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Energy Flow and Trophic Dynamics in African Savanna Ecosystems: A Comprehensive Analysis

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Abstract This study presents a comprehensive analysis of energy flow and trophic dynamics in African savanna ecosystems, emphasizing the critical roles of climate, human activities, and ecosystem-based approaches in shaping these landscapes. The study highlights that climate is the primary determinant of vegetation distribution, with significant implications for the structure and function of savanna ecosystems under changing environmental conditions. Human impacts, including land use changes and habitat fragmentation, have increasingly altered plant diversity and ecosystem resilience, necessitating integrated monitoring and management strategies. Additionally, the potential of ecosystem-based bioenergy production is explored as a sustainable solution for both energy needs and ecological restoration. The study concludes by stressing the importance of incorporating these insights into practical conservation efforts to ensure the long-term sustainability of savanna ecosystems.
Keywords Energy flow; Trophic dynamics; African savannas; Climate impact; Ecosystem management

1 Introduction

Tropical savannas, characterized by a ground cover dominated by C4 grasses and a discontinuous tree or shrub layer, cover approximately 50% of the African continent. These ecosystems range from densely wooded Miombo woodlands to the Serengeti grasslands with scattered trees (Osborne et al., 2018). African savannas are crucial for providing water, grazing, food, and fuel for tens of millions of people and support a unique biodiversity that is vital for wildlife tourism. However, these ecosystems are facing significant threats from human activities, including land cover change, landscape fragmentation, climate change, and rising atmospheric CO_2 levels, leading to widespread degradation (Stevens et al., 2017). Additionally, the phenomenon of woody encroachment, driven by factors such as CO_2 enrichment and changes in land management, is altering the structure and function of these ecosystems (Devine et al., 2017).

Understanding the energy flow and nutrient dynamics within savanna ecosystems is essential for comprehending their overall functioning and resilience. Energy flow, which involves the transfer of energy through different trophic levels, is a fundamental aspect of ecosystem ecology. It helps in identifying the sources and pathways of energy resources, which are crucial for maintaining the balance and health of the ecosystem (Masese et al., 2018). Nutrient dynamics, on the other hand, involve the cycling of essential elements like carbon and nitrogen, which are vital for plant growth and ecosystem productivity. For instance, the carbon dioxide fluxes in different savanna ecosystems are influenced by factors such as land use, water availability, and seasonal changes, affecting the overall carbon balance and ecosystem respiration (Quansah et al., 2015). Moreover, the interactions between different plant functional traits and their responses to environmental changes play a significant role in determining the resilience and vulnerability of savanna ecosystems to global change (Osborne et al., 2018; Siebert and Dreber, 2019).

This study aims to provide a comprehensive analysis of the energy flow and trophic dynamics in African savanna ecosystems. This includes examining the current status of these ecosystems, understanding the importance of energy flow and nutrient dynamics, and identifying the key drivers and consequences of ecosystem changes. The objective of this study is to synthesize existing knowledge from various studies to highlight the complex interactions and feedback mechanisms that govern savanna ecosystems. By doing so, it seeks to inform appropriate management strategies that can help maintain ecosystem integrity, biodiversity, and human livelihoods in the face of ongoing environmental changes. The scope of the study encompasses a wide range of topics, including the impact of human activities, climate change, and land use on savanna ecosystems, as well as the role of different plant and animal species in shaping the energy flow and trophic dynamics within these ecosystems.

2 Characteristics of African Savanna Ecosystems

2.1 Geographical distribution

African savannas are primarily located in the tropical and subtropical regions of the continent, spanning across countries such as Kenya, Tanzania, South Africa, and Botswana. These ecosystems are characterized by a mix of grasslands and scattered trees, creating a unique landscape that supports a diverse range of flora and fauna. The distribution of savannas is largely influenced by climatic factors, particularly rainfall patterns, which vary significantly across different regions (Fundisi et al., 2022). The spatial distribution of savanna environments is also shaped by historical disturbances and species interactions, which can lead to variations in vegetation types even within similar climatic zones (Higgins et al., 2023; Shan, 2024).

2.2 Climate and environmental conditions

The climate of African savannas is typically marked by distinct wet and dry seasons, with rainfall being a critical determinant of vegetation patterns. Savannas receive moderate to low annual rainfall, usually between 500 to 1 500 mm, which is sufficient to support grasses but not dense forests (Martens et al., 2020; Higgins et al., 2023). The seasonal precipitation influences the structure and composition of plant communities, with grasses dominating during the wet season and trees becoming more prominent in the dry season (Ferreira et al., 2022). Additionally, the savanna climate is subject to significant variability, both spatially and temporally, which can lead to changes in woody plant species compositions and overall ecosystem dynamics (Ma et al., 2020; Fundisi et al., 2022). Figure 1 illustrates the climatic suitability surfaces for major plant growth forms across Africa, highlighting the spatial distribution of different vegetation types influenced by climatic factors (Higgins et al., 2023).

2.3 Vegetation and plant diversity

African savannas are known for their heterogeneous vegetation, comprising a mix of woody and herbaceous plants. This diversity is influenced by a combination of climatic conditions, soil types, and human activities. The vegetation structure includes a variety of grasses, shrubs, and trees, with species composition varying across different regions and environmental gradients (Muumbe et al., 2021; Western et al., 2021). Remote sensing studies have highlighted the functional diversity of savanna vegetation, emphasizing the importance of monitoring woody plant species to inform sustainable biodiversity management. Furthermore, traditional management practices by indigenous communities have played a significant role in maintaining the diversity and structure of savanna ecosystems, promoting species that are beneficial for human use and ecosystem health (Ferreira et al., 2022).

The plant diversity in African savannas is also crucial for ecosystem functions such as carbon storage and primary productivity. Studies have shown that higher tree species diversity is associated with increased aboveground biomass and structural diversity, which in turn supports greater ecosystem resilience and function. However, land use changes, such as agricultural expansion, have led to significant reductions in plant biodiversity and carbon storage, highlighting the need for sustainable land management practices to preserve these vital ecosystems (Balima et al., 2020; Godlee et al., 2021).

3 Energy Flow in African Savannas

3.1 Primary production

Primary production in African savannas is driven by photosynthesis, where plants convert solar energy into biomass. This process is influenced by various factors, including water availability, soil fertility, and climatic conditions. Key primary producers in these ecosystems include grasses and trees, which exhibit distinct phenological characteristics and contribute differently to the ecosystem's gross primary production (GPP) (Higgins et al., 2023). Studies have shown that GPP in savannas can vary significantly with rainfall and other climatic factors. For instance, in the North Australian Tropical Transect (NATT), GPP decreases dramatically with reduced precipitation, highlighting the sensitivity of these ecosystems to hydroclimatic variability (Muumbe et al., 2021). Remote sensing models have been effective in estimating GPP, with the Vegetation Photosynthesis Model (VPM) showing the best performance in capturing seasonal dynamics in a mixed woodland-grassland savanna (Martens et al., 2020).

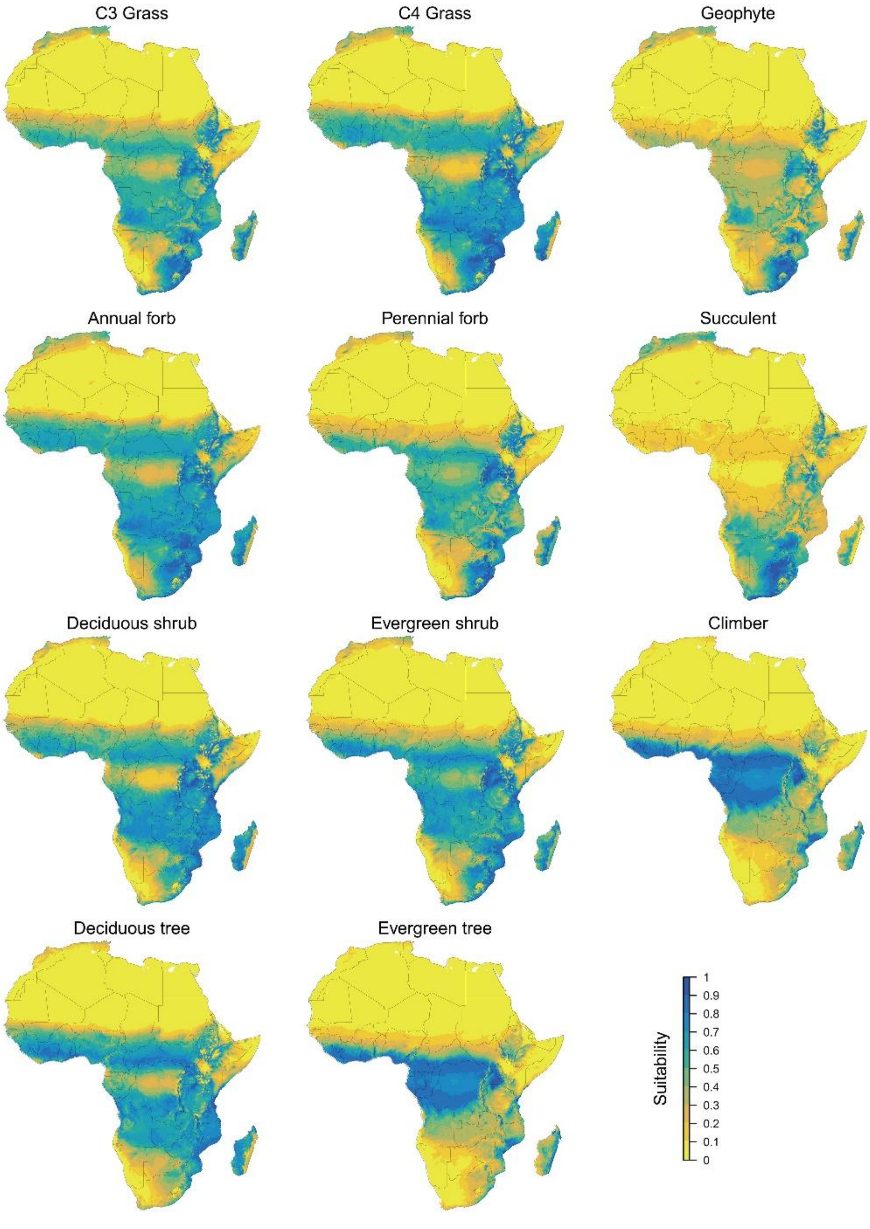

Figure 1 Climatic suitability surfaces for major plant growth forms (Adopted from Higgins et al., 2023)
Image caption: Suitability is the averaged suitability scores of the species belonging to each growth form (Adopted from Higgins et al., 2023)

3.2 Energy transfer efficiency

Energy transfer efficiency in savanna ecosystems involves the conversion of energy from one trophic level to the next. This process is characterized by significant losses, primarily due to metabolic processes and heat dissipation. The efficiency of energy transfer between trophic levels is typically low, with only a small fraction of the energy being passed on to the next level. In headwater streams of the Brazilian Savanna, secondary production estimates have shown that detrital pathways account for most energy flow, with gatherers, shredders, and predators being the most important contributors to production (Fundisi et al., 2022). This indicates that energy transfer efficiency is influenced by the availability of food resources and the roles of different consumer groups in the ecosystem.

3.3 Factors influencing energy flow

Several factors influence energy flow in African savannas, including climate, soil fertility, and water availability. Climate change and elevated CO_2 levels are expected to impact ecosystem structure and function, potentially leading to woody encroachment and changes in carbon storage (Ferreira et al., 2022). Rainfall seasonality also plays a crucial role, affecting soil biodiversity, litter production, and decomposition rates, which in turn influence nutrient cycling and energy flow (Ma et al., 2020). Human activities, such as agricultural land use and fire management, have significant impacts on energy flow in savanna ecosystems. Agricultural practices can reduce plant biodiversity and carbon storage, leading to ecosystem degradation and altered energy dynamics (Catarino and Romeiras, 2020). Fire and herbivory also shape soil arthropod communities and nutrient cycling, with herbivory having more pronounced effects on arthropod abundance, biomass, and diversity (Godlee et al., 2021). These human-induced changes necessitate flexible adaptation strategies to mitigate their impact on savanna ecosystems (Western et al., 2021).

4 Trophic Dynamics in African Savannas

4.1 Trophic levels and food web structure

Trophic levels in African savannas are defined by the hierarchical positions organisms occupy in the food web, starting from primary producers (plants) to apex predators. These levels include primary producers, primary consumers (herbivores), secondary consumers (carnivores), and tertiary consumers (top predators). The complexity of the food web in these ecosystems is characterized by multiple trophic interactions and pathways, which contribute to the stability and resilience of the ecosystem (Qin et al., 2021).

The structure of food webs in African savannas is influenced by various factors, including species diversity, resource availability, and environmental conditions. For instance, stable isotope analysis has revealed the presence of multiple trophic pathways and a long food chain length, indicating a complex and interconnected food web. Furthermore, the emergence of new trophic levels can occur naturally as a strategy for species to avoid competition, further adding to the complexity of the food web (Cropp and Norbury, 2020).

4.2 Herbivory and plant-herbivore interactions

Herbivory plays a crucial role in shaping plant communities and ecosystem dynamics in African savannas. Key herbivore species include large mammals such as elephants, giraffes, zebras, and various antelope species. These herbivores exhibit diverse feeding habits, with some being grazers that primarily consume grasses, while others are browsers that feed on leaves, twigs, and bark of woody plants (Pansu et al., 2022). The impact of herbivory on plant communities is significant, as herbivores can reduce the abundance of grasses and trees, thereby influencing the overall vegetation structure. For example, herbivore exclusion experiments have shown that the absence of herbivores leads to increased grass and tree abundance, highlighting the top-down control exerted by herbivores on vegetation (Staver et al., 2021). The nutrient content of herbivore dung can affect plant competition, with different nutrient ratios favoring either grasses or trees (Sitter and Venterink, 2020). This interaction between herbivores and plants is further complicated by factors such as fire and nutrient cycling, which can alter habitat structure and nutrient availability (Thoresen et al., 2020).

4.3 Predator-prey relationships

Predator-prey relationships are a fundamental aspect of trophic dynamics in African savannas. Major predator species include lions, leopards, cheetahs, and hyenas, each playing a critical ecological role in regulating prey populations and maintaining the balance of the ecosystem. Predation pressure can influence the behavior, distribution, and population dynamics of prey species, leading to trophic cascades that affect the entire food web (Webster et al., 2021). The influence of predation on prey populations is evident in the way predators control the abundance and distribution of herbivores, which in turn affects vegetation and other trophic levels. For instance, the presence of large predators can suppress herbivore populations, reducing their grazing pressure on plants and allowing for greater plant diversity and abundance (Coverdale et al., 2021). This top-down regulation is essential for maintaining the ecological balance and preventing overgrazing, which can lead to habitat degradation and loss of biodiversity.

5 Case Studies

5.1 Case study 1: serengeti ecosystem

5.1.1 Energy flow and trophic dynamics in the serengeti

The Serengeti ecosystem is renowned for its complex trophic dynamics and energy flow, driven by a diverse array of species interactions. The energy flow in this ecosystem is characterized by a well-defined hierarchy of primary producers, herbivores, and predators. Primary production is largely driven by grasses and other vegetation, which support a wide range of herbivores, including wildebeest, zebras, and gazelles. These herbivores, in turn, provide a crucial energy source for predators such as lions, cheetahs, and hyenas. The intricate balance between these trophic levels ensures the stability and resilience of the ecosystem (Western et al., 2021).

5.1.2 Role of migratory species and seasonal changes

Migratory species play a pivotal role in the Serengeti's energy dynamics. The annual migration of over a million wildebeest, along with hundreds of thousands of zebras and gazelles, is a key driver of nutrient cycling and energy distribution. This migration is closely linked to seasonal changes, particularly the availability of water and forage. During the wet season, the abundance of resources supports high herbivore biomass, which in turn sustains predator populations. Conversely, the dry season sees a reduction in available resources, leading to increased competition and predation pressure (Figure 2). These seasonal fluctuations are critical in maintaining the dynamic equilibrium of the Serengeti ecosystem (Western et al., 2021; Mtewele et al., 2023).

5.2 Case study 2: kruger national park

5.2.1 Impact of fire regimes and human intervention

Kruger National Park has been significantly influenced by fire regimes and human intervention. Fire is a natural and essential component of savanna ecosystems, shaping vegetation structure and composition. In Kruger, controlled burns are used as a management tool to mimic natural fire cycles, promoting biodiversity and preventing bush encroachment. However, human activities, including tourism and infrastructure development, have also impacted the park's ecological dynamics. These interventions can alter fire regimes and disrupt natural processes, necessitating careful management to balance conservation goals with human interests (Western et al., 2021).

5.2.2 Interactions between large herbivores and predators

The interactions between large herbivores and predators in Kruger National Park are central to its trophic dynamics. Herbivores such as elephants, buffalo, and various antelope species play a crucial role in shaping vegetation and influencing nutrient cycling. Predators, including lions, leopards, and wild dogs, regulate herbivore populations, preventing overgrazing and promoting ecosystem health. The balance between these trophic levels is delicate, with changes in herbivore or predator populations having cascading effects throughout the ecosystem. Human interventions, such as anti-poaching efforts and habitat management, are essential in maintaining this balance and ensuring the long-term sustainability of Kruger's biodiversity (Western et al., 2021).

5.3 Case study 3: okavango delta

5.3.1 Unique hydrological conditions and energy dynamics

The Okavango Delta is characterized by its unique hydrological conditions, which play a crucial role in its energy dynamics. Seasonal flooding creates a mosaic of aquatic and terrestrial habitats, supporting a diverse array of species. The flood pulse is the primary driver of energy flow, mediating the availability of resources and shaping species interactions. During the wet season, the influx of water supports high primary productivity, which in turn sustains a complex food web. Fish populations, for example, rely on different basal production sources such as seston and C4 grasses, with their foraging strategies shifting in response to seasonal changes in water levels (Bokhutlo et al., 2021; Mosepele and Mosepele, 2021).

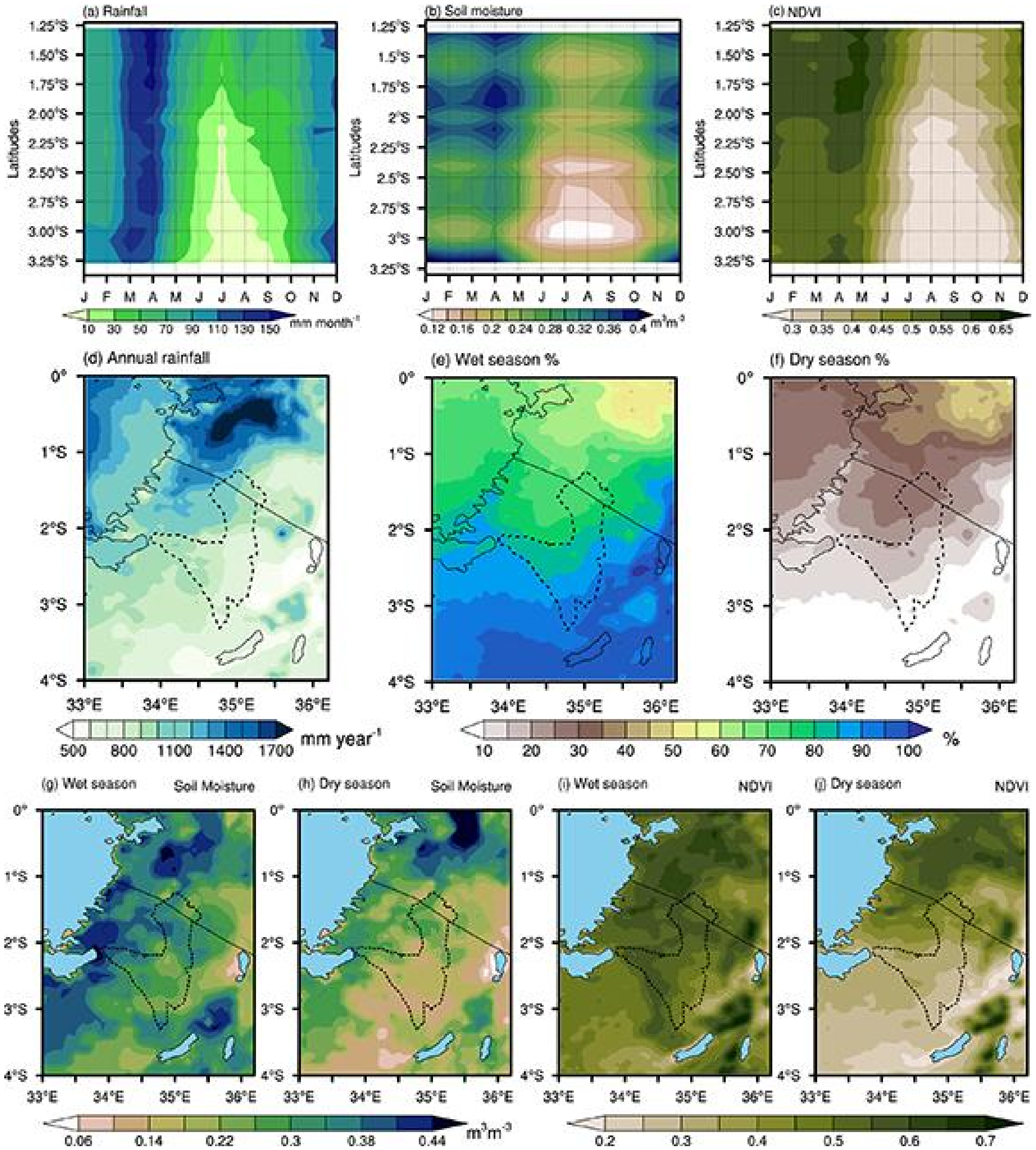

Figure 2 The Serengeti-Masai Mara Ecosystem (SMME) zonal annual cycle (Adapted from Mtewele et al., 2023)

Image caption: (a) rainfall, (b) soil moisture, and (c) NDVI. Spatial distribution of (d) mean annual rainfall and its percentage accumulation from (e) wet and (f) dry seasons. Climatological mean spatial distribution of soil moisture during (e) wet and (f) dry seasons and the corresponding NDVI patterns, (g) and (h), respectively (Adapted from Mtewele et al., 2023)

5.3.2 Biodiversity and trophic interactions in a wetland-savanna interface

The Okavango Delta's biodiversity is a testament to its dynamic trophic interactions. The interface between wetland and savanna habitats creates a unique environment where species from both ecosystems interact. This diversity is maintained by the Delta's resilience to environmental perturbations, such as channel or lagoon failures. Despite these disturbances, the Delta has consistently absorbed changes and retained its overall ecological character. The resilience framework, which emphasizes the importance of maintaining dynamic characteristics, is crucial for managing the Delta's biodiversity and ensuring the stability of its trophic interactions (Mosepele and Mosepele, 2021; Mosepele et al., 2022).

6 Challenges and Threats to Savanna Ecosystems

6.1 Climate change

Climate change poses significant threats to the energy flow and trophic dynamics in African savanna ecosystems. Predicted impacts include shifts in vegetation types and changes in the distribution of species, which can alter the entire food web. For instance, climate-driven vegetation changes are expected to increase tree cover in savannas, potentially leading to woody encroachment into grasslands. This shift can disrupt the balance between herbivores and their food sources, affecting the entire trophic structure (Martens et al., 2022). Additionally, the increase in carbon in aboveground biomass due to elevated CO_2 levels could further exacerbate these changes, leading to a decline in grassland areas and a subsequent impact on herbivores that depend on these grasses. The predictability of these changes is complicated by the interaction of climate with other factors such as fire and human activities, making it essential to develop flexible adaptation strategies (Martens et al., 2020).

6.2 Habitat fragmentation and land use change

Habitat fragmentation and land use change, driven by agriculture, urbanization, and infrastructure development, are major threats to savanna ecosystems. Agricultural expansion, in particular, has been shown to reduce plant biodiversity and carbon storage, leading to ecosystem degradation (Balima et al., 2020). In the miombo woodlands of northern Mozambique, small-scale agricultural expansion has resulted in a non-linear relationship with biodiversity, where moderate levels of land use change initially increase species richness but extreme levels lead to significant declines. This fragmentation not only affects plant communities but also has profound impacts on mammal species, leading to homogenization of mammal communities and increased dissimilarity among tree communities (Tripathi et al., 2021). The combined pressures of land use change and climate change further threaten the integrity of protected areas, which are crucial for conserving biodiversity (Martens et al., 2022).

6.3 Invasive species

The introduction and spread of non-native species pose significant challenges to the trophic dynamics of savanna ecosystems. Invasive species can outcompete native species for resources, leading to shifts in species composition and disruptions in trophic interactions. For example, the introduction of non-native plant species can alter the availability of food for herbivores, which in turn affects predator populations. This cascading effect can lead to a decline in native biodiversity and changes in ecosystem functioning (Irob et al., 2022). In the Brazilian Cerrado, a savanna-like ecosystem, anthropogenic disturbances such as cattle grazing and the introduction of non-native species have been shown to reduce taxonomic and phylogenetic diversity, further highlighting the vulnerability of these ecosystems to invasive species (Coelho et al., 2020). Effective management strategies are needed to control the spread of invasive species and mitigate their impacts on native trophic interactions.

7 Conservation and Management Strategies

7.1 Ecosystem restoration and management

Restoring energy flow and trophic balance in African savanna ecosystems requires a multifaceted approach that integrates both ecological and socio-economic strategies. Long-term ecological monitoring, as demonstrated in the Amboseli landscape, is crucial for understanding the spatial and temporal changes in species composition, structure, and function of rangeland ecosystems. This monitoring helps in identifying the declining role of natural agencies and the increasing impact of human activities, thereby guiding effective restoration efforts (Western and Mose, 2021; Western et al., 2021). The rewilding of key species, such as the African savannah elephant, has shown to promote landscape openness and modify fauna habitats, which are essential for maintaining a balanced trophic structure (Gordon et al., 2023).

Protected areas and wildlife corridors play a significant role in conserving biodiversity and maintaining ecological processes. Studies have shown that protected areas, such as the Tswalu Kalahari Reserve and Manyeleti Nature Reserve, are effective in preserving essential trace elements across different trophic levels, which is vital for the health and sustainability of wildlife populations (Webster et al., 2021). Moreover, the establishment of wildlife corridors can facilitate the movement of species, thereby enhancing genetic diversity and resilience against environmental changes. The Amboseli Conservation Program highlights the importance of space, landscape heterogeneity, and social networks in sustaining large herbivore populations, which are critical for ecosystem stability (Western and Mose, 2021).

7.2 Sustainable land use practices

Sustainable land use practices that integrate agriculture and livestock with ecosystem conservation are essential for maintaining the ecological integrity of savanna ecosystems. The miombo ecosystem in Southern Africa, for instance, supports varied land uses and demonstrates the importance of conserving spatial structure for sustainable farming, which leads to significant crop yield increases (Wei and Barros, 2021). Ecosystem-based approaches to bioenergy generation, such as the use of agricultural residues and promotion of agroforestry, can provide sustainable energy solutions while restoring degraded lands (Duguma et al., 2020). These practices not only enhance food security but also contribute to the conservation of biodiversity and ecosystem services.

7.3 Policy and community involvement

Effective conservation and management of savanna ecosystems require robust local and national policies that address both environmental and socio-economic challenges. Policies should focus on reducing land degradation, promoting sustainable land use practices, and ensuring the equitable distribution of benefits from ecosystem services. The UN Decade on Ecosystem Restoration emphasizes the need for well-designed restoration initiatives that tackle multiple Sustainable Development Goals, including biodiversity conservation, agricultural production, and local livelihoods (Edwards et al., 2021). National adaptation and mitigation plans should also highlight the key ecological attributes of land degradation and the underlying processes to inform policy decisions (Balima et al., 2020).

Engaging and empowering local communities is crucial for the success of conservation efforts. Indigenous and traditional management practices have been shown to maintain the diversity of ecosystems and promote sustainable use of resources (Ferreira et al., 2022). Local knowledge and participation in conservation activities can enhance the effectiveness of ecosystem management and restoration projects. For instance, communities in Burkina Faso have demonstrated significant knowledge of ecosystem services and have suggested raising awareness on the importance of biodiversity and ecosystem preservation as a means to reduce further degradation (Nabaloum et al., 2021). Empowering local communities through education, capacity building, and inclusive decision-making processes can lead to more sustainable and resilient ecosystems.

8 Future Directions and Research Needs

8.1 Gaps in current knowledge

Despite significant advancements in understanding energy flow and trophic dynamics in African savanna ecosystems, several gaps remain. One major area requiring further investigation is the impact of human activities on these ecosystems. Studies have shown that human influence is increasingly shaping the ecology of savannas, leading to declines in plant diversity and productivity, and increased biomass turnover (Western et al., 2021). However, the specific mechanisms through which human activities alter these dynamics are not fully understood. There is a lack of comprehensive data on the movement ecology of large herbivores, which play a crucial role in energy flow and trophic interactions. Current research is fragmented and focuses on a limited number of species, leaving significant gaps in our understanding of how these animals interact with their changing environments (Owen-Smith et al., 2020).

8.2 Technological and methodological advancements

Innovations in remote sensing technologies, such as Terrestrial Laser Scanning (TLS), offer promising avenues for studying energy flow and trophic dynamics in savannas. TLS has proven effective in characterizing 3D vegetation structures, but its application in savanna ecosystems has been limited. Future research should focus on developing new algorithms for vegetation parameter extraction and integrating TLS data with other remote sensing platforms to improve accuracy and scalability (Muumbe et al., 2021). Mixed-pixel analysis using Earth Observation data can provide detailed land cover information at sub-pixel levels, essential for understanding the spatial-temporal dynamics of savannas (Nghiyalwa et al., 2021). These technological advancements can significantly enhance our ability to monitor and model ecosystem changes.

8.3 Long-term monitoring and data collection

Continuous long-term monitoring is crucial for adaptive management of savanna ecosystems. Long-term studies, such as those conducted in the Amboseli landscape, have highlighted the value of integrated ecological monitoring in tracking changes in species composition, structure, and function over time (Western et al., 2021). Such monitoring efforts are essential for understanding the impacts of both natural and human-induced changes and for developing effective conservation strategies. The use of remote sensing data for long-term monitoring of vegetation dynamics and water availability can provide valuable insights into the resilience of different savanna ecosystems to climatic and anthropogenic pressures (Wei and Barros, 2021). Establishing robust, long-term data collection frameworks will be vital for adaptive management and conservation of these dynamic ecosystems.

9 Concluding Remarks

This study has synthesized current research on energy flow and trophic dynamics in African savanna ecosystems, revealing several critical insights. The distribution of vegetation types, such as forests and savannas, is predominantly determined by climatic factors. The study demonstrated that climate alone can predict the distribution of these ecosystems with high accuracy, suggesting that the effects of climate change on these ecosystems may be more predictable than previously thought. The role of human impact on savanna ecosystems has been increasingly significant. Long-term studies in regions like Amboseli, Kenya, have shown that human activities have led to a decline in plant diversity and productivity, increased biomass turnover, and reduced ecological resilience. Ecosystem-based approaches to bioenergy generation have been proposed as a sustainable solution to the energy crisis in Africa. These approaches emphasize the restoration of degraded ecosystems and the use of agricultural residues, which could potentially generate substantial energy and support large populations.

The findings from this study have several practical implications for ecosystem management and conservation. The strong influence of climate on vegetation distribution underscores the importance of incorporating climate models in conservation planning to predict and mitigate the impacts of climate change on savanna ecosystems. The significant human impact on these ecosystems highlights the need for integrated monitoring and management strategies that consider both natural and anthropogenic factors. Long-term ecological monitoring, as demonstrated in the Amboseli study, is crucial for tracking changes in ecosystem properties and informing conservation policies. Furthermore, adopting ecosystem-based approaches to bioenergy can provide a dual benefit of sustainable energy production and ecosystem restoration. This approach requires a balanced involvement of various sectors and knowledgeable management to ensure beneficial outcomes for both society and the environment.

In conclusion, the research reviewed here provides a comprehensive understanding of the energy flow and trophic dynamics in African savanna ecosystems. The dominant role of climate, the increasing human impact, and the potential of ecosystem-based bioenergy approaches are key themes that emerge from this analysis. Moving forward, it is essential to integrate these insights into practical conservation and management strategies to enhance the resilience and sustainability of savanna ecosystems. By doing so, we can better safeguard these vital landscapes for future generations.

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Conflict of Interest Disclosure

The authors affirm that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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