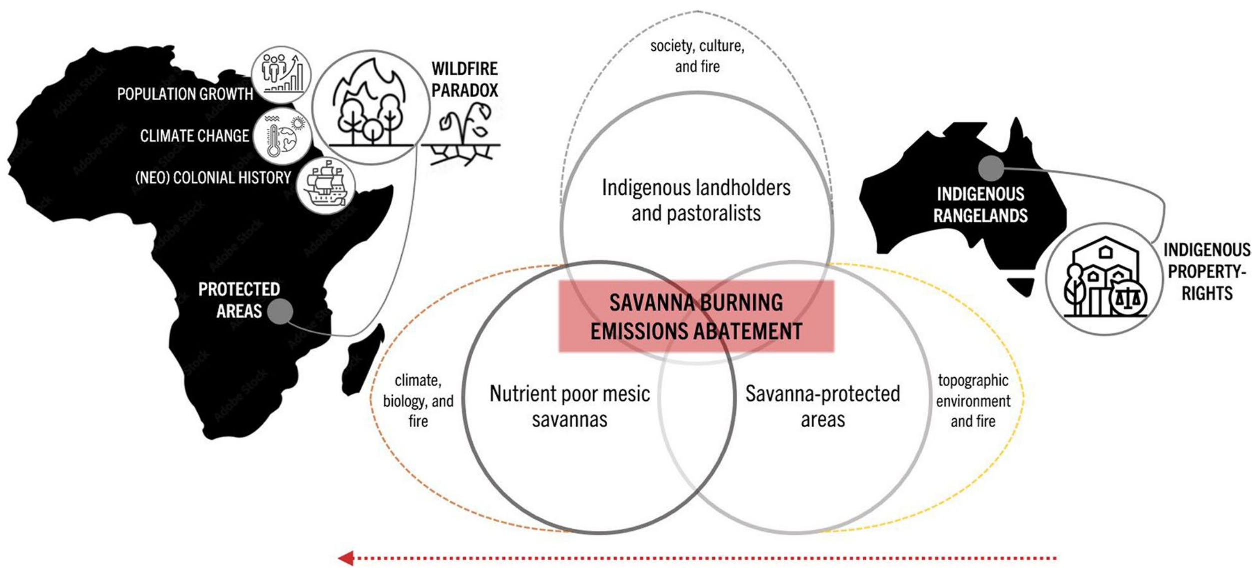

Fig. 2 Pyro-geographic framework applied to the three main assumptions informing the transfer of Northern Australia's indigenous-led savanna burning emissions abatement methodologies to East and Southern African savanna-protected areas (e.g., similarities between nutrient-poor mesic savannas; presence of extensive unpopulated savannas; presence of indigenous landholders and pastoralists interested in carbon benefit generation), highlighting the interconnectedness of biogeophysical (e.g., "climate, biology, and fire"), environmental (e.g., "topographic environment and fire"), and socio-cultural (e.g., "society, culture, and fire") dynamics in fire management. Transferability assumptions need to be considered in relation to the contextual opportunities and challenges that differentiate indigenous rangelands in Northern Australia from protected areas in Africa (adapted from Humphrey et al. 2021)

2011). Across this arid transition, high soil and vegetation nutrient availability supports large herbivore populations who directly compete with fire to reduce fuel loads (Marchant 2010), influence tree-grass competition (van der Waal et al. 2011), expose woodlands to grass invasions and maintain open savanna formations (Donaldson et al. 2022), and distribute nutrients throughout the system to promote spatially diverse vegetation communities (Asner et al. 2009).

Across the mesic transition (> 1000 mm MAP), tree-cover is bimodal and there are extensive climatic overlaps between forests and savannas (Michele and Accatino 2014). Woody thickening is typical in East and Southern African savannas where mean annual precipitation (MAP) exceeds 650–700 mm (Luvuno et al. 2018) and a reduction in the movement and habitat selection of large herbivores necessitates an increase in high-intensity fires to prevent ecological succession (Burkepile et al. 2013). This is unachievable under a low-intensity early-dry season fire regime (Nieman et al. 2021). When MAP > 1500 mm, the probability of fire also rapidly declines due to canopy closure and landscape fragmentation (Archer et al. 2017). In contrast, Northern Australian savannas are characterized by (i) higher arid limits (> 250 mm MAP) and dependency on prior fire occurrence, (ii) greater probability of fire occurrence across the entire precipitation gradient, (iii) strong correlations between fire occurrence and savanna extent, (iv) low mammalian populations that are resistant to extreme fire oscillations,[4] and (v) higher mesic limits (2000 mm MAP) where fires persist (Lehmann et al. 2011). Fire-resistant *Eucalyptus* species capable of growing through fire-mediated recruitment bottlenecks and traps are ecologically dominant across this region, supporting open canopies under higher MAP (Staver et al. 2011; Murphy et al. 2014).

Savanna ecosystems prone to woody thickening are incompatible with SBEA development due to uncertainty over the long-term feedbacks between climate change, woody component dynamics, severe fire-weather conditions, and greenhouse gas emissions (Russell-Smith et al. 2013). Despite this, SBEA pilot sites are concentrated in semi-arid and mesic African savannas where MAP

[4] Mobile modern humans, savanna ecosystems, and megafauna have co-evolved for millennia in Africa, whereas in Australia, mega-herbivores were eradicated over 20,000 years ago due to modern human expansion and sustained environmental changes, such as increased fire frequency (Hocknull et al. 2020; Millhauser and Earle 2022). The conservation of extant megafauna in Australia ranks among the lowest in the world (134/152 nations), whereas nine East and Southern African countries rank in the top 20, with all countries across the region, excluding South Africa, performing above the global average (Ceballos and Ehrlich 2006; Lindsey et al. 2017). The discrepancy between fire and savanna extent across the arid end of the continuum in Africa can partly be attributed to the presence of large herbivores.

exceeds 600 mm, and high-intensity fires are required to maintain open vegetation structures (Devine et al. 2017; Lipsett-Moore et al. 2018). In the short-term, late-dry season fires conflict with carbon emissions reductions objectives (Corey et al. 2019; Nieman et al. 2021). In the long-term, the suppression of late-dry season fires under an exclusive early-dry season fire regime reduces grass cover and belowground carbon sequestration (Grace et al. 2006; Parr et al. 2014; Zhou et al. 2022).

To date, CBFiM projects aiming to eliminate fire and reduce carbon emissions from deforestation are more widespread across this region than active burning schemes (Smith and Mistry 2021), with forest succession promoted where ecologically viable (Kull 2002; Alvarado et al. 2015). Recent SBEA proposals advocate for the incorporation of complimentary methodologies that account for bio-sequestration through multiple carbon pools (e.g., above-ground non-living biomass, live woody biomass, and soil carbon) to increase emissions mitigation potential and carbon revenue from early-dry season burning (Khatun et al. 2016; Lipsett-Moore et al. 2021; Tear et al. 2021). However, the application of voluntary carbon accounting mechanisms such as REDD + and the Clean Development Mechanism to increase carbon sequestration in SBEA projects can further promote woody thickening across savanna ecosystems, having negative consequences on biodiversity and local livelihoods (Edwards et al. 2021; Russell-Smith et al. 2021).

The establishment of arbitrary divisions differentiating the early- from the late-dry season to align prescribed burning activities with carbon accounting requirements does not consider how fire and local biogeophysical processes interact to effect combustion efficiency, emissions factors (Russell-Smith et al. 2014), soil health, vegetation structure, and biodiversity (Corey et al. 2019; Nieman et al. 2021). Savanna burning projects only consider CH_4 and N_2O emissions in their accounting methodologies based on the understanding that CO_2 uptake in post-fire vegetation regrowth replaces CO_2 emitted during biomass burning within a year of the ignition date (IPCC 1997; Henry et al. 2005). However, shifting fires from the late- to the early-dry season primarily aims to mitigate savanna-CO_2 emissions (Lipsett-Moore et al. 2018), while long-term data on CH_4 and N_2O emissions trajectories in response to land use and cover change, fire occurrences, and changes in soil microbial and decomposer activity is limited across East and Southern Africa (Maraseni et al. 2016). Recent evidence shows that soil moisture and the dormancy of the grass sward take precedence over seasonality in determining the impacts of fire on African savannas and associated greenhouse gas emissions, such that burning in the early-dry season can increase CH_4 emission factors by 50–400% due to higher fuel moisture content following the wet season (Laris 2021). An increase in CH_4 and N_2O emissions with greater global warming potential values is likely to offset CO_2 emissions reductions achieved through a shift in fire seasonality, compromising SBEA objectives (Maraseni et al. 2016). Additionally, the relevancy of seasonal divisions in SBEA methodologies is increasingly questionable given shifts in East and Southern Africa's wet and dry seasons attributed to anthropogenic climate change, including increased prolonged dry periods, unpredictable rainfall, and changing fire weather conditions and fuel loads (IPCC 2021; Laris 2021).

Ecological parameters calibrated in Northern Australia continue to inform project implementation across fire-prone savannas worldwide, even though mesic savannas in East and Southern Africa do not meet the biogeophysical requirements for SBEA development (Murphy et al. 2015). Nutrient-poor mesic African savannas and Northern Australian savannas support comparatively lower mammalian populations than nutrient-rich semi-arid African savannas. This similarity reinforces the assumption that mesic African savannas are appropriate for SBEA implementation (UNU-IAS 2015). However, this is inconsistent with the unsuitability of savannas prone to woody thickening for SBEA, likely resulting in large biodiversity-emissions trade-offs (Andersen et al. 2012; Edwards et al. 2021). For example, SBEA projects have been proposed for development across the Miombo Woodland ecoregion due to its high contribution to late-dry season fire emissions (Russell-Smith et al. 2021; van Wilgen et al. 2022), despite having comparatively high average MAP (> 1000 mm) and extensive woody plant cover (> 90% above-ground biomass). The Miombo Woodlands are also characterized by spatial and temporal variation in greenhouse gas emissions driven by edaphic conditions rather than fire, making fire-related emissions calculations unreliable (Frost 1996; Ribeiro et al. 2020).

In accordance with Articles 7 and 8 of The Convention on Biological Diversity, SBEA projects are expected to encourage fire regimes that support multiple facets of biodiversity, where "pyro-diversity[5] begets biodiversity" (Parr and Andersen 2006), while also generating investment opportunities in protected areas. This includes greater anti-poaching and protection efforts and human-wildlife conflict resolution activities (Lipsett-Moore et al. 2018; Russell-Smith et al. 2021; Tear et al. 2021). The importance of metrics for calculating potential trade-offs between carbon offsetting methodologies and biodiversity conservation in development projects is acknowledged in the literature (Tallis et al. 2008; Lindenmayer

[5] Pyrodiversity refers to biological, physiochemical, spatial, and temporal variations in a fire regime and its interactions with local ecological systems (Martin and Sapsis 1991; Bowman and Legge, 2016; Jones and Tingley 2021).

et al. 2012). However, such metrics have not yet been developed for SBEA projects (Corey et al. 2019), and challenges in measuring the indirect effects of increased fortress conservation approaches on inter-group conflict and resulting negative social and environmental outcomes will likely delay this process. Additionally, more than 60% of pyrodiversity research has focused on and been sourced from Australia, while only four studies are from Africa (Jones and Tingley 2021). There is limited evidence to suggest that the exclusive application of early-dry season patch-mosaic burns can curb biodiversity loss in African savanna-protected areas; SBEA schemes fix multiple fire management variables in time and space to fulfill contractual obligations (Moura et al. 2019; Laris 2021), rather than adopting pyro-diverse traditional burning practices informed by place-based ecological knowledge.

To date, satellite monitoring, decadal-long data, and one-off studies or ecological surveys from other regions have been used to attribute causality between fire and biodiversity (Perry et al. 2021), presenting multiple implementation challenges for SBEA projects. Firstly, satellite data may not detect smaller fragmented burns which create fine-scale dynamic trophic networks (Russell-Smith et al. 2021). Secondly, East and Southern Africa's climate is subject to decadal variability driven by variations in sea surface temperature over the Pacific Ocean coupled with warming over the Indian Ocean (Wang et al. 2014; Hoell et al. 2017). Therefore, species' responses to changes in the fire regime measured over 10-year intervals are likely to exhibit time-lags representative of phenotypic plastic adaptations to environmental variability. This does not allow biodiversity responses to be attributed to the adoption of early-dry season fire regimes (Oostra et al. 2018). However, these concerns have not been addressed in SBEA projects due to concerns over rising operating costs and resource provisioning to support accredited biodiversity monitoring programs (Bowman et al. 2016; Edwards et al. 2021).

Topographic environment and fire

Northern Australian savanna rangelands and East and Southern African savanna-protected areas are both characterized by low human and livestock populations and large wildfire events. However, the political, economic, and social factors governing these processes are opposed, limiting opportunities for CBFiM in SBEA projects implemented in protected areas.

Northern Australia's savannas are sparsely populated, remote, unfragmented with limited infrastructure, and are formally owned or managed by indigenous people under the Aboriginal Land Rights Act 1976 and Native Title Act 1993 (Russell-Smith et al. 2017; Sangha et al. 2021). Statutory recognition of pastoral and indigenous land tenure arrangements across Northern Australia, including rangeland ownership, Aboriginal reserves, native land titles, and aboriginal-owned pastoral leases (Edwards et al. 2021), have contributed to the success of SBEA projects across this region as landholders directly benefit from a reduction in pasture loss due to wildfires and carbon credit generation (Skroblin et al. 2014; Lipsett-Moore et al. 2018). In contrast, savanna-protected areas in East and Southern Africa are mostly state-owned, centrally governed, highly excludable and subtractable, have strict delimited boundaries that are under pressure from surrounding human populations, and are fragmented by tourism infrastructure (Croker et al. 2023). The customary rights of pastoralists are not typically recognized in national legislation, and enduring legacies of exclusion and skepticism towards local fire use, combined with rising migration and conflict challenges (Eriksen 2007), have prevented indigenous people from securing property rights across protected area landscapes (Kull 2002; Mistry and Bizerril 2011).

These tensions are predicted to intensify under the UN Convention on Biodiversity's new Global Deal for Nature which aims to protect 30% of the terrestrial ecosystems by 2030, and 50% by 2050 (Dinerstein et al. 2019), as well as in response to the rapid conversion of East and Southern Africa's communal rangelands to statutory and private property regimes for large-scale commercial developments, mostly initiated by international private companies[6] (Osabuohien et al. 2013; Cochrane and Andrews 2021). Since African governments are key shareholders in many of these listed companies and benefit from leasing land to private investors, it is in their interest to secure large-scale land deals (Blejer and Khan 1984; Nolte et al. 2016). Contracts drawn between governments and investors are not required to include indigenous and local people in SBEA negotiations, decision-making, and management (Bachram 2006; Cotula 2011). For this reason, large investment projects have been described as a contemporary form of "land-grabbing" or "development-driven displacement" in low-income African countries, removing indigenous and local people from their ancestral lands, driving unplanned migrations (Ferrando 2013), and turning land "into a pure commodity, devoid of its cultural and spiritual values" (Barume 2014).

Society, culture, and fire

The presence of pastoralists and indigenous landholders who practice traditional fire-stick burning methods and are interested in diversifying their income through carbon benefits is a pre-requisite for SBEA development in

[6] Private international companies account for more than 50% of concluded land deals in sub-Saharan Africa (Lind et al. 2020a, b).

Africa (UNU-IAS 2015; Lipsett-Moore et al. 2018). However, there are multiple spatiotemporal incompatibilities between SBEA projects managed to achieve national emissions reductions objectives and local fire practices for diverse livelihoods (Cash and Moser, 2000).

The Clean Development Mechanism instituted by the Kyoto Protocol (UN 1998: Article 12) is one of the largest sources of climate mitigation finance to developing countries, offering a flexible instrument for developed countries to achieve their national greenhouse emissions reductions through cost-effective public–private offset projects (Frankhauser and Hepburn 2010; Russell-Smith et al. 2015). SBEA projects operating under the Clean Development Mechanism are presented as a market opportunity with "real, measurable and long-term benefits related to the mitigation of climate change" (UN 1998) due to increased investment, transfer of green technologies, and employment opportunities (UNFCCC 2011). Given the high contribution of sub-Saharan African savannas to global CO_2 emissions, conservation-development projects are increasingly managed and prioritized based on their carbon revenue potential (Douglass et al. 2011). Additionally, the emergence of a global jurisprudence in respect of indigenous land rights and legal empowerment has mounted pressure on African governments, NGOs, and corporations to address structural inequalities in protected area conservation (Fodella 2013; Gilbert and Lennox 2019). SBEA schemes that reconcile traditional fire management with modern market-based approaches present an opportunity for political and economic constituencies in Africa to generate carbon credits while mitigating inter-group conflict between park authorities and customary land rightsholders (Paterson and P-Laberge 2018; Fisher et al. 2021; Humphrey et al. 2021). This can result in a reduction of uncontrolled fires associated with local political resistance (Kull 2002), human-wildlife conflict and biodiversity loss, habitat and edge degradation (Veldhuis et al. 2019), and resource depletion (Archibald 2016).

However, discordance between global and local decisions over fire use, such as burning to maximize carbon revenue versus to fulfill socio-cultural aspirations, has resulted in traditional fire knowledge often being left out of SBEA design (Hoffman et al. 2021; Sangha et al. 2021). Complexity in global climate policy, including the number of actors, variation in values, uncertainty, and high implementation and regulation costs, necessitates centralized policy design approaches (Dzebo 2019). Few powerful entities can control decision-making processes and the rules governing climate action. For example, climate finance mechanisms, technological developments, and experts involved in climate negotiations and the authorship of influential reports (e.g., IPCC assessments), are predominantly based in the Global North (Karlsson et al. 2007; Corbera et al. 2016; Biermann and Moller 2019). The eligibility of SBEA projects to international financing is contingent upon the enactment of accounting methodologies accredited by the Kyoto Protocol, and the establishment of a National Greenhouse Inventory, a National Emissions Registry, and a Designated National Authority to oversee SBEA activities (Russell-Smith et al. 2017).

SBEA projects spanning internationally regulated carbon markets, national environmental policies, and local-scale carbon credit producers are assumed to promote multi-level cooperation for the implementation of Nationally Determined Contributions, while simultaneously generating revenue for underfunded protected-areas (Evans and Russell-Smith 2020; da Veiga and Nikolakis 2022). East and Southern Africa is the least competitive region for travel globally and highly dependent on foreign visitors (Musavengane et al. 2020). Its over-relied upon but small tourism industry is affected by increased competition, limited business opportunities, and unpredictability (Monnier 2021). The economic benefits of SBEA accrued at the national level are recognized in the literature (Russell-Smith et al. 2017; Lipsett-Moore et al. 2018), such as that it can provide opportunities for capital diversification across conservation landscapes, offering some buffering against future shocks (Tear et al. 2021). At the local level, a lack of formal procedures and distributive processes safeguarding the long-term supply of carbon benefits to indigenous and local people creates a highly uncertain environment (Ganz et al. 2003; Paris Agreement 2015), compounded by price volatility in carbon markets in response to geopolitical risks and climate change (Sangha et al. 2021; da Veiga and Nikolakis 2022; Yu et al. 2022).

Free, Prior, and Informed Consent (FPIC) is a fundamental component of Article 6 of the ILO Convention 169 on Indigenous and Tribal Peoples (ILO 1989) when developing carbon offset projects on indigenous and community lands (Russell-Smith et al. 2017). However, it is not legally binding and, so far, no East and Southern African country has ratified the convention. In protected areas, indigenous and local people mostly hold ancestral land rights without statutory basis; therefore, consent to develop public–private SBEA schemes is exercised by central authorities (Edwards et al. 2021). Annual emissions reductions objectives contrast with local burning practices which often occur in the absence of formal management arrangements and are informed by experiential knowledge and changes in local conditions, requiring indigenous and local people to constantly renegotiate with their environment (Radeny et al. 2019). Though local fire practices are deeply embedded in cultural and spiritual traditions transmitted between generations (Croker et al. 2023), their incompatibility with fixed SBEA accounting methodologies has contributed to the preservation of colonial wisdoms opposing local fire use as "heavily influenced by short-term economic needs, which frequently ignore long-term sustainability issues and environmental concerns" (UNU-IAS 2015). As a result, local elites who traverse subsistence, social, and political economies are often employed by the state in SBEA schemes through the creation of indigenous ranger positions (McKemey et al. 2020; Millhauser and Earle 2022), transferring burning responsibilities from indigenous custodians and customary landowners to indigenous rangers and other external agencies to implement centralized fire suppression policies (Fache and Moizo 2015). Employment trends in SBEA projects are consistent with the Theory of Predatory Rule where the bargaining power of centralized authorities and their control over property-rights systems facilitates the expansion of decision-making elites in savanna burning management, isolating these individuals from the marginalized groups most impacted by policy implementation yet demanded to comply with prescribed activities (Levi 1981; Fratton 1992). This can drive a decline in local democratic decision-making and traditional governance systems protecting community rights (Whitehead et al. 2008).

Large-scale land investments demand extensive land use and tenure change and often introduce market networks in rural areas, driving a shift in local livelihoods and burning practices. Supported by government policies incentivizing permanent settlement, this can promote the sedentarization of pastoralist societies, particularly around roadside villages (Gil-Romera et al. 2011; Kaye-Zwiebel and King 2014; Korf et al. 2015). The emerging class of pastoral entrepreneurs and traders in Africa place more value on non-livestock goods and services compared to their ancestors (Lind et al. 2020a). SBEA feasibility assessments do not typically account for the distinctive evolutionary trajectories of pastoral societies in the two regions and their differences in fire use and values, aiming to provide a systematic approach to fire management and reduce development costs and barriers that might delay project implementation (UNU-IAS 2015). For example, the International Savanna Fire Management Initiative led an experimental fire exchange in Botswana with Aboriginal rangers that "convinced the fire managers of Botswana that traditional fire management Northern Australian-style was much better than the European-style fire management they had been undertaking." (ISFMI et al. n.d.). The transfer of methodologies to Botswana was internally validated by project developers prior to the exchange based on conclusions that pastoralist societies have accrued analogous fire strategies and produced "similar heterogenous landscapes from early season burning" worldwide (UNU-IAS 2015; ISFMI 2018). During the exchange, Australian rangers identified local communities using similar fire sticks and inferred homogeneity in traditional fire techniques (Johnston 2020), even though fire-stick farming methods, or cultural burns, have divergently evolved over millennia to achieve diverse socio-cultural objectives in specific savanna contexts (Adlam et al. 2021).

To date, prior knowledge elicitation of traditional fire management practices to develop integrated SBEA projects in protected areas is missing in the literature, undermining local knowledge that could otherwise contribute to the success of SBEA (Donald et al. 2022; Millhauser and Earle 2022). Without formal guidelines that define the roles, rights, and responsibilities of indigenous and local people in project development, SBEA implementation in protected areas might be used as a top-down strategy to mitigate conflicts where local activities are considered a threat to conservation-development objectives (Croker et al 2023).

Conclusion

This study highlights the multiple challenges preventing SBEA schemes from providing an alternative CBFiM approach across East and Southern African savanna-protected areas. SBEA projects have the potential to reconcile traditional and modern fire management approaches in Northern Australia. However, East and Southern Africa's colonial history, population growth, and climatic changes create challenging conditions for SBEA development, restructuring the human and physical environment across savanna-protected areas and undermining the basic requirements for the effective transfer of the Australian SBEA model. Rather than providing a win–win-win solution by simultaneously mitigating biodiversity loss, anthropogenic climate change, and socio-economic vulnerabilities, SBEA schemes implemented in African savanna-protected areas present multiple trade-offs which jeopardize long-term emissions reductions and the attainability of these objectives.

For SBEA schemes to provide an alternative CBFiM approach in East and Southern Africa, they need to address asymmetries between political institutions and local land governance systems that prevent the benefits acquired at the community level across indigenous-owned and indigenous-managed savannas in Northern Australian from being realized in African savanna-protected areas.

SBEA schemes are required to utilize scale-dependent advantages, such as technical expertise and equipment, resource allocation, and institutionalized market opportunities, while prioritizing local, non-expert knowledge, interpretations, and practices in project design, decision-making, and implementation, gradually transferring management rights to indigenous and local people. This will need to be supported through tripartite environmental justice frameworks (e.g., distributional, recognition, and procedural) to address ongoing challenges associated with the lack of political autonomy and negotiating power currently held by indigenous and local people in SBEA methodologies and the reproduction of colonial hegemonies in climate governance.

Future research on the opportunities for equitable indigenous-led SBEA schemes in East and Southern African savanna-protected areas needs to prioritize the development of legal frameworks that safeguard the roles and responsibilities of indigenous and local people in project management, their supply and distribution of carbon benefits, and the right to FPIC. Making technologies available to local communities can also assist in empowering democratic self-governance and long-term support for SBEA schemes, including the development of formal regulatory incentives and metrics for biodiversity conservation, as well as reducing operational costs that might compromise economic objectives. Such processes of decentralization can assist in creating new narratives in climate policy development which are of greater use and relevancy at the local level and promote win–win-win solutions at the national level. However, it is also important to recognize how processes of colonialism and the contemporary land rush in sub-Saharan Africa have and continue to impact local livelihoods and drive agrarian change, creating new challenges at the local level which can prevent equitable decentralization in resource management and accelerate distributional inequalities in the carbon economy.

Abbreviations

CBFiM	Community-based fire management
ISFMI	International Savanna Fire Management Initiative
MAP	Mean annual precipitation
SBEA	Savanna burning emissions abatement
FPIC	Free, Prior, and Informed Consent

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s42408-023-00215-1.

Additional file 1: Table S1. Test-list of 10 articles identified prior to and independently from the search as relevant to the aims of the review – to critically examine the development and influence of Northern Australian savanna burning methodologies on proposed community-based fire management in East and Southern African savanna-protected areas – and applied to develop and assess the performance of the search strategy. **Table S2.** Search string syntax development structured on Interest (I) and Context (Co) components of PICo framework. Interest category "Savanna ecosystem" was applied under Field Code: TITLE-ABS-KEY, and Interest and Context categories "Savanna burning emissions abatement scheme" (I) and "East and Southern Africa" (Co) were applied under Field Code: ALL. Search terms added to each search string are bolded in green. "[no change in syntax]" indicates use of syntax applied in previous search string with no modification. **Figure S1.** Number of studies returned in Scopus in response to changes in search string (grey bar) and retrieval performance assessed on percentage of test-list literature retrieved in each search (dashed line). **Table S3.** Final sample of papers retrieved in a systematic review of the published literature on the development of Northern Australian savanna burning emissions abatement schemes in East and Southern African savanna-protected areas. **Table S4.** Papers excluded during full-text screening and reason for exclusion based on pre-established review criteria.

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Authors' contributions
AC: conceptualization, investigation, methodology, formal analysis, data curation, writing — original draft, writing — review and editing; JW: conceptualization, writing — original draft, writing — review and editing, supervision; YK: conceptualization, writing — original draft, writing — review and editing, supervision, funding acquisition.

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Declarations

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Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no known competing interests.

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