

Feedbacks between Hard Infrastructure and Cultural Ecosystem Services in South Africa's National Parks

by

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ABSTRACT

While protected areas are critical for safeguarding nature, the role of hard (i.e., human-made) infrastructure in mediating their ecological and social outcomes remains poorly understood. This thesis examines hard infrastructure investment and condition across South Africa's national park system and explores the relationship between patterns of infrastructure investment and visitor preferences for cultural ecosystem services (CES). The study draws on an existing registry of above-ground infrastructure assets (including roads, buildings, and fences) across 19 of South Africa's 20 National Parks, comprising several thousand individual assets. Infrastructure condition and quality were assessed using indicators of age, condition, and retained economic value, while investment intensity was standardised at the park level (unit cost per square kilometre). K-means clustering of parks based on variables of infrastructure investment intensity identified three distinct infrastructure archetypes: (i) remote parks with low overall infrastructure investment, (ii) high-access urban or peri-urban parks with high investment but no fence infrastructure, and (iii) well-funded parks with integrated infrastructure and relatively balanced investment across asset types. Visitor preferences for CES were analysed using an existing national visitor survey dataset (n = 3,131 respondents) collected across South African National Parks by Ament et al. (2017). The survey used Likert-scale statements capturing visitors' motivations and valued experiences. Factor analysis identified five CES bundles (Natural History, Recreation, Sense of Place, Safari Experience, and Outdoor Living), and k-means clustering of park-level mean factor scores revealed four CES-based park clusters: (i) Nature-Learning & Heritage, (ii) Safari & Charismatic Wildlife, (iii) Place-Attachment & Immersive Experiences, and (iv) Urban Recreation. Relationships between infrastructure archetypes and CES clusters were explored using MANOVA and Kruskal-Wallis tests with post-hoc comparisons. Results showed partial alignment between infrastructure and CES patterns: Recreation-oriented CES were associated with high-access, infrastructure-dense parks, while Natural History values were more prominent in infrastructure-light parks. In contrast, Sense of Place and Outdoor Living did not differ significantly across infrastructure archetypes. Overall, the findings support the hypothesis that institutional priorities for infrastructure investment in South Africa's national park system are shaped by visitor demand-driven feedback loops, and an emerging differentiation in park roles. Where misalignments between CES and infrastructure were observed, these may reflect weak or lagged feedbacks between visitor values and governance responses. This study contributes to a better understanding of protected area dynamics and the importance of infrastructure within conservation contexts, particularly in mediating the delivery of cultural ecosystem services. Future research could extend this work through longitudinal monitoring of infrastructure-CES feedbacks, deeper investigation of links between

infrastructure and ecological outcomes, more explicit examination of governance processes, “soft infrastructure,” and justice and equity in protected area systems.

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CHAPTER 1 INTRODUCTION

1.1 Context and Problem Statement

1.1.1 The Global Role of Protected Areas

Protected areas (PAs) are essential for biodiversity conservation (CBD, 2022; Venter et al., 2018). They play a critical role in maintaining ecological resilience and supporting ecosystem functioning across multiple scales (Cumming et al., 2015; Maxwell et al., 2020). However, as global biodiversity and climate challenges intensify, PAs face mounting pressures from human activity and increasingly need to justify their existence (both ecologically and socio-economically) amid competing land uses (Belgrano et al., 2023; Cumming, 2016; Folke et al., 2021). Beyond conservation, PAs generate tangible benefits such as revenue and intangible ones, including their ability to offer meaningful ecotourism experiences (Cumming et al., 2015; Infield, 2001; Maciejewski & Cumming, 2016). These non-material benefits are often framed in terms of cultural ecosystem services (CES) (Romanazzi et al., 2023), and there is a need for a deeper understanding of how protected areas can better deliver such socio-cultural benefits.

Defining a “protected area” is complex, as its interpretation varies across regions and organisations, which has led to discrepancies in conservation standards and management strategies (Archibald et al., 2020; Hoffmann, 2022). For consistency and clarity, this study adopts the IUCN definition of a protected area: “A clearly defined geographical space, recognised, dedicated, and managed through legal or other effective means to achieve the long-term conservation of nature, along with associated ecosystem services and cultural values” (CBD, 2008). This is a globally recognised definition and aligns with international biodiversity conservation targets and assessments. The focus of this thesis is on national parks (NPs), usually classified as IUCN Category II protected areas, which are managed primarily for ecosystem protection, education, and recreation (Bosworth & Curry, 2020). While South Africa (SA) does not formally adopt the IUCN classification system, South Africa’s National Parks function in agreement with its principles. National parks are legally protected by national governments to preserve ecosystem integrity for future generations, restrict harmful exploitation, and provide opportunities for spiritual, educational, and recreational activities in environmentally and culturally compatible ways (Curry, 2009). In many countries around the world NPs are flagship conservation sites and attract significant attention, funding, and

management efforts (Protected Planet, 2024). In South Africa, the current 20 national parks (excluding Grasslands, which is in the process of being established) comprise more than 4 million hectares, approximately 4% of South Africa's land area, and an estimated 39% of the country's total area under formal protection (Roux et al., 2023). Though they are not the most common protected area type, national parks are vital to South Africa's conservation estate and tend to attract more financial support and public visibility than other PA types, such as provincial parks. Importantly, some of South Africa's national parks (such as Kruger National Park and Kgalagadi Transfrontier Park) also comprise exceptionally large and contiguous landscapes that require intensive/ larger scale management compared to smaller non-national protected areas.

National parks are key components of the global protected area network. Global expectations for the expansion of this network continue to rise, driven by international commitments, such as the Kunming-Montreal Global Biodiversity Framework (GBF), which outlines a post-2020 agenda for stopping biodiversity loss and ecosystem restoration (CBD, 2022). Central to this agenda is the "30 by 30" goal, which calls for the protection of at least 30% of terrestrial, inland water and coastal and marine areas by 2030 (CBD, 2020) and corresponds with broader development goals, including: SDG 14 (Life Below Water) and 15 (Life on Land) (United Nations, 2015). Ambitious proposals (like the Global Deal for Nature which aims for 50% protected area coverage) speak to the urgency of large-scale protection efforts (Dinerstein et al., 2019; Ellis & Mehrabi, 2019). As one of the most prominent and politically visible forms of protected areas around the world, national parks are expected to continue making significant contributions to global biodiversity goals, even as conservation increasingly adopts landscape-scale and OECM-based approaches.

Despite growing global policy support for expanding protected area networks, there is also evidence that these spaces are being undermined (Cook et al., 2017; Forrest et al., 2015; Pack et al., 2016). This is illustrated by ongoing downgrading, downsizing and degazettement (PADDD) events across the world that challenge longstanding presumptions about the permanence of national parks and other PAs (Golden Kroner et al., 2019; Mascia & Pailler, 2011). Furthermore, designating more protected land alone is not sufficient, as the effectiveness of protected areas depends largely on how they are managed and governed (Geldmann et al., 2023; Leverington et al., 2010; Li et al., 2024; Rodrigues & Cazalis, 2020; Watson et al., 2014)

and conservation success requires a recognition that the outcomes of protected areas depend on social-ecological interactions (Cumming & Allen, 2017).

To improve the effectiveness of protected areas, greater attention needs to be paid to the fundamental elements that enable them to function. Among these, the role and relevance of infrastructure have been underexplored (Anderies, 2014). Infrastructure provides the basis for nearly all aspects of protected area functioning, so when poorly maintained or unevenly distributed (or lacking altogether), it may limit the ability of parks to deliver on both their conservation and social mandates and as demands on parks continue to grow, infrastructure becomes central to mediating these often-competing goals. Although the built environment has historically received limited attention in conservation research, existing studies show it contributes to enabling access, visitor use, cultural ecosystem service delivery, and the financial sustainability of protected areas (Biggs et al., 2014; De Vos et al., 2016; Eagles et al., 2002; Echeverri et al., 2022; Heagney et al., 2018). In this context, a clear understanding of: where infrastructure is located, what types of infrastructure are present and where investment is directed is important to assess whether PAs are equipped to meet the expectations placed upon them. These themes and key knowledge gaps are explored in greater detail in Chapter 2.

1.1.2 The Case of SANParks' National Park System

South Africa's National Parks provide an appropriate context to explore how infrastructure, governance, and social-ecological dynamics interact to shape conservation outcomes. The agency of South African National Parks (SANParks) is the governing body responsible for managing the country's national parks. Hereafter, SANParks refers to the organisation, while South Africa's National Parks refers to the parks themselves. This system of 20 national parks has a dual purpose of biodiversity preservation while also being a driver of ecotourism and local economic development (De Witt et al., 2014; van der Merwe et al., 2020). However, SANParks faces several significant challenges that threaten its conservation and operational efficiency, including, but not limited to: tensions surrounding land reform, poaching and illegal harvesting, urban encroachment, human-wildlife conflicts and environmental threats (Ferreira et al., 2017). Additionally, the organisation is grappling with ageing infrastructure, with particularly slow progress in maintaining existing facilities, especially in older parks (SANParks, 2023b). Perhaps the most pressing challenge is financial sustainability. As public funding is in continuous decline, SANParks heavily relies on ecotourism as its primary revenue source, with approximately 80% of its income coming from tourism-related activities (van der

Merwe et al., 2020). However, ecotourism also comes with a myriad of challenges, for example, the potential for environmental degradation and the introduction of invasive species through visitor activities (Bouchard et al., 2015; Foxcroft et al., 2017).

The competitive landscape of tourism in South Africa necessitates national parks to continually adapt their offerings to attract visitors. With numerous private game reserves and alternative tourism options, SANParks has to prioritise its service quality and visitor experience to maintain its status as a premier ecotourism destination (Engelbrecht et al., 2014; Saayman & Van Der Merwe, 2017). To do so, it is paramount for the organisation to understand tourist motivations and preferences (De Witt et al., 2014; Van Der Merwe & Saayman, 2007) and increasingly, research shows that infrastructure influences how visitors perceive cultural ecosystem services (De Vos et al., 2016; Mancini et al., 2019).

SANParks' 2025-2030 Strategic Plan explicitly recognises infrastructure as a key enabler to achieve Vision 2040 and the organisation's strategic outcomes (SANParks, 2025). Vision 2040, which will be discussed in more detail in Chapter 3, refers to SANParks's ambitious goal of reimagining and co-creating national parks for people to live in harmony with nature, in a way that moves away from isolated parks and towards landscape level approaches (SANParks, 2024c). Over the next five years, SANParks aims to expand sustainable tourism infrastructure and replace outdated facilities that reduce the appeal of tourism offerings and compromise the visitor experience (SANParks, 2025). The Strategic Plan also outlines climate-resilient and "green" infrastructure as one of the ways to defend against climate-related risks; from now on, all infrastructure developments will incorporate sustainability considerations from the outset (SANParks, 2025).

The infrastructure-related priorities mentioned above demonstrate SANParks' growing recognition of the strategic importance of infrastructure. However, there is still a limited understanding of how infrastructure is distributed, maintained, and invested in across national parks. Without system-wide evidence, it is difficult to assess whether existing infrastructure is able to support the organisation's multi-functional goals and the diverse roles national parks are expected to fulfil. A poor understanding of infrastructure in NPs could lead to misaligned planning and missed opportunities to improve visitor experiences, which would be detrimental, especially as pressures on these spaces continue to grow and expectations to deliver equitable cultural value intensify.

1.2 Rationale and Purpose of the Study

The existing literature on protected areas highlights the need to consider the multifaceted dynamics of social-ecological systems (SESs) (Cumming et al., 2015; Palomo et al., 2014; Reyers & Bennett, 2025). However, infrastructure remains an underexplored component in conservation research, with much of the focus being on ecological function (Ahlborg et al., 2019; Anderies, 2014; Chester et al., 2023; Markolf et al., 2018). In protected areas, the material structures that enable access, management, and use (such as roads, buildings, visitor facilities, trails and fences) are collectively termed hard infrastructure (HI) (Anderies et al., 2016). However, little is known about how HI mediates the outcomes of efforts to sustainably manage PAs. Although previous studies have shed some light on how infrastructure shapes visitor experiences and ecological processes, the focus has largely been on infrastructure as a direct threat to ecological integrity or as a supporting variable within existing frameworks. Far fewer studies have analysed hard infrastructure from an SES perspective as a system component in its own right, or examined its role in mediating how ecosystem services (particularly cultural ecosystem services) are produced and experienced. There is also still a notable absence of cross-park studies that provide data on key aspects, such as age, condition, and the costs associated with protected area infrastructure, which are needed to assess the financial sustainability of PAs, their effectiveness in achieving strategic objectives, and to inform conservation investments.

To address this gap, I present a detailed analysis of the current infrastructure in South Africa's National Parks and assess the alignment between infrastructure provision and visitor preferences for cultural ecosystem services. To interpret my findings, I draw on the Coupled Infrastructure Systems (CIS) Framework, which provides a useful lens for understanding protected area dynamics. The CIS Framework conceptualises SES components, including natural and built, as co-evolving "infrastructures" within the broader system (Anderies et al., 2022) making it useful for understanding how infrastructure interacts with governance and visitor experiences. While the framework has had some empirical application in conservation contexts (Anderies et al., 2016, 2022), it hasn't yet been fully applied with real-world data.

South Africa's NPs are an ideal case study for exploring these dynamics. The system is a long-standing and well-developed protected area network, with socially and ecologically diverse parks, as well as an available infrastructure inventory and existing visitor survey data. No prior study has provided a system-wide analysis of infrastructure variation across this (or any

national park system), nor has it examined the implications of infrastructure patterns for CES delivery. Additionally, there is minimal literature within the broader context on the role of hard infrastructure in protected areas. Furthermore, investigating the relationship between conservation, tourism, and infrastructure also directly supports SANParks' strategic outcomes and the associated strategic pillars to achieve Vision 2040 (SANParks, 2025).

Hence, this research contributes to global knowledge on protected area management and the role of infrastructure in social-ecological dynamics. Conceptually, this thesis contributes to our understanding of the human-nature interactions within protected areas and is a step towards operationalising the CIS framework and the dynamic modelling of SES. More practically, the study addresses an important knowledge gap for SANParks and provides the first system-wide analysis of infrastructure patterns and their relationship to CES delivery, which can inform strategic infrastructure planning for both South Africa's National Parks and other protected area networks facing similar challenges.

1.3 Research Objectives and Key Questions

This research examines the patterns of infrastructure condition, investment, and distribution in South Africa's National Parks, and how they relate to variations in CES preferences. The following thesis is organised around two main objectives:

1. To assess patterns in the condition, investment, and spatial distribution of different types of hard infrastructure across SANParks, and to develop park-level profiles or archetypes that reflect variation in infrastructure investment.
2. To explore the relationship between infrastructure investment patterns and visitor preferences for CES.

To address these objectives, the study answers the following research questions:

1. What is the general condition (in terms of quality, age, and longevity) of infrastructure in South Africa's national parks, and how does this vary across parks and infrastructure types/categories?
2. How is infrastructure investment distributed across South Africa's national park system through park-level and infrastructure category allocations, and how do park size and visitor numbers relate to investment decisions?

3. Are there identifiable clusters of parks based on their similarities in infrastructure profiles?
4. What is the relationship between patterns of hard infrastructure and visitor preferences for cultural ecosystem services, and how do these interactions inform infrastructure planning and CES delivery?

To answer these questions, I draw on infrastructure data from the SANParks' Fixed Asset Report, visitor number records, and CES preference survey data originally published by Ament et al. (2017), using a mixed-methods approach across two data chapters. The first of these, Chapter 4, uses descriptive and multivariate techniques (including Principal Components Analysis, k-means clustering, and regressions) to assess infrastructure condition, investment patterns, and identify park archetypes. Chapter 5 then employs factor analysis, k-means cluster clustering, followed by parametric and non-parametric tests, Fisher's Exact Test, and linear regression to investigate how CES preferences vary across parks and relate to the infrastructure clusters identified in Chapter 4.

1.4 Structure of Thesis

This thesis is organised into the following chapters:

Chapter 1: Introduction outlines the broader research context, identifies key knowledge gaps, presents the purpose of the study, and provides the research objectives and questions.

Chapter 2: Literature Review and Conceptual Framework provides a critical review of the literature on SES theory and the resilience of protected areas. It introduces the CIS framework in more detail and positions the study within current debates in conservation science, CES theory, infrastructure studies and equitable resilience.

Chapter 3: Study Areas provides an overview of the SANParks system, with a focus on the 19 NPs included in the analysis.

Chapter 4: Assessing Infrastructure Patterns across South Africa's National Parks addresses research questions 1, 2 and 3.

Chapter 5: The Relationship between Hard Infrastructure and Visitor Preferences for Cultural Ecosystem Services addresses research question 4.

Chapter 6: Synthesis, Conclusions, and Recommendations brings together the findings from the previous chapters to reflect on how the research questions were answered and the implications of the findings for protected area management, infrastructure planning, and CES delivery. It outlines recommendations for policy and future research, with a particular focus on the equity and resilience of protected areas.

CHAPTER 2 LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

2.1 Social-Ecological Systems Thinking in Conservation

The concept of protected areas has undergone significant evolution over time. The modern notion of protected areas originated in the 1800s, primarily in North America, Europe, and South Africa, where iconic landscapes were set aside for conservation (Watson et al., 2014). These areas were, however, often established through the forced and unjust removal of indigenous peoples (Mbaria & Ogada, 2016). Early approaches to conservation management followed an “island” model, in which protected areas were treated as isolated units with limited public access and little consideration of social dimensions or broader landscape interactions (Palomo et al., 2014; Cumming et al., 2015). Tourism in PAs surged by the mid-twentieth century, particularly in developing regions, and with it brought both economic benefits and social trade-offs (Child, 2009). In particular, the rapid expansion of protected area networks caused friction with local communities over land use and access (Watson et al., 2014). In the late 1980s and early 1990s, a growing global recognition of Indigenous rights ultimately led to a shift towards more holistic and inclusive conservation management approaches (Mace, 2014).

PAs are now increasingly understood as social-ecological systems (Cumming, 2016). This transition has been strongly shaped by the rise of landscape approaches, such as biosphere reserves, and the development of community-based natural resource management (CBNRM) models, which draw heavily on Ostrom’s work on the commons (and have also informed adaptive management and resilience theory) (Berkes, 2004; Bridgewater, 2016; Ostrom, 1990b). In the Anthropocene era, where human impacts are the main driver of planetary change, the management of protected areas has become more and more complex and requires the integration of social needs, governance dynamics and ecological integrity (Cumming, 2011). The shift towards integrative approaches reflects a deeper understanding of the interconnectedness of human societies and the natural environment, often called the “people and nature” paradigm, which views humans as embedded within and dependent on natural systems (Mace, 2014). Recent reflections by Reyers & Bennett (2025) have presented a ‘people *with* nature’ perspective, with even greater recognition of the intertwined and co-constitutive relationships between humans and ecosystems, and therefore the need for holistic and transdisciplinary approaches.

Social-ecological systems are complex adaptive systems (CAS) with interdependent social, ecological, and economic components (Allen & Holling, 2010; Holling, 2001). SES theory helps explain how feedbacks and interactions among these components shape system resilience and response to change (Folke et al., 2010). Framing conservation challenges as social-ecological recognises that: 1) human well-being depends on natural systems, 2) people do not exist outside of natural systems, making “command and control” approaches redundant; and 3) social factors like governance are as much a part of biodiversity conservation as ‘ecological’ concerns (Cumming, 2016; Cumming et al., 2015; Mathevet et al., 2016; Palomo et al., 2014). Protected areas are best understood as dynamic SESs (therefore complex adaptive) nested within larger social and ecological landscapes (De Vos & Cumming, 2019). This means that their effectiveness is influenced by environmental factors such as climate and biodiversity variability in conjunction with societal factors like evolving social demands, policy priorities, and local livelihoods (De Vos & Cumming, 2019). These complexities require adaptive, multi-scale governance approaches that recognise PAs as integrated components of larger SESs that are subject to change (Cumming, 2016; Preiser et al., 2018).

This framing provides a foundation for understanding the dynamic, multi-dimensional nature of protected areas. As embedded SESs, parks are shaped by a range of factors that interact across scales and over time (Cumming, 2016). Within this complexity, infrastructure and governance help mediate the resilience of protected areas, for example, in structuring how they manage trade-offs and respond to shifting social and environmental pressures. In particular, infrastructure influences both the ecological functioning of parks (e.g. fences that regulate animal movement, roads that enable monitoring and anti-poaching patrols) and the ways in which people experience and value them (e.g. road networks facilitating wildlife viewing, accommodation enabling overnight stays). This is especially relevant in contexts like South Africa, where national parks are expected to meet a diversity of social, ecological and economic objectives. Therefore, taking a social-ecological systems perspective on the interplay between infrastructure, governance, and the delivery of CES provides an entry point for understanding protected area resilience and equity.

2.2 Resilience Theory

The features of CAS (that they are radically open, adaptive, dynamic, relationally constituted, have complex causality and emergence) also have implications for how we manage and govern these systems, mainly in that interventions can have far-reaching and unpredictable effects

(Preiser et al., 2018). Resilience theory offers a way to approach such complexity in pursuit of desirable outcomes. Given that they are vulnerable to socio-economic and environmental change, a key normative outcome for area-based conservation systems, including PAs, is to be resilient (De Vos et al., 2016). I define resilience as the capacity of a system to adapt and reorganise itself to retain a desired system identity (including essential structure, functions, feedbacks and ecosystem services). In this study, resilience is used conceptually to interpret how protected areas function as complex social-ecological systems, to ultimately support the broader objective of understanding protected area dynamics.

Resilience theory was promoted by Holling (1973) as a concept that describes the capacity of ecosystems with alternative attractors to endure perturbation while remaining in their original state. At its conception, resilience theory represented a departure from the prevailing ecological paradigm of stable equilibria (Folke, 2006). Since then, resilience has been outlined in two ways in ecological literature, firstly, as the time it takes for a system to return to equilibrium or steady state following a perturbation (Gunderson, 2000; Holling, 1973). Secondly, which is the interpretation I use in this thesis, it is seen as (presuming the existence of multiple stable states or regimes) a system's ability to absorb disturbance and reorganise while undergoing change to maintain its fundamental function, structure, identity, and feedbacks (Walker et al., 2004). Carpenter et al. (2001) offers a three-part understanding of resilience: 1) the ability of a system to endure a certain level of disturbance and remain within the same state or domain of attraction, 2) the system's capacity for self-organisation, 3) the extent to which the system can develop and enhance its capacity for learning and adaptation.

The resilience of a system is closely linked to its identity. This study's definition of resilience posits that following perturbation, the system does not need to fully revert to its original state, but rather persevere in desirable states and maintain its core characteristics. The identity of a protected area reflects its stated aims, as determined by society, generally referring to the species and habitats that the area intends to conserve, as well as the provision of ecosystem services, such as supporting, regulating, provisioning, and cultural services (Cumming et al., 2005; De Vos et al., 2016). Resilience, then, can be understood as the ability of the social-ecological system to maintain these key elements of its identity in space and time despite ongoing environmental or institutional change (Cumming et al., 2005; De Vos et al., 2016). Therefore, resilience can be determined by the ability of parks to continue delivering core ecosystem services, particularly cultural services, amidst perturbations. As most protected

areas (including South Africa's National Parks) are vulnerable to both ecological and social change, understanding resilience is key to managing PAs as complex social-ecological systems.

It is important to note that while resilience is often considered desirable, it is not necessarily a positive trait in all systems (Carpenter, 2001). Systems in highly undesirable states (e.g., macro-algae-dominated reefs or poverty traps) may be exceedingly resilient and withstand attempts to transform them into a different configuration (Angeler & Allen, 2016; Cinner & Barnes, 2019). In light of this, contemporary perspectives view resilience as a normative outcome (i.e. something to be fostered in socially and ecologically desirable systems) (Folke, 2016; Folke et al., 2010). This encompasses a system's ability to *adapt* to change, while retaining its key positive characteristics and overall identity; or, if the existing configuration becomes untenable, to *transform* into a fundamentally new and more desirable configuration, which would entail a loss of system identity (Berkes & Turner, 2006; Carpenter & Brock, 2008; IPCC, 2023; Olsson et al., 2014; Walker et al., 2004; Walker, 2020). Many of the proponents of transformation argue for deliberate transformation that uses windows of opportunity to shift regimes into new states and identities, even if they were sustainable under the old regime (Folke et al., 2010; Olsson et al., 2006; Westley et al., 2011). However, it's important to also note that some scholars have critiqued that discourse on transformation often lacks conceptual clarity, particularly regarding what constitutes the system and its identity, which makes it difficult to distinguish adaptation from transformation (Blythe et al., 2018; Neuhuber, 2025).

2.3 The Coupled-Infrastructure Systems Framework

Understanding the resilience of protected areas requires consideration of the interacting system components that shape their overall functioning/adaptiveness. The CIS framework is useful in this context as it makes explicit feedbacks that sustain or erode a system's robustness (i.e., the ability to maintain desired system characteristics despite fluctuations in the behaviour of its components or its environment) over time (Anderies et al., 2004). The Coupled Infrastructure Systems Framework builds on a long lineage of institutional and social-ecological systems theory. Specifically, the framework emerged directly from the Robustness of Social-Ecological Systems Framework by Anderies et al. (2004), which itself extends Ostrom's Institutional Analysis and Development (IAD) framework (Anderies et al., 2016). The IAD framework was developed in response to the "tragedy of the commons" narrative as a way of analysing how institutional arrangements shape the outcomes of collective decision-making in shared-resource settings (Kiser & Ostrom, 1982; Ostrom, 2005; Ostrom et al., 1994). The framework

conceptualised human–environment interactions through action arenas, using three key elements: attributes of the (bio)physical world (characteristics and ecological setting of the resource system), attributes of the community (socio-cultural features of the users), and rules in use (formal and informal institutions that guide use) (Ostrom, 1990).

The Robustness framework extended the IAD framework to better account for the dynamics of social-ecological systems (Anderies et al., 2004). The purpose of the framework was to understand the internal dynamics within SES and how these factors influence how a system responds to change, and help identify potential vulnerabilities to disturbance (Anderies et al., 2004). The key contributions were a focus on thinking in terms of infrastructure and reemphasising the importance of feedbacks in systems (Anderies et al., 2016). In this context, “infrastructure” refers to the underlying structures (whether physical, institutional, ecological, or social) that enable systems to function and produce certain outcomes (Anderies et al., 2016; Janssen & Anderies, 2023). The Robustness framework identified four core system components: resource, resource users, public infrastructure, and infrastructure providers (Anderies et al., 2004). Incorporating Ostrom's institutional standpoint made it one of the few approaches at the time that directly bridged the gap between social-ecological systems theory, resilience, and empirical analysis (Anderies & Janssen, 2013).

In the same way that the IAD framework evolved over time, the authors of the Robustness framework proposed an extension that placed greater emphasis on how action situations change over time, particularly regarding the creation, maintenance, and distribution of shared infrastructure and its outputs (Anderies et al., 2016; Ostrom, 2011). This resulted in the development of a CIS framework that redefined the unit of analysis to the coupled infrastructure system (Anderies et al., 2016). Anderies et al. (2016) argue that thinking in terms of “coupled infrastructure systems” is more appropriate than “social-ecological systems” as the latter implies a separation between social and ecological domains. In contrast, the CIS perspective views system components (whether natural, social, institutional, or built) as interdependent and interacting infrastructures that co-produce system outcomes (Anderies et al., 2016). Hence, SESs can be thought of as special cases of CIS in which the importance of some classes of infrastructure (e.g., natural infrastructure) is assumed to be more significant or of greater interest than others (e.g., man-made infrastructure) (Anderies et al., 2016).

The CIS framework explicitly acknowledges the influence of human-made infrastructures on resource management, decision-making processes, and overall system functioning, and offers

a more comprehensive understanding of CAS dynamics (Anderies et al., 2016, 2022; Janssen et al., 2022). The framework is particularly useful in collective action problems related to shared infrastructure. At the same time, it addresses a number of critiques of resilience and SES theory, especially the challenges posed by the lack of off-the-shelf models and analytical tools that allow for generalisation and comparison across multiple contexts (Anderies et al., 2022). The CIS framework is used in this study as it helps make sense of the complexity of PAs and provides a way to better understand the relationships between system components, and how the various feedbacks enhance/erode PAs' ability to adapt to change while maintaining their core functions and values.

The CIS Framework (Fig. 1) describes CISs using four key elements: resource users (RU), natural infrastructure (NI), public infrastructure (PI), and public infrastructure providers (PIP) (Anderies et al., 2022). Resource users (RU) refer to individuals, communities, or organisations that rely on and interact with the natural resources in the SES, drawing their livelihoods from them either directly or indirectly (Anderies et al., 2022). Natural infrastructure (NI) is the ecological component of the SES, including natural resources, ecosystems, and biodiversity (Anderies et al., 2022). NI plays a crucial role in supporting the functioning and resilience of the SES, providing essential services like water purification, carbon sequestration, and habitat for wildlife. Public (i.e., shared) infrastructure (PI) denotes the built environment and human-made systems that provide support and services to the SES and are open to public use (Anderies et al., 2022). PI consists of hard infrastructure and soft infrastructure. Hard infrastructure refers to tangible physical components, whereas soft infrastructure refers to the intangible elements that support the functioning and operations of a society (e.g., governance systems, regulations, and information networks). Public infrastructure providers (PIPs) are the actors involved in the decision-making and governance of the SES (Anderies et al., 2022). They can be governmental agencies, non-governmental organisations, or other entities involved in infrastructure development and management.

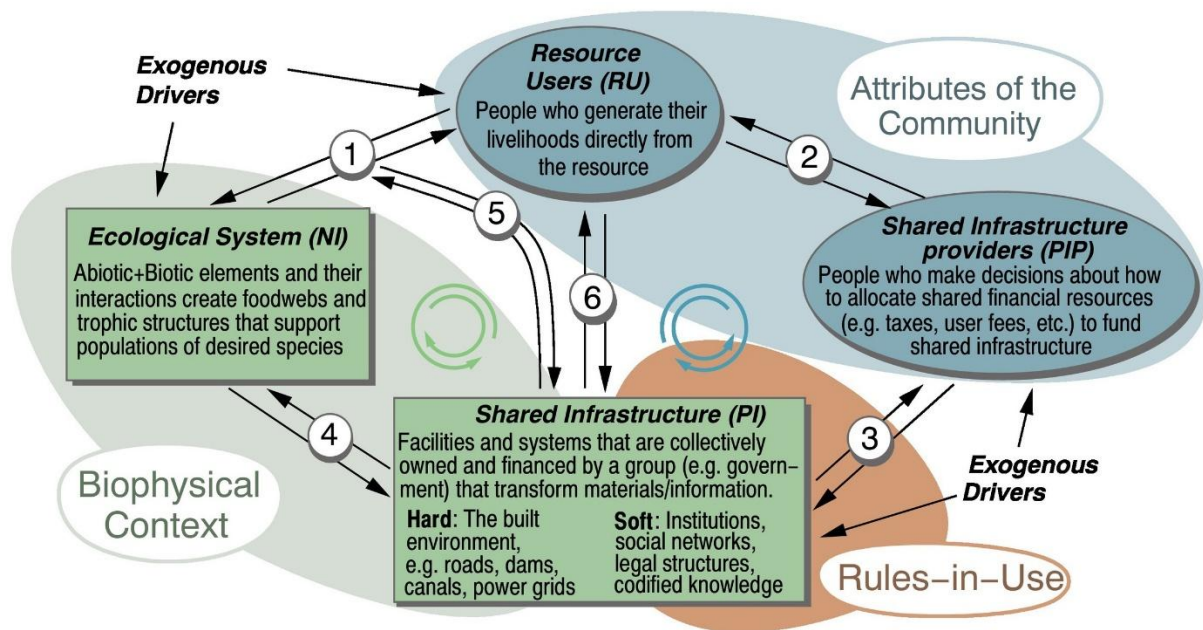


Figure 1. The CIS Framework (Anderies et al., 2022). The framework depicts the fundamental elements and interactions (arrows 1–6) that comprise any ‘Coupled Infrastructure System’. The green and blue circles represent feedback loops.

The framework gives special attention to the importance of feedbacks (flows of information, influence, and resources) between system components, which shape how infrastructure (natural and shared), governance, and resource users interact over time. These feedbacks are represented in the model through six connecting links and four major feedback loops that influence the overall robustness and resilience of the system (Anderies et al., 2022). Disruptions or dysfunctions in the links or the absence of critical processes within system elements can significantly impact the functioning of the entire system (Anderies et al., 2022). In Fig. 1, the green loops represent management or operational feedbacks, where actions taken by infrastructure providers respond to ecological conditions (natural infrastructure), influencing how public infrastructure supports resource use. The counterclockwise loop represents traditional, top-down governance and formal policy processes. The clockwise loop represents co-management, where information flows in both directions, indicating collaborative decision-making processes. The blue loops represent political economy feedbacks that shape how public infrastructure providers interact with resource users and influence decisions around public infrastructure. The outer blue loop reflects standard political and investment processes, where PIPs propose infrastructure changes or funding requests that are processed through formal government budgeting systems. The inner blue loop represents co-managed political feedback, where collective action by stakeholders or resource users influences the prioritisation of infrastructure. The functioning and coupling of these feedback

loops vary across contexts, and their effectiveness determines whether “effective conservation” or “good governance” is achieved (Anderies et al., 2022).

While the CIS framework provides a valuable systems perspective for analysing complex systems, it has several methodological limitations that are worth acknowledging. Although the framework helps identify key components and feedbacks it does not prescribe standardised analytical methods or quantitative metrics for measuring the strength and direction of these dynamics, although there have been recent attempts to use the CIS framework in the modelling of SES (Anderies et al., 2022). However, empirical operationalisation of the framework has proven challenging; empirical studies are constrained by data availability, which could lead to an emphasis on those components that are most readily observable or quantifiable (such as a focus on hard infrastructure rather than soft infrastructure). Because feedback and system dynamics are central to the framework, its application ideally requires longitudinal data; in practice, many studies (including this one) rely on cross-sectional data, which limits the extent to which dynamic interactions can be captured. Due to these data constraints, there is also the risk that applications of this framework will be largely applications of the CIS framework are largely descriptive rather than predictive. The analytical complexity of the framework could also make comparisons across case studies difficult and the complexity of the different system components and their feedbacks operating across scales would likely result in simplified or partial representations of the system. The fact that system outcomes typically emerge from multiple interaction factors can also lead to attribution challenges (i.e. limits the ability to infer clear causal pathways or predict system responses to specific interventions). A further methodological challenge of the CIS framework is the interpretation and classification of system components, as assigning real-world actors and institutions to categories such as resource users or public infrastructure providers can be ambiguous and context-dependent. Lastly, CIS explicitly recognises institutional and social components but does not inherently address the political economy or historical inequities within a system, which may lead analyses to underemphasise how power dynamics shape infrastructure outcomes and resilience.

The limitations discussed above do not negate the usefulness of the CIS framework, but they do shape the kinds of insights that can be drawn from this study in particular. However, it's important to note that the effectiveness of resilience-based approaches (such as the CIS framework) lies not in their ability to predict the exact outcomes of management actions (Anderies et al., 2006). They are most helpful in identifying and understanding system attributes that significantly influence the system's dynamics and ultimately develop a guiding

set of principles for interventions that enhance the long-term resilience of SESs (Anderies et al., 2006). In line with this, the CIS framework highlights the interdependencies and feedback loops within SESs/CISs which can either enhance or erode the resilience of the system. The CIS framework enables the identification of key system components and the feedbacks shaping system resilience, allowing researchers and managers to pinpoint leverage points for strategic intervention. Here, I use the CIS framework as a tool to analyse how hard public infrastructure and its governance influence the resilience of South Africa's National Parks, predominantly through their relationship with the delivery of cultural ecosystem services.

2.4 Hard Infrastructure in Protected Areas

Hard infrastructure is a key component in coupled infrastructure systems that facilitates the interactions and interdependencies between different system components that collectively shape a system's dynamics. Hence, the resilience of a protected area is related, in addition to many other factors, to how infrastructure is planned, maintained, and governed, particularly in response to evolving cultural and recreational demands. SES research has often overlooked the influence of intentionally designed or constructed elements, but the growing scale of human activity and infrastructural systems means the interactions and feedbacks between built environments and the biophysical context in which they operate can no longer be ignored (Ahlborg et al., 2019; Anderies, 2014; Chester et al., 2023; Markolf et al., 2018). Where it has been considered, the focus is often on infrastructure as a threat to ecological integrity or within social-ecological frameworks. Very few studies have actually analysed infrastructure through an SES perspective or examined it as a mediator of ecosystem services. In this section, I will examine the types, roles, and impacts of hard infrastructure in protected areas, and then identify gaps in the existing literature.

Hard infrastructure in PAs may take many forms and consist of facilities in support of conservation (such as management roads and tracks, office facilities, staff housing, fences, bulk services, workshops, and stores) and tourism (such as tourist roads and tracks, walking trails, public viewing points, bird hides, picnic sites and tourist accommodation) (SANParks, 2021). Park management faces the complex task of sustainably combining recreational and ecological objectives (Zelenka & Kacetl, 2013). Infrastructure is pivotal to this objective as it enables public access, facilitates visitor use, supports conservation, and assists in management activities (Hennig, 2017). Consequently, knowledge of infrastructure provisions and design is necessary to protected area management.

As previously stated, infrastructure plays a major role in facilitating access to protected areas, particularly in the context of tourism. Within many protected areas globally (including South Africa's NP network), most revenue comes from tourism, so infrastructure that enables public access and incentivises visitation is important to the system's financial sustainability (Biggs et al., 2014). Beyond monetary return, infrastructure also delivers important socio-economic benefits to surrounding communities. Studies have shown that well-developed park infrastructure can stimulate local economies through job creation, small business development, and improved service delivery (Mabibibi et al., 2021; Saayman et al., 2009). Moreover, conservation-related infrastructure (e.g. monitoring stations, ranger outposts, and research facilities) supports the implementation of adaptive management strategies by generating knowledge that guides evidence-based decision-making (Gaylard & Ferreira, 2011; Kruger & MacFadyen, 1970).

However, despite its benefits, infrastructure expansion can lead to significant ecological consequences. While development is often seen as a marker of progress, overdevelopment, particularly in ecologically sensitive areas, can erode the environmental integrity of protected areas. For example, Bouchard et al. (2015) found that park visitors to Table Mountain, including dog walkers, hikers, and cyclists, contribute to the dispersal of alien plant seeds. Other studies on the impact of recreational trails have found that they can lead to adverse ecological impacts, such as decreased vegetation cover, altered plant species composition, soil loss, and compaction (Ballantyne & Pickering, 2015; Marion et al., 2011). There is a large body of research on the negative impact of roads in PAs and their association with issues like habitat loss and fragmentation, wildlife-vehicle collisions, and decreased landscape permeability (Barrientos et al., 2021; Bennett, 2017).

Importantly, hard infrastructure that increases accessibility and visitor capacity can also intensify crowding and over-tourism. In South Africa's Kruger National Park, infrastructure-dense and highly accessible areas (particularly in the southern region) have been shown to experience persistent crowding at wildlife sightings, rest camps, and day-visitor facilities (Van der Merwe, 2023). Visitors in these crowded areas reported feelings of frustration, disappointment, and reduced enjoyment, alongside behavioural changes such as prolonged congestion at sightings and early departure from facilities (Van der Merwe, 2023). Therefore, infrastructure development can lead to overcrowding in PAs and thereby reduce the quality of visitor experiences and erode CES, including solitude, sense of place and immersive wildlife

experiences. In other cases, infrastructure may even restrict rather than enable access, for instance, through fences, barriers, or signage (Hayward & Kerley, 2009).

Lastly, infrastructure is embedded in complex adaptive systems, which are self-organising and consist of independent agents interacting in non-linear ways at multiple scales (Anderies, 2014). So, when infrastructure is constructed without considering how complex systems behave, it can lead to larger, unanticipated consequences (Anderies, 2014). For example, long-term research in the Kruger National Park showed that the erection of boundary fences disrupted historical migration routes of blue wildebeest and resulted in the decline of the Western Boundary sub-population due to severing access to seasonal grazing areas, (Whyte & Joubert, 1988). In this case, fencing resulted in small, sedentary herds confined to fragmented habitat patches, which illustrates how infrastructure decisions can reconfigure feedbacks within social-ecological systems and produce long-term ecological consequences that may not be apparent at the time of implementation.

Despite growing recognition of the importance of infrastructure in shaping the functioning of protected areas, several key gaps remain in the literature. Firstly, existing studies are primarily based on the park level, limiting our understanding of how infrastructure co-occurs at the protected area network level. There is also a need for studies that examine the governance and planning processes surrounding infrastructure development in protected areas and how they shape the relevant outcomes (Najat & Masoud, 2014). Furthermore, much of the current focus remains on infrastructure provision rather than its long-term sustainability and condition over time (Astani, 2019). This is important because poorly maintained infrastructure can itself become a source of environmental harm, for example, through animals becoming trapped in dilapidated fencing or increased soil erosion due to deteriorating road networks. Many of the remaining gaps relate to access and visitor use and there is limited research that examines the relationship between infrastructure development and visitor behaviour within protected areas (Nazneen et al., 2019). Notably, no previous studies have directly explored the relationship between infrastructure and CES in these kinds of conservation systems. There has been some research on the impact of infrastructure on the accessibility of protected areas (Tverijonaite et al., 2018), but existing studies are limited in scope. These gaps point to a need for more studies that explicitly view infrastructure as an active SES component and explore its role in mediating PA outcomes (particularly as it relates to CES delivery, governance, and financial or ecological resilience).

2.5 Cultural Ecosystems in Protected Areas

The role of infrastructure in protected areas is deeply intertwined with the intangible benefits derived from these landscapes, particularly through the lens of cultural ecosystem services, which capture the societal and emotional connections people forge with natural spaces (Fish et al., 2016). Protected areas attract people because of their natural setting and scenic beauty (Mancini et al., 2019). They are considered prime recreational destinations, and for most PAs, nature-based tourism and recreational use are primary management objectives (Lupp et al., 2016). However, it is important to note that PA management should facilitate public access for recreational purposes while not adversely affecting the natural environment (Dudley, 2008).

The Ecosystem Services Framework has gained prominence as a tool for understanding the benefits and services provided by ecological systems, as well as their connections to ecological structures and processes, utilisation, and valuation (Carpenter et al., 2009; Costanza et al., 1997; Daily, 1997; Guerry et al., 2015). Ecosystem services are the direct and indirect contributions ecosystems provide for human well-being and quality of life; they are divided into four categories: provisioning, regulating, supporting and cultural (Millennium Ecosystem Assessment, 2005). Given that the significance of a natural resource is intricately linked to the diverse social and economic values that society derives from it, the Ecosystem Services Framework acts as a means to formally describe, categorise and assign value to the different ways in which societies depend on ecosystems, hence creating a bridge between conservation and economics (Boyd & Banzhaf, 2007; Daniel et al., 2012). Cultural services encompass the “non-material benefits derived from nature” and include spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences (Hernández-Morcillo et al., 2013). Difficult-to-measure cultural ecosystem services still receive relatively scant attention in analysis and planning (Millennium Ecosystem Assessment, 2005) despite the importance of cultural values in motivating ecosystem protection and reinforcing conservation efforts (Daniel et al., 2012; Infield, 2001). The challenges in quantifying cultural services contribute to the scarcity of in-depth analyses, often relegating assessments to qualitative approaches. Furthermore, assessments often focus on the supply of cultural services while neglecting demand and access. The provision and valuation of cultural services should encompass both their potential value and their utilisation by society (De Groot et al., 2002; Robards et al., 2011). Cultural services hold particular significance for conservation efforts, especially in protected areas. These areas often rely on the provision of cultural services, such as recreational experiences or solitude, to attract visitors and ensure their continued existence (Kettunen & ten

Brink, 2013). The success of protected areas as conservation tools is closely tied to their use and valuation by the surrounding societies (De Vos et al., 2016). Hence, it becomes imperative to accurately quantify and communicate benefits of protected areas, especially those related to cultural services (Braat & de Groot, 2012).

One significant study by Ament et al. (2017) examined the cultural ecosystem service demands in South Africa's National Parks and identified five distinct bundles of visitor preferences: "natural history," "recreation," "sense of place," "safari experiences," and "outdoor lifestyle." Each bundle represented a cluster of related services that visitors valued. The natural history bundle encompassed services related to learning about the natural environment, biodiversity, and conservation efforts within the parks. Visitors in the recreation bundle engage in activities like boating, swimming, sunbathing, hiking, and off-road driving. The sense of place bundle highlighted visitors' emotional connections to the ecosystems, emphasising intangible benefits such as psychological well-being, social interactions, and experiential aspects like camping that help people feel closer to nature. The safari experiences bundle focuses on enjoying traditional safari activities, such as viewing large mammals, taking photographs, and participating in game drives. Visitors in the outdoor lifestyle bundle preferred sedentary, low-key activities like cooking, reading, and relaxing at the campsite or chalet. Overall, the findings highlight that visitors have diverse preferences, and their interests shape the experiences they seek in national parks. Understanding these preferences allows park management to tailor their offerings to meet the specific demands of their primary user groups. (Ament et al., 2017).

The influence of socio-demographic factors on perceptions of cultural ecosystem services has been explored. Ament et al. (2017) also found correlations between bundles and different visitor demographics; for example, a preference for safari experiences was associated with younger people, Europeans and North Americans. Similarly, Zoeller et al. (2022) found that perceptions of cultural services associated with birds varied significantly across different demographic groups in South Africa, which emphasises the need for tailored management strategies that consider the diverse cultural backgrounds and preferences of park visitors. The study also highlighted how landscape attributes (such as biome, vegetation type, and elevation) significantly influence the benefits from CES provided by birds and ecosystems, which further shows the need to explore how different factors interact to shape visitor perceptions around and preferences for different cultural ecosystem services (Zoeller et al., 2022).

2.6 Hard Infrastructure and Visitor Preferences for Cultural Ecosystem Services

As previously stated, the societal value assigned to PAs has a significant impact on their long-term viability (Mascia & Pailler, 2011). Among these, tourism stands out as a cultural service that can create mutually beneficial scenarios for conservation and development, with the revenue derived from PA visitors being a potentially important source of income to aid PA sustainability (Lindsey et al., 2007). Numerous interacting variables have been shown to affect visitation rates in protected areas; these drivers are both ecological (e.g. the presence of large mammal species or higher species richness) and socio-economic (e.g. infrastructure, location, business model and marketing) (Baum et al., 2017; De Vos et al., 2016; Echeverri et al., 2022; Grünwald et al., 2016; Lindsey et al., 2007; Mancini et al., 2019; Zoeller et al., 2022). While findings differ on the relative importance of ecological versus socio-economic drivers, evidence suggests that it is the interaction of these factors that ultimately shapes visitation patterns (Arkema et al., 2021; Graves et al., 2019; Hausmann et al., 2018; Heagney et al., 2018; Naidoo et al., 2016).

A growing body of global research shows that infrastructure, in particular, can be as important as, or even more important than, ecological attributes in driving recreation demand in protected areas. For instance, a study in Australia found that roads and parking facilities were stronger predictors of visitation than biodiversity or scenic beauty (Heagney et al., 2018). Similar patterns have been observed elsewhere. Improved accessibility in Iceland has shifted visitor preferences toward more developed sites (Tverijonaite et al., 2018); in Tanzania, non-wildlife infrastructure enhances tourist satisfaction alongside wildlife viewing (Okello & Yerian, 2009); and in Scotland, the intensity of wildlife watching correlates with infrastructure like accommodation and transport links (Mancini et al., 2019). South African studies found that visitor satisfaction and accommodation preferences in Kruger hinge on quality facilities and diversified offerings (Engelbrecht et al., 2014; Kruger et al., 2019). Echeverri et al. (2022) demonstrated that in Costa Rica, infrastructure factors (e.g. hotel density and road proximity) were key national-level drivers of tourism, while biodiversity played a stronger role within protected areas and specialised activities such as birdwatching. Beyond visitation numbers alone, infrastructure influences the demand for and utilisation of cultural services within PAs (Baum et al., 2017; De Vos et al., 2016; Maes et al., 2012; Peña et al., 2015; Schägner et al., 2016). For example, studies in South Africa's National Parks and private reserves showed that

the economic sustainability of CES depends on the interaction of infrastructure characteristics and ecological attributes (Baum et al., 2017; De Vos et al., 2016).

However, some studies have also found that infrastructure can detract from visitors' experiences of protected areas. Lupp et al. (2016) examined the use and appreciation of the Alpine Mountain farming landscape in a protected area in the German Alps. They found that hikers disliked the visible traces of necessary infrastructure and landscape management. Similarly, Tverijonaite et al. (2023) state that attitudes of tourism service providers in Iceland towards wilderness use and development are largely pro-environmental, preferring basic tourism infrastructure, such as maintaining the current state of roads or better maintenance and showing less support for further energy, road developments or infrastructure like hotels and food services. These findings align with research on sense of place and place attachment, which suggests that visitors often develop emotional bonds with protected landscapes, which in turn shape their responses to development (Dang & Maurer, 2021; Ramkissoon et al., 2012) Public resistance to infrastructure projects, such as the Standard Gauge Railway route through Nairobi National Park over concerns of disrupting elephant migration patterns and habitat fragmentation, or luxury hotel developments in the Kruger National Park (which sparked debates over commercialisation at the cost of conservation), demonstrates how development can conflict with the place-based values associated with protected areas (In On Africa, 2011; Kushner, 2016).

Effective recreation management within protected areas requires a comprehensive understanding of why people visit and value protected areas (Ament et al., 2017). Therefore, enhancing the benefits derived from cultural ecosystem services may require protected areas to be designed to align with visitor preferences. Visitor preferences in the context of CES refer to the ways people demonstrate the cultural benefits they value in natural landscapes. These preferences can be expressed (e.g., through surveys or reviews) or revealed (e.g., through visitation patterns) (Martín-López et al., 2012; Plieninger et al., 2013). Importantly, visitor preferences are shaped by different contexts and are not universal; they vary across demographics, cultures, and experiences with nature, as shown in Ament et al. (2017) and Zoeller et al. (2022). This raises the question of equity, as infrastructure strongly influences who can access protected areas and which CES experiences are available. According to Ribot & Peluso (2003), access is not just about legal rights (like ownership or the permission to enter and make use of land) it also relates to the ability to derive benefits from resources. In PAs,

infrastructure affects people's ability to enjoy cultural ecosystem services, even if everyone "can" visit the park. In South Africa, especially, infrastructure may amplify or reduce existing inequalities; for example, facilities designed around the dominant/income-generating preferences may marginalise other user groups (such as low-income visitors, people with disabilities, or local communities). While this study does not focus directly on equity, it is important to note that consideration of diverse social needs and values is needed if infrastructure planning is to be informed by CES preferences.

All in all, the existing literature suggests that while infrastructure can enhance CES delivery by improving access and interpretive quality, it may also erode CES value when overdeveloped or misaligned with visitor preferences, particularly in situations where visitors have strong place attachment and infrastructure that alters the perceived wilderness character of a landscape (Lupp et al., 2016; van der Merwe, 2023). This points to the need for careful and context-responsive planning in the development of protected area infrastructure. Despite growing recognition of infrastructure's role in shaping CES, there are still critical gaps in both theory and practice. There is a particular lack of system-wide empirical studies that explore how infrastructure patterns co-occur across parks and how these patterns correspond to visitor preferences for different types of CES. Furthermore, the managing bodies of many protected areas (including SANParks) often lack integrated tools/frameworks to measure and manage CES quality in relation to infrastructure development, which makes it difficult to assess trade-offs or align investment with both conservation goals and cultural service provision.

2.7 Understanding the Relationship Between Infrastructure and Visitor Preferences for CES using the CIS Framework

In protected areas, infrastructure and visitor experiences are closely interconnected (Andrea et al., 2013). The types of infrastructure provided are expected to influence the kinds of cultural services visitors can access and enjoy. Over time, patterns of visitor use and demand may shape decision-making regarding what kinds of infrastructure are maintained, developed, and prioritised in response to these expectations. Consequently, differences in infrastructure across parks are likely to align (at least partially) with differences in dominant CES preferences. For example, one might expect that in Kruger National Park, which is known largely for its safaris and the presence of megafauna (Engelbrecht et al., 2015; Hausmann et al., 2020), significant investments are likely made in infrastructure such as road networks, rest camps, and wildlife hides that support game-viewing activities.

The interactions in the thought example above operate through dynamic feedback loops, as conceptualised in the CIS framework. natural infrastructure provides the foundation for visitor experiences while hard infrastructure mediates access to and interpretation of these features, thereby shaping visitor satisfaction and patterns of use. In turn, sustained trends of visitor activity and demand may encourage further infrastructure investment by public infrastructure providers. For instance, the scenic trails and climbing routes in Table Mountain National Park may have initially attracted visitors seeking recreational outdoor activities, and over time, the addition of infrastructure, such as the cableway, expanded access to this kind of use.

2.8 Conclusion

The reviewed literature indicates that protected areas are best understood as complex social-ecological systems. Within this context, the role of hard infrastructure has been underexplored. In this review, I examined the evolution of protected area concepts, the application of resilience and social-ecological systems theory, the emergence of the CIS framework, and existing work on hard infrastructure, cultural ecosystem services, and their interactions. Few studies have analysed infrastructure at the scale of protected area networks or explored its role in mediating the delivery of CES. Building on this literature review, my study uses the CIS framework to examine the role of hard infrastructure in ultimately shaping the resilience of protected areas. In particular, this study examines how infrastructure patterns across South Africa's NPs interact with visitor preferences for cultural ecosystem services, using the CES bundles developed by Ament et al. (2017) to assess whether parks that cluster according to particular CES demands also exhibit similar patterns of infrastructure investment and development.

CHAPTER 3 STUDY AREAS

3.1 Introduction to SANParks and Study Area

SANParks currently manages 20 official terrestrial national parks (SANParks, 2021). The Grasslands National Park is in the process of being proclaimed and is not yet formally included in the network (SANParks, 2023b). The park system extends over four million hectares of land across seven provinces, spanning a diverse range of vegetation types and representing approximately 70% of state-owned terrestrial protected areas (SANParks, 2023b, 2024c). Administratively, the parks are divided between the Kruger National Park and the Parks Division (SANParks, 2024b). The latter is further organised into five regions: the Arid, Cape, Frontier, Garden Route, and Northern regions (SANParks, 2024b). In this study, I will analyse 19 National Parks (see Figure 2 and Table 1). The Meerkat National Park, which was established in 2020 primarily to accommodate the Square Kilometre Array radio telescope project (SANParks, 2022), was not included in this study as it does not allow for general public visitation and has no tourism infrastructure (SANParks, 2022). The selected 19 parks correspond to the parks previously analysed by Ament et al. (2017), whose data will be used as the CES component in Chapter 5's analysis.

The geographic distribution of the parks included in this study is shown in Figure 2, and detailed information is provided in Table 1. National Parks contributed 37,4% to South Africa's protected area estate at the end of 2020 (Statistics South Africa, 2021). South Africa's National Parks boast a wide range of ecosystems and vegetation types that span seven biomes (Mucina & Rutherford, 2006). These national parks are also highly socially and ecologically diverse (Table 1). Their sizes range from less than 40 km² to over 19,000 km², and annual visitation varies from fewer than 5,000 visitors to over two million (Table 1).



Figure 2. Study context map showing 19 national parks, South Africa (made in ArcGIS Pro).

Table 1. Study Site Characteristics

Region	Park	Biome(s)	Unique Features	Approximate Distance from Nearest Major City (km)	Years Since Establishment (2026)	Area (km ²)	Visitors (2022/23)
Kruger	Kruger National Park	Savannah	One of the world's largest conservation areas, a tourism hotspot, generates high revenue, contains "Big Five"	60	100	19 171,61	1 603 521
Arid	Kgalagadi	Savanna	Transfrontier Park, high campsite occupancy; UNESCO World Heritage Site	265	95	9 589,55	49 068
	Augrabies	Nama Karoo	Augrabies Falls waterfall	520	60	493,54	88 529
	Namaqua	Succulent Karoo, Fynbos	Biodiversity hotspot; Seasonal wildflower displays	495	27	1 546,42	14 334
	Richtersveld	Succulent Karoo	Transfrontier Park; UNESCO World Heritage Site, Fish River Canyon (world's second largest canyon)	580	35	1 702,76	3 569
	Mokala	Savanna, Succulent Karoo	Breeding sanctuary for endangered species	340	19	284,73	12 699
Cape	Table Mountain	Fynbos	In Cape Town; Table Mountain; within the Cape Floristic Region	10	28	222,88	2 444 687
	Agulhas	Thicket, Fynbos	Southernmost tip of Africa; where Atlantic and Indian oceans meet;	220	27	215,78	26 506
	West Coast	Thicket, Fynbos	Langebaan Lagoon; seasonal wildflowers; birdwatching	100	41	365,66	156 439
	Bontebok	Fynbos	Smallest national park; contains rare endemic bontebok antelope	6	95	34,14	16 675
	Tankwa Karoo	Succulent Karoo, Thicket	Biodiversity hotspot (Succulent Karoo)	340	40	1 435,00	4 279
Frontier	Addo Elephant	Thicket, Nama-Karoo, Savanna, Fynbos, Forest	Largest coastal dune in the southern hemisphere; contains "Big Seven", densest African elephant population in the world	72	95	1 523,55	195 474
	Camdeboo	Nama-Karoo, Thicket	Valley of Desolation	260	21	187,90	31 208
	Karoo	Nama-Karoo	Semi-arid landscapes, Nuweveld Mountains, five species of tortoises	50	47	844,70	29 503
	Mountain Zebra	Nama-Karoo, Grassland	Cape Mountain Zebra; Bushmen paintings	320	89	202,47	23 765
Garden Route	Tsitsikamma, Wilderness, Knysna	Forest, Fynbos, Thicket	Managed as a single entity; extensive tourism infrastructure, Knysna Forest & Storms River Mouth	170	17	1 257,89	372 218 (total)

Northern	Golden Gate Highlands	Grassland	Part of Maloti-Drakensberg complex; palaeontological significance	400	63	330,94	45 082
	Mapungubwe	Savanna	The Lost City” (Mapungubwe Hill); Transfrontier Park	260	31	152,36	27 660
	Marakele	Savanna	Cape Vulture Colony, Waterberg Mountains	300	32	592,72	20 757

3.2 The Evolution of Conservation in South Africa

As one of the world's most biodiverse regions, Southern Africa has emerged as a global leader in conservation (IUCN & ESARO, 2020). The region holds diverse examples of innovative and transformative models for managing land in natural or near-natural states that range from formal state-owned and privately-owned protected areas to communal and private conservancies and wildlife ranches (IUCN & ESARO, 2020; Lindsey et al., 2016). South Africa's National Parks play a pivotal role in Southern Africa's wider conservation effort, while also being embedded in a complex history (Carruthers, 1995; Ndlovu, 2024).

Colonial settlement of South Africa led to wildlife decimation as a result of unregulated harvesting and land conversion, which prompted early legislative efforts to regulate hunting and conserve species (although these laws aimed to ensure economic sustainability rather than addressing conservation concerns) (Child, 2009). By the late 19th and early 20th centuries, global conversations on wildlife protection gained traction, leading to international conventions, such as the London Conference of 1900 (Child, 2009). This era witnessed the establishment of game reserves in South Africa, such as the Sabie Game Reserve in 1898 and the Singwedzi Game Reserve in 1903 (Carruthers, 1995). During this era, conservation areas were often demarcated through the exclusion and forced removal of local African communities, whose historical presence and land-use practices were erased from official narratives of "pristine" wilderness (Carruthers, 1995; Child, 2009; Ramutsindela, 2007).

In 1926, the National Parks Act was passed, forming SANParks' predecessor, the National Parks Board (Carruthers, 1995, 2008). The same year, the Sabie and Shingwedzi Game Reserves merged to form the Kruger National Park (Carruthers, 2008). Between 1931 and the 1990s, numerous other significant national parks were proclaimed, including Kalahari Gemsbok National Park (now part of Kgalagadi Transfrontier Park), Addo Elephant National Park and the Mountain Zebra National Park (Carruthers, 2008). Throughout much of the 20th century, access to national parks was racially segregated, with white visitors enjoying preferential access and benefits (Carruthers, 2008; Ramutsindela, 2007).

The post-apartheid era in South Africa witnessed a significant shift towards more inclusive conservation strategies, including community-based approaches, acknowledgement of Indigenous rights and the need for sustainable development (Thondhlana et al., 2011; van der Merwe et al., 2020). Nevertheless, contemporary conservation remains influenced by historical

inequalities in land ownership, economic access, and representation. Today, South Africa's conservation landscape continues to evolve through a mix of formal protected areas (including national parks), private reserves and Transfrontier conservation areas, with a continued effort to reconcile biodiversity protection with social justice (which often includes community involvement) to ensure equitable access to benefits from protected areas (SANParks, 2024c).

3.3 South Africa's Protected Area Legislation

In South Africa, protected areas are governed by the National Environmental Management: Protected Areas Act (NEM: PAA) (Republic of South Africa, 2003). Key provisions of this Act include: 1) the designation of areas for biodiversity protection, cultural heritage, and sustainable use, 2) restrictions on development, resource extraction, and activities that are inconsistent with PAs' conservation objectives, and 3) requirements for stakeholder engagement in planning and management and equitable benefit-sharing with local communities (Republic of South Africa, 2003). Protected areas under the Act are classified into national parks, nature reserves, and protected environments. SANParks is specifically responsible for managing national parks, under the jurisdiction of the Department of Forestry, Fisheries, and the Environment (DFFE) (Republic of South Africa, 2003). Within NPs, permissible activities include those directly related to biodiversity conservation, sustainable tourism and research, whereas prohibited activities are mining, large-scale development, and any actions that threaten biodiversity (such as introducing invasive species) (Republic of South Africa, 2003).

NEM: PAA also establishes requirements for infrastructure development within protected areas. The Act requires that all national parks have management plans (Section 41), which must include guidelines for infrastructure development (Republic of South Africa, 2003). It also empowers the Minister to prescribe norms and standards (Section 11) to guide infrastructure management (Republic of South Africa, 2003). The “Norms and Standards for the Management of Protected Areas in South Africa” (Government Gazette No. 37802 of 2014) necessitates that protected areas maintain adequate operational infrastructure and equipment to effectively implement their management plans, supported by a formal maintenance program (Norm 16) (Republic of South Africa, 2014). Visitor facilities must enhance visitor experiences without causing environmental harm, be appropriate to visitor numbers, and be properly maintained to prevent environmental degradation (Norm 18) (Republic of South Africa, 2014). Infrastructure development within parks is also subject to environmental impact assessment (EIA) under the

National Environmental Management Act (NEMA) and the EIA Regulations (Republic of South Africa, 1998; Republic of South Africa, 2014).

Infrastructure development and tourism activities within South Africa's national parks are regulated through internal zoning systems defined in park management plans, as required under the National Environmental Management: Protected Areas Act (NEM:PAA). SANParks Management Plans typically apply a development-intensity gradient through a set of use zones that regulate what types of access, activities, and infrastructure are appropriate in different parts of the park. This includes wilderness or remote zones with no permanent infrastructure; primitive zones that allow limited access and small-scale infrastructure; low-intensity leisure zones that allow self-drive access and basic visitor facilities; and high-intensity leisure or development zones where visitor infrastructure and commercial activities are concentrated.

3.4 Vision 2040 and Strategic Direction

SANParks' Vision 2040 outlines an ambitious future strategy that reimagines conservation in South Africa, where nature and people thrive together in harmony (SANParks, 2024c). A central focus of this vision is “Mega Living Landscapes” (MLL), which refers to expansive, interconnected conservation landscapes that integrate national parks with communal lands, private reserves, botanical gardens, and farmlands (SANParks, 2024c). Mega Living Landscapes are meant to be multifunctional spaces that create sustainable human livelihoods, meaning parks such as Kgalagadi and Mapungubwe already reflect elements of this vision in their community co-management agreements and Transfrontier conservation style. Similarly, the Richtersveld National Park allows resident Nama pastoralists to retain grazing rights under a contractual park arrangement (Hendricks et al., 2004).

Infrastructure will be instrumental to achieving the goals of Vision 2040 and MLL, particularly when it comes to spatial connectivity and permeability (SANParks, 2024c). Traditional protected areas have hard boundaries that isolate them from surrounding communities and landscapes; however, the strategic placement of infrastructure like roads, trails, and other access points can enable social-ecological connectivity between parks and adjacent lands. Vision 2040 also emphasises the importance of equitable benefit-sharing, as many communities living near national parks still experience exclusion from the economic and cultural benefits of conservation (SANParks, 2024c; Swemmer et al., 2015, 2017, 2020). Infrastructure in South Africa's NPs (e.g. lodges, concessions, transport, visitor facilities) can

facilitate access for local communities and expand their participation in tourism, education and job creation. However, if investment is concentrated in high-tourism parks, infrastructure can also reinforce spatial inequalities. This study seeks to identify patterns of infrastructure investment across South Africa's National Parks, which could allow for the identification of imbalances that run counter to the equitable development aspirations of Vision 2040.

3.5 Application of the CIS Framework to South Africa's National Parks

As described in the Literature Review, the CIS Framework conceptualises CISs (including protected areas) using four components connected by dynamic interactions: resource users (RU), natural infrastructure (NI), public infrastructure (PI), and public infrastructure providers (PIP) (Anderies et al., 2022). Below, I describe how each of the CIS components is represented within South Africa's National Parks:

3.5.1. Resource Users

Resource users are actors whose livelihoods or ongoing activities depend on repeated interaction with the system's natural infrastructure (Janssen & Anderies, 2023). Many commonly studied resource users derive material flows from ecosystems (e.g. fishing, grazing, timber harvesting); however, in South Africa, national parks are state-owned and governed under strict mandates which largely prohibit or restrict extractive resource use, although SANParks does permit certain types of regulated natural resource harvesting as part of its community benefit-sharing policies (Scheepers et al., 1970; van Wilgen et al., 2013; Vermeulen et al., 2019). There are also a number of co-management agreements and community land use rights claimants; for example, in the Kgalagadi Transfrontier Park, the adjacent Khomani San and Mier have land rights both inside and outside of the park (Thondhlana et al., 2011). A survey across 19 South Africa's NPs found a total of 382 resources harvested, mostly for subsistence and financial purposes (49%), with the majority of harvesting (42%) being unauthorised and a further 39% involving partial or inconsistent authorisation (van Wilgen et al., 2013). Other resource users include ecotourism operators, park concessionaires, and community members employed in park-related enterprises.

Importantly, under the CIS framework, actors who do not derive livelihood-supporting benefits from the system (i.e. the actors who *consume* products extracted from the resource system) are not considered resource users (Anderies et al., 2022). Therefore, while visitors interact with and derive value from national parks through recreational and experiential use, these

interactions do not constitute livelihood dependence. Visitors are therefore not classified as resource users in this study, but are instead treated as exogenous demand-side drivers (see 3.5.5).

3.5.2. Natural Infrastructure

Natural infrastructure (otherwise known as the ecological system) is the biotic and abiotic elements within national parks and their interactions. NI in this context includes landscapes, wildlife populations, vegetation cover, and hydrological systems. The diverse ecosystems of each park form the basis for why visitors visit and the kinds of experiences available. In much the same way that a fisher uses a hook (hard infrastructure) to catch a fish, ecotourism operators use ecosystems to “catch” tourists (Anderies et al., 2022).

3.5.3. Public Infrastructure

Public infrastructure refers to the shared facilities, systems, and institutional arrangements that shape how resource users interact with both natural and human-made infrastructure, as well as with one another (Anderies et al., 2022). All man-made structures within the parks are hard public infrastructure. While HI is the primary focus of this study, it is important to also acknowledge the importance of soft public infrastructure, i.e. the non-tangible human-made “instructions” for using other types of infrastructure (Anderies et al., 2016). In SA’s national parks, these include institutional arrangements and governance structures (e.g. co-management agreements), legal and policy frameworks (like NEM: PAA, Natural Resource Use Policy), planning tools and codified knowledge systems (such as park management plans, monitoring tools, asset registers), social and participatory networks (e.g. environmental education programmes, volunteer and citizen science initiatives).

The organisation of SANParks (and the park staff employed by SANParks) would also be considered as soft infrastructure in this context, as the management agency created by the PIP (South African Government) to carry out its conservation mandate. SANParks is governed by a Board whose members are appointed by the Minister of DFFE. The organisational structure can be summarised as follows: the CEO oversees the Executive Management Committee (COO, CFO, and four Managing Executives (EXCO) for Conservation Services, Tourism, Kruger National Park, and the remaining parks) and supporting units, such as Human Capital Management, Socio-Economic Transformation, and Communications, report to EXCO (SANParks, 2025). Then there are the various specialised and sub-units (for example, Scientific

Services, The People and Parks Programme, Infrastructure & Special Projects) that fall under these broader portfolios, which include the regional and park managers (SANParks, 2025).

3.5.4. Public Infrastructure Providers

The South African Government is the PIP for South Africa's National Parks. The government establishes the legal and policy framework, but much of its authority is delegated to SANParks, making its role/relevance in this case relatively small. However, SANParks is accountable to national legislation and ultimately answers to the DFFE.

3.5.5. Exogenous Drivers

Exogenous drivers are external social, economic, political, and environmental forces that influence the functioning of the system but originate outside of it (Anderies et al., 2022). For SA's National Parks, this would include things like tourism trends, visitor preferences, climate change, policy shifts, the state of the economy and global conservation agendas.

3.5.6 Interactions between RU, NI, PIP, PI

In South Africa's NPs, the components of the CIS discussed above interact through dynamic feedbacks that collectively shape system resilience. RU (such as harvesters, concessionaires, and ecotourism operators) influence NI through their activities (e.g., conservation, trampling, extraction), and the condition of ecosystems in turn determines the benefits available to them. PIP interact with SANParks (soft PIP) by allocating resources and through legislation. There is also an interaction between hard and soft PI where SANParks builds and governs the parks' built infrastructure. These infrastructures mediate interactions between resource users and natural systems, for example, by enabling or restricting access through roads and fences. At the same time, user demands (and exogenous pressures from visitors) feed back into decisions about which infrastructures are maintained or expanded.

3.6 Infrastructural and CES Differences Across National Parks

Visitor preferences across South Africa's National Parks vary significantly due to differences in park size, location, cultural contexts, biodiversity, and infrastructure (Slabbert & Viviers, 2012). These preferences reflect varying interests in types of activities, experiences, and cultural ecosystem services. For example, a study by Hausmann et al. (2020) used sentiment analysis of social media data to understand visitors' preferences for specific park features across four of South Africa's NPs. They identified two park profiles based on the nature-based

experiences as described by visitors: wildlife-experience parks (Addo and Kruger) and scenery-experience parks (Garden Route and Table Mountain). Similar descriptors were used in parks with similar characteristics, which suggests people tend to perceive parks according to the type of experience they offer. In other words, park-specific attributes, such as charismatic species or beautiful views in this case, can be strong determinants of the cultural ecosystem services that tourists value.

SA's national parks also vary in their levels of development and the kinds of infrastructure they have (SANParks, 2024b). The Kruger, for example, is both the largest and most popular national park and has diverse facilities to support high visitor numbers and cater to a broader range of CES preferences (van der Merwe, 2023). Kruger also has extensive road networks, multiple rest camps with different accommodation types (ranging from luxury lodges to self-catering chalets) and numerous administrative facilities to support park operations and research (van der Merwe, 2023). On the other hand, smaller and/or more remote parks (e.g. Tankwa or Richtersveld) with lower visitation tend to focus on low-impact tourism, offering basic facilities such as rustic camps and off-road 4x4 routes (SANParks, 2017). Some parks also require specialised infrastructure based on their environmental characteristics. For instance, the Garden Route has a number of marine-focused facilities (e.g. boat launches, boardwalks) that support water-based activities, including kayaking and snorkelling (SANParks, 2017).

The differences above illustrate the need for tailored management strategies that ensure infrastructure and service delivery align with each park's unique context and the preferences and expectations of its target audience. It is also important to note that infrastructure planning is embedded within complex governance frameworks and historical, ecological, and socio-economic contexts; these contextual factors should be considered when interpreting the patterns and outcomes that are explored in the following analyses. From a CIS perspective, hard infrastructure interacts with other system elements. These interactions are examined empirically in the following chapters and synthesised more explicitly in the Discussion (Chapter 6).

CHAPTER 4 ASSESSING INFRASTRUCTURE PATTERNS ACROSS SOUTH AFRICA'S NATIONAL PARKS

This chapter is written in the style of a journal article based on a manuscript submitted for publication in Biological Conservation (currently under peer review). Minor edits have been made to minimise overlap with previous chapters.

Abstract: Hard infrastructure plays an important role in shaping the identity and impact of protected areas. Roads, buildings, and fences, for example, can support both the management of animal populations and park accessibility to the public. Understanding how hard infrastructure influences conservation outcomes requires recognising infrastructure as both a cause and a response relative to protected area objectives. Using a registry of above-ground infrastructure asset data and multivariate statistical techniques, I investigated patterns of infrastructure investment and condition across all of South Africa's proclaimed National Parks open to visitors. I found substantial variation in investment intensity and infrastructure quality, both across parks and infrastructure types and categories. Three archetypes emerged: remote parks with low overall investment; high-access urban or peri-urban parks with high investment and no fences; and well-funded parks with relatively balanced investment across infrastructure types. Visitor numbers were a significant predictor of infrastructure investment in roads and buildings. Investment scaled non-linearly with park size. The findings suggest that patterns of infrastructure investment in South Africa's national park system are indicative of underlying institutional priorities/decision-making, demand-driven feedback loops and an emerging differentiation in park roles and objectives. This approach to identifying infrastructure investment typologies could be applied in other protected area networks to detect mismatches in park roles or visitor demand and infrastructure provision, and it offers opportunities to advance strategic, equitable development planning and enhance protected area resilience.

4.1 Introduction

Protected areas are widely considered to be the cornerstone of global biodiversity conservation strategies (CBD, 2022; Dudley, 2008; Watson et al., 2014). However, the ability of PAs to provide both ecological and socio-cultural benefits is increasingly at risk due to human pressures from climate change, land-use transformation, and declining public investment (Geldmann et al., 2023; Venter et al., 2018). Understanding how protected areas navigate these complexities requires a social-ecological approach (Cumming et al., 2015), and while much attention in SES research on PAs has been given to ecological processes and governance

structures, the role and relevance of built infrastructure have been underexplored (Ahlborg et al., 2019; Chester et al., 2023; Markolf et al., 2018).

In this study, “hard infrastructure” refers specifically to the major above-ground capital assets captured in SANParks’ formal asset registry, namely roads, buildings, and fences. However, hard infrastructure in protected areas extends beyond these categories and also includes features such as erosion-control structures, artificial waterholes, lookout towers, signage, picnic sites, launch sites, jetties, etc. While these elements are important components of protected area systems, the present analysis focuses on the primary capital asset categories recorded in the national infrastructure portfolio.

In a world where human activity and infrastructure are increasingly expanding, it is important to understand the feedbacks and interactions between built environments and the natural and social systems in which they are embedded (Anderies, 2014). Importantly, infrastructure shapes the delivery of ecosystem services, particularly CES, which are important to the long-term relevance of tourism-dependent PAs (Ibisch et al., 2016; Kifworo & Dube, 2024; Martín-López et al., 2012; Phillips et al., 2020; Schägner et al., 2016). In line with this, a growing body of literature, as discussed in Chapter 2, highlights how infrastructure supports recreational use and economic sustainability in conservation landscapes and is often a stronger predictor than ecological attributes alone in determining tourism decisions (Baum et al., 2017; De Vos et al., 2017; Echeverri et al., 2022; Engelbrecht et al., 2014; Grünewald et al., 2016; Heagney et al., 2018; Hennig, 2017; M. Kruger et al., 2019; Maciejewski & Cumming, 2016; Mancini et al., 2019; Okello & Yerian, 2009). However, some literature cautions that infrastructure can have unintended ecological consequences and diminish the quality of nature-based experiences (Ballantyne & Pickering, 2015; Donázar et al., 2018; Lerm et al., 2023; Lupp et al., 2016; Tverijonaite et al., 2023; Zoeller et al., 2022).

One way to understand the social-ecological effect of infrastructure in protected areas is through the CIS framework (Anderies, 2014; Anderies et al., 2016). From a CIS perspective, hard infrastructure is integral to the feedbacks within protected areas. For instance, if roads deteriorate and access is reduced, visitation may decline, in turn reducing future investment and eroding support for conservation. Thus, dysfunctional or uneven infrastructure can ultimately undermine the robustness of conservation outcomes (Anderies et al., 2004; Cumming, 2023). There is therefore a need to better understand infrastructure-investment

feedback loops and identify leverage points for intervention or design strategies that can enhance the system's ecological and financial resilience.

While existing studies offer valuable insights into how infrastructure influences visitor experiences and ecological outcomes, there remains a lack of systematic, cross-park studies (particularly in the Global South and from an SES perspective) that provide fundamental information about the age, status, and maintenance costs of protected area infrastructure. This information, which is usually buried in conservation agency reports and files, is critical for efforts to understand and model the economic sustainability of protected areas as well as for guiding local and international conservation investment decisions. This study addresses the existing information gap relating to protected area infrastructure by presenting a detailed analysis of the full portfolio of existing infrastructure in South Africa's National Parks, placing it in the context of a set of broader management initiatives. While this chapter does not directly analyse how existing infrastructure configurations relate to CES outcomes, it considers how infrastructure enables or constrains certain uses and experiences, which are closely tied to CES delivery. Although the case study focuses on a single country, it has general relevance for understanding the economic and management constraints faced by protected areas as well as the critical role of infrastructure in social-ecological dynamics.

Specifically, the study investigates: 1) What is the general condition (in terms of quality, age, and longevity) of infrastructure in South Africa's national parks, and how does this vary across parks and infrastructure types/categories? 2) How is infrastructure investment distributed across South Africa's national park system through park-level and infrastructure category allocations, and what factors drive investment decisions? And 3) Are there identifiable clusters or groups of parks based on their similarities in infrastructure profiles?

4.2 Methods

4.2.1 Data Collection

i. Data Sources

SANParks Fixed Asset Report

The SANParks Fixed Asset Report is an internal asset management dataset that contains detailed records of all above-ground infrastructure across South Africa's National Parks, including roads, buildings and fences. The dataset, provided by SANParks as an Excel spreadsheet, includes over 15,000 assets with associated spatial, descriptive and financial

information. The data were derived from a condition assessment conducted for SANParks by consultants during the 2021/22 financial year.

Within the dataset, assets are classified by Park (e.g., “Addo”), Region (e.g., “Frontier”), Location Type (e.g., Rest Camp, Main Camp, Ranger Post, Road Network), and Group Name (Boundary Fence, Roads, Buildings). Each asset is identified by Asset Type, which specifies its general function, e.g. (Staff House, Road – Flexible, Tent, Chalet, Administration, Kitchen, Ablutions, Carport, Storage, etc) and by Asset Name, which provides a unique identifier or description of the infrastructure asset (e.g. Colchester Staff House 2, Darlington East Guest House 2, Zuurberg Reception, W/Cape Staff Toilet 307, etc). Linear infrastructure, such as roads and fences, is represented as individual assets with associated length (km), while buildings are characterised by area (m²). For Roads, the “Asset Type” field distinguished the kind of road: flexible (tarred), gravel, earth tracks and block paved. Earth tracks are assigned no monetary replacement value.

Other descriptive variables include the Condition Index (CI), which describes infrastructure quality for each asset (1 = poor condition, 100 = perfect condition). The Estimated Useful Life (EUL) denotes the expected lifespan of the asset in years, and the Remaining Useful Life (RUL) is an approximation of the time left before major maintenance or replacement is required. Financial fields include Total Current Replacement Cost (CRC) and Total Depreciated Replacement Cost (DRC), which respectively reflect the full replacement value and depreciated value of each asset as of the 2021/22 financial year. Additional variables include rate per square metre (VAT inclusive and exclusive).

Supporting Data

Visitor number data for each park (April 2022 to March 2023) were obtained from the SANParks Annual Report and used as a proxy for infrastructure demand (SANParks, 2023b). These figures were calculated as every person who entered the park’s gate (i.e. both day and overnight guests). All of SANParks’ Annual Report documents are publicly available through their website and summarise the organisation’s yearly performance, achievements, and financial status. Park size data (2023, quarter 4) were derived from the South African Protected Areas Database (SAPAD), which is an open-access national geospatial dataset managed by the DFFE. The total park area (in km²) for each national park was calculated in ArcGIS Pro (version 3.3.0). Investment metrics were standardised by park size (investment/km²) to allow for meaningful comparison across parks. Though not included directly in the quantitative analysis,

National Park management plans were used to inform infrastructure categorisation. Approved management plans are publicly accessible and were downloaded from the SANParks website (<https://www.sanparks.org/conservation/management-plans/approved>).

ii. Infrastructure Categorisation Framework

Infrastructure assets classified as “buildings” in the SANParks Fixed Asset Report were grouped into three functional categories: Visitor, Conservation Management, and Operations and Support. This categorisation was informed by SANParks’ internal infrastructure classifications and refined through consultation with SANParks representatives to remain consistent with the organisation’s reporting practices. Roads and fences are tracked separately by SANParks and were hence analysed independently from buildings.

Visitor infrastructure refers to assets that directly support tourism and visitor experiences. This includes accommodation (e.g. chalets, cottages, tents, lodges, camping sites) and general facilities used by visitors (e.g. ablutions, kitchens, lapas, pavilions, shelters, restaurants, shops, hides, viewpoints, visitor centres). SANParks groups these assets under “Tourism Infrastructure,” which aligns well with my definition of visitor infrastructure. Conservation infrastructure supports ecological management and biodiversity protection efforts and includes assets such as ranger posts, monitoring stations, research facilities, conservation offices, fire control infrastructure, nurseries, bomas, reservoirs, and waterholes. While SANParks does not use this category explicitly in its internal reporting (it tends to fall under “Support” infrastructure), these facilities are functionally discrete and key to SANParks’ conservation mandate. Operations and Support infrastructure encompasses all assets that help sustain parks’ core administrative, logistical and day-to-day functions. This includes park offices, workshops, staff housing, garages, water and sewage infrastructure, substations, generator houses and storage buildings. SANParks typically classify these assets under “Support Infrastructure” and “Bulk Services/Utilities”, while handling staff housing as a separate category due to its strategic importance. However, for the purpose of this study, these facilities are grouped together here as they all contribute to the operational “backbone” of park management.

iii. Data cleaning and Preparation

The SANParks Fixed Asset dataset was cleaned for consistency and usability. Duplicate entries were removed and naming conventions were standardised. Missing values were assessed in the raw datasets prior to cleaning. In the buildings dataset, 879 observations (9.93%) had missing

values for the Area (m²) variable. Missing building area values were imputed using the mean area within each infrastructure category to retain observations for subsequent density calculations, while missing asset names were retained as they were not used in quantitative analyses. In the roads dataset, eight observations (0.31%) had missing values for each of CI, RUL, and Total DRC. These were imputed using the median value within each park. No missing values were detected in the fences dataset.

Building infrastructure was categorised into Visitor, Conservation Management, and Operations and Support, per the framework outlined above, using a classification key developed in Excel. Assets were initially classified based on common terms in asset names and descriptions (e.g. “chalet” → Visitor; “ranger post” → Conservation) using lookup functions. Unmatched or ambiguous assets were reviewed manually and assigned to the appropriate category. Final checks were then made to ensure that classification was consistent across parks.

iv. Data Limitations

Fencing data provided by SANParks presented a limitation in this study. Quality variables, namely, Condition Index (CI), Estimated Useful Life (EUL), and Remaining Useful Life (RUL), were identical across all parks that had fence infrastructure. As confirmed through correspondence with SANParks, fence condition assessments were not conducted due to time and cost constraints, so uniform placeholder values were assigned for the purpose of completing the asset register. As a result, all fence-related quality data were excluded from the analysis.

4.2.2 Data Analysis

All analyses were conducted in R (version 4.2.1). using data from 19 national parks (n = 19).

i. Infrastructure Quality

Three indicators were used to assess infrastructure quality across national parks: Condition Index (CI), Relative Age (RA), and Relative Value (RV). The Condition Index was taken directly from the dataset as a score from 1 (poor) to 100 (perfect). Relative Age was calculated as the proportion of an asset’s estimated lifespan already used (where EUL = Estimated Useful Life and RUL = Remaining Useful Life):

$$\text{Relative Age} = \frac{EUL - RUL}{EUL} \times 100$$

A lower Relative Age indicates newer infrastructure; a higher Relative Age suggests older or more worn assets.

Relative Value reflects retained economic value after depreciation and was calculated as follows (where DRC = Depreciated Replacement Cost and CRC = Current Replacement Cost):

$$\text{Relative Value} = \frac{\text{Total DRC}}{\text{Total CRC}} \times 100$$

A low Relative Value indicates that an infrastructure asset has undergone significant depreciation, i.e., lost much of its original economic value.

I analysed infrastructure quality across two of the three asset types, namely roads and buildings. Due to the absence of reliable quality data for fences, all fences were excluded from quality analysis. Summary statistics (mean, median, standard deviation, range) were calculated by park and infrastructure type. Principal Component Analysis (PCA) was used to reduce dimensionality in Condition Index, Relative Age, and Relative Value for buildings and roads to calculate a composite infrastructure quality index per park. Using the *prcomp* () function, a PCA was performed on scaled and centred mean park-level values. The principal components (PCs) were examined to determine the proportion of variance explained by each. I generated scree plots to determine the number of PCs to retain, and biplots to visualise the distribution of parks along the primary components. PC1 scores, which captured the majority of variance (>90%), were used to rank parks: older, more deteriorated condition (PC1 < -1), newer, better-maintained condition (PC1 > 1), and mixed condition (-1 ≤ PC1 ≤ 1). These rankings were displayed using bar plots.

A Shapiro-Wilk test confirmed non-normal data distributions, so non-parametric statistical tests were applied. Kruskal-Wallis tests were used to assess park-level differences in Condition Index, Relative Age, and Relative Value, followed by Dunn's post-hoc tests with Bonferroni correction where significant. A separate PCA was conducted on building infrastructure, grouped by functional category (Visitor, Conservation Management, Operations and Support), to assess the quality variation across categories. Results were visualised using dot plots and box plots, and statistical comparisons were again made using Kruskal-Wallis and Dunn's tests due to non-normal data distributions.

ii. Infrastructure Investment Patterns

Infrastructure investment was assessed using each park's Total Current Replacement Cost (CRC), disaggregated by infrastructure type (buildings, roads, fences). To account for variation

in park size, Investment Intensity was calculated as CRC per km² (ZAR/km²). For building infrastructure, investment was further broken down by category (Visitor, Conservation, Operations and Support) to assess relative prioritisation. Due to non-normal distributions (confirmed via Shapiro-Wilk and Anderson-Darling tests), non-normal Kruskal-Wallis tests were used to assess differences in investment intensity across types and categories, followed by Dunn's post-hoc tests with Bonferroni correction to identify significant pairwise differences. This correction method was used because each analysis involved a small number of pairwise comparisons applied to individual infrastructure variables.

Multiple linear regression models were used to determine the influence of park area and visitor numbers on infrastructure investment. Two types of models were specified, each with a different response variable; in both, park area and visitor numbers were included as independent variables. The first set of models examined investment intensity (ZAR/km²), with separate models run for buildings, roads, and fences. The second model examined total infrastructure investment per park. All 19 parks were included in each model, including those with no recorded investment in roads (Richtersveld only has earth tracks) or boundary fences (Agulhas, Garden Route, Table Mountain). The models were specified as follows:

$$\text{Investment per km}^2 = \beta_0 + \beta_1(\text{Park Area}) + \beta_2(\text{Visitor Numbers}) + \epsilon$$

$$\text{Total Investment} = \beta_0 + \beta_1(\text{Park Area}) + \beta_2(\text{Visitor Numbers}) + \epsilon$$

iii. Cluster Analysis of Infrastructure Investment

To identify patterns in infrastructure investment across parks, I performed k-means clustering using four variables: investment per km² in buildings, roads, fences, and total infrastructure. To avoid overfitting, given the small sample size (n = 19 parks), the number of clustering variables was limited to four, in line with recommended observation-to-variable ratios for reliable pattern detection. Investment data were log-transformed (log(x+1)) to reduce skew and standardised using z-scores. A PCA was then applied to the transformed data, and the first two principal components (PC1 and PC2) were retained as they captured over 90% of the total variance. PCA loadings were examined to interpret each investment variable's contribution to the principal components.

K-means clustering was performed on the PC scores, with the optimal number of clusters (k = 3) selected using the Elbow Method and Silhouette Analysis. Parks were assigned to clusters and visualised in PCA space (PC1 vs. PC2). Cluster centroids were interpreted to characterise

typical investment profiles. The average investment in the different variables was calculated across clusters. Kruskal-Wallis tests were applied to each investment variable to test for differences in investment patterns across clusters, followed by Dunn’s post-hoc tests with Bonferroni correction, where significant differences were found. Differences in the investment variables across park clusters were visualised using box plots.

4.3 Results

4.3.1 Infrastructure Quality

Summary statistics indicated notable differences in quality between road and building infrastructure (Table 2). Roads had the lowest overall condition scores and the greatest variability across quality metrics. They were also the oldest infrastructure type and retained the least economic value relative to their replacement cost. Buildings were generally in better condition, with consistently high Condition Index scores and moderate variability. Buildings tended to be newer than roads (lower Relative Age and Actual Age) and retained a greater proportion of their replacement value.

Table 2. Summary statistics for infrastructure quality across two of South Africa’s National Parks’ infrastructure types (roads and buildings), showing mean values and standard deviation (SD). CI = Condition Index, RA = Relative Age, RV = Relative Value, AA = Actual Age.

Infrastructure Type	Mean CI	SD CI	Mean RA (%)	SD RA (%)	Mean RV (%)	SD RV (%)	Mean AA (yrs)	SD AA (yrs)
Roads	61.64	24.37	56.44	27.72	44.76	31.38	15.85	13.55
Buildings	80.13	9.88	41.50	9.87	57.44	9.68	7.97	2.97

PC 1 for buildings explained 96.19% of the total variance (see Figure A1 and A4 in Appendix A). Loadings indicated higher PC1 scores for newer, better-maintained buildings with higher retained value, while lower scores reflected older, more depreciated infrastructure. This was supported by the correlation analysis: there were strong negative correlations between Condition Index and Relative Age ($r = -0.967, p < 0.001$) and between Relative Value and Relative Age ($r = -0.963, p < 0.001$). Condition Index and Relative Value were positively correlated ($r = 0.944, p < 0.001$). Figure 3(a) shows the ranking of parks based on the PC1 scores for building infrastructure quality. Mokala, Bontebok, Addo, and Kgalagadi ranked highest for building quality, whereas Tankwa Karoo, Namaqua, Marakele, West Coast, and

Agulhas ranked lowest. Parks such as Golden Gate, Kruger, Garden Route, and Karoo fall within the middle range of PC1 scores. Statistical testing confirmed these differences. Kruskal-Wallis tests revealed highly significant variation in Condition Index ($\chi^2 = 313.3, p < 0.001$), Relative Age ($\chi^2 = 271.5, p < 0.001$), and Relative Value ($\chi^2 = 305.1, p < 0.001$). Post-hoc Dunn's tests with Bonferroni adjustment confirmed that many park pairs differed significantly in Condition Index, Relative Age, and Relative Value (see Table A1-A3, Appendix A for full pairwise results).

The road infrastructure PCA also yielded a strong first principal component, which accounted for 96.2% of the total variance (Figure A2 and A5, Appendix A). PC1 loadings showed a negative association with Relative Age (-0.58) and positive associations with Condition (0.57) and Relative Value (0.58), indicating that higher PC1 scores reflected newer, better-maintained roads with greater retained value, while lower scores indicated older, more depreciated roads in poorer condition. The correlation analysis confirmed these relationships: Relative Age was strongly negatively correlated with Condition Index ($r = -0.956, p < 0.001$) and Relative Value ($r = -0.814, p < 0.001$), while Condition Index and Relative Value showed a positive correlation ($r = 0.801, p < 0.001$). As shown in Fig. 3(b), Karoo, Golden Gate, and Kruger had the best road quality, while Tankwa Karoo, Mokala, and Kgalagadi ranked lowest. Parks such as Garden Route, Table Mountain, and West Coast showed mixed profiles. There were significant differences in road Condition Indices ($\chi^2 = 412.07, p < 0.001$), Relative Age ($\chi^2 = 333.67, p < 0.001$), and Relative Value ($\chi^2 = 491.31, p < 0.001$) across parks. Pairwise comparisons indicated widespread significant differences between parks for all three variables (Table A4-A6, Appendix A).

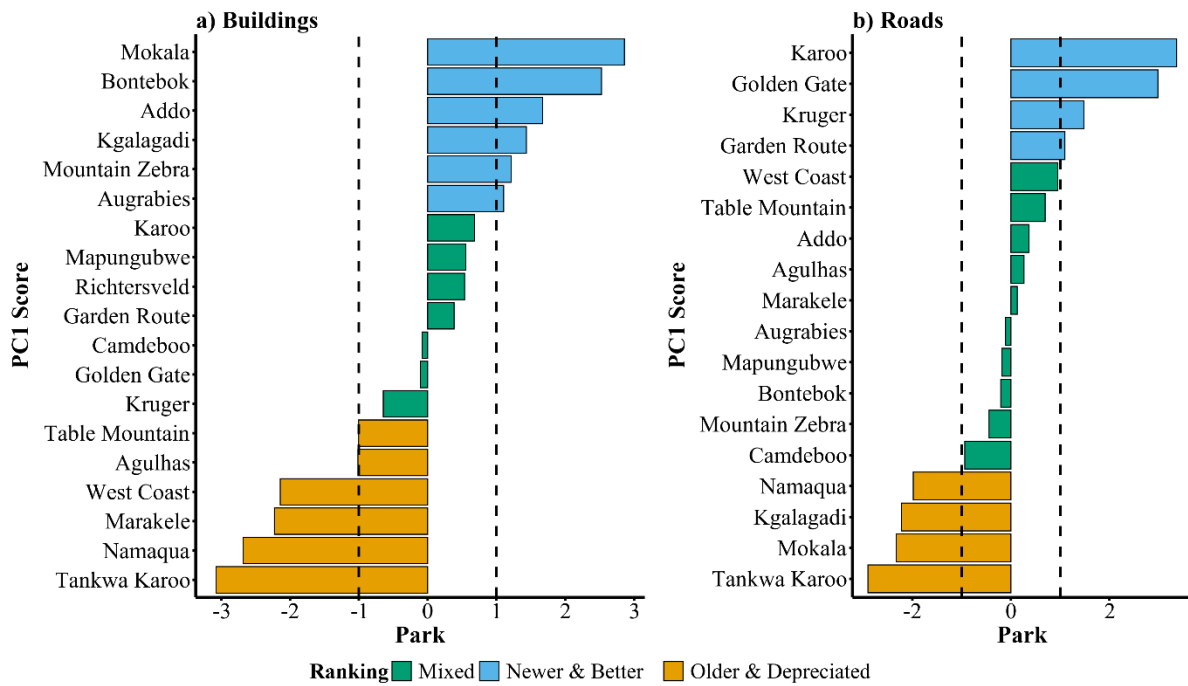


Figure 3. PCI scores for (a) Buildings and (b) Roads across National Parks. Parks are ordered by PCI score, and colour categories reflect qualitative groupings.

PCA results for the building categories (PC1 = 97.86%, Figure A3, Appendix A) revealed that Visitor infrastructure was the newest, best maintained and retained the most value (PC1 score = 1.8), while Operations and Support infrastructure was the oldest and most depreciated (-1.6), with Conservation Management falling in between (-0.2) (Fig. 4). Correlations confirmed that ageing infrastructure deteriorated ($r = -0.942, p < 0.001$) and lost value ($r = -0.946, p < 0.001$), while well-maintained infrastructure retained value ($r = 0.944, p < 0.001$). Kruskal-Wallis and Dunn’s tests confirmed significant differences across the building categories (all $p < 0.001$) in Condition Index, Relative Age, and Relative Value (except between Conservation and Operations infrastructure for Relative Value).

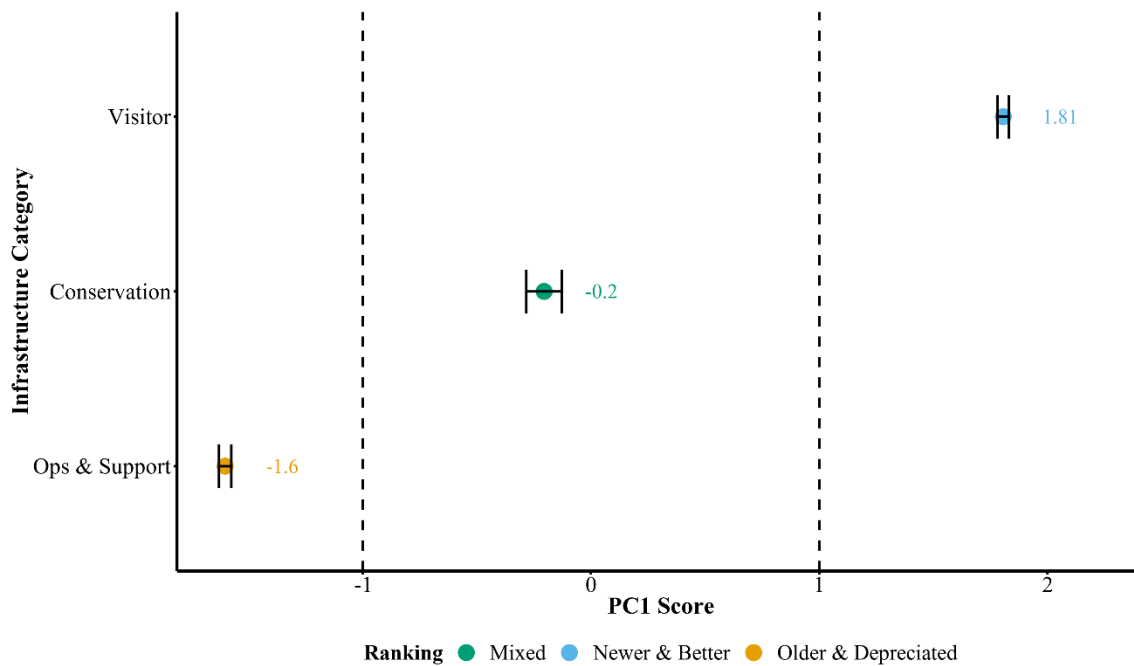


Figure 4. Mean PCI scores for building subcategories based on PCA of asset condition, age and value metrics. Categories are ranked by PCI score, and colour categories reflect qualitative groupings.

4.3.2 Infrastructure Investment Patterns

Across all parks, investment was approximately ZAR 7.9 billion for buildings, ZAR 7.5 billion for roads, and ZAR 922 million for fences, amounting to a total investment of about ZAR 16.3 billion. Investment per km² differed significantly among infrastructure categories (Kruskal–Wallis $\chi^2 = 26.58$, $p < 0.001$). Mean investment per km² was highest for buildings (ZAR 1.29 million/km²), followed by roads (ZAR 246,000/km²) and fences (ZAR 77,000/km²). Dunn’s post-hoc tests indicated that buildings received significantly higher investment than both roads ($Z = 3.31$, $p = 0.0028$) and fences ($Z = 5.08$, $p < 0.001$), whereas roads and fences did not differ significantly ($Z = -1.77$, $p = 0.231$).

At the building category level, most investment was allocated to Operations and Support (ZAR 4.04 billion), followed by Visitor infrastructure (ZAR 3.48 billion), with Conservation Management receiving the least (ZAR 349 million). This pattern held when standardised by park area: Operations and Support had the highest mean investment intensity (ZAR 268,000/km²), followed by Visitor (ZAR 171,000/km²) and Conservation Management (ZAR 15,700/km²). A Kruskal–Wallis test indicated a significant difference in investment intensity across the categories ($\chi^2 = 26.17$, $p < 0.001$). Post-hoc Dunn’s tests showed significantly lower investment in Conservation Management compared to both Operations and Support ($Z = -4.76$,

$p < 0.001$) and Visitor infrastructure ($Z = -4.16, p < 0.001$). No significant difference was found between Operations and Support and Visitor infrastructure ($Z = 0.63, p = 1.00$).

When adjusted for park size, investment intensity (ZAR/km²) varied markedly across South Africa's national park network, with smaller or more urbanised parks receiving substantially higher investment per unit area. Figure 5(a) and (b) show how investment is distributed by park, disaggregated by infrastructure type and category. Parks like Table Mountain, Golden Gate and Bontebok showed particularly high investment intensity per km², while larger parks, such as Kruger, had lower relative intensity despite higher absolute totals. Tankwa Karoo, Namaqua, Richtersveld and Karoo had the lowest investment intensity.

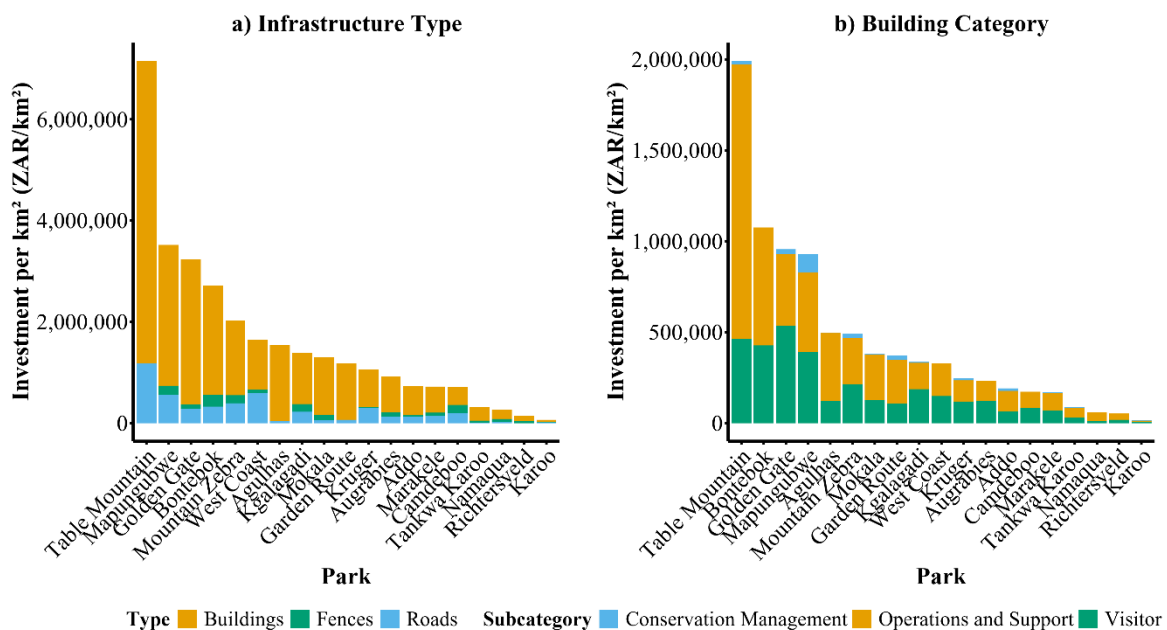


Figure 5. Investment intensity across South Africa's National Parks. (a) investment in building categories per park, standardised by park area. (b) Total infrastructure investment intensity per park, disaggregated by infrastructure type.

The model predicting investment in buildings per km² revealed that visitor numbers were positively associated with investment intensity ($\beta = 1.95, p < 0.001$), indicating that parks with higher visitation tend to receive greater investment per unit area (Table 3). Park area had a negative relationship with building investment ($\beta = -180.67, p = 0.001$). The model explained a large proportion of the variance and had a strong overall fit ($F = 18.8, p < 0.001, R^2 = 0.701, \text{Adjusted } R^2 = 0.664$).

The road investment model also showed a good fit ($F = 14.9, p < 0.001; R^2 = 0.665, \text{Adjusted } R^2 = 0.621$). Visitor numbers again had a strong positive effect ($B = 0.35, p < 0.001$), and park

area had a negative effect ($\beta = -28.37, p = 0.012$) (Table 2). In the fencing model, park area showed a weak negative association with investment ($\beta = -12.06, p = 0.089$), and visitor numbers had little relationship with investment levels ($\beta = 0.07, p = 0.384$). This model had limited explanatory power ($R^2 = 0.301, \text{Adjusted } R^2 = 0.193, F = 2.79, p = 0.098$).

For total investment, park area was a strong positive predictor ($\beta = 776,243, p < 0.001$) while visitor numbers also had a marginally significant association with higher investment ($\beta = 1,651, p = 0.054$) (Table 2). This model exhibited the strongest fit overall ($R^2 = 0.833, \text{Adjusted } R^2 = 0.812, F = 39.8, p < 0.001$). The intercepts for the buildings, roads, and fences models were substantially different from zero ($p < 0.001$), while the intercept for the total investment model was not ($p = 0.433$).

Table 3. Regression coefficients, confidence intervals, and p-values for models predicting infrastructure investment across parks. β = unstandardized coefficient estimate (ZAR/km² for buildings, roads, fences models and ZAR for total investment model). CI = 95% confidence interval. Significance: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.

Model	Predictor	β	CI Lower	CI Upper	p-value
Buildings	Park Area	-180.67	-269.33	-92.02	0.001**
	Visitor Numbers	1.95	1.24	2.66	<0.001***
Roads	Park Area	-28.37	-47.87	-8.87	0.012*
	Visitor Numbers	0.35	0.18	0.53	<0.001***
Fences	Park Area	-12.06	-24.82	0.71	0.089
	Visitor Numbers	0.07	-0.18	0.18	0.384
Total Investment	Park Area	776.24	563.06	993.22	<0.001***
	Visitor Numbers	1.65	92	3.21	0.054

4.3.3 Cluster Analysis of Infrastructure Investment

The first two principal components captured 90% of the variance in the data (PC1 captured 65,4% and PC2 captured 24,6%). The PCA loadings (Table 4) indicate that PC1 primarily captures overall investment intensity with strong positive contributions from total investment (0.60), buildings (0.60), and roads (0.50). Fences load most strongly on PC2 (0.96), suggesting PC2 reflects variability in fence investment across parks.

Table 4. Loadings of infrastructure investment intensity variables on the first two principal components (PC1 and PC2). Variables represent log-transformed and standardised investment per square kilometre (ZAR/km²).

Infrastructure Type	PC1 Loadings	PC 2 Loadings
Buildings	0.60	-0.01

Roads	0.50	0.27
Fences	-0.17	0.96
Total	0.60	0.06

K-means clustering on the first two principal components revealed three groups of parks based on investment profiles (Fig. 6). The first cluster, labelled “Large, Low-Visitation, Infrastructure-Light” (hereafter, “Infrastructure-Light”), includes Richtersveld, Karoo, Namaqua and Tankwa Karoo. These parks show low overall investment, particularly in buildings and roads, but some moderate investment in fencing (Table 5). They are typically remote and arid, with sparse infrastructure and limited tourism development. Cluster two “High-Access, Infrastructure-Dense” parks (hereafter, “Infrastructure-Dense”) includes Table Mountain, Agulhas, and the Garden Route. These parks are urban or peri-urban parks with high levels of public access and high investment intensity in buildings and roads, with no investment in fences. The third and largest cluster includes the remaining parks, including Kruger, Kgalagadi, Addo, Bontebok, and Camdeboo. These represent “Integrated Infrastructure” parks (hereafter, “Integrated”), well-funded and multifunctional parks with balanced, high investment across all the infrastructure types.

Cluster Description	Building Investment	Road Investment	Fence Investment	Total Investment	Number of Parks
‘Large, Low-Visitation, Infrastructure-Light’	150 508	10 724	35 088	196 320	4
‘High-Access, Infrastructure-Dense’	2 863 288	428 633	0	3 291 921	3
‘Integrated Infrastructure’	1 273 520	279 362	110 325	1 663 206	12

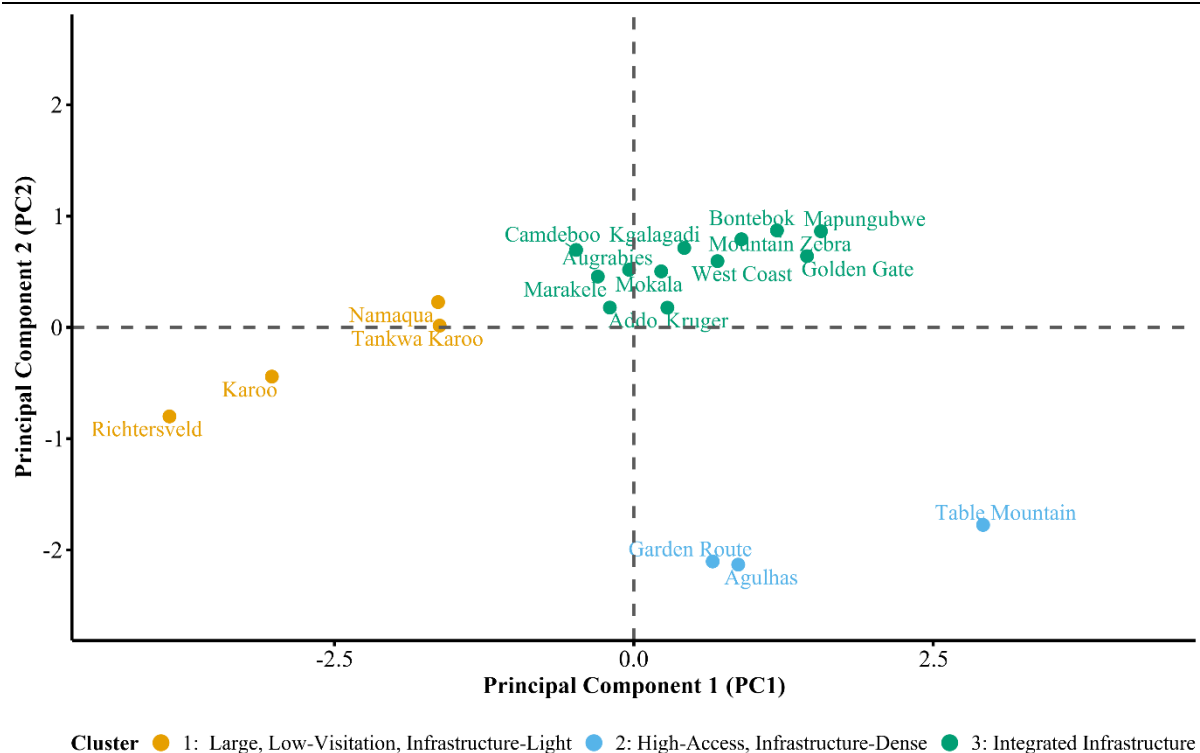


Figure 6. PCA plot of infrastructure investment (ZAR/km²) across National Parks. Parks are plotted based on k-means clustering from PC1 and PC2 scores, from log-transformed, standardised investment in buildings, roads, fences, and total infrastructure.

Table 5. Summary of infrastructure investment patterns across k-means clusters. Values shown are mean investment per cluster (ZAR/km²).

Kruskal–Wallis tests indicated significant differences in investment intensity among infrastructure clusters for buildings ($\chi^2 = 10.3, p = 0.006$), fences ($\chi^2 = 10.6, p = 0.005$), roads ($\chi^2 = 9.33, p = 0.009$), and total investment ($\chi^2 = 9.47, p = 0.009$). Post-hoc Dunn’s tests revealed that for buildings, investment was significantly higher in the second (‘Infrastructure-

Dense”) and third (“Integrated”) clusters compared to the first cluster (“Infrastructure-Light”) ($Z = -2.99, p = 0.008$ and $Z = -2.67, p = 0.023$, respectively), with no significant difference between “Infrastructure-Dense” and “Integrated” ($Z = 1.15, p = 0.754$) (Fig. 7a). For roads, only the difference in investment between “Infrastructure-Light” parks and “Integrated” parks was significant ($Z = -3.05, p = 0.007$) (Fig. 7b). Other comparisons were not significant (“Infrastructure-Light” vs. “Infrastructure-Dense”: $Z = -1.82, p = 0.205$; “Infrastructure-Dense” vs “Integrated”: $Z = 0.57, p = 1.000$). In the case of fences, “Integrated” parks showed significantly higher investment than “Infrastructure-Dense” ($Z = -3.03, p = 0.007$), whereas other pairwise comparisons were not significant (“Infrastructure-Light” vs “Infrastructure-Dense”: $Z = 1.17, p = 0.732$; “Infrastructure-Light” vs. “Integrated”: $Z = -1.85, p = 0.193$) (Fig. 7c). For total investment per km², “Infrastructure-Dense” ($Z = -2.68, p = 0.022$) and “Integrated” ($Z = -2.77, p = 0.017$) had significantly greater investment than Cluster 1 “Infrastructure-Light” with no significant difference between “Infrastructure-Dense” and “Integrated” ($Z = 0.69, p = 1.000$) (Fig. 7d).

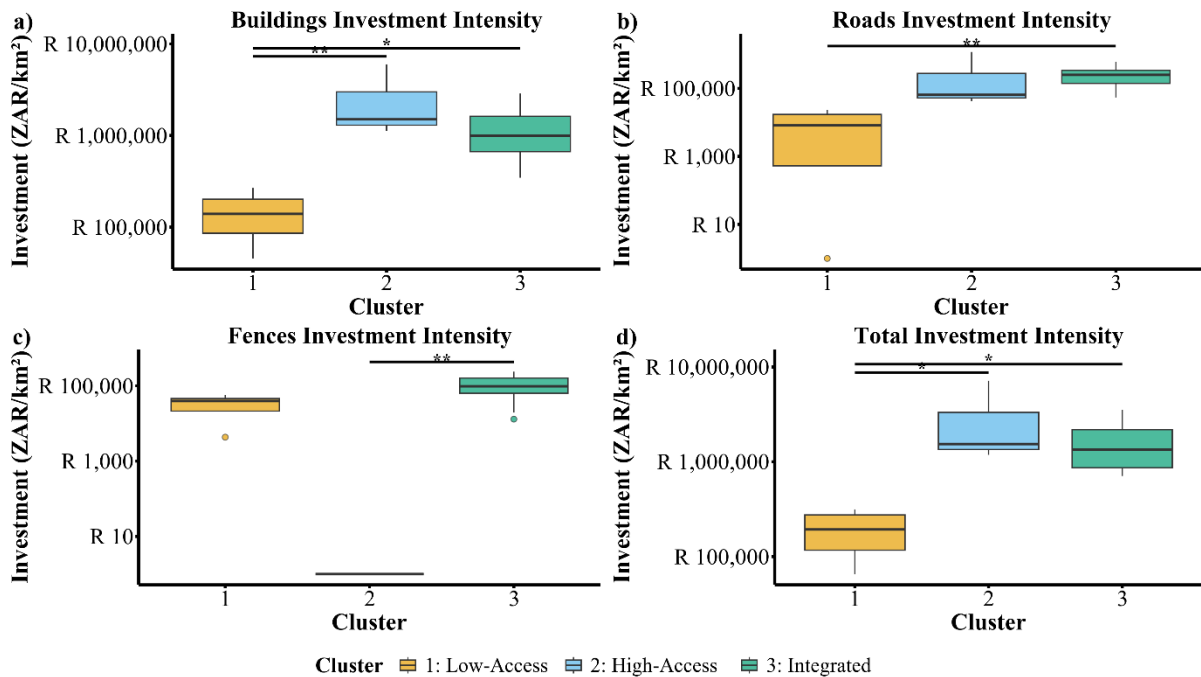


Figure 7. Investment intensity across infrastructure clusters in National Parks in a) buildings, b) roads, c) fences, and d) total infrastructure. The y-axis is log-scaled but labelled in real ZAR values. Horizontal lines with asterisks denote significant differences between clusters based on Dunn’s post-hoc tests. Significance: * $p < 0.05$, ** $p < 0.01$.

4.4 Discussion

The findings suggest that infrastructure condition and investment are highly uneven across South Africa's national park network. Roads were the oldest and most deteriorated asset type, whereas buildings were generally newer and better maintained. Among the building subcategories, Operations and Support received the most investment, Visitor buildings were in the best condition, while Conservation lagged behind both in investment. High-Access, Infrastructure-Dense parks received more infrastructure investment per unit area than larger, arid (Infrastructure-Light) parks. Regression models revealed that visitor demand (measured by annual visitor numbers) was positively associated with investment per unit area, whereas park size was negatively associated with investment per unit area across national parks. The cluster analysis identified three park groupings (High-Access, Infrastructure-Dense; Large, Low-Visitation, Infrastructure-Light; and Integrated Infrastructure), which imply a structural divergence in how parks are developed. Taken together, these findings reveal systemic patterns in how hard infrastructure is prioritised and spatially distributed across South Africa's national park network, which are indicative of governance logics (soft infrastructure) that may shape how infrastructure is funded and the feedbacks between built infrastructure and other system components (including natural and soft infrastructures) and visitor demand.

While SANParks organises parks into regional clusters, it has not adopted differentiated models based on infrastructure and function, and our results suggest that parks already fulfil different roles in practice. "Large, Low-Visitation, Infrastructure-Light" parks are characterised by extensive land areas, predominantly arid or semi-arid landscapes, and relatively low annual visitor numbers. In contrast, the other parks in the system are either considerably smaller in size or, if they are similarly large (e.g. Kruger or Kgalagadi), they receive substantially higher visitor numbers. These parks are strategically important for representing ecosystem types and biodiversity features that are under-represented elsewhere in the national protected area network. As such, they may be best positioned to function as biodiversity refugia, low-impact wilderness destinations, or sites for alternative conservation approaches. In such parks, low levels of infrastructure investment may be appropriate, but investment in the right kinds of infrastructure is important to support these functions. "High-Access, Infrastructure-Dense" parks (characterised by high building and road investment, urban or peri-urban locations and open access) already show a strong orientation towards tourism and high public use. Given their accessibility and infrastructure density, these parks could be well-suited to serve as recreational hubs or as gateway parks that are entry points into the national park system for

diverse user groups. “Integrated Infrastructure” parks displayed balanced investment across the infrastructure types and likely fill multiple roles. For these middle-ground parks, accessibility is less of a limiting factor, so infrastructure investment may play a more important role in shaping outcomes such as CES delivery. More broadly, infrastructure can strongly influence how visitors access and perceive protected areas. For example, in Garden Route National Park (classified within the “Infrastructure-Dense” cluster but illustrative of this principle) the presence of the Storms River Bridge, a spectacular gorge crossing on South Africa’s main southern highway, has arguably made what would otherwise have been a relatively obscure section of the park into a highly visited one. The majority of parks fell into the “Integrated Infrastructure” category; notably, some parks that appeared distinctive in the analyses did not separate more cleanly and were also grouped within this cluster, such as Bontebok, which showed exceptionally high infrastructure investment per square kilometre and the second-highest average building quality score. This could mean that while this broadly captures parks with balanced roles, it may also serve as a “catch-all” category, including parks with overlapping roles or transitional profiles. This indicates that there are likely more complex or evolving park functions that could not be fully captured by the clustering.

Internationally, protected area scholars have advocated for differentiated governance models (such as functional zoning, role-based governance, and context-specific management) that take into account parks’ unique contexts, of which infrastructure is an important aspect to consider (Berkes, 2004; Cumming & Allen, 2017; Lockwood, 2010; Nyaupane et al., 2022; Song et al., 2024). In South Africa, national parks similarly serve different purposes (as reflected in our park clusters). In practice, each park is funded through centrally allocated operating budgets (which cover things like human capital, general operating costs and routine infrastructure maintenance) that are managed locally (SANParks, 2023a, 2024b). However, large-scale infrastructure projects are determined nationally, not by individual parks, through the Medium-Term Expenditure Framework, which is approved by SANParks’ Executive Committee, with a key priority being to address the R.3.4 billion (approximately \$180 million) recapitalisation backlog to replace ageing infrastructure (SANParks, 2024a, 2024b). So, while big infrastructure decisions are centrally coordinated, there does appear to be some level of differentiation and context-specific decision-making in how infrastructure investment is directed.

The regression results show a strong relationship between visitor numbers and infrastructure investment intensity for buildings and roads, which suggests investment pattern that is

responsive to visitation demand. There is tentative support for the existence of a reinforcing feedback loop where parks with high visitation receive greater infrastructure investment, which enhances visitor experience and accessibility, leading to more visitation. However, this relationship is inferred from cross-sectional patterns, and cannot be evaluated fully without examining longitudinal data of changes in visitation and infrastructure investment over time. However, such dynamics could disadvantage “Infrastructure-Light” parks, as over time, investment into parks may become path dependent, meaning past development and perceived importance shape ongoing funding decisions (Anderies et al., 2016). This dynamic reflects the Matthew principle (Merton, 1968), also described in systems thinking as ‘success to the successful’ (Meadows, 2008), in which initial advantages compound over time. Similar funding patterns have been observed in other conservation contexts, for example, in a number of lion-range African PAs, where donor and state funding are channelled mainly to fenced, tourism-oriented parks or those with cornerstone species such as rhinos, which ultimately reinforces system inequalities (Lindsey et al., 2018). Although, alternative trajectories are also possible, where increases in visitation occur independently of major infrastructure investment (for example, visitor numbers in Karoo National Park increased from approximately 3 555 in 2005/2006 to 30 226 in 2023/2024) hence the need for future research in this area.

However, in the case of South Africa’s National Parks, uneven investment is not necessarily the result of neglect, as many of the “underfunded” parks are geographically remote, ecologically sensitive, or cater to niche forms of tourism. For example, the “Low Access” cluster included mostly arid parks that receive limited investment and tend to have lower visitation. These park landscapes (e.g. Tankwa Karoo, Namaqua, and Richtersveld) tend to have high conservation value and lower visitor carrying capacities, so limited facilities and accessibility may help protect vulnerable habitats. Infrastructure expansion, especially roads, could also compound issues like cycad poaching in dryland parks (Ndou et al., 2021). At the same time, the wilderness character or perceived remoteness of these parks is actually a drawcard for some visitors. Ament et al. (2017) found that visitors to these parks particularly value CES bundles centred on natural history and sense of place, so investing in high-volume tourism would likely undermine the CESs that attract people to these parks.

One might question how parks in which it is ecologically appropriate to have limited infrastructure can remain financially viable. However, it is important to note that SANParks retains all revenues generated across its park network and redirects them to support its conservation mandate; hence, revenue from higher-income parks supports less popular parks

(SANParks, 2024d). Infrastructure investment may also not substantially affect financial sustainability in such contexts. Even if SANParks were to take a “build it and they will come” approach, this would require massive infrastructure investment, not just within parks, but regionally in roads and airports. Research shows that nature-based tourism decisions are made based on a number of “push” and “pull” factors (such as location, ecology, discoverability, and affordability), so infrastructure alone may not overcome fundamental barriers for potential visitors (Baum et al., 2017; De Vos et al., 2016). Also, in many cases, the park’s business model or visitor demand may simply not warrant such a large-scale investment. Because they pool resources, SANParks’ financial model does not necessarily require every park to be optimised for profit, hence they can be managed for different purposes as long as the system remains financially sustainable overall (given also the role of government funding in support of national parks as they serve a “public good”). So, infrastructure investment, particularly in terms of the kinds of infrastructure invested in, can serve varying objectives across park contexts and potentially should not be driven by visitor demand alone.

While total infrastructure spending tends to increase with park size (see Figure A9, Appendix A) investment intensity per km² remains much higher in smaller parks, as regressions showed that area had a negative effect on investment intensity in both the building and road models. The results suggest that larger parks (while more costly overall) have more spatially dispersed infrastructure, making them cheaper per unit area to manage, whereas smaller parks tend to be more intensely developed and expensive per km². My findings suggest that infrastructure investment does not necessarily scale linearly with park size (see Figure A8, Appendix A); economies of scale likely exist in South Africa’s larger parks, making them more economical, while their greater size also inherently supports ecological connectivity. Research in other contexts, such as studies of forested ecosystems in the eastern United States and Appalachian Mountains, also found that larger protected areas tend to be more cost-effective by delivering greater ecological returns per dollar invested (Cho et al., 2019; Armsworth et al., 2018). The influence of protected area size on conservation benefit and acquisition cost should be taken into consideration as SANParks or other agencies expand their protected area estate (Cho et al., 2019).

However, the above-mentioned cost-efficiency logic likely does not hold in multifunctional conservation systems where ecotourism is not the only business model, such as sustainable use areas, community-managed landscapes, and Other Effective Area-Based Conservation Measures (OECMs), which will be important for SANParks to consider in their emerging

“Mega-Living” landscape initiative (SANParks, 2024c). The governance structures and socio-ecological functions of these landscapes tend to differ from strictly conserved areas, so their infrastructure needs and patterns can be expected to also differ significantly from those observed in national parks (Jonas et al., 2018). At the same time, some degree of economies of scale may still apply; for instance, collective investments across larger landscapes may reduce the need for duplicating costly infrastructure (e.g. abattoirs), but the appropriate investment model would depend heavily on the landscape’s nature and objectives.

Parks have numerous aims and pressures to balance; the investment dynamics discussed above (including the link between visitation and infrastructure investment, uneven spatial distribution of funding, and non-linear scaling with park size) raise an important question for SANParks and general protected area governance: which goals should infrastructure investment serve? A useful comparison comes from Botswana, which has adopted a “low-volume, high-value” approach. Botswana’s government strategically invests in roads, facilities, and fences in certain zones to enhance tourist access and visibility, while leaving other areas undeveloped to retain the sense of “wilderness” and limit human impact (LaRocco, 2020). Visitor studies in Moremi also show that tourists are willing to pay the high entry fees, provided that key infrastructure and experiences are well managed (Mmopelwa et al., 2007). Yet Botswana’s model is far from unproblematic. LaRocco (2020) show how selective infrastructure provision can entrench social exclusion, rendering some communities “illegible” to the state (i.e. excluded from formal planning and service provision) in service of tourist expectations. On the other end of the spectrum, Kenya has long followed a higher-volume, and comparatively lower-value tourism model, which they are now actively trying to shift away from due to issues of over-visitation and environmental degradation (Cheung, 2012; Ministry of Tourism and Wildlife, 2022). These examples illustrate the trade-offs inherent in different infrastructure strategies – concentrated infrastructure can protect ecological values but marginalise people groups, whilst open-access infrastructure might increase economic returns but degrade natural resources. The implication is that SANParks and similar state-governed protected area systems may benefit from taking a systematic approach which uses the diversity of the parks within their system to achieve broader goals of protecting biodiversity and national heritage (which may mean different things in different parks).

According to regression results, fence investment patterns differed from other infrastructure types and were not associated with visitation or park area. The findings suggest that fencing in South Africa’s national park network follows a different logic than the other infrastructure

categories and likely has a fundamentally different function that is less influenced by visitor access or park income. Interestingly, although “Infrastructure-Dense” parks had minimal or no recorded fence investment, the difference between “Infrastructure-Light” and “Infrastructure-Dense” clusters was not statistically significant. This likely reflects the small number of parks per cluster and the relatively low levels of fence investment within the “Infrastructure-Light” cluster. The PCA from my cluster analysis results reinforce this distinction as fences loaded on a separate component from roads and buildings. In South Africa, fencing of PAs is often shaped by legal mandates, such as the Game Theft Act, which stipulates the use of clear boundaries for wildlife ownership and containment (Republic of South Africa, 1991). So, SANParks likely funds fences based on regulation rather than tourism. Internal fencing within SANParks may be influenced by factors like the number of visitor camps, but this represents a relatively small proportion of total fencing investment. Internationally and in parts of South Africa outside of formal national parks (such as private or mixed-use reserves), fencing investment, particularly internal fencing, may be more directly shaped by visitor patterns. In Kenya, for example, where PAs tend to have far less fencing than in South Africa’s national parks, small electrified fences in conservancies like Ol Pejeta are used to reduce human-wildlife conflict and manage tourism access (Graham et al., 2009); while in Maasai Mara’s community conservancies, fencing separates tourists from grazing lands (Weldemichel & Lein, 2019).

Operational infrastructure was the most heavily funded building subcategory across South Africa’s national park network, but interestingly, these assets were older and more depreciated than Visitor and Conservation infrastructure. Despite their centrality to the day-to-day functioning of parks, operational infrastructure is rarely discussed in conservation discourse. Conservation buildings appeared to be systematically underfunded, which may raise concerns about long-term ecological resilience and a potential trade-off between tourism and conservation. The high investment in Operations & Support infrastructure within SANParks may reflect institutional priorities around internal system functionality. Visitors do not typically encounter these infrastructures, so they may lack public visibility and “appeal”, but still support tourism as they provide staff capacity to manage visitors (Worboys et al., 2015). Investments into operational infrastructure also indirectly support conservation by enabling scientific work, which provides CES, such as education (Smit et al., 2017) and anti-poaching operations, which require large amounts of infrastructure and staff, particularly in the Kruger National Park.

Road infrastructure was the most deteriorated asset type with the lowest average Condition Index, highest Relative Age, and the least retained economic value, alongside substantial variability compared to buildings and fences. This may be due to a number of factors like environmental exposures, the cost of maintenance, or lower strategic priority compared to buildings, which high-value, visitor-facing assets. Within South Africa's National Parks, roads are maintained by SANParks except for in cases when national or provincial roads traverse parks (for example, the R342 in Addo), which are under the jurisdiction of SANRAL or provincial transport departments, respectively. Roads are also ecologically sensitive infrastructure, and overdevelopment can lead to fragmentation, so upkeep may be conservative or reactive in nature (Perumal et al., 2021). Road access can also facilitate poaching and illegal resource extraction (de Matos Dias et al., 2020). But at the same time, well-designed and maintained roads can allow sustainable access to and within protected areas (Şakar et al., 2022), by controlling tourist movement, providing routes for rangers and staff, and in some cases improving access for neighbouring communities. Hence, the deterioration of roads within a park network may have cascading effects on ecological resilience and park effectiveness.

Infrastructure investment also sheds light on protected area governance in terms of what parks and what kinds of infrastructure are prioritised, which gives insights into the underlying institutional logic and also reveals potential tensions between conservation and recreational use/access. For instance, the high investment in Operations & Support and Visitor infrastructure (relative to Conservation buildings or roads) suggests that decisions are shaped as much by operational needs and demand-driven performance as by ecological need, or perhaps even more so. The CIS framework places importance on the feedbacks and interactions between hard and soft infrastructure ecosystems, users, and governing institutions (Anderies et al., 2022). My findings highlight some of these interactions, for example, how soft infrastructure (i.e. SANParks decision-makers) respond to pressures from exogenous drivers (visitor numbers) by investing in hard Public Infrastructure, which in turn shapes access and use. However, governance responses are not always well-aligned as feedbacks between demand and infrastructure provision can be delayed, uneven, or based on incorrect assumptions about demand and park function.

My findings also have clear implications for CES delivery. The infrastructure investment and distribution patterns we observed impact which parks are accessible, what kinds of nature-based experiences are possible, and which visitor groups are served. For example, parks that are accessible and have all the relevant infrastructure (such as "Infrastructure-Dense" parks or

even “Integrated” parks) are more likely to support aesthetic enjoyment, recreational or educational services. Whereas, “underfunded” (most likely those that fall within the “Infrastructure-Light” cluster), despite high ecological or experiential value, may be unable to realise their full CES “potential” due to limited access, but at the same time, expanding infrastructure could bring trade-offs by eroding existing CES that shape park identity. The results reveal substantial differences in infrastructure investment and condition, which suggest the potential for “mismatches” between the kinds of CES that parks can deliver and the available infrastructure, which will be further explored in the next chapter.

Several limitations should be acknowledged when assessing this chapter’s results. First, because the fence infrastructure displayed no variation in quality metrics, it could not be used in some analyses. Second, the analysis was based on infrastructure value and asset data captured at a single point in time. Longitudinal data would provide deeper insight into how infrastructure investment evolves and relates to changes in park function, visitor numbers, or conservation performance. Future studies could explore the relationship between built infrastructure and biodiversity outcomes, visitor satisfaction, or the delivery of cultural ecosystem services. Lastly, the drivers of investment decisions were inferred statistically but not explored through institutional or political analysis; hence, qualitative research involving SANParks planners and decision-makers (such as document reviews or stakeholder interviews) could provide important insights into the decision-making logics and trade-offs/constraints behind infrastructure allocation.

In summary, the findings demonstrate how protected areas operate as coupled infrastructure systems, with a focus on hard-infrastructure related feedbacks which have previously been underexplored in SES research. The analysis also shows the usefulness of an archetype approach for context-appropriate generalisability to support management decisions in protected areas. I found significant disparities in infrastructure investment and condition across South Africa’s National Parks, with regression results showing that visitation and park size are key investment drivers, and cluster analysis revealing divergent development pathways with varying levels of infrastructure investment. Infrastructure emerges as a window into the institutional dynamics at play within a protected area system and how man-made physical systems shape and are shaped by the relationships between people, nature, and institutions. This chapter lays a comparative, empirical foundation for understanding the role of hard infrastructure in conservation, tourism and delivering access to the cultural ecosystem services that uphold protected areas’ long-term relevance. The following chapter (Chapter 5) builds on

these infrastructure clusters to investigate how patterns of hard infrastructure relate to visitor preferences for CES.

CHAPTER 5 THE RELATIONSHIP BETWEEN HARD INFRASTRUCTURE AND VISITOR PREFERENCES FOR CULTURAL ECOSYSTEM SERVICES

This chapter is written as a standalone journal article that is still to be submitted for publication. Minor edits have been made to the original manuscript.

Abstract: Built or hard infrastructure plays a critical role in biodiversity conservation. In addition to its well-documented impacts on plants and animals, it both shapes and is shaped by visitor experiences. The alignment of hard infrastructure with visitor needs influences the sustainability and social relevance of protected areas, but the relationship between hard infrastructure and the cultural ecosystem services valued by visitors across national park networks has not been previously explored. To address this gap, I used two unusually extensive datasets from all 19 of South Africa’s National Parks that are open to public visitation: (1) CES preferences from more than 3,000 visitor surveys, and (2) a park-level infrastructure inventory of all above-ground assets (>15,000 buildings, roads, and fences). Using factor analysis, I extracted five CES “bundles”: Natural History, Recreation, Sense of Place, Safari Experience, and Outdoor Living, derived from earlier work. I calculated park-level mean scores for each bundle and identified distinct CES preference profiles: Nature-learning & Heritage, Safari & Wildlife, Place-Attachment & Immersive, and Urban Recreation. I then examined how these CES clusters compared to the infrastructure clusters identified in the previous chapter: Infrastructure patterns explained substantial variation in specific CES bundles: Recreation was associated with infrastructure-dense parks, whereas Natural History was strongest in minimally developed parks. Sense of Place and Outdoor Living showed weak or inconsistent relationships with infrastructure. Patterns of infrastructure investment in South Africa’s national park system reveal underlying institutional priorities and resulting decision-making, demand-driven feedback loops, and an emerging differentiation in park roles. Misalignment in some cases between CES and infrastructure clusters might be due to weak or lagged feedbacks between visitor demands and governance responses. Overall, hard infrastructure and CES are tightly and predictably coupled across South African National Parks, highlighting the importance of hard infrastructure in mediating the delivery of cultural ecosystem services from protected areas and the role of cultural services in influencing hard infrastructure provision.

5.1 Introduction

In protected areas, cultural ecosystem services are increasingly recognised as vital to public support and long-term conservation success (Braat & de Groot, 2012; Cumming et al., 2015; Daniel et al., 2012). PAs can be thought of as cultural landscapes that provide opportunities for benefits such as recreation, education, spiritual connection, and aesthetic enjoyment, particularly through nature-based tourism. These services are shaped by how people perceive and engage with PAs (Maldonado et al., 2019; Martinez-Harms et al., 2018; Taff et al., 2019); therefore, understanding CES demand and delivery requires a social-ecological systems perspective that recognises how CES are co-produced through the dynamic interactions between people, ecosystems, and institutions (Fish et al., 2016; Jiang & Marggraf, 2025; Kachler et al., 2023).

Within the social-ecological research domain, hard infrastructure is an underexplored mediator of the non-material benefits to people from nature. However, a growing body of literature, as discussed in Chapter 2, suggests that infrastructure plays an important role in determining the perceived value of CES in PAs (Baum et al., 2017; De Vos et al., 2016; Echeverri et al., 2022; Engelbrecht et al., 2014; Heagney et al., 2018; Hennig, 2017; Hermann et al., 2016; Kruger et al., 2019; Mancini et al., 2019; Saayman & Van Der Merwe, 2017; van der Merwe et al., 2020; Van Der Merwe & Saayman, 2007; Zelenka & Kacatl, 2013). Yet, no empirical studies have examined how patterns of infrastructure investment align with actual CES preferences across park networks.

The Coupled Infrastructure Systems framework offers a useful lens through which to understand the dynamic relationships between hard infrastructure, cultural ecosystem services, and institutional decision-making in protected areas (Anderies et al., 2022). Infrastructure mediates such interactions, ultimately shaping how PAs function and their capacity to deliver equitable and resilient outcomes. Visitor infrastructure, in particular, determines which CES are accessible (e.g. through trails, interpretation signage, hides, or viewpoints), who can access them (depending on the affordability, accessibility, or visibility of facilities) and how they are experienced (different infrastructure supports different kinds of CES) (De Vos et al., 2016; Mancini et al., 2019; Naumann et al., 2018). Although this chapter focuses empirically on major capital asset categories (roads, buildings, and fences), the delivery of CES is also shaped by finer-scale enabling infrastructure and activities that may contribute disproportionately to visitor experience relative to their financial value or physical footprint. It is also important to

note that the relationship between infrastructure and CES is unlikely to be unidirectional. In practice, while infrastructure enables CES, visitor preferences may also influence where and how infrastructure is developed. Over time, such interactions create feedbacks that reinforce particular CES experiences or expose mismatches between infrastructure provision and evolving visitor demand.

There is already a fairly well-established understanding of the kinds of cultural ecosystem services within South Africa’s national park system (Brill et al., 2022; Cheng, 2023; Cumming & Maciejewski, 2017; Roux et al., 2020; Smit et al., 2017). Specifically, Ament et al. (2017) identified five bundles of CES preferences across these parks, ranging from learning about nature and active recreation to emotional connection, iconic wildlife experiences, and quiet relaxation (Table 6) . Building on this work, this research aims to examine how variation in hard infrastructure investment corresponds to differences in visitor preferences for CES. I make use of an extensive data set with information on CES from over 3,000 visitor surveys (from which Ament et al.’s CES archetypes were derived) and infrastructure data from 19 of South Africa’s National Parks, to address the question: what is the relationship between patterns of hard infrastructure and visitor preferences for cultural ecosystem services, and how do these interactions inform infrastructure planning and CES delivery?

Table 6. Description of CES bundles derived from factor analysis of visitor survey responses (adapted from Ament et al., 2017). Strongest loading statements are shown for each bundle.

CES Bundle	Description	Strongest Loading Survey Statements (Factor loadings > ~0.45)
Natural History	Appreciation of biodiversity, species identification, and learning about nature	Looking at flowers; Trying to identify plants; Looking at birds; Looking at reptiles; Looking for/listening to frogs; Learning more about nature
Recreation	Active, high-energy, outdoor recreational activities	Boating or canoeing; Swimming/surfing/watersports; Sunbathing; Hiking/climbing; Fishing; Off-road driving; Having a party with friends
Sense of Place	Emotional, spiritual, and relational attachment to protected areas	It refreshes my spirit; It helps me relax; Feeling closer to God; Getting away from modern conveniences; Spending time with family/friends; Camping
Safari Experience	Iconic wildlife viewing and photographic game-drive experiences	Looking at big mammals; Doing game drives; Taking photographs; Learning more about nature
Outdoor Lifestyle	Low-key, camp-based outdoor living and leisure	Cooking/braaing; Hanging out at the campsite/chalet; Reading/writing

To explore these questions, I test four hypotheses grouped into two sets that deal with different aspects of the CES-infrastructure relationship. The first set (set A) considers how different infrastructure contexts might correspond to different visitor value profiles. Given that visitor-facing infrastructure facilitates access and enables activity-based experiences (Eagles et al., 2002; Leung et al., 2018) parks with higher investment in such infrastructure are more likely to support access-dependent CES, particularly Recreation (H1a). Whereas parks with less infrastructure investment are likely to be associated with introspective CES like Sense of Place, Outdoor Living or Natural History (H1b), as overdevelopment or “obvious” infrastructure has been found to detract from the perceived naturalness of protected areas and lead to overcrowding (Lupp et al., 2016; Tverijonaite et al., 2023). Parks with sparse infrastructure would thus likely be attractive to visitors seeking reflective or aesthetically immersive experiences.

The second set of hypotheses (set B) focuses on the extent to which infrastructure patterns align with CES preferences, as an indicator of planning responsiveness. If infrastructure planning is responsive to dominant visitor preferences, then parks with similar CES profiles should exhibit similar infrastructure patterns (H2a). In contrast, misalignments between CES preferences and infrastructure profiles may indicate infrastructure planning is weakly coupled to current visitor demand (H2b). Such mismatches could be due to institutional inertia or lagged feedbacks, where planning fails to keep pace with changing values (Anderies et al., 2022; Cumming, 2023). To address these hypotheses in the remainder of this chapter, I identify clusters of parks based on their prevailing CES profiles, I compare these CES clusters with the infrastructure archetypes identified in Chapter 4, and examine the extent to which individual CES bundles vary across different infrastructure contexts and then interpret what the results reveal about the relationship between infrastructure and visitor preferences for CES.

5.2 Methods

5.2.1 Data Collection

i. CES Data

This study draws on the dataset originally published in Ament et al. (2017), which assessed CES demand across 19 of South Africa’s National Parks. The dataset comprised 3,131 complete responses collected between February 2013 and May 2015. Surveys were distributed at the entrance gates and reception desks of all national parks, with additional sampling

conducted by research assistants at campsites, restaurants, and picnic areas. Respondents rated 30 Likert-type statements (1 = strongly disagree, 5 = strongly agree) reflecting appreciation for six CES subcategories: aesthetic, recreational, educational, cultural/heritage, social, and spiritual values. Full details of the sampling design and analytical protocol can be found in Ament et al. (2017).

ii. Infrastructure Data

Data on park-level infrastructure investment were derived from the SANParks Fixed Asset Report, a registry of all above-ground infrastructure for all of South Africa's proclaimed National Parks. I used aggregated Current Replacement Cost (CRC) values for buildings, roads, and fences, which were log-transformed, standardised by park area, and z-score standardised to ensure comparability. A Principal Components Analysis (PCA) was conducted on four variables: investment in buildings, roads, fences, and total infrastructure investment, and we retained the first two principal components (>90% of variance explained). K-means clustering ($k = 3$) was applied to the PC scores, and the optimal number of clusters was selected using the Elbow Method and silhouette widths. This clustering procedure, as detailed in Chapter 4, resulted in each park being assigned to one of three clusters: 1) 'Large, Low-Visitation, Infrastructure-Light', 2) 'High-Access, Infrastructure-Dense, and 3) 'Integrated Infrastructure' Parks. In this chapter, these clusters are treated as categorical predictors in all statistical models to assess potential relationships with CES preferences.

5.2.2 Data Limitations

The visitor survey dataset has several limitations. Sampling bias may be present, with possible seasonal and domestic–international differences influencing responses. Response numbers also varied greatly between parks, so smaller and less visited parks with low response numbers may skew the factor scores. The data were collected between 2013 and 2015, and visitor preferences may have shifted since then. However, there is likely a lag between visitor demand and infrastructure construction, so current infrastructure provision may come from past visitor preferences. Lastly, the limitations associated with the infrastructure data have been discussed in the previous chapter (see section 4.2.1) and mainly relate to the incompleteness of the fencing quality data.

5.2.3 Data Analysis

i. Factor Analysis

All analyses were conducted in R (version 4.2.1). To derive CES bundles, I followed the analytical approach of Ament et al. (2017). Exploratory factor analysis was conducted on a subset of CES-related variables using the *factanal* () function with varimax rotation. The number of factors to retain was determined through scree and parallel analysis. Five CES bundles were extracted: Natural History, Recreation, Sense of Place, Safari Experience and Outdoor Lifestyle, with factor loadings and bundle structure consistent with those reported by Ament et al. (2017) (see Appendix D for variable loadings). The remaining analyses were original to this study. CES Factor scores were averaged at the park level for subsequent analysis. Factor scores were first calculated at the respondent level ($n = 3,131$), then averaged per park ($n = 19$ parks) to produce mean CES factor scores per bundle, per park, which were used in subsequent cluster analyses.

ii. CES Cluster Analysis

I used k-means clustering to identify patterns of CES preferences across national parks. Clustering is a widely used technique in recreation and park management research to segment visitor groups based on shared preferences, behaviours, and use patterns (Benson et al., 2013; Borrie et al., 2002; Botha et al., 2016; Derek et al., 2019; Fix & Taylor, 2011; Sardana et al., 2016). In this study, K-means clustering was applied to park-level CES data ($n = 19$ parks), using the standardised mean factor scores for each of the five CES bundles identified in the factor analysis above. The optimal number of clusters ($k = 4$) was determined using the Elbow method and silhouette widths (average silhouette width = 0.29). A PCA was used to visualise the clusters, with the first two components explaining 71% of the total variance. I tested for differences in CES bundles across clusters using one-way Analysis of Variance (ANOVAs). Normality of factor score distributions was confirmed with the Shapiro-Wilk test, and Tukey's HSD post-hoc tests were used to identify pairwise differences.

iii. Comparing CES and Infrastructure Clusters

The alignment between the CES and infrastructure clusters was visualised using an alluvial plot. A Fisher's Exact Test was used to test for non-random association between CES and infrastructure clusters, which was chosen over a Chi-squared test due to the small sample size ($n = 19$ parks). A Cramér's V test was then used to test the strength of association. To assess

patterns of infrastructure investment and condition across CES preference clusters, summary statistics were calculated for each cluster using park-level data. The mean values for road age, visitor building age, investment intensity (ZAR/km²), and per-visitor investment (ZAR/visitor) were calculated for each cluster. Mean road age and visitor building age were derived by subtracting the Remaining Useful Life (RUL) from the Estimated Useful Life (EUL) for each asset and averaging these values across parks within each CES cluster. Note that this (absolute mean age in years) differs from Chapter 4, where relative age was calculated as a proportion of the lifespan used. Total infrastructure investment per km² and per visitor was then calculated using Current Replacement Cost (CRC) data standardised by park area and annual visitor numbers, respectively.

iv. Statistical Testing of CES Differences by Infrastructure Cluster

A Multivariate Analysis of Variance (MANOVA) with Pillai's Trace was first conducted to test whether CES factor scores differed significantly across infrastructure clusters. Pillai's Trace was selected because it is considered robust to violations of assumptions (such as unequal covariance matrices) and is commonly used when multiple dependent variables are analysed simultaneously (Olson, 1976). The five CES factor scores (i.e. park-level mean scores for each CES bundle) were treated as dependent variables, and the three infrastructure clusters were used as the grouping factor. Where the MANOVA indicated significant multivariate differences, I carried out follow-up univariate tests to identify which CES bundles contributed to overall differences. Where the assumption of normality was satisfied (based on Shapiro–Wilk tests of residuals), one-way ANOVAs were conducted, followed by Tukey's HSD for post-hoc comparisons. Kruskal-Wallis tests were used for CES bundles that violated normality across one or more of the infrastructure clusters, followed by Dunn's post-hoc pairwise comparisons. P-values were adjusted using the Benjamini-Hochberg procedure, which controls the false discovery rate and is less conservative than the Bonferroni method and is appropriate here given that multiple related comparisons were conducted across the five CES bundles (Benjamini & Hochberg, 1995).

Separate linear regression models were fitted for each CES factor using the infrastructure cluster as the categorical predictor. These models showed the relationship between infrastructure and CES but do not imply causality/directionality. Model residuals were tested for normality using the Shapiro–Wilk test. To evaluate the influence of individual parks, Cook's Distance was calculated for each model. Cook's Distance is a standard influence

diagnostic used to identify observations that have a disproportionate effect on the model's fitted values, which is particularly important in small or unbalanced samples (Cook, 1977). As per standard guidelines, observations with a Cook's Distance greater than $4/(n-2)$ (where $n = 19$ parks, threshold ≈ 0.235) were flagged for further inspection. No parks were excluded on this basis.

5.3 Results

5.3.1 Factor Analysis

Park-level mean scores across the five CES bundles revealed meaningful variations in how different parks are experienced and valued by visitors, as shown in Table 6. For Natural History, the highest-scoring parks were Mokala, West Coast, Tankwa Karoo, Richtersveld, and Namaqua. Kruger National Park had the lowest score. For Recreation, the highest mean scores were observed in Garden Route, West Coast, Agulhas, and Table Mountain. Mokala, Kgalagadi and Mountain Zebra scored lowest on this bundle. For Sense of Place, the highest scores were seen in Golden Gate, Garden Route, and Richtersveld. In contrast, Table Mountain and Agulhas scored lowest. Safari Experience was highest in Marakele, Mountain Zebra, Kruger, Kgalagadi and Addo. The lowest Safari Experience scores were found in Agulhas and Garden Route. Outdoor Living was strongest in Golden Gate, Bontebok, and Richtersveld. West Coast and Table Mountain had the lowest scores for Outdoor Living.

Table 7. Mean factor scores for each CES bundle across South Africa's National Parks. Cell shading reflects the relative magnitude of each mean factor score. Scores that are ≤ -0.4 (dark red) represent parks negatively associated with that CES bundle, -0.4 to -0.2 represent moderately negative associations (light red), -0.2 to $+0.2$ (white) indicate neutral/average associations, $+0.2$ and $+0.4$ indicate moderately positive associations (light blue), and $\geq +0.4$ (dark blue) denote strong positive associations.

Park	Natural	Recreation	Sense of Place	Safari	Outdoor Living
Addo Elephant	0.07	-0.24	0.03	0.26	0.06
Agulhas	-0.04	0.55	-0.20	-0.55	-0.24
Augrabies	0.10	0.00	0.21	0.13	-0.13
Bontebok	-0.06	0.18	0.23	-0.19	0.41
Camdeboo	0.17	-0.13	0.04	-0.29	-0.17
Garden Route	-0.12	0.58	0.28	-0.41	0.31
Golden Gate	0.00	0.40	0.36	-0.03	0.42
Karoo	0.15	-0.45	-0.02	0.04	-0.08
Kgalagadi	0.03	-0.52	-0.16	0.36	0.27
Kruger	-0.20	-0.31	-0.15	0.26	-0.11
Mapungubwe	-0.03	-0.09	0.15	0.01	-0.16

Park	Natural	Recreation	Sense of Place	Safari	Outdoor Living
Marakele	-0.06	-0.17	0.07	0.33	0.32
Mokala	0.33	-0.62	0.13	-0.01	0.14
Mountain Zebra	0.11	-0.50	-0.04	0.28	0.22
Namaqua	0.35	-0.22	-0.12	0.14	-0.05
Richtersveld	0.36	0.21	0.25	-0.27	0.37
Table Mountain	-0.11	0.52	-0.27	-0.21	-0.54
Tankwa Karoo	0.38	-0.24	0.06	0.16	0.18
West Coast	0.37	0.55	-0.04	-0.38	-0.55

5.3.2 CES Cluster Analysis

From the PCA, the first two principal components together explained 70.6% of the total variance, with PC1 accounting for 39.2% and PC2 for 31.4%. The PC1 showed a gradient from recreation-oriented preferences to wildlife and nature immersion: Recreation had a strong negative loading and strong positive loadings for Safari Experience and Outdoor Living (Table 7). PC2 was dominated by strong negative loadings for Sense of Place and Outdoor Living, with smaller negative contributions from Recreation and a moderate positive contribution from Safari Experience (Table 7). Therefore, the second principal component represented a gradient from place attachment and emotional engagement to safari / wildlife-oriented experiences.

Table 8. PC 1 and PC2 loadings across CES bundles

CES Bundle	PC1 Loading	PC 2 Loading
Natural History	0.115	0.021
Recreation	-0.634	-0.266
Sense of Place	0.094	-0.742
Safari Experience	0.632	0.221
Outdoor Living	0.420	-0.573

Cluster 1 (n = 7), described as “Nature-learning and Heritage” parks (hereafter “Nature-learning” parks) included Mapungubwe, Augrabies, Namaqua, Mokala and others, and clustered near the centre-right of the PCA space with intermediate PC1 scores and slightly positive PC2 scores (Fig. 8). This cluster had the highest mean score for Natural History and scored lower for Recreation (Table 8). The second cluster (n = 5), “Safari and Charismatic Wildlife” (hereafter, “Safari”), comprised mainly larger, well-known or “flagship” parks like

Addo, Kruger, and Kgalagadi, which clustered in the upper-right quadrant (high PC1, high PC2). This cluster had the highest mean Safari Experience score and positive Outdoor Living, but the lowest Recreation score and a slightly negative Sense of Place score. Cluster 3 (n = 4), “Place Attachment, Immersive” (hereafter, “Place Attachment”) parks (e.g. Garden Route, Golden Gate, Bontebok) were located in the upper-left quadrant (low PC1, low PC2). These parks scored highest on Sense of Place and Outdoor Living, as well as Recreation, but low on Safari Experiences. “Urban, Recreation” (hereafter, “Urban”) parks (Cluster 4, n = 3), comprised of high-access, high-use urban and peri-urban parks such as Agulhas, West Coast and Table Mountain, were positioned in the upper-left quadrant (low PC1, high PC2). Cluster 4 had the highest Recreation score but the lowest scores for Safari Experience, Outdoor Living, and Sense of Place.

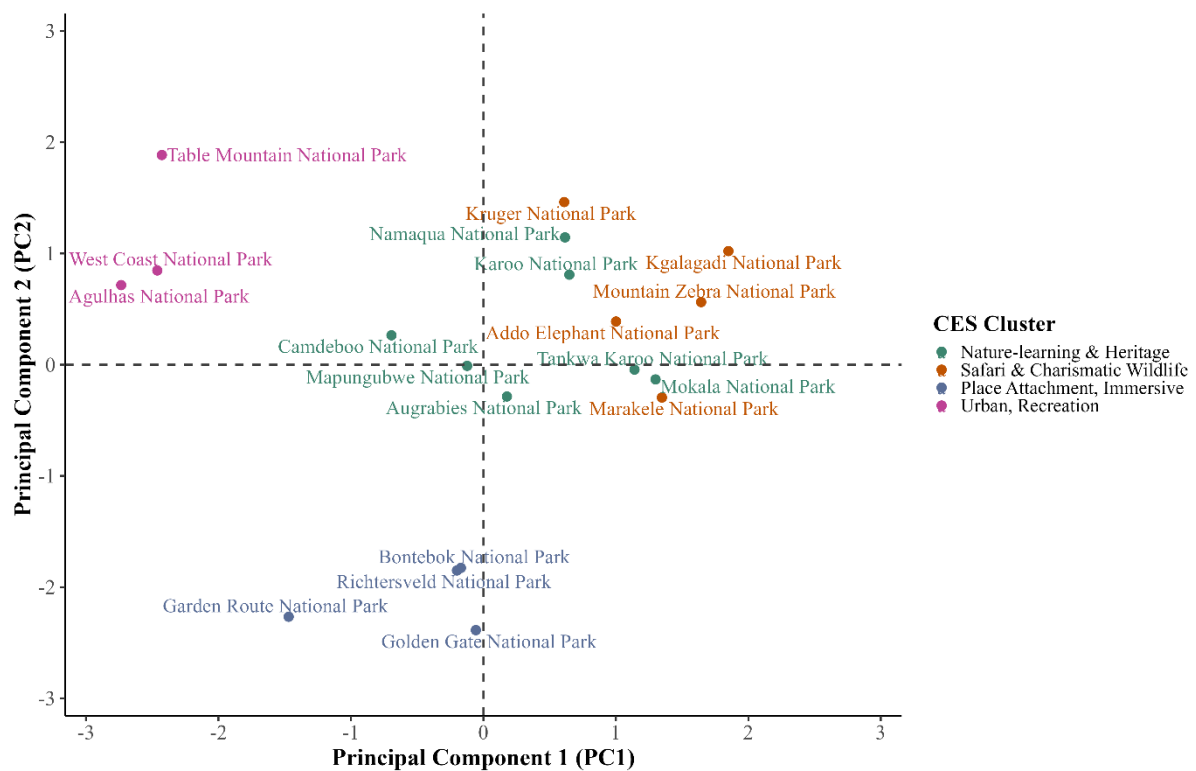


Figure 8. PCA plot of visitor CES preferences across South Africa’s National Parks, showing four clusters identified through k-means clustering

Table 9. Mean CES factor scores by CES cluster, showing dominant visitor preference across South Africa’s National Parks.

Cluster	Natural History	Recreation	Sense of Place	Safari Experience	Outdoor Living	No. of Parks
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‘Nature-learning & Heritage’	0.21	-0.25	0.06	0.03	-0.04	7
‘Safari & Charismatic Wildlife’	-0.01	-0.35	-0.05	0.30	0.15	5
‘Place Attachment, Immersive’	0.05	0.34	0.28	-0.23	0.38	4
‘Urban, Recreation’	0.07	0.54	-0.17	-0.38	-0.45	3

One-way ANOVAs revealed significant differences in visitor preferences for four of the five CES bundles across the CES clusters (Table 9). No significant differences were observed for Natural History scores across clusters. Recreation, Sense of Place, Safari Experience and Outdoor Living showed significant variation across clusters.

Table 10. One-way ANOVA results showing variation in CES bundle scores among CES clusters. Each F-statistic is reported with numerator and denominator degrees of freedom (3, 15). η^2 represents the proportion of total variance in CES scores explained by cluster membership.

CES Bundle	F(3,15)	p-value	η^2
Natural History	1.67	0.217	0.25
Recreation	24.82	< 0.001	0.83
Sense of Place	13.47	< 0.001	0.73
Safari Experience	19.08	< 0.001	0.79
Outdoor Living	20.02	< 0.001	0.80

Post-hoc Tukey’s HSD tests (Table 10) indicated that Recreation scores were significantly higher in the “Place Attachment” and “Urban” cluster compared to “Nature-learning” and “Safari”. For Sense of Place, the “Place Attachment” cluster had the highest scores. Safari Experience scores were highest in “Safari”, which was significantly greater than “Place Attachment” and “Urban”. “Place Attachment” and “Urban” additionally showed significantly lower Safari scores than “Nature-learning”. Outdoor Living scores were highest in “Place Attachment”, while “Urban” parks had the lowest values for this bundle.

Table 11. Significant pairwise differences among CES clusters from Tukey's HSD post-hoc tests. Values show group means \pm SE for each cluster, the mean difference between clusters, 95 % confidence intervals, and associated *p*-values. Positive mean differences indicate higher CES scores in the first-named cluster.

CES Bundle	Cluster A	Cluster A (Mean \pm SE)	Cluster B	Cluster B (Mean \pm SE)	Mean Diff	95% CI	<i>p</i> -value
Recreation	Place	0.34 \pm 0.09	Nature	-0.25 \pm 0.08	0.59	[0.27, 0.91]	< 0.001
	Urban	0.54 \pm 0.01	Nature	-0.25 \pm 0.08	0.79	[0.44, 1.14]	< 0.001
	Place	0.34 \pm 0.09	Safari	-0.35 \pm 0.07	0.69	[0.34, 1.03]	< 0.001
	Urban	0.54 \pm 0.01	Safari	-0.35 \pm 0.07	0.89	[0.51, 1.26]	< 0.001
Sense of Place	Place	0.28 \pm 0.03	Nature	0.06 \pm 0.04	0.22	[0.04, 0.40]	0.017
	Urban	-0.17 \pm 0.07	Nature	0.06 \pm 0.04	-0.23	[-0.43, -0.03]	0.020
	Place	0.28 \pm 0.03	Safari	-0.05 \pm 0.05	0.33	[0.14, 0.53]	< 0.001
	Urban	-0.17 \pm 0.07	Place	0.28 \pm 0.03	-0.45	[-0.67, -0.23]	< 0.001
Safari	Safari	0.30 \pm 0.02	Nature	0.03 \pm 0.06	0.27	[0.04, 0.50]	0.019
Experience	Place	-0.23 \pm 0.08	Nature	0.03 \pm 0.06	-0.25	[-0.50, -0.00]	0.046
	Urban	-0.38 \pm 0.10	Nature	0.03 \pm 0.06	-0.41	[-0.68, -0.13]	0.003
	Place	-0.23 \pm 0.08	Safari	0.30 \pm 0.02	-0.52	[-0.79, -0.26]	< 0.001
	Urban	-0.38 \pm 0.10	Safari	0.30 \pm 0.02	-0.68	[-0.97, -0.39]	< 0.001
Outdoor Living	Place	0.38 \pm 0.02	Nature	-0.04 \pm 0.05	0.42	[0.15, 0.68]	0.002
	Urban	-0.45 \pm 0.10	Nature	-0.04 \pm 0.05	-0.41	[-0.70, -0.12]	0.005
	Urban	-0.45 \pm 0.10	Safari	0.15 \pm 0.08	-0.60	[-0.90, -0.29]	< 0.001
	Urban	-0.45 \pm 0.10	Place	0.38 \pm 0.02	-0.82	[-1.14, -0.50]	< 0.001

5.3.3 Comparing CES and Infrastructure Clusters

In the alluvial plot below, each “flow” represents the number of parks shared between a CES cluster and an infrastructure cluster, to illustrate the overlap between the two classifications. Parks in the “Nature-learning” CES cluster flowed into infrastructure profiles: “Large, Low-Visitation, Infrastructure-Light” (hereafter, “Infrastructure-Light”) and “Integrated Infrastructure” (hereafter “Integrated” (Fig. 9). The “Safari” CES cluster corresponded entirely with “Integrated” parks. “Place Attachment, Immersive” parks spanned all three infrastructure clusters, while the “Urban” CES cluster was divided between “High-Access, Infrastructure-Dense” (hereafter “High Access”) and “Integrated” parks. The result of a Fisher’s Exact Test to assess the association between CES and infrastructure was $p = 0.084$. However, the strength of association was large (Cramér’s $V = 0.56$).

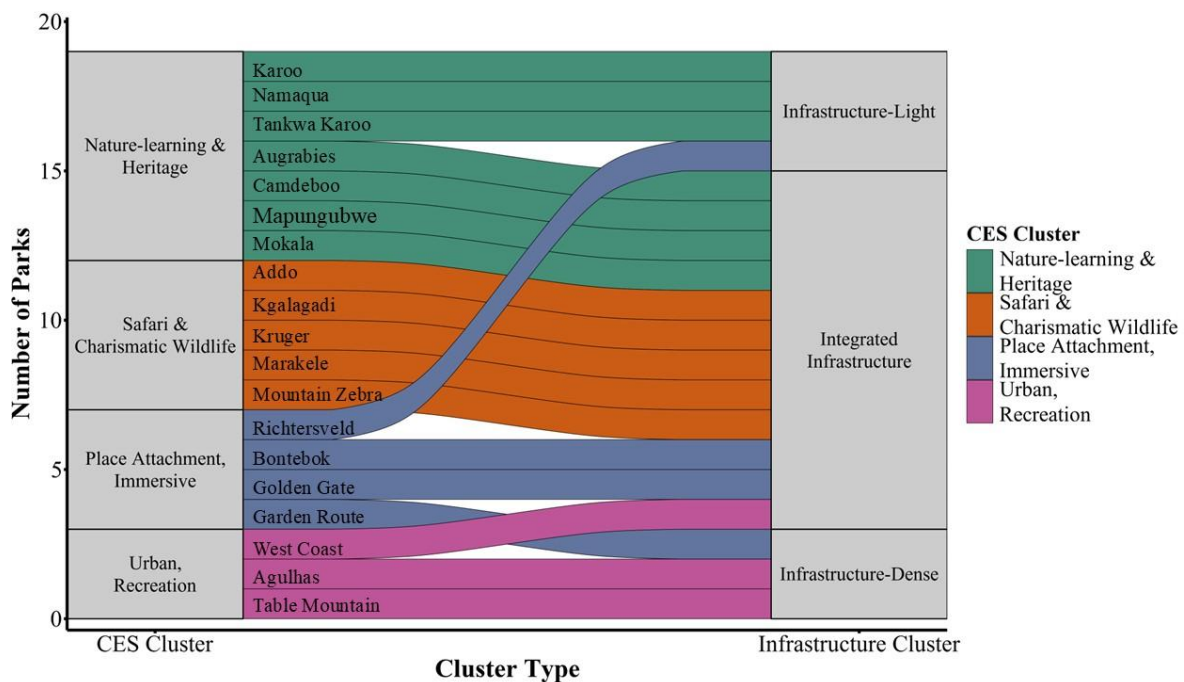


Figure 9. Alluvial diagram showing the relationship between CES clusters and infrastructure clusters in South Africa’s National Parks.

Infrastructure characteristics varied across CES clusters (Figure 10). Parks in the “Place Attachment” cluster were characterised by relatively new infrastructure and high investment intensity. The “Urban” cluster showed the highest investment per unit area but the lowest spending per visitor. Whereas the “Nature-learning” cluster had older infrastructure with the highest per-visitor investment. The “Safari” cluster showed similar infrastructure ages to the “Nature-learning” parks, but with lower per-visitor investment.

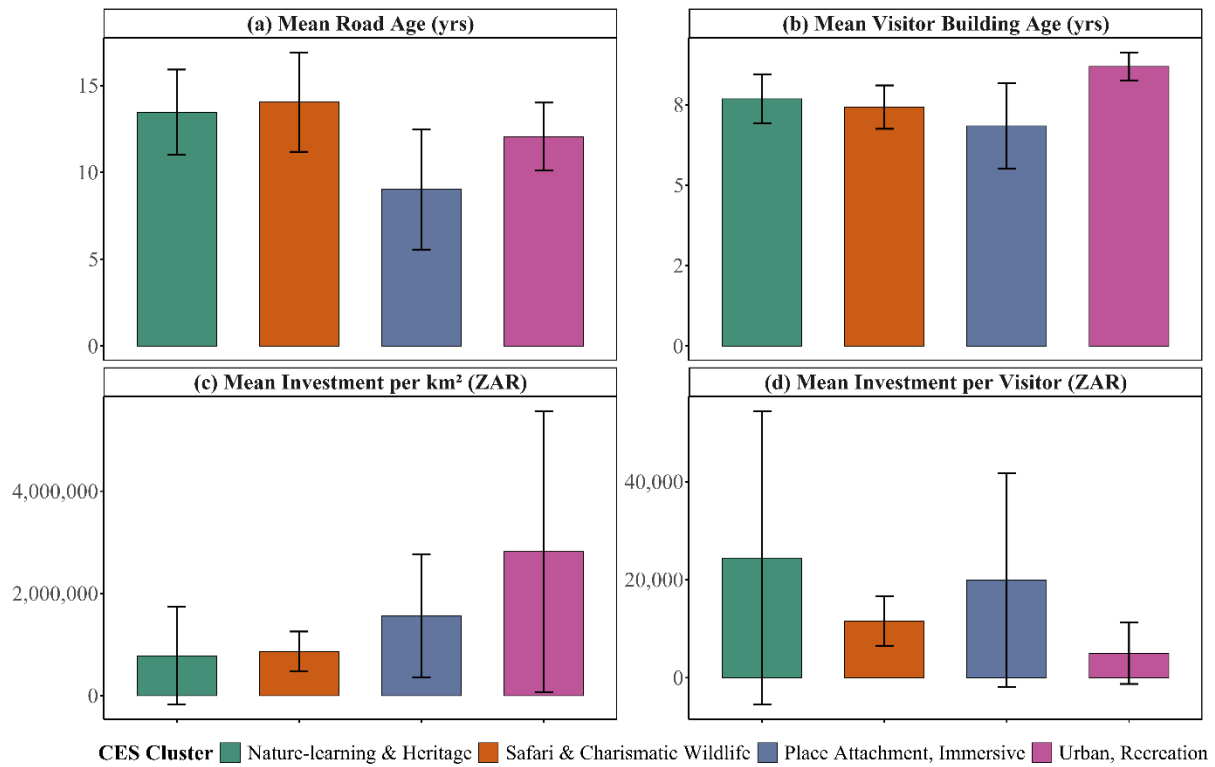


Figure 10. Mean infrastructure characteristics (\pm SD) across CES clusters in South Africa’s National Parks.

5.3.4 Statistical Testing of CES Differences by Infrastructure Cluster

A MANOVA showed that CES bundles differed significantly across infrastructure clusters (Pillai’s Trace = 1.10, $F(10, 26) = 3.15$, $p = 0.009$). Follow-up tests showed significant variation in Natural History, Recreation, and Safari Experience, but not in Sense of Place or Outdoor Living (Fig. 11, Table 11). These comparisons are based on mean CES factor scores within each infrastructure cluster (i.e., treating CES bundles as continuous variables), rather than on CES cluster membership. Post-hoc comparisons indicated that Natural History scores were highest in “Infrastructure-Light” parks, Recreation scores were highest in “Infrastructure-Dense” parks, and Safari Experience was lowest in “Infrastructure-Dense” parks (Table 12). Linear regressions confirmed these patterns, with infrastructure cluster membership explaining 36–48% of the variation in these CES bundles ($R^2 = 0.36$ – 0.48 ; Table 13). No significant effects were found for Sense of Place or Outdoor Living. Cook’s Distance diagnostics identified Garden Route and Table Mountain as influential cases for the latter two models.

“

Table 12. Summary of univariate tests assessing differences in CES bundle scores among infrastructure clusters

CES bundle	Test type	Test statistic	p-value	Effect size
Natural History	Kruskal–Wallis	$\chi^2(2) = 8.83$	0.012	$\eta^2_h = 0.43$
Recreation	One-way ANOVA	$F(2, 16) = 5.77$	0.013	$\eta^2 = 0.42$
Sense of Place	One-way ANOVA	$F(2, 16) = 0.65$	0.536	$\eta^2 = 0.07$
Safari Experience	One-way ANOVA	$F(2, 16) = 4.56$	0.027	$\eta^2 = 0.36$
Outdoor Living	One-way ANOVA	$F(2, 16) = 0.76$	0.486	$\eta^2 = 0.09$

Table 13. Significant post-hoc pairwise comparisons of CES bundle scores across infrastructure clusters.

CES Bundle	Cluster A	Cluster A (Mean ± SE)	Cluster B	Cluster B (Mean ± SE)	Mean Diff	95% CI	p-value
Natural History	Infrastructure -Light	0.31 ± 0.05	Infrastructure- Dense	-0.09 ± 0.02	—	—	0.010
Recreation	Infrastructure -Dense	-0.09 ± 0.02	Infrastructure- Light	0.31 ± 0.05	0.72	[0.09, 1.36]	0.024
Recreation	Integrated	0.07 ± 0.05	Infrastructure- Dense	-0.09 ± 0.02	-0.67	[-1.21, -0.14]	0.014
Safari Experience	Integrated	0.07 ± 0.05	Infrastructure- Dense	-0.09 ± 0.02	0.45	[0.06, 0.84]	0.022

CES Bundle	F(df)	p-value	R²	High Access (vs Infrastructure-Light)	Integrated (vs. Infrastructure-Light)
Natural History	7.33 (2,16)	0.005	0.48	-0.40 ± 0.11 (**)	-0.25 ± 0.08 (**)
Recreation	5.77 (2,16)	0.013	0.42	+0.72 ± 0.25 (**)	+0.05 ± 0.19 (ns)
Sense of Place	0.65 (2,16)	0.536	0.07	-0.11 ± 0.14 (ns)	+0.03 ± 0.10 (ns)
Safari Experience	4.56 (2,16)	0.027	0.36	-0.41 ± 0.18 (*)	+0.04 ± 0.13 (ns)
Outdoor Living	0.76 (2,16)	0.486	0.09	-0.26 ± 0.23 (ns)	-0.05 ± 0.17 (ns)

Table 14. Linear regression models testing differences in CES bundle scores across infrastructure clusters. Reference category = Infrastructure-Light. Estimates represent differences in mean CES scores relative to the reference category. Significance: * $p < 0.05$, ** $p < 0.01$; ns = not significant.

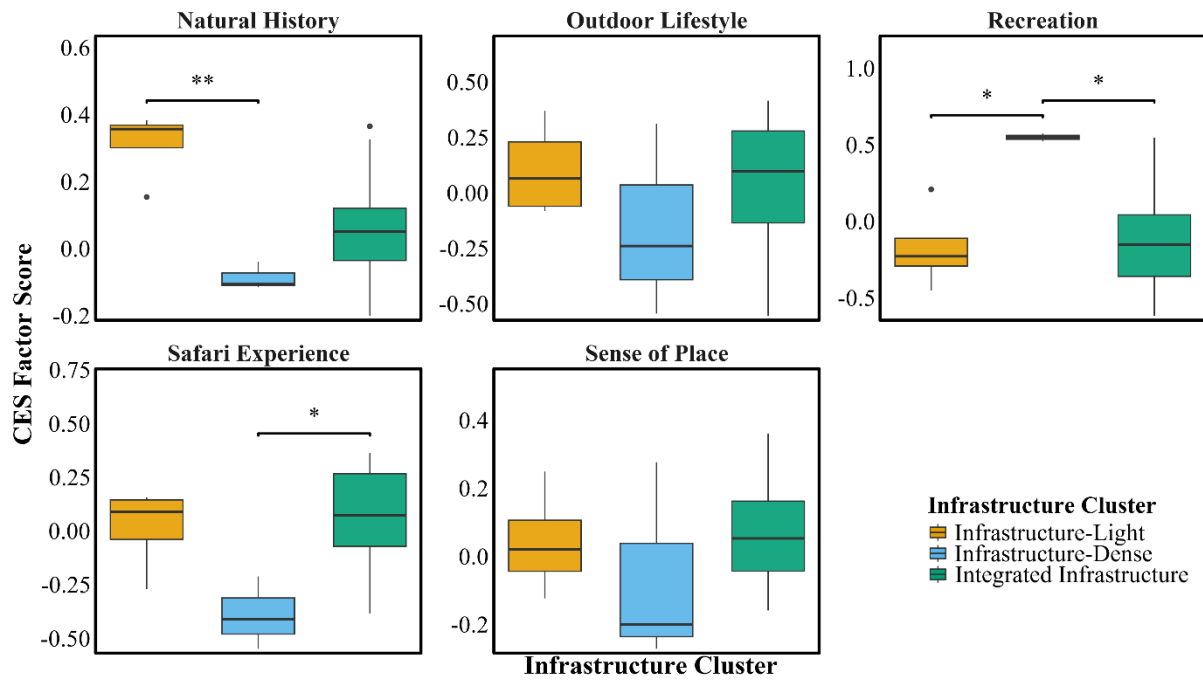


Figure 11. Boxplots showing variation in mean CES factor scores across infrastructure clusters. Asterisks denote statistically significant differences. Significance: * $p < 0.05$, ** $p < 0.01$.

5.4 Discussion

Overall, the findings provide evidence that visitor place emphasis on different kinds of CES in different parks. Four clusters of parks emerged based on visitor preferences for CES, which show that visitors engage with nature through different “modes” of cultural use. CES clusters were partially aligned with infrastructure archetypes identified in Chapter 4. At the bundle level, Recreation was associated with infrastructure-dense parks, Natural History was more prominent in minimally developed parks, while Sense of Place and Outdoor Living showed no meaningful relationship with infrastructure. The observed infrastructure-CES mismatches may point to limited responsiveness of infrastructure planning to visitor values and possible lagging, weak or missing feedbacks between tourist demand and investment decisions made by SANParks. In the sections that follow, I first discuss the characteristics of the four CES clusters, how they relate to patterns observed in other studies of visitor experiences and implications for infrastructure. I then interpret the degree of alignment between CES and infrastructure clusters, through the hypotheses set out in the introduction. Lastly, I consider what these findings reveal about feedbacks within coupled infrastructure systems and inferences for park governance and future research.

Parks in the “Nature -learning” cluster were characterised by high Natural History and low Recreation scores. Parks within this cluster (as is the case with most national parks) have natural history significance; for example, Mapungubwe is a UNESCO World Heritage Site, Namaqua and Tankwa Karoo are within the Succulent Karoo biodiversity hotspot, and Camdeboo’s Valley of Desolation is a unique geological feature. The literature suggests that interpretive infrastructure (such as signage, guided routes, or educational and cultural centres) enhances natural-history type experiences by making ecological cultural meanings more legible to visitors (Nowacki, 2021; Kempiak et al., 2017; Moreno-Melgarejo et al., 2019), and such infrastructure has been shown to contribute to more engaging and memorable experiences leading to increased visitor satisfaction and repeat visits (Botha et al., 2016; van der Merwe et al., 2020).

In NPs grouped into the “Safari” cluster, visitors favoured game drives, wildlife photography, and viewing large mammals. These parks scored high on Safari Experience and low on Recreation; this trade-off was also noted by Ament et al. (2017) and is most likely due to the presence of large and dangerous wildlife, which restricts a range of recreational activities, such as hiking and walking. Interestingly, Ament et al. (2017) also found that parks with a strong Safari Experience scored highly for Natural History, whereas in this study, the Natural History scores for the “Safari” cluster were slightly negative. This difference likely reflects methodological differences from the original study in how factor scores were standardised and aggregated at the park level in my analysis. The slightly negative score also does not imply that the cluster is low in Natural History importance per se, but rather that it has lower scores relative to other CES bundles. Notably, parks grouped into the “Safari” and “Nature-learning” clusters largely correspond to systems where visitor movement is restricted due to the presence of dangerous wildlife, whereas parks in the “Place Attachment” and “Urban” clusters allow visitors to move more freely on foot without armed guides. This distinction may help explain why “Safari” and “Nature-learning” parks are positioned relatively close to one another in the clustering space. Research has found that visitor volumes within Kruger are more closely associated with the likelihood of seeing megafauna than with proximity to such facilities (Grünewald et al., 2016). That being said, even if infrastructure doesn’t affect where people go in a particular park, it is likely to shape the quality of the viewing experience. Due to the importance visitors place on landscape features, authors have recommended preserving natural structures and habitats rather than further developing artificial features (Grünewald et al.,

2016). This could be achieved through inconspicuous infrastructure in “Safari” parks (e.g. camouflaged hides or dirt tracks).

“Place Attachment” parks scored high for Recreation, Sense of Place, and Outdoor Living. Sense of Place relates to activities such as relaxation, spiritual connection, and spending time with family and friends, while the Outdoor Living bundle captures activities like camping, braaiing (barbequing), and socialising (Ament et al., 2017). These parks offer a number of low-impact outdoor activities, such as camping and hiking, and have unique landscapes (like the Garden Route’s forests or the desert landscape of Richtersveld), which likely foster connections with nature and strengthen place attachment (Pearce et al., 2017; Rajala et al., 2020; Wartmann & Purves, 2018; Wright & Matthews, 2015; Wynveen et al., 2011). This cluster also showed low mean scores for Safari Experience, which can be explained by the parks’ lack of charismatic megafauna; however, they do have a number of endemic species (such as the Bontebok National Park’s namesake). In these parks, investment in infrastructure such as trails, picnic areas, camping grounds, and lookout points could help enhance the cultural ecosystem services that visitors have displayed a preference for. Visitors to the Tsitsikamma in the Garden Route have shown accommodation preferences for outdoor cooking areas, a natural setting, and good quality ablution facilities (Saayman & Van Der Merwe, 2017). Research also shows that place attachment is often linked to pro-environmental attitudes and behaviours (Ardoin, 2014; Yoon et al., 2024), which could give some context as to why visitors in these parks may prioritise natural settings and low-impact forms of nature engagement.

“Urban” parks scored highly for Recreation (and particularly low for Outdoor Living and Safari Experience), and visitors appear to value them for short-term, convenience-based leisure such as walking, picnicking, and sightseeing. The low Sense of Place score associated with Table Mountain was unexpected, given the mountain’s deep-rooted significance to local cultural identity (Ferreira, 2011). However, as the park is a popular tourist destination, it’s possible that the survey sampled mainly foreign or domestic tourists, as opposed to residents who likely value the park in more personal ways. Research in other urban parks shows that while dense infrastructure can enhance recreation, excessive development risks crowding and loss of CES value (Dushkova et al., 2025; Sever et al., 2018; Wang et al., 2022).

Among the CES bundles examined, Recreation was strongly associated with infrastructure-dense parks, which offers support for the hypothesis that parks with higher investment in visitor-facing infrastructure would be more likely to support access-dependent CES, namely,

Recreation (H1a). The alluvial analysis showed that two of the parks in the “Urban, Recreation” cluster (which was defined mainly by high Recreation scores) were also grouped into the “Infrastructure-Dense” infrastructure cluster, and one flowed into the “Integrated” infrastructure cluster, which further suggests that parks with lower infrastructure investment are less likely to deliver Recreation CES, which often require specific features, such as trails, picnic areas, and designated day-use zones. Infrastructure also tends to determine where and how people engage with parks, as indicated by the broader literature, which shows that access-oriented infrastructure (e.g., roads and airports) is a critical enabler of experiences in protected areas (Echeverri et al., 2022; Mancini et al., 2019).

Hypothesis 1b suggested that introspective or immersive CES, such as Sense of Place, Outdoor Living, and Natural History, would be more prominent in minimally developed parks, as these CES rely more on intangible aspects, which can actually be diminished by overdevelopment. Sense of Place and Outdoor Living CES showed no significant variation across infrastructure clusters. This finding does not necessarily contradict H1b, though it suggests that some CES may emerge more independently of infrastructure or be shaped by other system elements that were not captured in the analysis. Therefore, in parks where visitors exhibit high preferences for Sense of Place or Outdoor Living, infrastructure may neither be a strong enabler nor a barrier to visitor satisfaction. However, the regression analysis showed that Natural History CES was more prominent in infrastructure-light parks. This is likely because experiences associated with the Natural History bundle, which are mainly related to appreciating biodiversity, are more prevalent in more ecologically intact environments. For example, research has found that human disturbance diminishes birding opportunities (Huhta & Sulkava, 2014; Lerm et al., 2023; Zoeller et al., 2022), and a US study of environmental education showed that the naturalness of a site was linked to positive learning outcomes for field trip programs (Dale et al., 2020).

Evidence for the hypothesis that parks with similar CES profiles would exhibit similar infrastructure patterns, indicating that infrastructure planning is responsive to visitor preferences (H2a), was mixed. Parks in the CES “Safari” cluster also belonged to the “Integrated” infrastructure cluster, which suggests relatively strong alignment. However, it's important to note that “Integrated Infrastructure” was by far the largest cluster, so some overlap is unsurprising. In contrast, parks in “Nature-Learning”, “Place Attachment” and “Urban” were distributed across multiple infrastructure clusters. The Fisher’s Exact Test did not provide strong statistical evidence, but the corresponding Cramér’s V value indicated a large effect size.

This suggests that there is some degree of association between CES and infrastructure clusters though the limited number of parks per category likely reduced statistical power. However, the lack of clear alignment of park groupings between the two cluster types points to mismatches between CES preferences and infrastructure profiles within South Africa's National Parks (H2b). Furthermore, as previously stated, two of the infrastructure bundles (Outdoor Living and Sense of Place) did not exhibit a significant relationship with infrastructure levels, which suggests a lack of alignment. The observed mismatches may be due to delayed feedback or missing feedbacks between SANParks' decision makers and visitor preferences for cultural ecosystem services. Similar patterns have been documented in other studies that show CES values are often not incorporated into formal PA management (Gould et al., 2019; McElwee et al., 2022; Roux et al., 2020). Lags may be a result of past investments in infrastructure to serve priorities that no longer align with CES demands, as well as institutional inertia related to the slowness of bureaucratic/funding processes. CES-infrastructure mismatches could also be due to weak information flows, i.e. SANParks may not consistently know what visitors value, or it might not be a priority to align infrastructure with the kinds of CES visitors want.

The patterns of infrastructure characteristics across CES clusters also did not provide a clear indication of the directionality of the relationship between CES demand and infrastructure provision. For example, if Mountain Zebra National Park had not historically supported dangerous game, it is plausible that it may have evolved into a "Nature-learning" or "Outdoor Living" park rather than being in the "Safari" Cluster. Similarly, in Karoo National Park, the reintroduction of lions in 2010 meant certain recreational activities (e.g. hiking and cycling) are no longer allowed in the park, which may have shifted both visitor experiences and the park's CES profile over time. In some parks, it appears infrastructure may be shaping CES engagement, while in others, infrastructure is likely responding to existing visitor demand or reflecting legacy conditions. For example, the "Place Attachment" cluster had the newest infrastructure and relatively large investment per visitor and square kilometre, signifying that infrastructure could be reinforcing CES engagement. On the other hand, "Safari" parks displayed older infrastructure and low per-visitor investment, indicating that CES demand may be outpacing the provision of infrastructure. Interestingly, "Nature-learning" parks displayed the lowest investment per unit area and the highest investment per visitor on average across the clusters, and vice versa for "Urban" parks. This is likely because "Nature-learning" parks are larger on average but attract fewer visitors compared to "Urban, Recreation" parks.

CES have historically been underrepresented in conservation planning compared to more tangible ecosystem services (Ament et al., 2017; Fisher & Brown, 2014; Roux et al., 2020); however, neglecting the diversity of CES values across demographic, cultural, and mobility lines risks over-investing in certain visitor values while underserving others. There is a broad area of literature about how the values of many people groups, particularly those of indigenous peoples and local communities, are not recognised by protected area governance (Dawson et al., 2018, 2023; Schreckenberg et al., 2016). The findings from this study demonstrate how infrastructure investment can unevenly support visitor engagement. For example, parks in the “Urban, Recreation” cluster received high infrastructure investment per km², but delivered only a narrow set of CES. It is also safe to assume that the CES that dominate design are likely the ones that generate income (Gross et al., 2023; Su et al., 2022). Research on staff perceptions in a sample of South Africa’s national parks has revealed tensions between generating revenue and equitable CES provision (Roux et al., 2020). For example, staff from Mountain Zebra National Park noted that income requirements constrained their ability to maintain niche activities with low visitor demand or to subsidise popular experiences, like cheetah tracking, to allow broader access (Roux et al., 2020). In light of these challenges, scholars have advocated for parks to be designed with multifunctionality and flexibility in mind (Dushkova et al., 2025). Based on this, we can infer that infrastructure ought to cater to the specific functions of a PA while also enabling a broad range of CES (especially considering that the clusters identified in this study represent the dominant CES preferences, not the absence of others). Therefore, an inclusive approach is necessary to achieve equitable delivery of CES, for example, through participatory planning processes that engage diverse stakeholders to account for a wide range of visitor experiences, particularly those not reflected in typical metrics such as visitor volumes or monetary returns.

The findings of this study carry several important implications for theory, park management and future research. The results contribute to the understanding that CES are co-produced through human-nature interactions within protected areas and also demonstrate how national parks function as coupled infrastructure systems – where outcomes emerge through the interplay between different system components. The attributes of parks, such as their ecosystems, topography and/or charismatic species (natural infrastructure), strongly determine their potential to deliver certain CES which can be mobilised through the activities and associated infrastructure provided by park management (soft infrastructure) or tourism concessionaires (resource users) (Roux et al., 2020). While the results suggest a connection

between infrastructure and CES, the directionality/nature of the relationship remains unclear and warrants further research, possibly by long-term monitoring of visitor values before and after infrastructure development, as well as qualitative methods to better understand why people value certain CES. Interpreting the mixed alignment between CES and infrastructure clusters through the lens of the CIS framework suggests variation in the strength of feedbacks between visitor experiences and demands (exogenous drivers) and SANParks decision-makers (soft infrastructure), which translates into the provision of infrastructure. While some mismatches may reflect CES that are less dependent on infrastructure, they also could be at least partially due to weak, lagged or absent feedbacks between visitors and higher-level park management. In any case, there are opportunities to strengthen governance-visitor-infrastructure feedbacks (which is relevant both for SANParks and PA management more broadly) via solutions such as visitor surveys or in-depth interviews, the inclusion of CES indicators in planning criteria, and participatory approaches like co-design workshops or the use of local knowledge from communities and concessionaries. This could lead to win-win outcomes, where improved visitor experiences generate greater support and revenue for protected areas, allowing management to further invest in conservation and therefore strengthen the financial and ecological resilience.

Overall, the findings advance our understanding of protected areas as coupled infrastructure systems and demonstrate how CES are co-produced through human-nature interactions. The relationship between infrastructure and CES is evident but not straightforward and in managing this complexity, park governance should aim to align infrastructure with visitor values and cater to a wide range of CES to ensure the long-term relevance of PAs.

CHAPTER 6 SYNTHESIS, CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

I addressed two primary objectives in this thesis, the first of which was to assess patterns of infrastructure (in terms of type, investment and quality) across SA's National Parks and develop park-level infrastructure profiles that reflect differences in investment priorities. The second was to investigate the relationship between infrastructure and visitors' CES preferences. This chapter synthesises the main findings of the thesis, drawing together the results from Chapters 4 and 5 and provides final conclusions and recommendations based on the study's findings. The following chapter is structured in four main sections: 1) an integrated summary of the cross-chapter findings, 2) a critical reflection on the CIS framework, 3) implications for SANParks, particularly in the context of Vision 2040 and Mega Living Landscapes, and 4) priority directions for future research and planning.

6.2 Summary of Empirical Findings

In response to research question 1: "What is the general condition (quality, age, and longevity) of infrastructure in South Africa's National Parks and how does this vary across parks and infrastructure types/categories?" my analysis showed variance across both asset types and park contexts. Among the three infrastructure types, roads were the oldest and in the poorest condition, with significant variability across parks. Buildings were generally the newest and had the highest retained value. Within the building subcategories, Visitor infrastructure exhibited the highest quality, while Operations and Support (and Conservation to a lesser extent) scored lower in terms of condition, with evidence of ageing and depreciation. Parks were ranked according to a PCA based on Condition Index, Relative Age and Relative Value for roads and buildings. Parks with the highest building quality were Mokala, Bontebok, Addo and Kgalagadi. Parks with the lowest building quality were Tankwa Karoo, Namaqua, Marakele and West Coast. Parks with the highest road quality were Karoo, Golden Gate and Kruger. Parks with the worst road quality were Tankwa Karoo, Mokala, Kgalagadi and Namaqua.

The second research question was: "How is infrastructure investment distributed across national parks in terms of park-level and infrastructure type/category allocations, and what

factors drive investment decisions?”. Investment was highly uneven across parks, with per km² investment being highest in small, urban parks. The parks with the highest investment intensity were Table Mountain, Golden Gate and Bontebok, and the parks with the lowest investment per km² were Tankwa Karoo, Namaqua, Richtersveld and Karoo. Buildings accounted for the majority of total infrastructure value. Within buildings, investment skewed toward Visitor and Operations infrastructure (with most investment being directed towards Operations and Support), whereas Conservation infrastructure received significantly less funding. For roads and buildings, a strong positive relationship was observed between the number of visitors and total investment. Notably, larger parks received more infrastructure investment in total, while smaller parks received more per square kilometre. Fencing, on the other hand, appeared to follow a different funding logic that was unrelated to visitation or park size.

Question 3 asked: “Do parks form clusters based on similarities in infrastructure profiles?”. The cluster analysis revealed three park archetypes: 1) “Large, Low-Visitation, Infrastructure-Light” parks (e.g., Richtersveld, Karoo, Namaqua, Tankwa Karoo) were characterised by low investment in roads and buildings but some investment in fencing, and are typically fairly remote, arid, and tourism-light; 2) “High-Access, Infrastructure-Dense” parks (e.g., Table Mountain, Agulhas, Garden Route) featured the highest investment intensity per km² in buildings and roads with no fence investment; 3) “Integrated Infrastructure Parks” (e.g., Kruger, Kgalagadi, Addo, Bontebok) were well-funded, multifunctional parks with high, balanced investment across all infrastructure types. Statistical comparisons revealed significant differences between clusters, with Cluster 1 receiving less investment per km² than Clusters 2 and 3.

Lastly, the fourth research question was: “What is the relationship between patterns of hard infrastructure and visitor preferences for cultural ecosystem services, and how do these interactions inform infrastructure planning and CES delivery?”. Visitor preferences for CES also clustered spatially across the park system. Four clusters were identified: 1) “Nature-learning & Heritage” parks were valued for biodiversity, learning and natural heritage; 2) “Safari & Charismatic Wildlife” parks showed strong preferences for iconic fauna and wildlife viewing; 3) “Place-Attachment, Immersive” parks, visitors sought emotional connection, social bonding, reflection and outdoor living; and 4) “Urban Recreation” parks were primarily used for accessible, recreation-focused experiences with lower engagement in symbolic or relational values. There was a strong relationship between Recreation CES and high-access parks in more densely built environments/landscapes. There was also a strong relationship between

infrastructure-light parks and visitor preferences for Natural History. However, other CES bundles (namely, Sense of Place and Outdoor Living) were not tightly linked to infrastructure in any way. There was only partial alignment between CES and infrastructure clusters; the mismatch could be due to a number of factors, but it suggests weak adaptiveness in how SANParks' infrastructure responds to visitor preferences in different parks.

6.3 Reflections on the CIS Framework

I used the CIS framework to understand protected areas in a way that captures social-ecological complexity while maintaining a requisite level of simplicity. Generally speaking, the CIS framework can be applied in many ways that range from comparative analysis to formal mathematical models. In this study, I used CIS to understand the role of hard infrastructure in South Africa's national park system and how CES emerge from feedback and interactions between different elements of the CIS facilitated by hard infrastructure. My findings also highlight how SANParks' governance does not occur in a top-down vacuum; according to Anderies et al. (2016), governance should be viewed not as something we *do*, but as an *emergent feature* of coupled infrastructure systems, so the influence of SANParks as a governing body dynamically arises from the interaction of different system components. This is demonstrated by my findings, which suggested that decisions about where and how to invest are likely a byproduct of historical infrastructure investment into certain parks.

Figure 12 shows a specified CIS framework, with 6 bidirectional links between the system components (RU, NI, PI, PIP) that visualise the findings of this study as they pertain to how patterns of infrastructure relate to CES outcomes. Link one reflects the interaction between resource users and the ecological system (i.e. natural infrastructure). Actors benefit from ecosystem features through income generated through tourism (tourism operators) and cultural practices/subsistence (local communities). They interact with the environment in a number of ways, for example, through general use, extraction, stewardship, and education. It is also important to note that local communities may make a living from tourism through both formal employment within the parks' tourism operations and informal activities, as higher visitation creates opportunities for small-scale enterprises such as craft markets, food vendors, and guiding services.

It's also important to note that local communities may still also be making a living from tourism, both via the formal and informal economy, as higher visitation could mean more opportunities

for small-scale enterprises such as craft markets, food vendors, and guiding services. So, the delivery of CES is important to them in this sense as well.

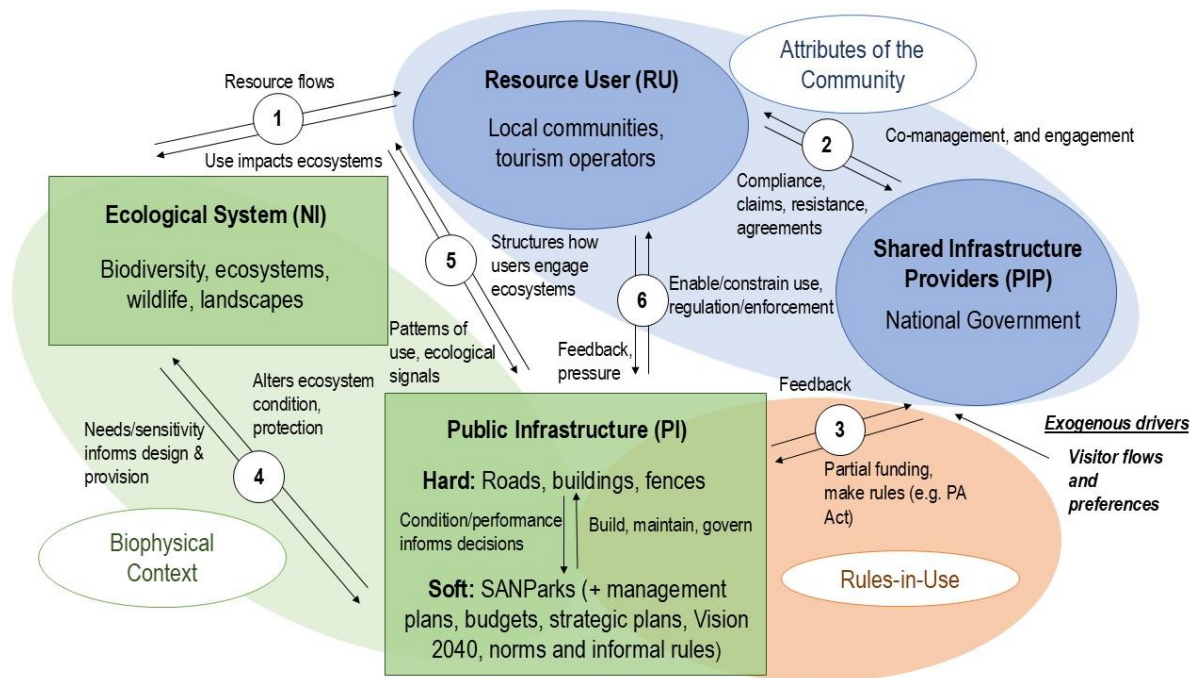


Figure 12. The CIS Framework applied to the study context

The relationship between resource users and public infrastructure providers (link two) is the governance interface in national parks. Resource users interact with the South African Government (the DFFE in particular) through mechanisms like co-management arrangements, park forums, lobbying, land claims and benefit-sharing schemes. They can also put pressure on the government through votes, which affect the actions taken by PIPs, for example, in them providing greater benefit sharing.

Link three captures the interaction between PIPs and Public Infrastructure (hard and soft). The national government partially funds SANPark’s operations, and they set the overarching rules and policy frameworks that determine the management of national parks (e.g. through the Protected Areas Act). SANParks (soft PI) provides feedback to the government (e.g. through liaisons, performance data, budget submissions, infrastructure audits or policy engagement), which can influence future rule-making and budget allocations. Within the PI “box”, there are also interactions between hard and soft infrastructure. The governing body (i.e. SANParks' higher-level actors) is responsible for building and maintaining infrastructure, with these decisions being guided by institutional mandates and strategic plans. In turn, information on the condition and performance of hard PI (like in the form of the Fixed Asset Registry) will

inform future decisions including where to invest, what to upgrade and how to revise soft infrastructures, like park management plans.

The interaction between shared infrastructure and natural infrastructure is denoted by link four. Infrastructure directly impacts ecological condition and shapes the natural environment, for example, roads and fences fragment landscapes and can disrupt processes such as the movement of wildlife. It is important to note that Conservation infrastructure consistently received lower levels of investment relative to visitor-facing infrastructure categories across the park system (and scored lowest in terms of quality out of the building categories), which may have consequences for ecological resilience. In the reverse link, each park has a zoning plan incorporated into its management plan, which provides a spatial framework for infrastructure development. These zoning plans are based on biophysical sensitivity, scenic value, and ecological priorities, and assign different zones, including “Remote”, “Primitive”, “Low-Intensity Leisure”, and “High-Intensity Leisure”, each with guidelines on the type and intensity of permitted infrastructure.

Link five signifies how public infrastructure mediates the interaction between the resource user and the ecological system. PI both physically and institutionally determine how users engage with ecosystems in enabling or constraining access to nature (e.g. roads, fences, hides, zoning) and putting in place the rules which say what is or isn't allowed (e.g. resource use policies and agreements, regulations). Finally, resource users interact with public infrastructure (link 6). Infrastructure shapes how users experience the park; at the same time, users generate feedback, which can influence infrastructure planning and prioritisation. Resource users also have a more direct impact on hard infrastructure, in that their use contributes to wear and tear. Visitors and visitor preferences are exogenous drivers in this context. Visitor preferences for cultural ecosystem services create demand-side pressure on PIPs to provide hard infrastructure that aligns with the experiences that visitors seek in different national parks.

The CIS framework places emphasis on feedback dynamics (Anderies et al., 2016), which helped this research identify a few important infrastructure-related feedbacks, which likely have implications for system resilience over time. Evidence suggesting a reinforcing feedback loop was identified between visitor numbers and infrastructure investment: high visitation drives greater investment in roads and buildings, which in turn improves accessibility and visitor experience, further increasing visitation. This relationship was supported by regression results, but causality cannot be definitively determined. In contrast, lower-visitation/remote

parks appeared to operate under a different logic, where increased infrastructure investment may not necessarily drive higher visitation. However, it is possible that there is some path dependency between infrastructure and visitor numbers in parks that have more potential for visitors and are more accessible. My findings also suggested potential lagged feedbacks between infrastructure provision and visitors' CES preferences. This was mainly inferred from the mismatches between CES clusters and infrastructure types in several parks, which suggest that infrastructure decisions are not always responsive to changing patterns of use and demand and may reflect legacy investments rather than current visitor needs or that visitor preferences and uses have not (yet) developed in response to existing infrastructure investments.

6.4 Practical and Policy Implications and Recommendations

A key implication for SANParks is the need to recognise that different parks serve different CES functions, and infrastructure should reflect and support these roles. Chapter 4 identified three park clusters with distinct infrastructure profiles, and Chapter 5 revealed four park clusters based on visitor preferences for CES. While there was some overlap between infrastructure and CES clusters, the alignment was not consistent, which suggests that infrastructure provision may not always be well-matched to the types of CES visitors value most in a given park. It is also important to note that there is already some overlap between the typologies I identified and SANParks' existing regional "clusters" (for example, two of the five parks in the Cape region were classified as 'Infrastructure-Dense' and 'Urban, Recreation').

SANParks may benefit from formally recognising park types based on infrastructure-CES configurations and developing targeted planning approaches for each, which would also help prioritise spending on infrastructure types that demonstrably support valued services. For example, parks in the "Place Attachment" cluster may benefit from continued investment in low-impact infrastructure (such as trails, campsites, and scenic lookouts), whereas parks in the "Safari" cluster may benefit less from expanding recreation-oriented facilities and more from maintaining road networks, hides, and viewing infrastructure that enhance wildlife encounters. Such differentiation would not necessarily require large increases in overall spending, as existing resources could be allocated toward infrastructure types that demonstrably support the dominant CES profile of each park.

The findings have implications for equity and inclusion in SANParks' infrastructure planning. Chapter 4 showed that small, urban parks receive disproportionately high levels of infrastructure investment per square kilometre. However, as demonstrated in Chapter 5, these

same parks often deliver limited CES diversity (primarily skewed towards Recreation) and show relatively low investment per visitor. Conversely, remote or lower-visitation parks tend to have greater CES diversity and often demonstrate a stronger support for relational or immersive experiences. The current model may value access quantity, in terms of visitor volume, over CES value, potentially inadvertently sidelining CES that are harder to measure (such as Sense of Place or Outdoor Living) or less easily monetised and the publics who value them. This has direct consequences for those whose preferences are prioritised and those whose preferences are ignored, potentially to the detriment of historically undeserved or marginalised groups. However, it's important to note that this study draws on CES data from existing visitors only, and does not capture the preferences or needs of non-visitors or historically marginalized/underrepresented groups hence the CES preferences of these groups cannot be inferred directly from the data (see section 6.6, Future Research Directions). In any case, a potential way to address equity concerns could be more deliberate investment in infrastructure that supports the CES valued by underrepresented groups, for example, remote parks could invest in infrastructure that supports or enhances the kind of CES valued by local communities that seek spiritual value and need access to be able to access them, in this sense, infrastructure can be a barrier to CES delivery.

Different interest groups within parks also value different forms of infrastructure and access. This is particularly relevant in parks located near urban centres, where diverse user groups (including local residents, tourists, recreational users, and cultural practitioners) may have contrasting expectations regarding development intensity, access, and conservation priorities. These differences could be more explicitly considered within park zonation schemes and infrastructure development frameworks. Furthermore, while SANParks already invests significantly in stakeholder engagement during its ten-year park management planning cycles and uses adaptive management approaches, the findings of this study (i.e. misalignment between clusters) suggest there is still scope to strengthen ongoing responsiveness to changing visitor values, particularly those related to CES. It's also important that this happens throughout the management process and not just during planning (Roux et al., 2021). Improved responsiveness could potentially be achieved through regular monitoring and performance reviews, introducing investment indicators to account for less visible but socially significant cultural benefits and a stronger focus on CES preferences and values in the management plan process.

Infrastructure can contribute to achieving long-term strategic goals as SANParks advances its Vision 2040 and transitions toward Mega Living Landscapes, which aim to create ecologically coherent systems that extend beyond park boundaries (SANParks, 2024c). Strategic infrastructure could enhance functional connectivity and increase permeability across parks and surrounding areas, for example, through roads and trails that connect internal park nodes to neighbouring communities. Vision 2040 speaks to “smart and sustainable infrastructure” and the need to “fund green” in relation to energy-efficient infrastructure and biodiversity-aligned investments, and positions infrastructure as one of the strategic enablers to achieving its goals (SANParks, 2024c). This could include increasing funding for what this thesis referred to as “Conservation” infrastructure, as well as other types of infrastructure that support wildlife economies and livelihoods, such as game meat processing facilities and eco-tourism ventures. Furthermore, SANParks’ high-level strategy towards Vision 2040 positions infrastructure as a strategic enabler to this goal (SANParks, 2024c); meaning there is a need to invest in multifunctional/adaptive infrastructure that is capable of accommodating shifting climate conditions and social values (including CES themselves). The findings of this study also suggest that some misalignments currently exist between infrastructure patterns and CES delivery, which might be a warning signal of lagging government responsiveness to visitor preferences that could undermine resilience by constraining the system's ability to respond to new demands or values.

6.5 Research Limitations

This study does have some limitations, other than the data-related limitations mentioned in the previous two chapters, which should be acknowledged. Firstly, SANParks’ infrastructure dataset was not spatially linked to CES survey sites, so I used park-level averages, which could obscure heterogeneity within the individual NPs. Second, the analyses were constrained by a sample size ($n = 19$ parks), which limited the number of variables that could be included in the k-means clustering and diminished the statistical power of some tests (like Fisher’s Exact) and could also exaggerate the influence of outlier parks. Lastly, the results are specific to SA’s National Parks which does limit the generalisability of my findings. Though the results do offer broader insights into the relationship between hard infrastructure and CES, they cannot be directly applied to other protected area networks which have different governance systems, user groups and environmental contexts.

6.6 Future Research Directions

These limitations bring with them opportunities for future research. There is a need for long-term monitoring to track how investment patterns, infrastructure condition and CES delivery/preferences change over time; longitudinal data could assist SANParks (and other conservation agencies) to detect delays or breakdowns in feedback loops and where infrastructure interventions do or do not enhance visitor engagement and CES outcomes. Such a system could include time-series data on infrastructure ageing, repair/maintenance, and reinvestment cycles (if this does not already exist) and periodic CES surveys, like that conducted by Ament et al. (2017).

As this study did not directly link infrastructure to ecological outcomes so future research could investigate whether and how infrastructure patterns relate to ecological integrity. For example, the relationship between conservation outcomes and conservation infrastructure, or the overall influence of different types of infrastructure on measurable ecological outcomes (e.g. the impact of road and fence networks on species movement, habitat fragmentation or ecological connectivity), and how they feed back into CES, potentially to identify trade-offs and synergies. There is also room for future work to explore the “soft infrastructure” related to institutional and governance processes that underpin infrastructure decisions, as questions remain about how infrastructure decisions are made, who is involved, and whose values count. Qualitative methods (such as key informant interviews, focus groups, or document analysis) could help uncover the drivers and constraints/trade-offs related to infrastructure investment.

Future research could also examine the relationships among infrastructure, justice, and equity in protected areas. While this study identified uneven patterns of infrastructure allocation and CES delivery across parks, it did not directly investigate how these patterns shape equitable justice. Moreover, this research focused primarily on visitors and tourism-related CES; future studies should expand beyond visitor populations to examine how infrastructure decisions affect local communities, particularly historically marginalised groups. Such work could explore who benefits from infrastructure investment, who faces barriers to access, and whose values are recognised or excluded in planning processes.

This research focused on five CES bundles related to visitor values, but future studies could explore additional types of CES that are important beyond tourism. In the context of Mega Living Landscapes, it would be useful to explore how infrastructure could facilitate or undermine many kinds of values and services for local communities and as conservation in

South Africa moves towards MLL, it will be important for research to expand from park-specific research to the landscape scale. Furthermore, in this new “era”, research opportunities may include investigating how infrastructure (both hard and soft) can relate to cultural narratives and community access across broader conservation landscapes and ecological corridors; whereas on the CES side, studies could explore whether connected landscapes support more diverse CES bundles than isolated parks.

6.7 Conclusion

This thesis aimed to investigate how patterns of hard infrastructure across South Africa's National Parks are related to the delivery of cultural ecosystem services. This was done by assessing variation in infrastructure investment and quality, identifying park-level infrastructure and CES archetypes, and exploring how infrastructure patterns align with different CES experiences. Practically, the study offers a replicable methodology for assessing infrastructure condition, investment patterns, and CES alignment that can be applied in other multi-park systems. The Infrastructure and CES clusters identified here can inform better infrastructure planning within SANParks, with the insights gained being directly relevant to Vision 2040 and Mega Living Landscapes. At a broader level, my research contributes to conservation science by providing insights into the multifaceted dynamics of social-ecological systems and the role of hard infrastructure in protected areas. It also represents a step towards operationalising the CIS framework and identifies important infrastructure-related feedbacks, hopefully laying the groundwork for future dynamic modelling efforts. In conclusion, this thesis demonstrates the importance of integrating systems-based approaches like the CIS framework into protected area management and provides a pathway to align infrastructure planning with cultural ecosystem services while remaining adaptive and equitable in the face of changing ecological and social realities.

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APPENDIX A: CHAPTER 4 SUPPLEMENTARY MATERIAL

A1: Infrastructure Quality

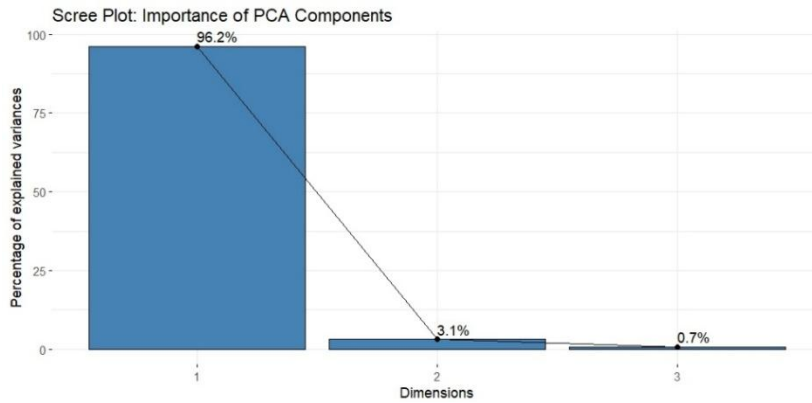


Figure A1. Scree plot showing the percentage of variance explained by each principal component for infrastructure category quality variables for building infrastructure type

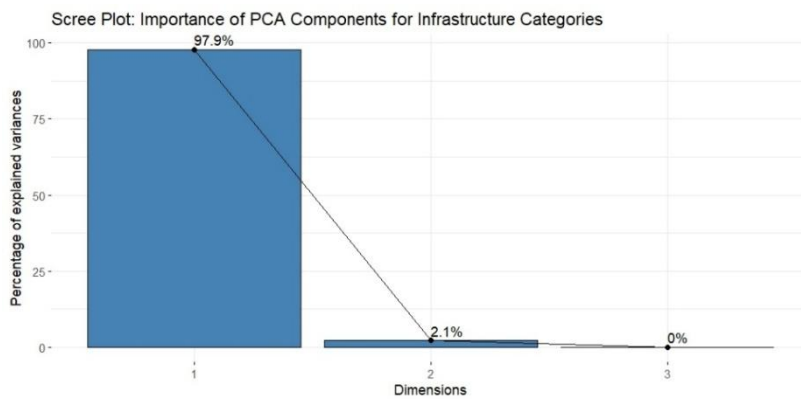


Figure A2. Scree plot showing the percentage of variance explained by each principal component for infrastructure category quality variables for building subcategories.

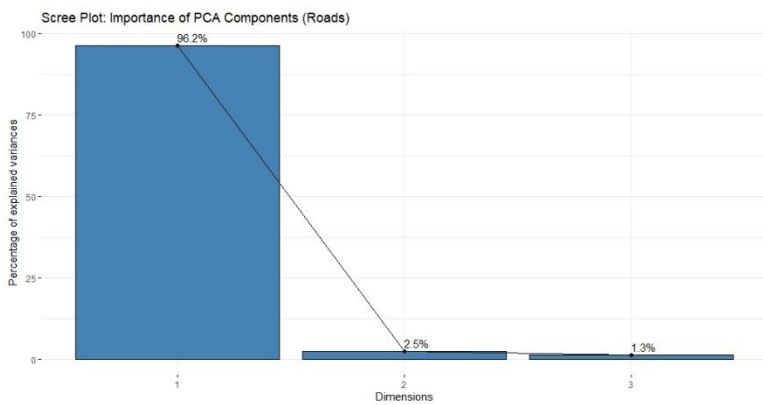


Figure A3. Scree plot showing the percentage of variance explained by each principal component for infrastructure category quality variables for roads.

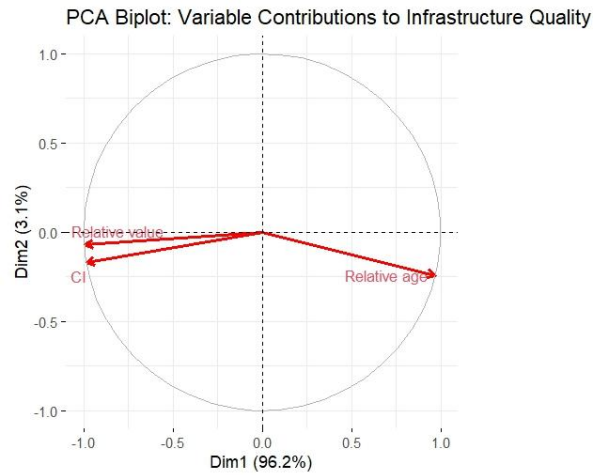


Figure A4. PCA biplot showing the contribution and direction of quality-related variables to the first two principal components: building infrastructure type

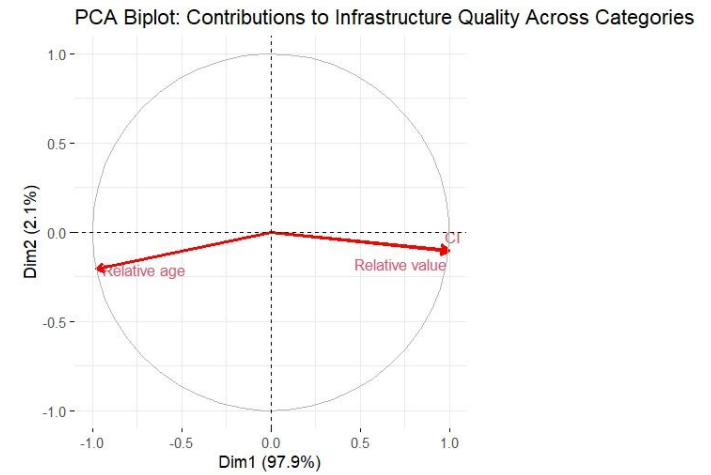


Figure A5. PCA biplot showing the contribution and direction of quality-related variables to the first two principal components: building subcategories

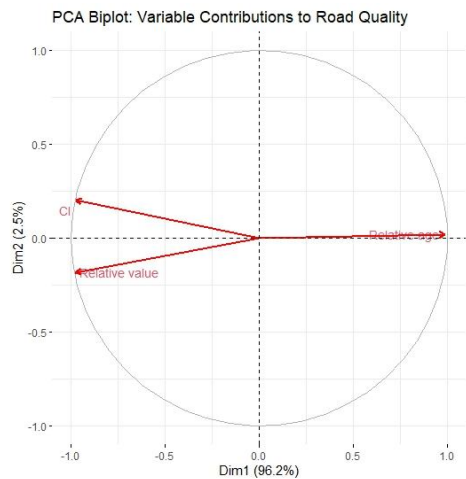


Figure A6. PCA biplot showing the contribution and direction of quality-related variables to the first two principal components: road infrastructure type

Table A1. Significant Dunn's Post-hoc Pairwise Comparisons for Buildings (Condition Index)

Comparison	Z statistic	Adjusted p-value
Addo – Garden Route	6.42	<0.001
Addo – Golden Gate	6.05	<0.001
Addo – Kruger	10.23	<0.001
Addo – Marakele	5.28	<0.001
Addo – Namaqua	8.00	<0.001
Addo – Table Mountain	6.51	<0.001
Addo – Tankwa Karoo	6.60	<0.001
Addo – West Coast	6.18	<0.001
Augrabies – Kruger	3.95	0.013
Bontebok – Kruger	3.99	0.011
Garden Route – Kgalagadi	-6.03	<0.001
Golden Gate – Kgalagadi	-5.83	<0.001
Kgalagadi – Kruger	9.24	<0.001
Kgalagadi – Namaqua	7.84	<0.001
Kgalagadi – Table Mountain	6.25	<0.001
Kgalagadi – Tankwa Karoo	6.49	<0.001
Kgalagadi – West Coast	6.06	<0.001
Kruger – Mapungubwe	-4.69	<0.001
Kruger – Mokala	-8.00	<0.001
Mapungubwe – Namaqua	5.61	<0.001
Mapungubwe – Tankwa Karoo	4.49	0.001
Mokala – Namaqua	8.17	<0.001
Mokala – Table Mountain	6.63	<0.001
Mokala – Tankwa Karoo	7.10	<0.001
Mokala – West Coast	6.72	<0.001
Mountain Zebra – Namaqua	4.69	<0.001
Namaqua – Garden Route	4.38	0.002
Namaqua – Karoo	4.35	0.002
Tankwa Karoo – Bontebok	4.56	0.001
Tankwa Karoo – Augrabies	4.36	0.002
West Coast – Bontebok	4.21	0.004

West Coast – Augrabies	3.86	0.020
West Coast – Mapungubwe	3.95	0.013

Table A2. Significant Dunn's Post-hoc Pairwise Comparisons for Buildings (Relative Age)

Comparison	Z statistic	Adjusted p-value
Bontebok – Camdeboo	-3.88	0.018
Addo – Garden Route	-4.98	<0.001
Bontebok – Garden Route	-4.49	0.001
Addo – Golden Gate	-4.52	0.001
Bontebok – Golden Gate	-4.59	<0.001
Bontebok – Karoo	-4.06	0.008
Garden Route – Kgalagadi	5.03	<0.001
Golden Gate – Kgalagadi	4.65	<0.001
Addo – Kruger	-8.32	<0.001
Augrabies – Kruger	-4.61	<0.001
Bontebok – Kruger	-5.16	<0.001
Kgalagadi – Kruger	-7.93	<0.001
Kruger – Mapungubwe	4.25	0.004
Addo – Marakele	-4.44	0.002
Bontebok – Marakele	-4.72	<0.001
Kgalagadi – Marakele	-4.58	<0.001
Camdeboo – Mokala	4.0	0.011
Garden Route – Mokala	6.31	<0.001
Golden Gate – Mokala	6.11	<0.001
Karoo – Mokala	4.86	<0.001
Kruger – Mokala	7.95	<0.001
Mapungubwe – Mokala	3.96	0.013
Marakele – Mokala	6.05	<0.001
Bontebok – Mountain Zebra	-3.67	0.041
Mokala – Mountain Zebra	-4.04	0.009
Addo – Namaqua	-7.82	<0.001
Agulhas – Namaqua	-4.0	0.011
Augrabies – Namaqua	-6.33	<0.001

Bontebok – Namaqua	-6.52	<0.001
Garden Route – Namaqua	-5.08	<0.001
Golden Gate – Namaqua	-4.19	0.005
Karoo – Namaqua	-4.34	0.002
Kgalagadi – Namaqua	-7.86	<0.001
Kruger – Namaqua	-4.24	0.004
Mapungubwe – Namaqua	-6.02	<0.001
Mokala – Namaqua	-8.72	<0.001
Mountain Zebra – Namaqua	-4.41	0.002
Bontebok – Richtersveld	-3.96	0.013
Mokala – Richtersveld	-4.49	0.001
Namaqua – Richtersveld	3.92	0.015
Addo – Table Mountain	-5.52	<0.001
Augrabies – Table Mountain	-3.95	0.013
Bontebok – Table Mountain	-4.92	<0.001
Kgalagadi – Table Mountain	-5.59	<0.001
Mokala – Table Mountain	-6.79	<0.001
Namaqua – Table Mountain	3.71	0.036
Addo – Tankwa Karoo	-5.56	<0.001
Augrabies – Tankwa Karoo	-4.67	<0.001
Bontebok – Tankwa Karoo	-5.51	<0.001
Kgalagadi – Tankwa Karoo	-5.68	<0.001
Mapungubwe – Tankwa Karoo	-4.08	0.008
Mokala – Tankwa Karoo	-6.92	<0.001
Addo – West Coast	-5.14	<0.001
Augrabies – West Coast	-4.25	0.004
Bontebok – West Coast	-5.21	<0.001
Kgalagadi – West Coast	-5.26	<0.001
Mokala – West Coast	-6.59	<0.001

Table A3. Significant Dunn's Post-hoc Pairwise Comparisons for Buildings (Relative Value)

Comparison	Z statistic	Adjusted p-value
Addo – Garden Route	5.61	< 0.001
Addo – Golden Gate	5.00	< 0.001
Addo – Kruger	9.24	< 0.001
Addo – Marakele	4.71	< 0.001
Addo – Namaqua	8.28	< 0.001
Addo – Table Mountain	4.99	< 0.001
Addo – Tankwa Karoo	5.82	< 0.001
Addo – West Coast	5.71	< 0.001
Augrabies – Kruger	4.31	0.003
Bontebok – Kruger	3.93	0.014
Bontebok – Camdeboo	2.65	0.018
Bontebok – Golden Gate	3.37	0.013
Bontebok – Marakele	3.48	0.001
Bontebok – Richtersveld	3.14	0.029
Bontebok – Table Mountain	3.32	0.016
Garden Route – Kgalagadi	-6.04	< 0.001
Golden Gate – Kgalagadi	-5.45	< 0.001
Kgalagadi – Kruger	9.25	< 0.001
Kgalagadi – Marakele	5.14	< 0.001
Kgalagadi – Namaqua	8.58	< 0.001
Kgalagadi – Table Mountain	5.45	< 0.001
Kgalagadi – Tankwa Karoo	6.18	< 0.001
Kgalagadi – West Coast	6.08	< 0.001
Kruger – Mapungubwe	-4.27	0.003
Kruger – Mokala	-8.36	< 0.001
Mapungubwe – Mokala	-4.28	0.003
Mokala – Namaqua	9.03	< 0.001
Mokala – Table Mountain	6.35	< 0.001
Mokala – Tankwa Karoo	7.07	< 0.001
Mokala – West Coast	6.98	< 0.001
Namaqua – Table Mountain	-4.52	0.001

Table A4. Significant Dunn's Post-hoc Pairwise Comparisons for Roads (Condition Index)

Comparison	Z	Adjusted p-value
Addo – Garden Route	6.42	< 0.001
Addo – Golden Gate	6.05	< 0.001
Addo – Kruger	10.23	< 0.001
Addo – Marakele	5.28	< 0.001
Addo – Namaqua	8.00	< 0.001
Addo – Table Mountain	6.51	< 0.001
Addo – Tankwa Karoo	6.60	< 0.001
Addo – West Coast	6.18	< 0.001
Garden Route – Kgalagadi	-6.03	< 0.001
Golden Gate – Kgalagadi	-5.83	< 0.001
Augrabies – Kruger	3.95	0.013
Bontebok – Kruger	3.99	0.011
Kgalagadi – Kruger	9.24	< 0.001
Kruger – Mapungubwe	-4.69	< 0.001
Kgalagadi – Marakele	5.15	< 0.001
Kruger – Mokala	-8.00	< 0.001
Garden Route – Mokala	-6.29	< 0.001
Golden Gate – Mokala	-6.36	< 0.001
Marakele – Mokala	-5.93	< 0.001
Mokala – Namaqua	8.17	< 0.001
Kgalagadi – Namaqua	7.84	< 0.001
Mapungubwe – Namaqua	5.61	< 0.001
Mountain Zebra – Namaqua	4.69	< 0.001
Mokala – Richtersveld	4.41	0.002
Kgalagadi – Table Mountain	6.25	< 0.001
Mokala – Table Mountain	6.63	< 0.001
Kgalagadi – Tankwa Karoo	6.49	< 0.001
Mokala – Tankwa Karoo	7.10	< 0.001
Augrabies – West Coast	3.86	0.019
Bontebok – West Coast	4.21	0.004
Kgalagadi – West Coast	6.06	< 0.001
Mokala – West Coast	6.72	< 0.001

Table A5. Significant Dunn's Post-hoc Pairwise Comparisons for Roads (Relative Age)

Comparison	Z	Adjusted p-value
Bontebok – Camdeboo	-3.88	0.018
Addo – Garden Route	-4.98	< 0.001
Bontebok – Garden Route	-4.49	0.001
Addo – Golden Gate	-4.52	0.001
Bontebok – Golden Gate	-4.59	< 0.001
Bontebok – Karoo	-4.06	0.008
Garden Route – Kgalagadi	5.03	< 0.001
Golden Gate – Kgalagadi	4.65	< 0.001
Addo – Kruger	-8.32	< 0.001
Augrabies – Kruger	-4.61	< 0.001
Bontebok – Kruger	-5.16	< 0.001
Kgalagadi – Kruger	-7.93	< 0.001
Kruger – Mapungubwe	4.25	0.004
Addo – Marakele	-4.44	0.002
Bontebok – Marakele	-4.72	< 0.001
Kgalagadi – Marakele	-4.58	< 0.001
Camdeboo – Mokala	4.00	0.011
Garden Route – Mokala	6.31	< 0.001
Golden Gate – Mokala	6.11	< 0.001
Karoo – Mokala	4.86	< 0.001
Kruger – Mokala	7.95	< 0.001
Mapungubwe – Mokala	3.96	0.013
Marakele – Mokala	6.05	< 0.001
Bontebok – Mountain Zebra	-3.67	0.041
Mokala – Mountain Zebra	-4.04	0.009
Addo – Namaqua	-7.82	< 0.001
Agulhas – Namaqua	-4.00	0.011
Augrabies – Namaqua	-6.33	< 0.001
Bontebok – Namaqua	-6.52	< 0.001
Garden Route – Namaqua	-5.08	< 0.001
Golden Gate – Namaqua	-4.19	0.005
Karoo – Namaqua	-4.34	0.002

Kgalagadi – Namaqua	-7.86	< 0.001
Kruger – Namaqua	-4.24	0.004
Mapungubwe – Namaqua	-6.02	< 0.001
Mokala – Namaqua	-8.72	< 0.001
Mountain Zebra – Namaqua	-4.41	0.002
Bontebok – Richtersveld	-3.96	0.013
Mokala – Richtersveld	-4.49	0.001
Namaqua – Richtersveld	3.92	0.015
Addo – Table Mountain	-5.52	< 0.001
Augrabies – Table Mountain	-3.95	0.013
Bontebok – Table Mountain	-4.92	< 0.001
Kgalagadi – Table Mountain	-5.59	< 0.001
Mokala – Table Mountain	-6.79	< 0.001
Namaqua – Table Mountain	3.71	0.036
Addo – Tankwa Karoo	-5.56	< 0.001
Augrabies – Tankwa Karoo	-4.67	< 0.001
Bontebok – Tankwa Karoo	-5.51	< 0.001
Kgalagadi – Tankwa Karoo	-5.68	< 0.001
Mapungubwe – Tankwa Karoo	-4.08	0.008
Mokala – Tankwa Karoo	-6.92	< 0.001
Addo – West Coast	-5.14	< 0.001
Augrabies – West Coast	-4.25	0.004
Bontebok – West Coast	-5.21	< 0.001
Kgalagadi – West Coast	-5.26	< 0.001
Mokala – West Coast	-6.59	< 0.001

Table A6. Significant Dunn's Post-hoc Pairwise Comparisons for Roads (Relative Value)

Comparison	Z	Adjusted p-value
Addo – Garden Route	5.61	< 0.001
Addo – Golden Gate	5.00	< 0.001
Addo – Kruger	9.24	< 0.001
Addo – Marakele	4.71	< 0.001
Addo – Namaqua	8.28	< 0.001
Addo – Table Mountain	4.99	< 0.001

Addo – Tankwa Karoo	5.82	< 0.001
Addo – West Coast	5.71	< 0.001
Augrabies – Kruger	4.31	0.0028
Bontebok – Kruger	3.93	0.014
Camdeboo – Mokala	-3.86	0.0196
Garden Route – Kgalagadi	-6.04	< 0.001
Garden Route – Mokala	-6.62	< 0.001
Golden Gate – Kgalagadi	-5.45	< 0.001
Golden Gate – Mokala	-6.37	< 0.001
Karoo – Namaqua	4.95	< 0.001
Kgalagadi – Kruger	9.25	< 0.001
Kgalagadi – Marakele	5.14	< 0.001
Kgalagadi – Namaqua	8.58	< 0.001
Kgalagadi – Table Mountain	5.45	< 0.001
Kgalagadi – Tankwa Karoo	6.18	< 0.001
Kgalagadi – West Coast	6.08	< 0.001
Kruger – Mapungubwe	-4.27	0.0034
Kruger – Mokala	-8.36	< 0.001
Mapungubwe – Mokala	-4.28	0.0032
Marakele – Mokala	-6.19	< 0.001
Mokala – Namaqua	9.03	< 0.001
Mokala – Richtersveld	5.20	< 0.001
Mokala – Table Mountain	6.35	< 0.001
Mokala – Tankwa Karoo	7.07	< 0.001
Mokala – West Coast	6.98	< 0.001
Mountain Zebra – Namaqua	5.44	< 0.001
Namaqua – Tankwa Karoo	-4.52	0.0011

A2: Infrastructure Investment

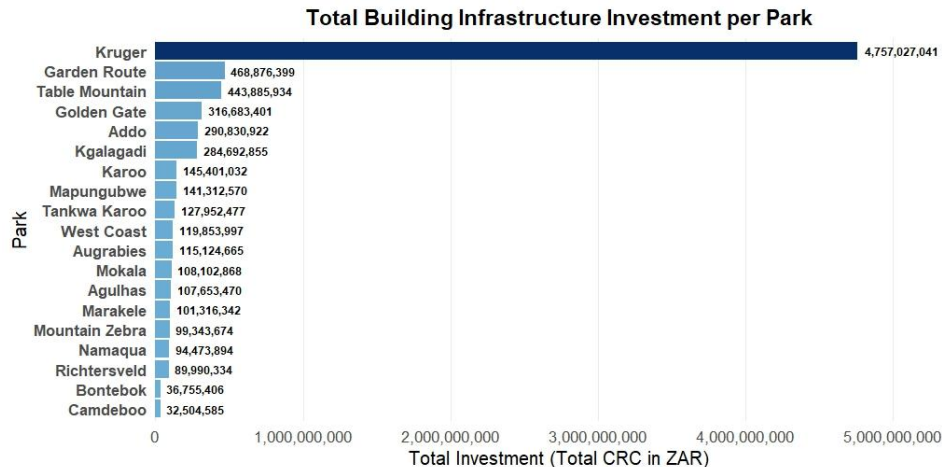


Figure A7. Bar plot showing total building infrastructure investment per park across SANParks.

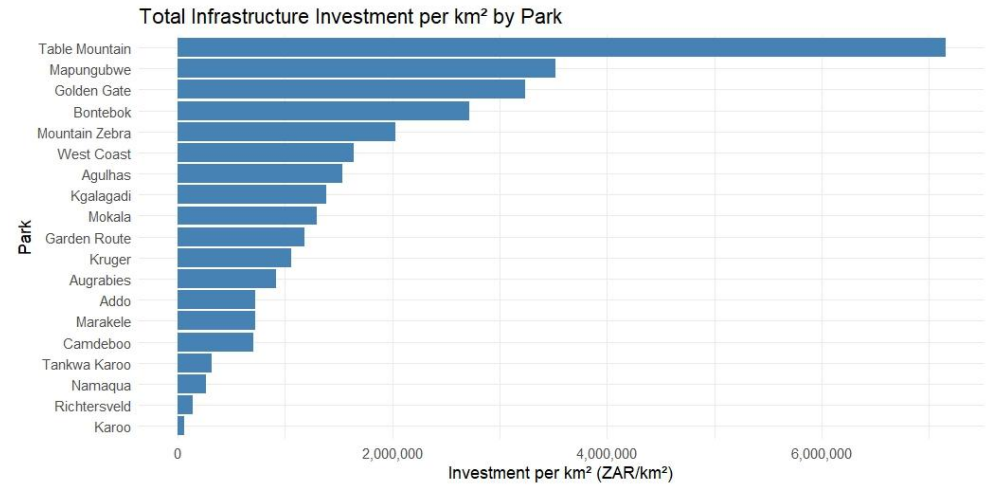


Figure A8. Bar plot showing infrastructure investment per square kilometre per park across SANParks.

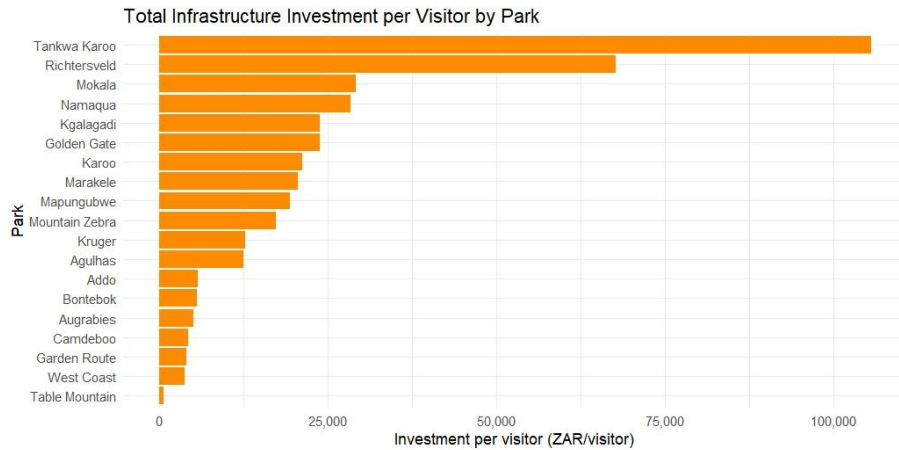


Figure A9. Bar plot showing infrastructure investment per visitor per park across SANParks.

A3: Cluster Analysis

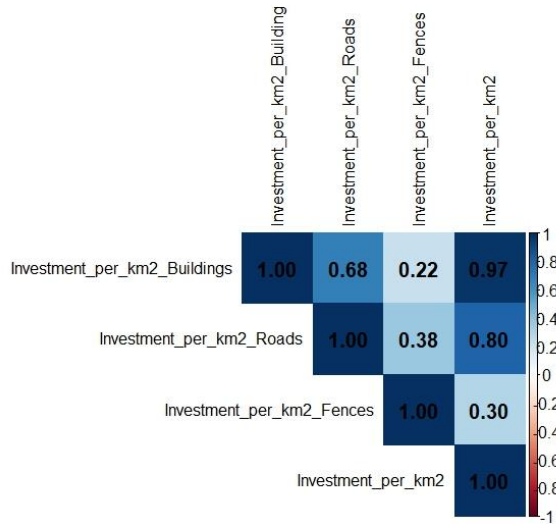


Figure A11. Correlation heatmap of infrastructure investment intensity variables

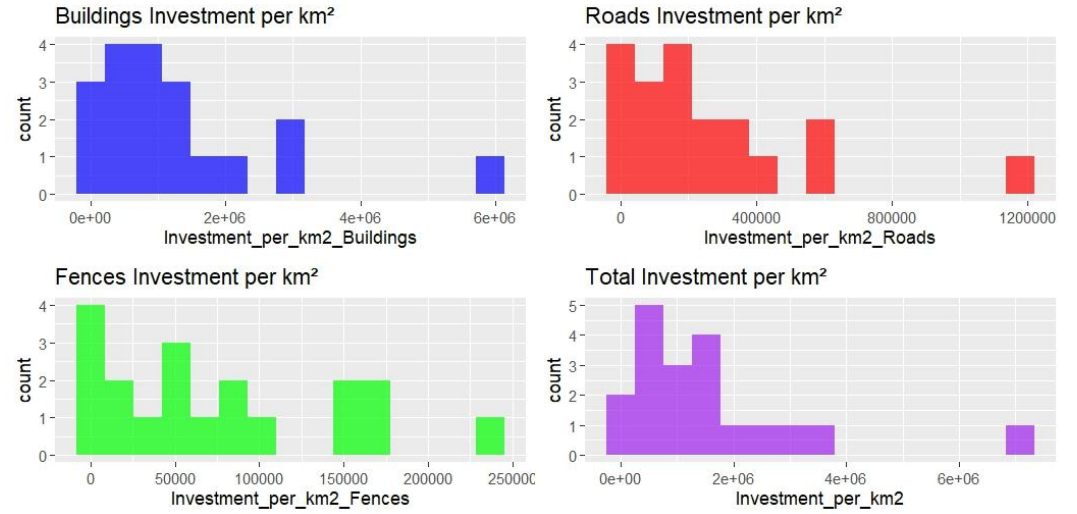


Figure A12. Histograms showing distribution of investment variables

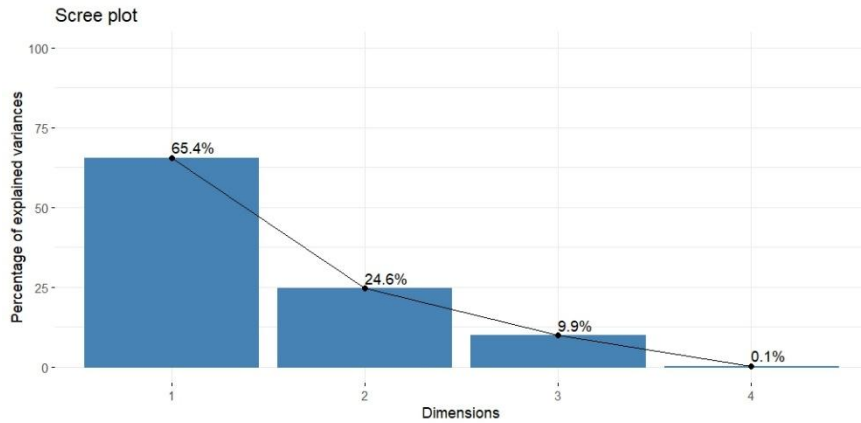


Figure A13. Scree plot showing the percentage of variance explained by each principal component (infrastructure investment variables)

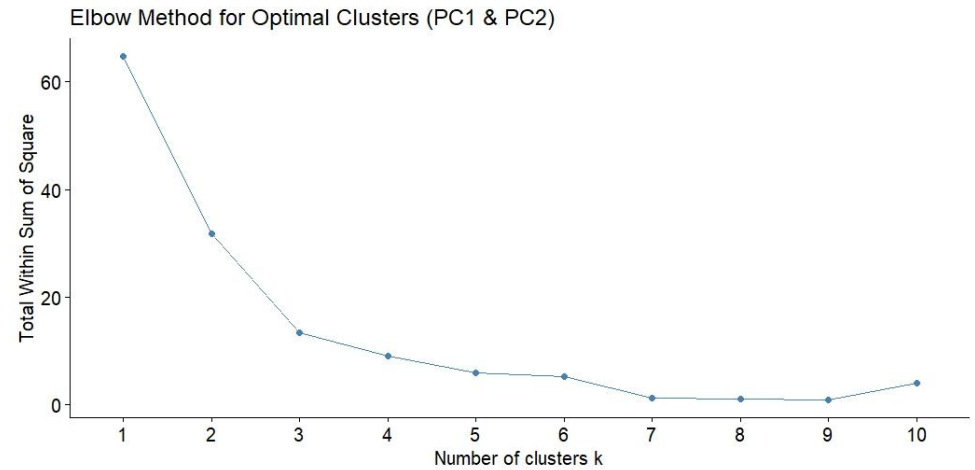


Figure A14. Elbow Method for determining optimal number of clusters (infrastructure investment)

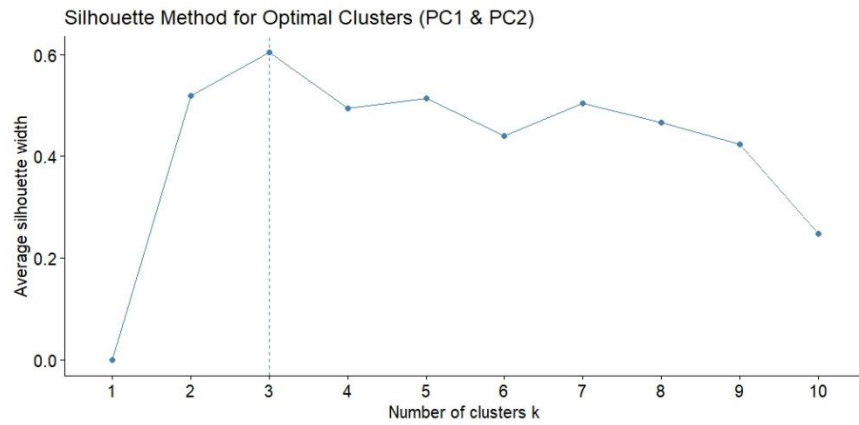


Figure A15. Silhouette Method for determining optimal number of clusters (infrastructure investment)

APPENDIX B: CHAPTER 5 SUPPLEMENTARY MATERIAL

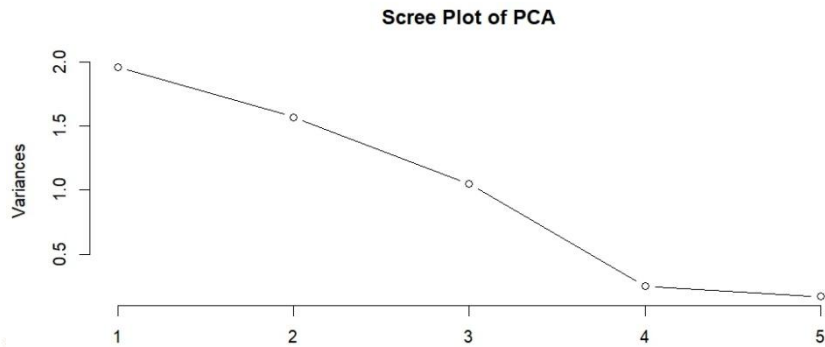


Figure A16. Scree plot showing the percentage of variance explained by each principal component (CES)

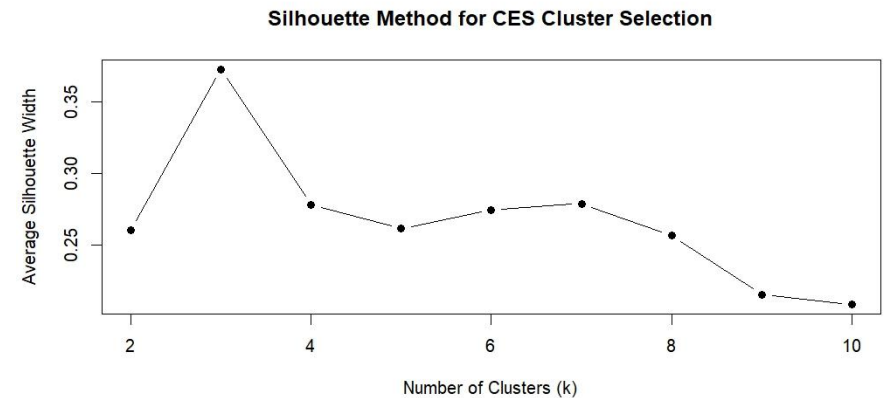


Figure A17. Silhouette method for optimal number of CES park clusters

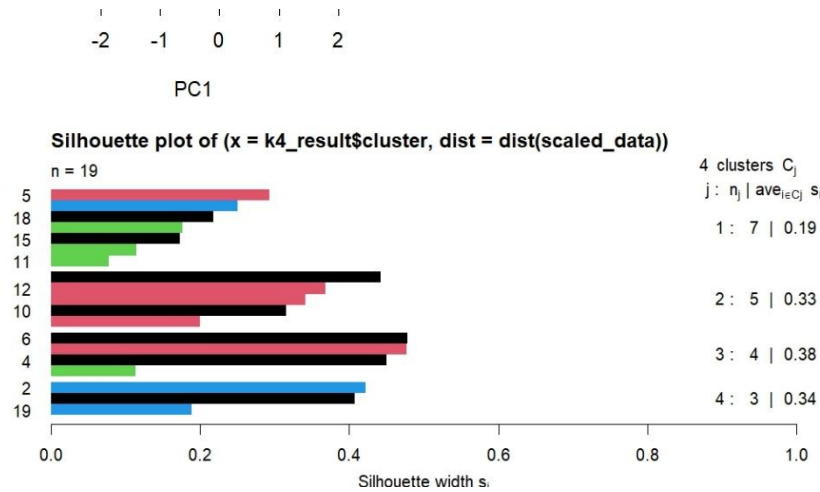


Figure A18. Silhouette plot for the four-cluster CES solution.

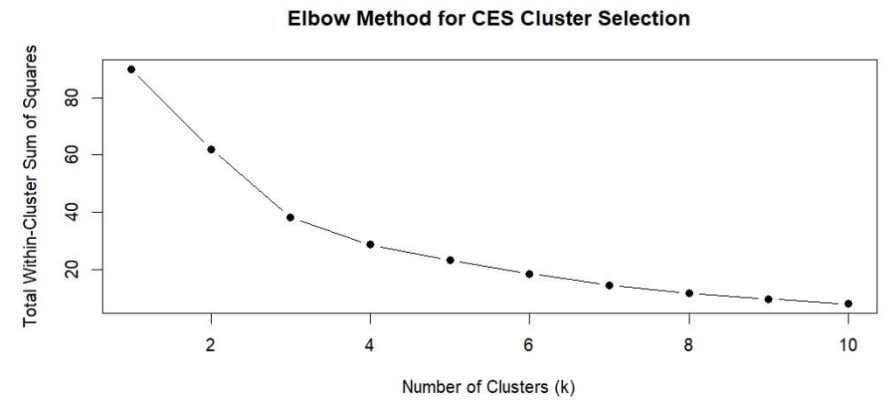


Figure A19. Elbow method for optimal number of CES park clusters



Figure A20. Cook's Distance plot for the Sense of Place regression model.

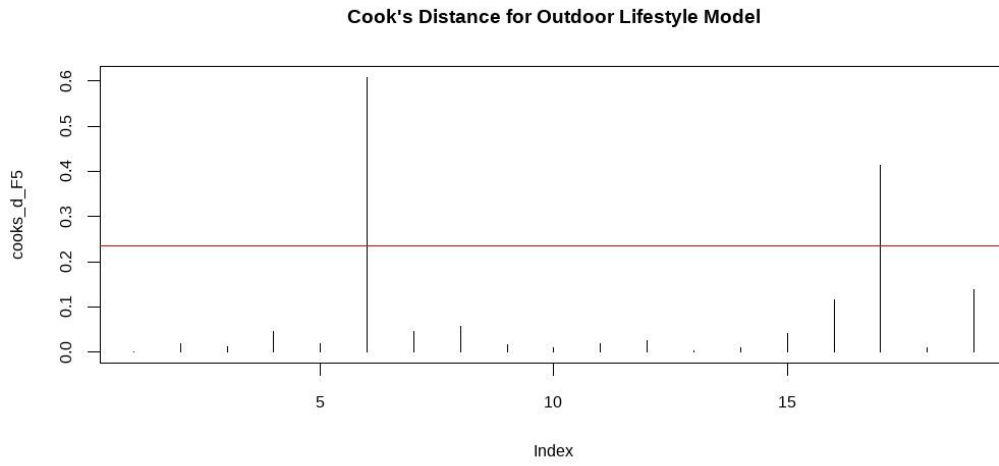


Figure A21. Cook's Distance plot for the Outdoor Lifestyle regression model.

APPENDIX C: CULTURAL ECOSYSTEM SERVICE BUNDLES FROM AMENT ET AL., 2017

Table D1. Mean and median responses of protected area visitors to preference statements on cultural ecosystem services. Responses were recorded on a five-point Likert scale (extracted from Ament et al., 2017).

Survey statement	Indicator variable	Mean response (\pm SD)	Median response
Aesthetic			
Looking at big mammals	Big mammals	4.43 (\pm 0.72)	5—Strongly agree
Sitting, enjoying the view	View	4.38 (\pm 0.70)	4—Agree
Looking at birds	Birds	4.11 (\pm 0.94)	4—Agree
Looking at flowers	Flowers	3.72 (\pm 1.02)	4—Agree
Looking at reptiles	Reptiles	3.52 (\pm 1.09)	4—Agree
Trying to identify plants	Plants	3.38 (\pm 1.10)	3—Neutral
Looking for and or listening to frogs	Frogs	3.06 (\pm 1.13)	3—Neutral
Cultural and heritage			
The experience reminds me of my childhood	Childhood	3.48 (\pm 1.21)	4—Agree
It helps me to understand my culture and or history	Culture and history	3.31 (\pm 1.11)	3—Neutral
Educational			
Learning more about nature	Learning	4.25 (\pm 0.75)	4—Agree
Doing guided tours	Guided tours	3.18 (\pm 1.16)	3—Neutral
Recreational			
I enjoy camping	Camping	3.85 (\pm 1.26)	4—Agree
Doing game drives	Game drives	4.11 (\pm 0.99)	4—Agree
Cooking or braaing	Cooking	3.89 (\pm 1.05)	4—Agree
Taking photographs	Photography	4.39 (\pm 0.82)	5—Strongly agree
Hiking or climbing	Hiking/climbing	3.72 (\pm 1.09)	4—Agree
Reading and/or writing	Reading/writing	3.52 (\pm 1.10)	4—Agree
Driving off road, four wheel driving, or dirt biking	Off-roading	3.28 (\pm 1.32)	3—Neutral
Swimming, surfing, or doing other watersports	Swimming	3.09 (\pm 1.26)	3—Neutral
Boating or canoeing	Boating	2.98 (\pm 1.24)	3—Neutral
Sunbathing	Sunbathing	2.51 (\pm 1.24)	2—Disagree
Fishing	Fishing	2.33 (\pm 1.26)	2—Disagree
Social			
It is a way to spend time with my family friends	Family/friends	4.24 (\pm 0.90)	4—Agree
Hanging out at the campsite or chalet	Hanging out	3.40 (\pm 1.19)	4—Agree
Talking to other visitors	Talking	3.31 (\pm 1.00)	3—Neutral
Having a party with my friends	Partying	2.59 (\pm 1.30)	3—Neutral
Spiritual and religious			
It refreshes my spirit	Spirit	4.52 (\pm 0.71)	5—Strongly agree
It makes me feel closer to God	God	3.45 (\pm 1.47)	4—Agree
It helps me to relax	Relaxation	4.59 (\pm 0.67)	5—Strongly agree
I like to get away from modern conveniences	Away	4.09 (\pm 0.97)	4—Agree

Table D2. Loadings of individual ecosystem services on cultural ecosystem service bundles/factors (extracted from Ament et al., 2017).

Indicator variable	Bundle 1: natural history	Bundle 2: recreation	Bundle 3: sense of place	Bundle 4: safari experience	Bundle 5: outdoor living
Flowers	0.760	0.089	0.084	0.141	0.061
Plants	0.750	-0.030	0.108	0.116	0.089
Birds	0.632	-0.149	0.124	0.258	0.041
Frogs	0.574	0.139	0.092	0.153	0.011
Learning	0.474	-0.080	0.223	0.415	-0.044
Reptiles	0.354	0.122	0.062	0.263	-0.063
Boating	0.116	0.781	0.083	0.049	0.024
Swimming	-0.019	0.738	0.124	0.064	0.058
Sunbathing	-0.072	0.600	0.040	0.030	0.119
Partying	-0.166	0.508	0.059	0.031	0.192
Hiking/climbing	0.217	0.446	0.258	0.099	-0.005
Fishing	0.149	0.453	0.078	0.099	0.160
Off-roading	-0.029	0.368	0.063	0.202	0.180
Spirit	0.188	-0.051	0.661	0.180	-0.030
Relaxation	0.062	0.012	0.562	0.225	0.057
Away	0.136	0.069	0.462	0.111	0.068
Family/friends	-0.056	0.185	0.460	0.087	0.182
God	0.086	-0.051	0.447	0.112	0.217
Camping	0.091	0.157	0.434	0.018	0.288
Childhood	0.167	0.188	0.388	0.010	0.136
Big mammals	0.160	0.009	0.140	0.619	0.039
Game drives	0.158	0.066	0.057	0.509	0.116
Photography	0.173	0.073	0.097	0.409	0.046
Cooking	0.056	0.165	0.287	0.141	0.639
Hanging out	-0.050	0.267	0.222	0.103	0.441
Reading/writing	0.269	0.126	0.167	0.081	0.354
View	0.244	0.140	0.260	0.333	0.209
Guided tours	0.082	0.303	0.059	0.322	-0.026
Culture and history	0.320	0.127	0.221	0.125	0.046
Talking	0.132	0.195	0.098	0.167	0.153

Note: Gray shading indicates strong loading (> 0.35) of ecosystem service on particular factor (i.e., service bundle).