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Adapting to an Era of Climate Change: The Case of South African UNESCO Biosphere Reserves

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Abstract

Escalating climate change in South Africa threatens ecosystems, livelihoods, and socio-economic stability through rising temperatures, erratic rainfall, and increasingly extreme weather. UNESCO Biosphere Reserves, which cover nearly 10% of the country's land area, offer a promising framework for climate adaptation by combining biodiversity conservation, sustainable development, and community engagement. This study investigates how South Africa's 10 biosphere reserves demonstrate organizational adaptive capacity across three dimensions: governance effectiveness, social capital, and access to financial, human, and technical resources. Using a mixed-methods approach, including a cross-sectional online survey of reserve experts and document analysis, the research assesses the integration of climate change into governance structures, the strength of stakeholder networks, and the extent of resource mobilization. Results reveal significant variation among reserves: Some, such as the Gouritz Cluster and Vhembe, have embedded climate considerations into management frameworks and secured funding through international partnerships, while others struggle with limited budgets, weak local engagement, and inconsistent application of UNESCO's zonation model. Social capital emerges as a critical enabler of adaptation, but challenges persist in communication and collaboration with local communities. The findings highlight the potential of biosphere reserves as "living laboratories" for climate adaptation while underscoring persistent gaps in resource distribution and governance. Strengthening formal policy support, diversifying funding, and deepening community engagement are recommended to enhance adaptive capacity. South Africa's biosphere reserves thus provide valuable lessons for integrating conservation and development in climate-vulnerable regions.

Keywords adaptive capacity, biosphere reserves, climate change, governance, resilience

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1. Introduction

Escalating climate change in South Africa threatens the stability of its ecosystems and the foundations of its socio-economic structures (Reddy et al., 2023). The country already experiences erratic precipitation, rising temperatures, and more frequent extreme weather events, all of which negatively impact agriculture and water supply (United States Agency for International Development [USAID], 2023). Notably, declining rainfall in southern regions and the weakening of the Agulhas Current—a key driver of South African rainfall—further jeopardize food security and rural livelihoods (Tim et al., 2023). Projections indicate that by 2100, interior temperatures could rise by up to 4°C, which will intensify existing economic pressures and accelerate migration to urban areas (Reddy et al., 2023; Scholes & Engelbrecht, 2021).

Climate-induced stresses already reverse economic growth, exacerbate unemployment, and deepen inequality, particularly among the most vulnerable groups (Adom et al., 2022). While some regions may temporarily benefit from increased rainfall, these gains are outweighed by the broader, adverse impacts of climate change on livelihoods, infrastructure, and natural systems (Nhemachena et al., 2020). In response to these pressures, South Africa must develop comprehensive adaptive strategies to safeguard its future. UNESCO Biosphere Reserves offer a promising framework for such adaptation. Covering 9.5% of the country's land area, these reserves aim to protect biodiversity and maintain ecosystem services essential for climate resilience. Their primary aim is to balance conservation, sustainable development, and community engagement (Pool-Stanvliet & Coetzer, 2020).

Through its "Man and the Biosphere" (MAB) program, UNESCO promotes biosphere reserves as models for balancing conservation with sustainable development, integrating economic, socio-cultural, and environmental goals. These reserves serve as *living laboratories* for climate change adaptation and mitigation, testing adaptive governance, enhancing resilience through projects, and monitoring environmental changes (Leibenath et al., 2024; UNESCO, 2022). Their landscape-scale zonation model—comprising core conservation areas (e.g., national parks), buffer zones (balancing economic activity and conservation), and transition areas (prioritizing economic activity with some conservation)—extends conservation to private and community lands and fosters inclusive and effective climate solutions, enhancing their adaptive capacity to address environmental challenges (Palliwoda et al., 2021).

South Africa increasingly recognizes buffer zones in biosphere reserves as "Other effective area-based conservation measures" that enhance conservation efforts (Jago, 2024). This move strengthens climate action by integrating conservation with sustainable use on privately owned lands, which broadens the scope and impact of adaptive management (Green et al., 2021). It also fosters greater community involvement and stewardship, which are key components of a biosphere reserve's adaptive capacity (Pool-Stanvliet & Coetzer, 2020). Through adaptive co-management—characterized by collaborative governance and stakeholder engagement—reserves achieve ecological and social benefits that strengthen their adaptive capacity to address climate disturbances (Plummer et al., 2017; Stroebel et al., 2025).

Building on the role of biosphere reserves in climate action and adaptive co-management, this study examines how South Africa's UNESCO Biosphere Reserves demonstrate organizational adaptive capacity in response to climate change. Specifically, the study focuses on three critical dimensions of adaptive capacity: governance effectiveness, social capital, and access to financial, human, and technical resources. To achieve this, the study pursues the following objectives:

- Identify the presence and strength of governance structures that integrate climate change considerations within biosphere reserves.
- Determine the strength of stakeholder networks, community participation, and the integration of local and Indigenous knowledge.
- Analyze the availability of resources that enable climate adaptation actions within the reserves by examining current and past climate actions.
- Compare the extent to which different biosphere reserves exhibit these indicators.

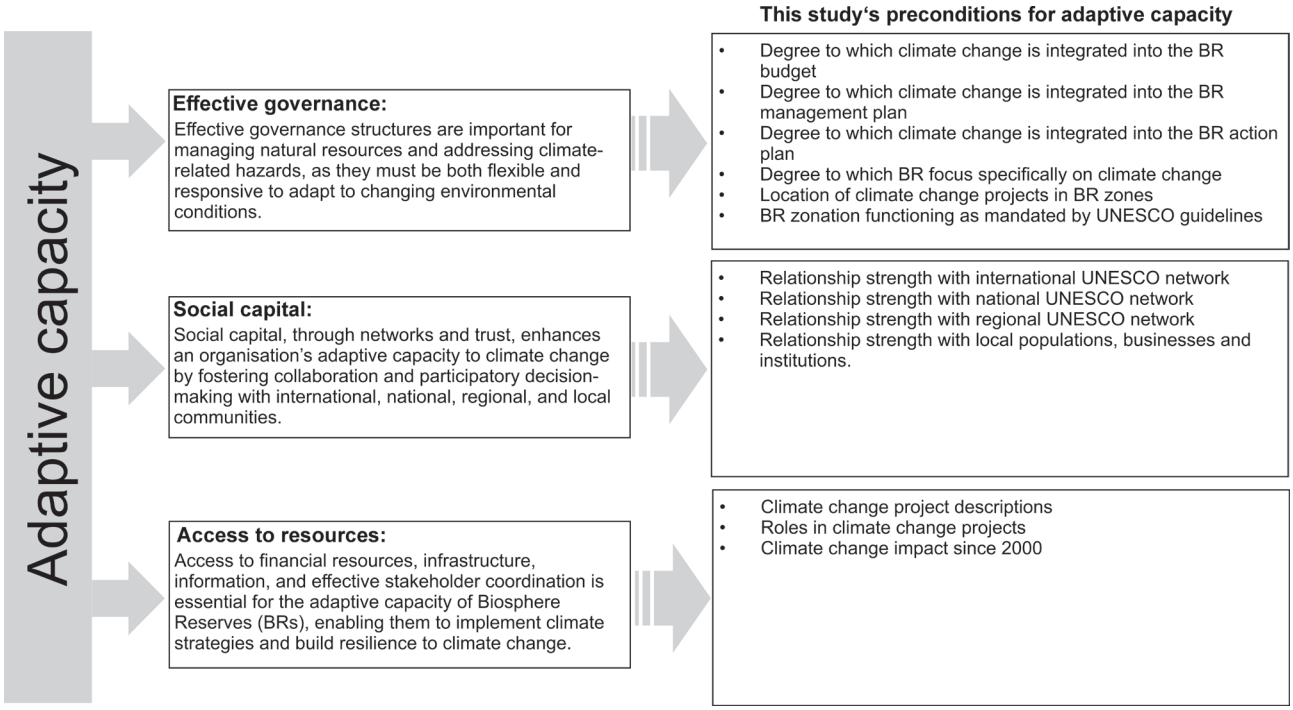
The study uses a mixed-methods approach with an online questionnaire to assess the effectiveness of South Africa's biosphere reserves in climate action and aims to identify strategies for improved adaptation efforts.

2. Theoretical Framework

This study is grounded in an adaptive capacity theoretical framework, recognizing that adaptive capacity is a complex, multidimensional concept studied across various disciplines, which results in diverse interpretations. Recent scholarship defines adaptive capacity as the dynamic ability of social-ecological systems to anticipate, respond to, and recover from environmental changes by mobilizing resources, knowledge, and institutional arrangements (Chapagain et al., 2025). It encompasses the availability of assets and the agency to activate these assets in response to shocks and stresses (Goswami, 2020). United Nations Framework Convention of Climate Change (UNFCCC, 2024) emphasizes the importance of flexible and responsive institutions that enable both incremental adjustments and transformative change in the face of uncertainty. Similarly, Seaborn et al. (2021) define adaptive capacity as the ability of social-ecological systems to adjust to environmental changes by incorporating both evolutionary biology and sociological factors, including policies and actions aimed at achieving desired outcomes. Despite these evolving perspectives, the Intergovernmental Panel on Climate Change (IPCC) definition remains foundational, describing adaptive capacity as "the ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences" (IPCC, 2014, p. 1758).

Recognizing adaptive capacity's role in enabling proactive responses to both challenges and opportunities in dynamic environments, this study builds upon the work of Siders (2019), whose comprehensive review identified 158 distinct indicators relevant to organizational responses to climate change. These indicators reflect a multifaceted understanding of adaptability along three main themes: effective governance, social capital, and access to resources (see Figure 1). Recent adaptive capacity research confirms that these three dimensions are the most widely recognized and foundational for understanding adaptive capacity in the context of climate change (Chapagain et al., 2025). Effective governance structures are essential for managing natural resources and responding to climate-related hazards (Meng, 2024). These structures must be flexible and responsive, enabling institutions to adapt to both incremental and abrupt changes in environmental conditions. This adaptability highlights the necessity for both formal policies and informal agreements among communities (Cinner et al., 2018; Jones et al., 2011). Central to effective governance is leadership, which mobilizes communities and resources towards adaptive strategies (Brahm & Poblete, 2024).

Figure 1 Adaptive Capacity Themes and How They Translate to This Study's Indicators



Note. Source: Adapted from Chapagain et al. (2025), Siders (2019).

Effective leaders inspire action, coordinate efforts, and ensure that adaptation initiatives receive the necessary support. By fostering collaboration and engagement among stakeholders, strong leadership enhances the resilience of communities facing climate change challenges (Jones et al., 2011).

Social capital refers to the networks, relationships, and norms that facilitate collective action and resource sharing among individuals and communities. It plays a crucial role in enhancing adaptive capacity by fostering collaboration and trust within communities (Javeed et al., 2024). For instance, in several Mexican cases, such as the Mapimí biosphere reserve, Mexico, local ecological knowledge is integrated into management plans, enhancing climate change adaptive capacity through participatory approaches (Brenner & Job, 2022). Another example is Jozani Chwaka Bay, where local communities are included in the decision-making processes and directly benefit from tourism activities (Carius & Job, 2019). Such activities foster climate change resilience and ensure that adaptation strategies are contextually relevant and tailored to the local communities' specific needs (Tagüeña et al., 2019).

Access to resources is another fundamental component of institutional adaptive capacity, especially with regards to climate action. This capacity includes financial resources, infrastructure, and information necessary for implementing adaptive strategies and enhancing climate action. Organizations with robust funding can invest in critical areas such as infrastructure development, research initiatives, and community engagement programs (Serdeczny et al., 2024). Coordination among various stakeholders—including government entities and non-governmental organizations (NGOs)—is vital for effective resource allocation and management strategies (Javeed et al., 2024). Moreover, organizations that leverage data on climate impacts can better anticipate changes and adapt accordingly (Thurman et al., 2022). Training and capacity-building initiatives empower local communities, enhancing their ability to manage resource sustainably in the face of climate change (Goswami, 2020).

3. Policy Context: The Lima Action Plan and South African Biosphere Reserve Strategy

While the adaptive capacity framework provides a robust conceptual lens for understanding how biosphere reserves can respond to climate change, it is essential to recognize that these theoretical dimensions are operationalized through concrete policy instruments and institutional arrangements (UNESCO, 2016). The translation of adaptive capacity from theory into practice depends largely on the policy frameworks that guide biosphere reserve management at both international and national levels. In this context, the current Lima Action Plan (2015–2025; UNESCO, 2016) and the South African Biosphere Reserve Strategy (2016–2020; Department of Environmental Affairs [DEA], 2016) serve as the principal policy documents shaping the governance, social capital, and resource access within South Africa's biosphere reserves. The following section examines how these policies articulate and support the core dimensions of adaptive capacity, providing a foundation for understanding their implementation and effectiveness in the South African context.

3.1 Effective Governance

The Lima Action Plan (UNESCO, 2016) emphasizes flexible, participatory, and multi-level governance for biosphere reserves, enabling adaptation to evolving environmental and socio-cultural contexts. It distributes responsibilities across Member States, national authorities, MAB Committees, and local management teams to support context-specific decisions. The plan advocates for formal policies, strengthened national legislation (Action A1.6), and integration of local and indigenous knowledge (Actions A2.2, A2.3) to ensure legitimacy, alongside stakeholder participation and regular reviews for adaptive governance (UNESCO, 2016). Similarly, the South African Biosphere Reserve Strategy (2016–2020) promotes clear, collaborative governance structures (Section 2.6.2), prioritizing partnerships, capacity building, and knowledge sharing (Sections 2.5.2, 2.5.4, 2.5.5; DEA, 2016). While both frameworks emphasize participatory governance, the Lima Action Plan provides clearer guidance on flexibility and informal agreements.

The adaptive capacity indicators used in this study—such as the degree to which climate change is integrated into biosphere reserve budgets, management and action plans, the specific focus on climate change, the location of climate projects within biosphere reserve zones, and adherence to UNESCO zonation guidelines—are grounded in these governance principles (DEA, 2016; UNESCO, 2016). These indicators

primarily represent preconditions or enabling factors that reflect institutional commitment and structural readiness for adaptation; for example, integrating climate change into planning and budgeting demonstrates institutional prioritization, while UNESCO-compliant zonation ensures spatially appropriate implementation of adaptation strategies. Collectively, these indicators reflect key aspects of effective governance necessary for biosphere reserves to meet international standards (Möller, 2011).

3.2 Social Capital

The Lima Action Plan (2016; UNESCO, 2016) highlights social capital—encompassing stakeholder networks, relationships, and collective action—as vital for biosphere reserves' adaptive capacity. It promotes alliances (Action A1.3), green and social economy initiatives for climate action (Action A1.5), and integration of local and indigenous knowledge (Actions A2.2, A2.3) for context-specific management (UNESCO, 2016). Capacity building and knowledge exchange within the World Network of Biosphere Reserves further strengthen adaptive governance. Similarly, the South African Biosphere Reserve Strategy (2016–2020) emphasizes collaboration, indigenous knowledge, capacity building, and knowledge sharing (Sections 2.5.2, 2.5.3, 2.5.4, 2.5.5, 2.5.7; DEA, 2016). While both frameworks prioritize partnerships, the Lima Action Plan includes performance indicators for alliances and emphasizes social economy initiatives.

The indicators used in this study (see Figure 1)—relationship strength with international, national, and regional UNESCO networks, as well as with local populations, businesses, and institutions—are supported by these frameworks (DEA, 2016; UNESCO, 2016). They represent important foundational capacities that underline adaptive governance and resource mobilization. Strong ties to UNESCO networks facilitate access to global expertise and resources, while robust local relationships support management and climate change initiatives (Plummer et al., 2017). These indicators capture the vertical and horizontal dimensions of social capital, enabling biosphere reserves to mobilize resources, enhance governance, and fulfil their role in sustainable development and climate action.

3.3 Access to Resources

The Lima Action Plan (2016) frames resource access—encompassing financial, infrastructural, informational, and coordination dimensions—as critical for biosphere reserves' adaptive capacity. It promotes financial investment in sustainable development, green and social economy projects, and resource mobilization through alliances, delegating financial strategies to Member States and local reserves (Action A1.5; UNESCO, 2016). Infrastructure and information access are supported through governance, communication systems, and reserves' roles as climate observatories (Action A1.4). Similarly, the South African Biosphere Reserve Strategy (2016–2020) acknowledges funding constraints but emphasizes sustainable financial resources, stakeholder coordination, and reserves as research and monitoring sites (Sections 2.5.2, 2.5.3, 2.5.6, 2.6.3; DEA, 2016).

The indicators used as areas of inquiry in this study—climate change project descriptions, roles of biosphere reserves in these projects, and their impacts since 2000 (see Figure 1)—are justified by these frameworks (DEA, 2016; UNESCO, 2016). They reflect the importance of resource access for climate adaptation, with project descriptions and defined roles demonstrating the observatory function of biosphere reserves, and impact assessments informing adaptive governance. They enable biosphere reserves to implement effective, context-specific climate actions and contribute to sustainable development.

4. Methods

This study adopted a mixed-methods empirical approach to comprehensively assess adaptive capacity across South Africa's UNESCO-designated biosphere reserves. Using a cross-sectional research design, all 10 reserves in the national network were invited to participate, with UNESCO designation as the sole inclusion criterion to ensure full network representation.

Data collection focused on individuals identified as experts within the biosphere reserve network, specifically those involved in organizational frameworks and participating in climate change initiatives. Expert-driven sampling is well established for organizational research, as it ensures that findings are informed by those with the most relevant knowledge and author-

ity (Etikan, 2016). The sample size (seven responses from six reserves) reflects the specialized nature of the target group (Guest et al., 2006).

To ensure data richness and depth, the survey combined closed-ended Likert scale items with open-ended questions aligned to each adaptive capacity theme. This mixed-methods design enabled both quantitative comparisons and the elicitation of nuanced, context-specific insights (Creswell & Clark, 2011). Direct quotations from expert responses are presented in the results to illustrate key themes and strengthen the empirical grounding of the study (Nowell et al., 2017). Qualitative findings were triangulated with previous research on South African biosphere reserve governance, further enhancing the reliability and contextual relevance of the results (Creswell & Clark, 2011).

Prior to the study, the questionnaire was piloted with six departmental researchers familiar with UNESCO Biosphere Reserves. Feedback from this pre-test informed revisions to improve clarity and structure. The final online questionnaire was distributed on January 19, 2023, and remained open for 10 weeks, with weekly reminders sent to maximize participation.

Ethical approval was obtained from the relevant institutional review board, which classified the study as low risk. The research team adhered to best practices in research integrity and responsible conduct throughout all phases.

For quantitative analysis, numerical values were assigned to Likert scale items to facilitate statistical comparison across biosphere reserves. While the use of Likert data is sometimes debated (Tanujaya et al., 2023), this approach is widely used within the UNESCO Biosphere Reserve World Network and allows for direct comparisons of organizational attributes (Matar & Anthony, 2017; Möller, 2011). This method captures both the presence and degree of commitment to key adaptive capacity indicators, reflecting structural readiness and engagement intensity (Möller, 2011). Where multiple respondents represented a single reserve, their responses were averaged to provide a composite score that reflects the collective perspective of the reserve's management, a standard practice for improving reliability in organizational research (James et al., 1984).

Study limitations include reliance on self-assessment, which may introduce bias such as over- or underestimation of adaptive capacity (Paulhus & Vazire, 2007), and a small sample size, which limits generalization but is common in expert-based research on biosphere reserves (Guest et al., 2006; Pool-Stanvliet & Coetzer, 2020). Nonetheless, both approaches are consistent with established practices in biosphere reserve research, where expert judgment and self-reporting are frequently employed to capture nuanced, context-specific insights (Matar & Anthony, 2017). The inclusion of open-ended responses and document review further enhances the richness, validity, and contextual relevance of the findings by enabling data triangulation and deeper exploration of organizational dynamics (Nowell et al., 2017).

Future research could strengthen validity by incorporating external evaluations or objective metrics, such as independent governance reviews, ecological monitoring, or financial audits, to complement organizational self-assessment. In addition, while qualitative quotes have been included to enrich interpretation and illustrate expert perspectives, they were used in an illustrative rather than systematically coded manner. This approach aligns with the study's exploratory design, but future work could adopt formal qualitative coding or thematic analysis to provide greater analytical depth.

5. Study Area

South Africa's formal protected areas date back to 1926 (Green & Job, 2025). Currently, this protection covers 112,806.84 km^2, or 9.2% of its terrestrial area. In addition, this country has 10 biosphere reserves, spanning 115,732 km^2, primarily located in the southern and northern regions. The buffer zones of these reserves add 37,653.98 km^2, contributing nearly 3% toward the Convention on Biological Diversity's global target of 30% protected land by 2030 (see Figure 2; Pool-Stanvliet & Coetzer, 2020). These reserves play a vital role in climate change adaptation, extending beyond formal protected areas (Möller, 2011).

South African biosphere reserves were selected as case studies for three main reasons. First, their extensive coverage, potentially the highest in Africa (UNESCO, 2024), underscores their significance in national and continental conservation efforts. Second, South Africa has the most biosphere reserves in Africa (UNESCO, 2024). Third, South Africa's vulnerability to climate change (USAID, 2023) makes these reserves

Figure 2 South African Biosphere Reserves

Note. Source: Designed by H. Job with W. Weber as cartographer and adapted from Department of Forestry, Fisheries and the Environment (2020).

ideal for examining adaptive strategies that support biodiversity goals and resilience in the face of environmental challenges.

Although biosphere reserves in South Africa are conceptually well-positioned in terms of area and guiding principles to lead effective climate change responses, practical implementation frequently encounters challenges (Pool-Stanvliet & Coetzer, 2020). The following sections provide a concise review of the academic literature addressing South African biosphere reserves governance, specifically addressing the adaptive capacity themes of effective governance, social capital, and resource accessibility. This overview highlights the potential and the constraints these reserves face in translating their organizational adaptive capacity into climate action.

South African biosphere reserves employ a collaborative, non-profit governance model, managed by boards

and operational teams that prioritize participatory decision-making and stakeholder engagement (Pool-Stanvliet, 2013). For example, the Kruger to Canyons biosphere reserve has a representatives' council and task teams to align research and management with local priorities, fostering adaptive governance and rapid response capabilities. This bottom-up, decentralized approach contrasts with top-down state conservation models and is designed to address historical socio-political tensions, promoting inclusivity and flexibility in climate adaptation strategies (Pool-Stanvliet et al., 2018; Wilson & Anthony, 2023). Effective governance within biosphere reserves also requires adherence to the UNESCO zonation model, with an emphasis on conservation within core areas (Jauro et al., 2020). However, the informal governance processes characteristic of South African biosphere reserves—rooted in a "soft law" framework that relies on collaboration and voluntary partnerships rather than legislative enforcement—can present challenges. This approach may lead to inconsistencies in policy application and enforcement, potentially undermining the effectiveness of governance and conservation outcomes (Carruthers, 2020; Klaver et al., 2024).

Social capital is another cornerstone of adaptive capacity. Strong relationships between international partners, local stakeholders, and the community enhance a biosphere reserve's capacity to practice conservation and execute climate change projects (Hedden-Dunkhorst & Schmitt, 2020). Biosphere reserves such as Vhembe and Kruger to Canyons build robust networks among local communities, academic institutions, NGOs, and international partners. In Vhembe, the integration of indigenous knowledge systems—such as traditional medicine and taxonomy—into conservation practices demonstrates how social capital and community participation enhance resilience and adaptive management (Kugara et al., 2024; Mphidi, 2019). These reserves institutionalize stakeholder participation through mandatory criteria, participatory processes, and community empowerment initiatives, although challenges like fragmented collaboration and uneven engagement persist (Carruthers, 2020).

Access to financial, human, and technical resources is a critical enabler of adaptive capacity. The Gouritz Cluster biosphere reserve, for example, leverages its UNESCO affiliation and partnerships with tertiary institutions to secure funding and expertise for climate adaptation projects, such as the "Jobs for Carbon" initiative that combines ecosystem restoration with socio-economic benefits (Pool-Stanvliet & Coetzer, 2020). Despite these successes, reserves face chronic funding shortages, over-reliance on small teams, and limited government support, which constrain their ability to scale up climate responses. Nonetheless, the ability to attract international funding and collaborate on research projects has allowed these reserves to serve as long-term study sites and demonstration areas for climate change adaptation (Klaver et al., 2024; Tucker, 2013).

6. Survey Results

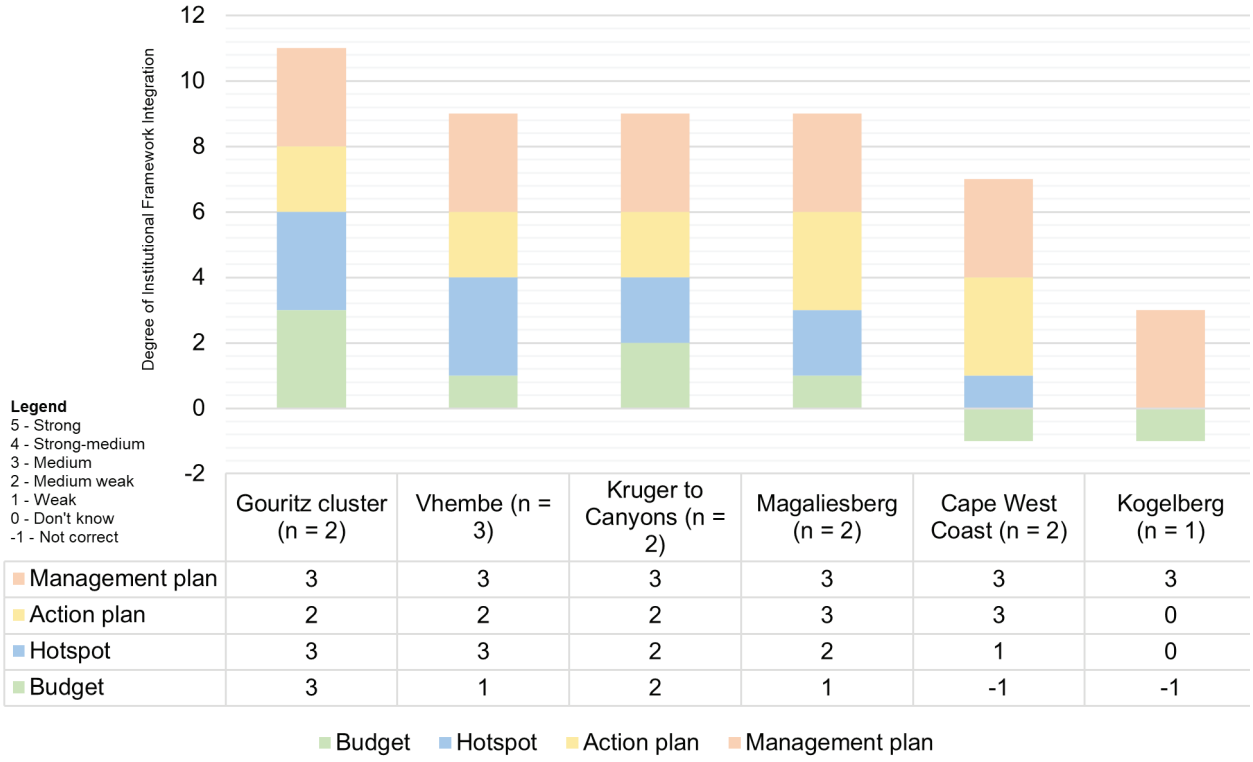
6.1 Effective Governance

The assessment of governance structures within South African biosphere reserves reveals varied levels of flexibility and responsiveness to climate change. Respondents evaluated the degree of climate change integration into institutional frameworks using a Likert scale across four governance indicators: (1) presence of a dedicated climate change budget, (2) positioning as a climate change action hotspot, (3) existence of a specific climate change action plan, and (4) the significance of climate change within the management plan (see Figure 3).

The Gouritz Cluster biosphere reserve demonstrates near-complete integration of climate change considerations, with high scores across all four indicators. This suggests a high level of governance adaptability and prioritization of climate issues within its management structure. In contrast, the Kogelberg biosphere reserve shows much lower scores and some uncertainty, particularly regarding the existence of a climate change action plan and its positioning as a climate change hotspot. These findings indicate that while some reserves have embedded climate change adaptation into their governance frameworks, others are still in the process of developing their approaches. A challenge identified by respondents across most biosphere reserves is the lack of dedicated budgets for climate change actions. The data does not suggest that any biosphere reserve has fully overcome this challenge, indicating that financial prioritization of climate action remains an issue.

UNESCO's biosphere reserve model mandates a zonation system comprising a core area, buffer zone, and transition area, each with distinct conservation

Figure 3 Degree of Integration of Climate Change Into Biosphere Reserve Institutional Framework



	Gouritz cluster (n = 2)	Vhembe (n = 3)	Kruger to Canyons (n = 2)	Magaliesberg (n = 2)	Cape West Coast (n = 2)	Kogelberg (n = 1)
Management plan	3	3	3	3	3	3
Action plan	2	2	2	3	3	0
Hotspot	3	3	2	2	1	0
Budget	3	1	2	1	-1	-1

Note. Source: Own compilation.

and development functions (UNESCO, 2024). Survey responses indicate that most biosphere reserves implement climate adaptation and mitigation projects across all three zones, with the exception of Kogelberg, which limits such activities to the transition area. This pattern reflects an attempt to integrate climate action throughout the landscape, although the extent of such integration varies.

Apart from the Magaliesberg and Cape West Coast biosphere reserves, all others confirmed that their zonation systems align with UNESCO's guidelines. This suggests that while the zonation model is widely adopted, its implementation is not yet uniform. The effectiveness of the zonation model is linked to the existence and clarity of management frameworks. Commentary from the survey highlights that, with exceptions such as Marico and Kruger to Canyons, biosphere reserves lack well-defined management frameworks for zonation. Furthermore, frameworks are often inaccessible to local communities. As one expert noted:

> The management framework for the zones is not known by the communities which are supposed to be guided by the framework. The information about the management framework for the zonation should be simplified and easily accessible on the biosphere reserve social platforms and fully accessible on the website.

This may undermine the potential for adaptive, participatory governance, which is emphasized in both the Lima Action Plan (2016, UNESCO, 2016, pp. 3–6) and the South African Strategy (2016–2020; DEA, 2016, Section 2.5.2, p. 17).

6.2 Social Capital

Social capital—the networks, relationships, and trust among stakeholders—is widely recognized as a core component of adaptive capacity within UNESCO Biosphere Reserves (Carruthers, 2020). The survey assessed the strength of biosphere reserves' relationships with regional, national, and international MAB networks, as well as their relationships with local communities and institutions. Strong relationships were defined in the survey as successful mutual contributions and effective communication (see Figure 4).

The results reveal significant variation in social capital among South African biosphere reserves. Gouritz Cluster and Vhembe biosphere reserves are identified as the most socially connected, reporting strong relationships both within the MAB network and with local partners. Other biosphere reserves, such as Kruger to Canyons, report weaker national and local ties despite institutional strengths, indicating that social capital does not always correlate with organizational capacity.

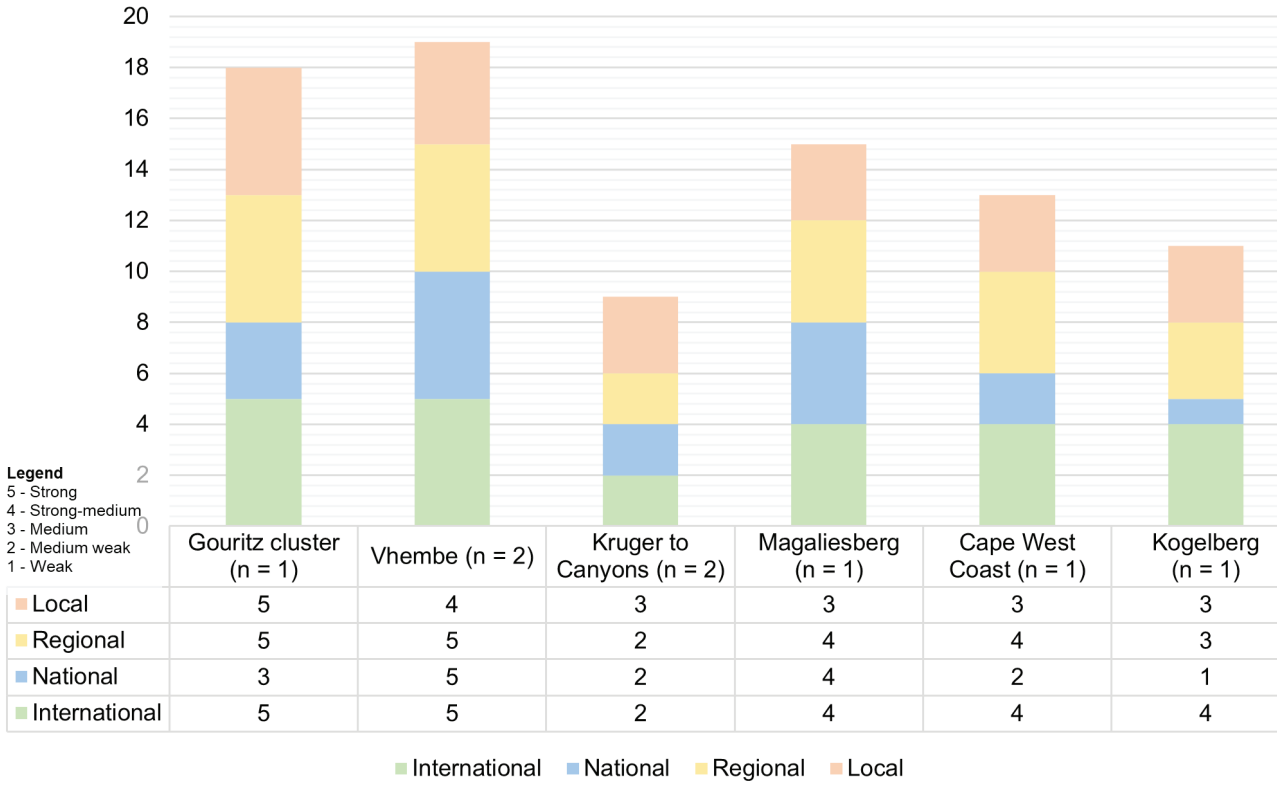
The survey also indicates that, while international connections are generally robust (reflecting UNESCO's MAB programme emphasis on global collaboration), national-level collaboration among South African biosphere reserves is less developed. This gap may limit opportunities for knowledge exchange and coordinated action. At the local scale, most biosphere reserves report medium-strength relationships with communities, businesses, and institutions, but challenges in effective communication and engagement persist. Despite these positive examples, challenges remain in translating climate change knowledge and solutions to diverse stakeholders. As one South African biosphere reserve expert observed:

> Biosphere reserves struggle to translate the climate change effects and solutions to the different local stakeholders. Each stakeholder requires a directed approach on how the solutions to resolving climate change effects will assist resolving the current challenges faced by these stakeholders.

6.3 Access to Resources

The analysis of current and past climate change projects (see Table 1) demonstrates that biosphere reserves with more robust project portfolios—such as Gouritz Cluster, Vhembe, and Kruger to Canyons—have managed to secure funding by acting as project leaders, partners, or coordinators (see Table 2). These roles enable them to access and manage funds directly, thereby enhancing their adaptive capacity and ability to implement climate change initiatives. For example, the Gouritz Cluster biosphere reserve has led or coordinated multiple projects, including wetland restoration, ecological corridor development, and water resource management, in partnership with local municipalities, NGOs, and international donors

Figure 4 Biosphere Reserves' Network and Local Relationship Strength as Indicator of Social Capital



	Gouritz cluster (n = 1)	Vhembe (n = 2)	Kruger to Canyons (n = 2)	Magaliesberg (n = 1)	Cape West Coast (n = 1)	Kogelberg (n = 1)
Local	5	4	3	3	3	3
Regional	5	5	2	4	4	3
National	3	5	2	4	2	1
International	5	5	2	4	4	4

Note. Source: Own compilation.

Table 1 Biosphere Reserves, Current and Past Climate Change Projects

Biosphere reserves	Project description	Duration	Partner
Biosphere reserves Gouritz Cluster (n = 2)	Waterwise Ways Fix'n Learn & Artificial Wetlands: Restoration and management of wetlands	2018–2021	Trapsuutjies, Oudtshoorn Municipality, DOB Ecology
	Jobs for Carbon: Restoration of semi-desert shrublands	2014–2025	DOB Ecology, Department of Forestry, Fisheries and the Environment, Wildlife and Environment Society of South Africa, Rhodes Restoration Research Group Rhodes University (pilot phase), European Union (initial phase: 2014–2016)
	Gouritz Resilient Rivers Project: Protection and management of water resources	2018–2025	DOB Ecology, Cape Nature; Local stakeholders, Hessequa Municipality, Cape Agency for Sustainable Integrated Development in Rural Areas, Working for Wetlands
	Gouritz Ecological Corridors Project	2019–2025	DOB Ecology, Local farmers, CapeNature, Southern Cape Fire Protection Association, Agri Wes Kaap, Working for Wetlands, LandCare, and other stakeholders
Vhembe (n = 2)	Addressing Climate Risk and Building Adaptive Capacity in South Africa's biosphere reserves: Towards Sustainable Water and Ecosystem Management		Vhembe District Municipality
	We are currently working with the Thulamela Makhado Adopt a River Team looking at the restoration of rivers, springs and wetlands. We have been working with them for over the years and they operate in 85 villages in the biosphere.	2021–2023	Flemish Government, Department of Environment, Fisheries and Forestry, South African Weather Services, Department of Water and Sanitation
Kruger to Canyons (n = 2)	Dinkwayane Water Smart project - Funded by Government of Flanders	2019–2023	Government of Flanders in partnership with Kruger to Canyon biosphere reserve, Hoedspruit Hub and Conservation of South Africa
	UNESCO BE-RESILLIENT Project	2021–2023	Flemish Government, Department of Environment, Fisheries and Forestry, South African Weather Services, Department of Water and Sanitation
Magaliesberg (n = 1)	Save our Species Project	2020	The German Commission for UNESCO and the German Federal Foreign Office
	Majakaneng Heritage Trail Project	2021–2022	German Commission for UNESCO
	Designation of the Crocodile River Reserve Protected Area	2017–2019	Grassland Stewardship Alliance, Gauteng Provincial Government, Landowners
	Hennops Revival: River clearing project	2023–2025	Hennops Revival
Cape West Coast (n = 2)	None		
Kogelberg (n = 1)	None		

Note. Source: Own compilation.

such as DOB Ecology and the European Union, indicating organizational adaptive capacity.

Conversely, biosphere reserves like Cape West Coast and Kogelberg, which report no active or past climate change projects, are likely to have more limited access to external funding and, consequently, reduced adaptive capacity. This disparity highlights the importance of institutional capacity and strategic partnerships in securing resources for adaptation to climate change.

Table 2 illustrates the varying degrees of involvement biosphere reserves have in climate change projects. Those with the highest number of projects—Gouritz Cluster, Vhembe, and Kruger to Canyons—frequently assume leading, partnering, or coordinating roles. These positions not only facilitate direct access to resources and funding but also enable biosphere reserves to shape project objectives and outcomes in alignment with local needs. In contrast, some biosphere reserves serve only as observers or have no role in projects implemented within their boundaries, which limits their influence and access to project-derived resources.

The South African Strategy for the Biosphere Reserve Programme (2016) recognizes these challenges, noting that "the absence of national guiding tools to effectively manage biosphere reserves remained a challenge," and that "constraints include funding, status and recognition across all spheres of government" (DEA, 2016, Executive Summary, p. viii).
Respondents reported a spectrum of experiences and outcomes regarding the impact of climate change projects adopted since 2000. The Kruger to Canyons (established 2001) biosphere reserve indicated that such projects contributed meaningfully to climate adaptation or mitigation. In contrast, representatives from the Gouritz Cluster (established 2015) and Vhembe (established 2009) biosphere reserves expressed limited knowledge of any long-term projects, with the Vhembe expert noting that current initiatives have yet to deliver measurable outcomes.

The Kogelberg (established 1998) biosphere reserve similarly indicated that projects are still in the planning phase, while the Magaliesberg (established 2015) biosphere reserve reported a lack of quantitative data regarding the impacts of activities such as alien invasive species removal, and that most climate-related initiatives by large businesses remain in the planning or conceptual stages. The Cape West Coast (established 2000) biosphere reserve reported that two projects had some positive impact, particularly the invasive vegetation removal (leading role) and a de-fencing project by the Cape West Coast National Park (observer role). They emphasized that efforts by the biosphere reserve itself must be broader, better financed, and more sustained to achieve significant results in the long run. Collectively, these insights highlight that, while some progress has been made, the impact of climate change projects in South African biosphere reserves remains limited and often constrained by resource availability. An explanation for this situation is provided by one expert:

> Biosphere reserves such as Kruger to Canyon have developed internal capacity for developing funding proposals for climate change adaptation projects which is linked to the community needs. For example, availability of water in the Kruger to Canyon Region (K2C) is a serious concern for

Table 1 *Biosphere Reserves, Current and Past Climate Change Projects*

Biosphere reserves	Leading role	Partner role	Coordinating role	Observer role	No role
Gouritz Cluster (n = 2)	x	x	x	x	
Vhembe (n = 2)	x	x	x	x	x
Kruger to Canyons (n = 2)	x		x		x
Magaliesberg (n = 1)	x			x	x
Cape West Coast (n = 2)					x
Kogelberg (n = 1)					x

Note. Source: Own compilation.

> the medium and large-scale farming community, therefore, K2C link their Climate Change Projects with issues around water availability, which will enable different contributors within the water sector to converge and come up with solutions. The impact of such projects is felt in a short and long term by the water users.

Another respondent suggested a way to improve the adaptive capacity of climate change projects in South Africa:

> Biosphere reserves need to consider having an advisory role in their institutional arrangement, for example, each district municipality has a professional who deals with issues on climate change activities, these professionals need to be co-opted in the biosphere reserves to assist in providing linkage between the community needs and activities outlined in the vulnerability assessment.

7. Discussion

This study set out to investigate how South Africa's UNESCO Biosphere Reserves demonstrate organizational adaptive capacity in response to climate change, with a focus on governance effectiveness, social capital, and access to resources. The results reveal that biosphere reserves across South Africa are operationalizing adaptive capacity through collaborative governance structures, stakeholder engagement, and resource mobilization. These findings are consistent with the adaptive capacity frameworks articulated in recent scholarship, which emphasize the importance of effective governance, robust social networks, and adequate resources as fundamental to climate adaptation (Chapagain et al., 2025; Siders, 2019).

The participatory governance structures observed in most biosphere reserves, such as representative boards, operational teams, and stakeholder councils, mirror the recommendations of the Lima Action Plan and the South African Biosphere Reserve Strategy. Both policy frameworks advocate for flexible, multi-level, and participatory governance that can adapt to changing environmental and socio-cultural contexts (DEA, 2016; UNESCO, 2016). The integration of climate change considerations into management plans and budgets, as reported by survey participants, reflects a strong institutional commitment and structural readiness for adaptation, echoing findings from Möller (2011) and aligning with international standards outlined in UNESCO's policy documents. However, the study also highlights the challenges inherent in the informal, soft law governance model prevalent in South African biosphere reserves. While this approach fosters collaboration and inclusivity, it can also lead to inconsistencies in policy application and enforcement, a tension noted in both the literature and recent policy reviews (Carruthers, 2020; Klaver et al., 2024). As local NGOs manage the biosphere reserves, they are not well distributed throughout the country and therefore only represent its southern and northern regions. This underscores the need for ongoing capacity building and clearer legislative support to ensure both flexibility and accountability in biosphere reserve governance (Plummer et al., 2017).

Social capital emerges as a pivotal factor in adaptive capacity, with strong networks among local communities, NGOs, academic institutions, and international partners being reported by several biosphere reserves. These networks facilitate knowledge exchange and collaborative action, supporting the integration of indigenous knowledge systems into conservation practice, as seen in the Vhembe biosphere reserve (Kugara et al., 2024). The literature and policy frameworks both emphasize the value of such participatory approaches for resilience and adaptive management (Hedden-Dunkhorst & Schmitt, 2020). The Lima Action Plan and the South African strategy both mandate the inclusion of local and indigenous knowledge and promote capacity building and communication. Despite these strengths, the study identifies persistent challenges such as fragmented collaboration and uneven stakeholder engagement, which are also documented in the literature (Carruthers, 2020). These findings suggest that while foundational elements of social capital are present, more systematic strategies are needed to ensure equitable and sustained participation.

Access to financial, human, and technical resources is pivotal for biosphere reserves' adaptive capacity, yet disparities persist. While some reserves leverage partnerships and diverse funding to implement climate adaptation projects, others face limitations, hindering their effectiveness. This aligns with research emphasizing collaboration's role in adaptation (Serdeczny et al., 2024; Thurman et al., 2022). The Lima Action Plan drives international resource allocation through UNESCO networks to fund conservation and

adaptation, while South Africa's strategy prioritizes national capacity building (e.g., training reserve managers) and knowledge sharing (e.g., sharing climate resilience research). Targeted investment and coordinated support are essential for maximizing impact. Benefits include enhanced funding and local empowerment, fostering sustainable climate action. However, challenges like unequal resource distribution, high capacity-building costs, and potential misalignment between global and local efforts must be addressed to ensure all reserves can effectively combat climate change.

By triangulating empirical findings with the literature and policy frameworks, this study demonstrates a high degree of alignment between the operational realities of South African biosphere reserves and the adaptive capacity principles articulated in both theory and policy. The landscape-scale zonation model, participatory governance, and emphasis on social capital observed in the case studies are all consistent with international best practices and the requirements of the Lima Action Plan and national strategy (Pool-Stanvliet & Coetzer, 2020; UNESCO, 2016). Nevertheless, persistent challenges—such as inconsistent policy implementation, resource disparities, and uneven stakeholder engagement—highlight areas where policy and practice diverge. Addressing these gaps will require continued adherence to policy frameworks, innovative and context-sensitive approaches, and a stronger focus on building and maintaining social capital, particularly among historically marginalized groups.

The study underscores the need for further research on the mechanisms through which social capital is built and maintained, the effectiveness of different governance models, and the long-term impacts of resource availability on climate adaptation outcomes. Comparative studies across biosphere reserves could yield valuable insights into best practices and inform targeted policy interventions. Strengthening formal governance processes, expanding resource mobilization, and deepening community engagement will be critical for enhancing the adaptive capacity of South Africa's biosphere reserves in the face of escalating climate risks.

Beyond immediate management implications, this study advances the academic debate on adaptive capacity and climate governance by demonstrating that adaptive capacity is an emergent property shaped by the dynamic interplay of governance, social capital, and resources. The South African case highlights the strengths of participatory, bottom-up approaches rooted in local knowledge and networks, especially in contexts of historical inequity and institutional complexity. At the same time, it reveals persistent tensions between flexibility and accountability, and between formal policy frameworks and informal local practice—echoing international calls for adaptive governance that is both inclusive and robust (Plummer et al., 2017; Schultz et al., 2011). The findings caution against over-reliance on voluntary, soft law mechanisms without adequate legislative support (Carruthers, 2020; Klaver et al., 2024), and underscore that the effectiveness of global policy frameworks like the Lima Action Plan ultimately depends on local interpretation and enactment as well as permanent funding. As such, South Africa's experience offers important lessons for the global academic conservation research community, illustrating both the opportunities and limitations of biosphere reserves as models for climate adaptation and sustainable development, as seen in other countries of sub-Saharan Africa (Green et al., 2021).

A further limitation lies in the reliance on descriptive indicators, which primarily capture enabling structures of adaptive capacity such as governance processes, social networks, and resource mobilization, rather than actual adaptive outcomes. These structural indicators are important preconditions, but they do not on their own demonstrate whether adaptation is taking place on the ground. Expanding future iterations of this research to include measurable outcomes, for example, biodiversity recovery, improvements in water security, or enhanced community livelihoods, would offer a more comprehensive picture of how adaptive capacity translates into tangible climate resilience.

8. Conclusion

This study sets out to investigate how South Africa's UNESCO Biosphere Reserves demonstrate organizational adaptive capacity in the face of escalating climate change impacts. By examining governance effectiveness, social capital, and access to resources across the national network, the research highlights both the strengths and ongoing challenges of biosphere reserves as vehicles for climate adaptation.

The findings reveal that many South African biosphere reserves have established participatory gov-

ernance structures, fostered robust stakeholder networks, and, in a few cases, secured diversified funding streams to support climate action. These capacities are closely aligned with both the adaptive capacity literature and the guiding principles articulated in the Lima Action Plan and the South African Biosphere Reserve Strategy. Notably, the integration of local and indigenous knowledge, as well as the emphasis on collaborative, bottom-up approaches, positions biosphere reserves as promising models for inclusive and context-responsive adaptation.

However, the study also identifies persistent constraints, including uneven resource distribution, fragmented collaboration, and the limitations of informal, soft law governance frameworks in ensuring consistent policy implementation. These challenges underscore the need for targeted investment, stronger legislative support, and more systematic strategies to build and sustain social capital.

To further enhance the adaptive capacity of South Africa's biosphere reserves, future efforts should focus on formalizing governance processes, expanding resource mobilization, and deepening community engagement. Continued research is needed to explore the mechanisms that underpin social capital and to evaluate the long-term impacts of different governance and funding models on climate adaptation outcomes. By addressing these areas, biosphere reserves can strengthen their role as critical nodes in South Africa's response to climate change, advancing both conservation and sustainable development in an era of increasing uncertainty.

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