Maximizing the Benefits of Patrol Systems in Protected Areas: Using Area Coverage as a Foundation for Effective Patrol Planning in the uMkhuze Game Reserve

by

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ABSTRACT

The uMkhuze Game Reserve in South Africa is a key biodiversity asset which protects diverse natural resources of regional, national and international importance. The park has a notorious history of poaching, which is considered to be the second most important threat to biodiversity. Paramilitary patrol operations are crucial to regulating poaching in the park, and to the collection of data important for the monitoring of the state of biodiversity. The effectiveness of the patrol system as a whole is gauged primarily from enforcement-related data, and it was the intention of this study to present a landscape level perspective that would bolster current evaluation metrics. Home range and use-availability analyses of patrol data collected in 2009 and 2010 were used to construct area coverage boundaries, and to understand whether the distribution of patrol effort within patrol areas was influenced by habitat type. Results suggest that average monthly patrol area coverage ranged from 8.38 km^2 to 23.15 km^2. This indicates that although designated patrol areas could be covered with relative ease within a few months, information gaps were consistently occurring in the system. To determine how differences in the amount of area covered by patrol units influenced the quantity of information collected, annual area coverage was correlated with the number of biological sightings, illegal incidents and snares reported. Results show that differences in the size of the area covered did not necessarily influence the quantity of information collected in the field. However, certain areas of the park remained unpatrolled annually. All patrol units visited habitats differently than expected based on the proportion of habitat types that were available to them. The preferential use of habitat types could result in incorrect inferences being made about information outputs generated by the patrol system. The number of biological sightings, illegal incidences and snares reported were associated with the total area of each habitat emphasizing the importance of covering habitats proportionately to their availability in the park.

DECLARATION

I, Delarey Paul Havemann, declare that:

(i) The research reported in this dissertation, except where otherwise indicated, is my original work,

(ii) This dissertation has not been submitted for any degree or examination at any other university,

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Chapter 1 - INTRODUCTION

1.1 Background

The KwaZulu-Natal Province in South Africa forms an important part of a somewhat ambiguous pre and post-Colonial African conservation legacy. In particular, the conservation of the southern white rhinoceros has emerged as one of its most important national and international achievements. By 1895 the proclamation of the Umfolozi Game Reserve, to protect the last remaining individuals (McCracken, 2008), defined the earliest political structure of Ezemvelo KZN Wildlife (EKZNW), the environmental and compliance agency for the province today. Moreover, the proclamation of Umfolozi solidified the protected area framework within which modern biodiversity management has evolved in the province.

Biodiversity in KwaZulu-Natal is well represented in its terrestrial protected area network system. Ninety nine protected areas cover some 8% of the total land surface of the province (Ezemvelo KZN Wildlife (EKZNW), 2009; World Wide Fund for Nature, 2011), and signify 117 years of successful conservation management. As in most of post-colonial Africa, protected areas in KwaZulu-Natal were typically established through the forcible removal of rural communities from areas that historically provided them with natural resources important to their livelihoods (Carruthers, 1989; Ellis, 1994; Draper, 1998; Picard, 2003). As a consequence, paramilitary patrol operations were, and continue to be, crucial to the mitigation of threats to biodiversity in the province (iSimangaliso Wetland Park (iSimangaliso), 2012). EKZNW has thus relied heavily on the application of intensive policing and patrolling strategies to achieve its conservation objectives (EKZNW, 2007).

The uMkhuze Game Reserve (hereafter uMkhuze) in KwaZulu-Natal is a key international biodiversity asset. It is located within an important center of plant endemism (Critical Ecosystem Partnership Fund (CEPF), 2010) and protects a remarkable diversity of natural and cultural resources. Threats to the park are exacerbated by continued economic disparity for rural communities, high unemployment rates and the subsequent demand on limited natural resources (iSimangaliso, 2010). As a result, significant investment has been made into the building of law enforcement capacity in uMkhuze (Conway *et al.,* 2002; Ransom, 2005; EKZNW, 2010). More recently, the role of EKZNW's patrol system is being expanded to include the collection of biological monitoring information that will address wider biodiversity management needs (EKZNW, 2007; see section 2.3).

1.2 Problem statement

The effectiveness of patrol effort in the field is typically evaluated by the ability of individual patrol units (see sections 1.6 and 3.1) to curb poaching activities, and is measured against indices such as number of arrests, encounters with poachers or conviction rates (Conway, 1981; Bell, 1985; Leader-Williams *et al*., 1990; Leader-Williams and Milner-Gulland, 1993; Jachmann, 2008a, b). Similarly these methodologies form the basis for the evaluation of patrol effectiveness in uMkhuze where additional indices, such as snares found and mortality thresholds, are used (Conway and Thusi, 2002; EKZNW, 2010). However, this measurement of patrol effectiveness can be problematic as it does not consider the ability of a patrol unit to detect illegal activities. This inability to account for observational bias, therefore, limits our understanding of illegal activities at the landscape level and hinders the ability to manage them accordingly. In other words, the interrelatedness between illegal activities and the spatial distribution of patrols is lacking synthesis. An evaluation of patrol effort that is focused primarily on illegal activities detracts from the ability to recognize the emerging properties of the patrol system as a whole, such as the effectiveness of area coverage and the quality of data (Morgan, 2005; see also section 2.5). For example, a reduction in the amount of poachers' snares being found in the field does not necessarily reflect a decrease in poaching. It could be a reflection of a decline in the detection of snares by patrol units, or a shift of poaching activities to a different area. A spatial metric that does not rely solely on the reports of patrol units to evaluate patrol effectiveness is needed.

In addition, the patrol effort was designed specifically around principles of counter-poaching, and the direction of the system as a whole remains largely focused on law enforcement. A host of other threats, such as invasive alien plants and habitat loss, affect biodiversity in the park, and the evaluation of the patrol effort should include its ability to maximize information outputs addressing this wider range of pressures. A better understanding of the benefits of the different patrol strategies currently employed to curb poaching in the park will capacitate managers to define measurable patrol objectives that can be evaluated and adjusted to meet multiple management needs. Knowledge learned from this process will improve the capacity and confidence of managers who are routinely required to make decisions that are informed by patrol-generated data.

1.3 Aim of the study

The aim of this study is to strengthen the patrol management framework in uMkhuze by expanding our understanding of the spatial effectiveness of patrols in the field. It is expected that the analysis of patrol deployment in the field will broaden our understanding of the patrol system as a whole, by synthesizing landscape level patrol distribution, policing and data collection activities. Increasing our understanding of how the patrol system operates on the ground will impart knowledge about patrol effectiveness that is based on the physical attributes of patrols, rather than on their ability to collect data. An analytical approach to patrol planning can relate the quality of information and data collected in the field with the effectiveness of a field patrol unit, or vice versa. Unbiased information addressing the occurrence of information gaps, areas that are subject to poorer levels of patrol coverage, is limiting and should be of particular concern to biodiversity managers. The study will present options for the establishment of more tangible patrol objectives that aim to maximize information outputs that can address a wider range of threats to the park.

1.4 Study objectives

1.4.1. To understand how different patrol strategies can affect information outputs, and how this knowledge can be applied to benefit patrol planning and effectiveness

1.4.2. To present an additional patrol evaluation metric that will strengthen the capacity to establish measurable landscape level patrol objectives

1.5 Study area

uMkhuze is located in the northeast of the KwaZulu-Natal Province in South Africa (Figure 1.1.). It was proclaimed primarily for the protection of certain species of animals not found in the Hluhluwe-iMfolozi Park to the south, and to protect one of two remaining populations of black rhinoceros, *Diceros bicornis minor,* in South Africa (Gush, 2000). The park covers an area of some 350km² and is one of sixteen pockets of land that was consolidated in 2000 to form the iSimangaliso Wetland Park World Heritage site (iSimangaliso, 2010).

The park is located in the northern section of the Maputaland-Pondoland-Albany biological hotspot, an important center for plant endemism (CEPF, 2010), and thus protects a remarkable diversity of vegetation and wildlife. It also safeguards important local catchments, fresh water systems and habitats that provide vital ecosystem services to local rural communities, and plays a defining role in the economic development of the region (Smith *et al.*, 2008; iSimangaliso, 2011). The park shares common boundaries to the north, northeast and west with rural Zulu communities and commercial cattle ranches, and to the southeast and south with private and commercial game reserves.

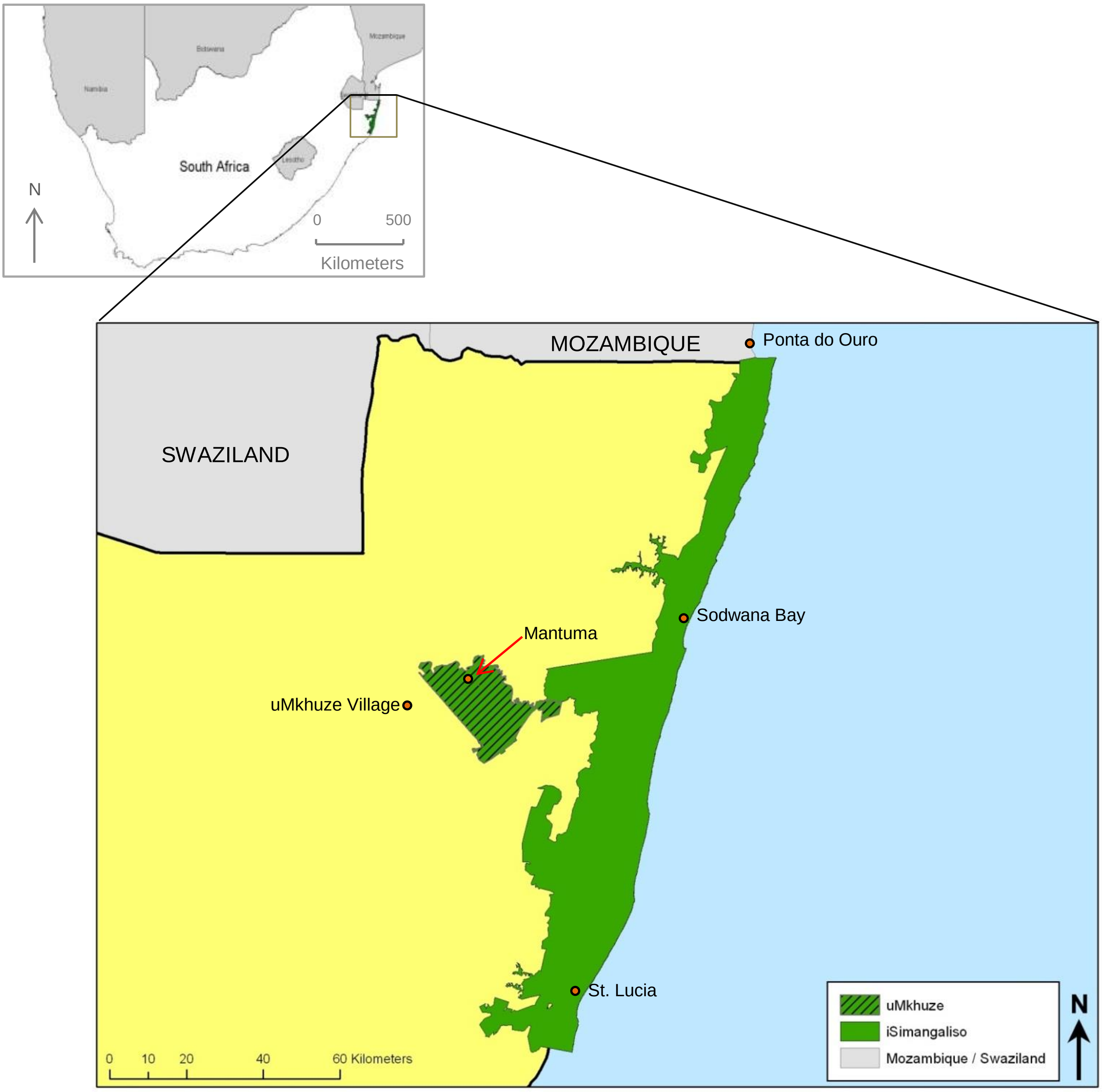

Figure 1.1. Location of the uMkhuze Game Reserve, iSimangaliso Wetland Park, South Africa

Altitude in uMkhuze ranges from approximately 20 to 474m above sea level, and it falls within a sub-tropical climate zone characterized by hot, humid summers (max. 45°C) and moderate winters (min. 5.5°C) (van Rooyen and Morgan, 2007). Relative humidity is high and may exceed 90% for most of the year (iSimangaliso, 2011). Annual rainfall averages from 600 to 650mm with the highest rainfall occurring between October and April. Terrain in uMkhuze consists of steep to gently undulating hills in the Lebombo Mountain range in the west, and transitions to flat coastal forest and wetlands in the east. The Lebombo Mountains occur as a north/south undulating plateau from 300 to 600m above sea level, with numerous steep valleys and gorges traversing it. Two major river systems, the uMkhuze and uMzinduzi, drain into Lake St. Lucia to the east. The uMkhuze Wetland System was declared a Wetland of International Importance under the Ramsar Convention (Barnes *et al.*, 2002), and is an important refuge and feeding area for many species of wetland birds, including the only remaining breeding site for pink-backed pelicans in KwaZulu-Natal (Bowker and Downs, 2008). The park protects a host of endemic, threatened and endangered species of birds, reptiles, plants and mammals, and a number of highly threatened and rare habitats.

1.6 Methods

In this study approximately 89,000 spatially referenced points collected by thirteen of uMkhuze's patrol units in 2009 and 2010 were analyzed to understand how areas were being covered. Each patrol unit in the park operates from a permanent patrol base camp and is responsible for patrolling a designated patrol area (Figure 1.2.).

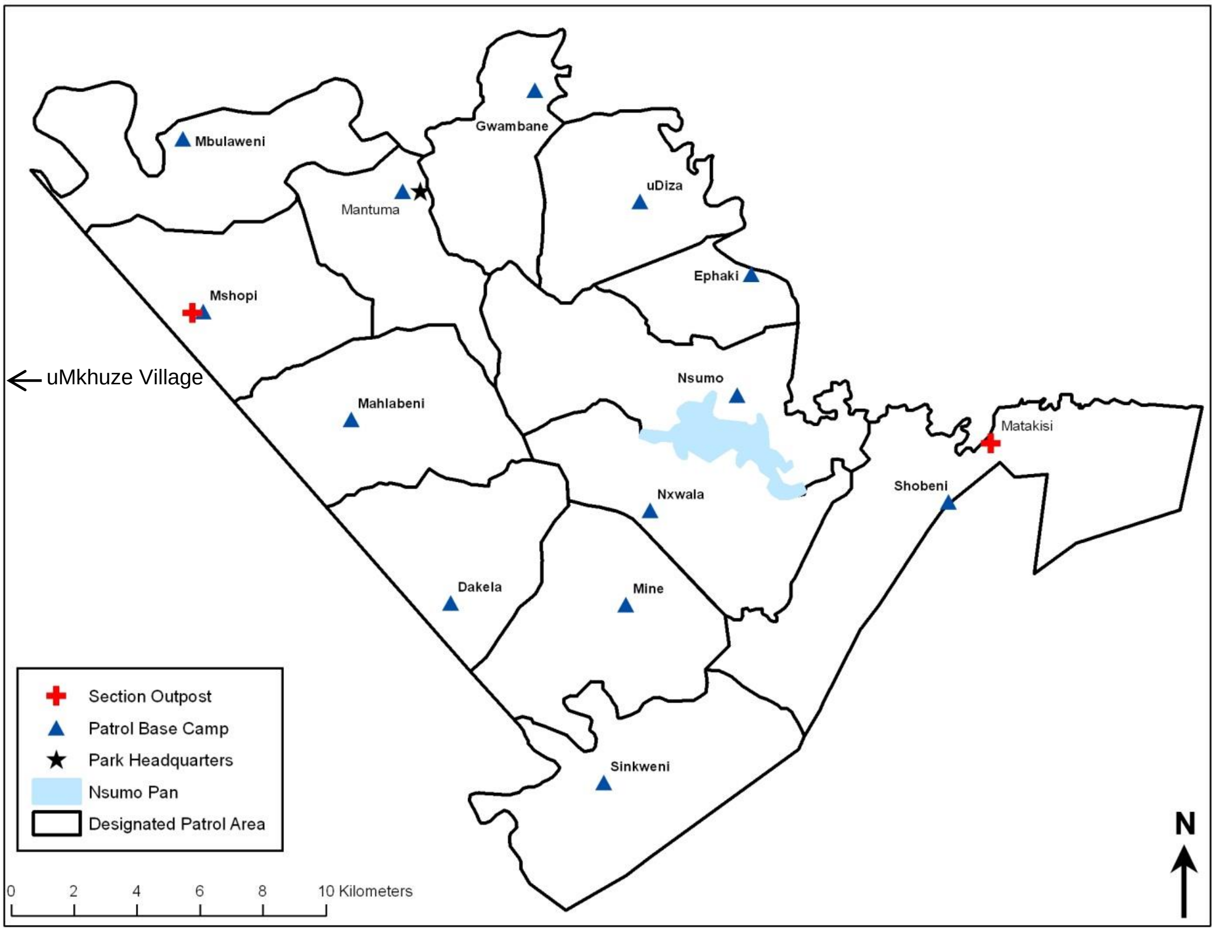

Figure 1.2. Patrol base camps and designated patrol areas in uMkhuze

Data collected by each patrol unit during each month of the study period was used to gain insight into how patrol units were deploying spatially and temporally in the field (see section 1.4.1). Kernel home range analyses were used to construct area coverage boundaries that delineated the spatial extent of the movements of patrol units during the course of their monthly patrols. Further habitat availability-use analyses were done to ascertain whether the distribution of patrol effort within a patrol area was influenced by vegetation type. In other words, whether patrol units had preferences for patrolling in certain habitats over others. To achieve this, patrol visits to different vegetation types were tabulated and compared to the number of visits that would be expected given the proportion of each vegetation type within the patrol area. Finally, to determine whether patrol area coverage influenced information outputs in any way (see section 1.4.1), the amount of area covered by patrol units each year was correlated with the number of biological sightings, illegal incidents and snares reported. All statistical analyses were completed using SPSS software. All spatial analyses were done using ArcView 3.3 and ArcView Spatial Analyst software.

1.7 Dissertation structure

The body of this dissertation consists of six chapters. Chapter one comprises a problem statement, aims and objectives, a description of the study area, and an overview of the study methods. This introduction to the work presents an overview of the development of field patrol strategies in KwaZulu-Natal and uMkhuze, and emphasizes the significance of patrol effort on effectively managing biodiversity in the park. It further suggests that the inclusion of a spatial metric into the evaluation process will improve the ability to evaluate patrol effectiveness (see section 1.2).

The literature review (Chapter two) provides a global perspective of the critical need for timeous, reliable and tangible information to address threats to protected areas. The development of patrol systems in KwaZulu-Natal is outlined giving more in depth insight into the uMkhuze model, and how patrol systems are emerging as important tools for the monitoring of threats in protected areas. It describes how the integration of a spatial patrol evaluation metric with metrics typically used (see sections 1.2 and 2.4) would benefit patrol planning and the achievement of positive system outcomes. It further proposes that the addition of a fundamental qualitative analytic will encourage a systems-based approach to patrol planning that will bolster patrol effectiveness in the field.

The methods (Chapter three) section of the dissertation explains how data was processed, and describes each analysis used to understand how patrols were deployed at the landscape level. This chapter focuses on three primary aspects of patrol deployment, namely; monthly area coverage, the distribution of patrols within routinely patrolled areas and the effect of patrol area coverage on information outputs.

The analysis of results (Chapter four) presents the outcomes of patrol deployment analyses and gives insight into the trade-offs of the different patrol strategies that are currently employed in the field. It further suggests that the addition of a spatial evaluation metric will maximize information outputs relating to a wider range of threats by capacitating managers to more clearly define landscape level patrol objectives (see section 1.4.2).The discussions and conclusions (Chapter five) outlines the significance of the results, and highlights how the analyses described in Chapter three can improve the reliability and confidence in patrol-related outputs through the establishment of more clearly defined landscape level patrol objectives (see section 1.4.2). Chapter six, recommendations, gives an overview of fundamental limitations in the ability to evaluate patrol effectiveness and makes suggestions pertaining to patrol planning and the definition of objectives that will serve to rectify them.

Chapter 2 – LITERATURE REVIEW

2.1 Protected areas and the need for informed decision making

At the *World Summit for Sustainable Development* held in Johannesburg, South Africa, in 2002, signatories to the Convention on Biological Diversity made a commitment to significantly reduce the loss of global biodiversity by 2010 (Bennett, 2004; Dobson, 2005; Butchart *et al.*, 2010). Notwithstanding concerted international efforts to achieve this goal, a decline in the state of global biodiversity had occurred by 2010 despite a remarkable 3.5% increase in the global terrestrial protected area footprint (Biodiversity Indicators Partnership, 2010; Butchart *et al.*, 2010). Protected areas provide crucial indicators of the state of global biodiversity (Glowka *et al*, 1994; Convention on Biological Diversity, 2004) and serve as important natural resources sponges in fragmented landscapes. In environmentally complex post-Apartheid South Africa, policy and institutional effectiveness are two of five key objectives mandating the responsible management of biodiversity and protected areas (Department of Environmental Affairs and Tourism, 2009). Since the passing of the CBD's 2010 goal, concerns over whether key conservation targets are being met on the ground in existing protected areas have arisen, and the need to mainstream the assessment of protected area management effectiveness has been highlighted as an overarching need (Hockings *et al.*, 2002; Chape *et al.*, 2005; International Union for Conservation of Nature, 2005). Consequently, questions concerning the capacity to meet global biodiversity targets have led to increased scrutiny of the efficacy of management actions taken to mitigate threats to protected areas (Hockings *et al.*, 2002; Luckett, *et al.,* 2003; Hockings *et al.*, 2006; Pullin and Knight, 2009).

A growing demand for accountability from funders, donors and policy makers requires that management decisions affecting protected areas are better quantified and substantiated (Hockings *et al.*, 2000; Hockings *et al*., 2002; Parrish, 2003; Gray and Kalpers, 2005; Schmitt, 2006). Abnormally accelerated species extinction rates in the near future (Terborgh and Van Schaik, 2002) further underscore the importance of well informed decision making processes that will lead to the realization of biodiversity management objectives. Effective protected area management into the future will rely heavily on the availability of up to date and relevant information addressing key management questions and threats (Gray and Kalpers, 2005). It is vital, therefore, that managers are well informed of the nature and magnitude of threats facing the protected areas that they manage, how these threats affect core conservation values, and how effective their management actions are in reducing them (Hockings *et al.*, 2002; Hockings, 2003).

2.2 Protected areas in KwaZulu-Natal

The establishment of protected areas in KwaZulu-Natal in the late 1800s brought about the stringent regulation of access to natural resources that rural communities had been historically dependent on (Carruthers, 1989; Dahlberg, 2010). Consequently, paramilitary patrol systems directed at the enforcement of game regulations emerged in the early 1900s (Vaughn-Kirby, 1917; McCracken, 2008). Historically, largely due to the inherent similarities between the enforcement of game laws and soldiering, there was a tendency for the appointment of protected area managers who came from military backgrounds (Ellis, 1994). Exacerbated by increasing human populations and unemployment that adversely affects limited biodiversity resources (Millard and le Hanie, 1999; iSimangaliso, 2010), a strong military ethos perpetuates the protected area management culture that exists in KwaZulu-Natal today. Particularly in protected areas, paramilitary patrol operations continue to be directed primarily as a response to the threat of poaching (Conway *et al*., 2010; see sections 1.1 and 1.2).

The poaching of animals in protected areas continues to be an emotive public issue in KwaZulu-Natal, particularly in uMkhuze where the bulk of poaching is done by means of snaring, a form of hunting involving the use of wire noose traps which kill animals by asphyxiation. Snare lines are frequently left unfound in the field and the killing or maiming of non-target, often high profile, species, such as endangered African wild dogs (*Lycaon pictus)* (Woodroffe & Ginsberg, 1999), is commonplace. Furthermore, the indiscriminate use of poisons threatens important populations of vultures and predators residing in and around the park (Mander *et al*., 2007). Concerns around the management of poaching in the park are elevated by an alarming upsurge in the poaching of rhino in the region (Lockwood, 2010; Kew, 2011; Blaine, 2012), and the direction of field patrol operations remains sharply focused on law enforcement as a result.

Threats to biodiversity in the park, however, are wider reaching and more complex than those posed by poaching alone. An evaluation of the most important threats to protected areas in KwaZulu-Natal's Coastal Region identified multiple threats that are likely to impact on the biodiversity resource in the near future (Goodman, 2003). These range in priority from alien plant invasions and poaching to dam building and the destruction of archaeological resources (Appendix 1). Goodman (2003) also emphasized that climate change will produce rapid and dynamic landscape level changes which could significantly affect the consequences of these threats. For example, the alien invasive weed *Chromolaena odorata*, considered to be one of the most destructive invasive alien plants occurring in the subtropics (Mack and Lonsdale, 2002), thrives throughout KwaZulu-Natal (Mulqueeny *et al*., 2010; te Beest, 2010). Although the hotter and wetter climatic conditions expected in the near future suggest that the weed will thrive, significantly more intense fires will likely limit its spread (Været, 2008; te Beest, 2010). Higher intensity fires burning in well-established stands of *C. odorata*, however, could have devastating effects on other important biodiversity resources, such as the world renowned sycamore fig and fever tree forests in uMkhuze (Swaine, 1992). Debate around the need and methodologies of management interventions in the field are made increasingly complex by the issue of climate change. Accordingly, knowledge about environmental and social responses to climate change should be learned from the most timeous and reliable information sources. If managers are to remain well and timeously informed about threats to uMkhuze, the expansion of the patrol system to maximize information outputs pertaining to a wider range of threats to biodiversity (see section 1.4.2) may be a prudent consideration.

2.3 Field ranger-based monitoring

A primary management action for the protection of biodiversity in uMkhuze is the practice of effective and efficient law enforcement (EKZNW, 2007; see Figure 2.1.). Patrol objectives are therefore constructed primarily around principles of law enforcement, and information outputs tend to be enforcement rather than threats driven (van der Westhuizen, 2007). Patrol effort that is focused on law enforcement may create information gaps, however, where the origin of information can be biased towards areas that are patrolled specifically to address illegal activities (Gray and Kalpers, 2005). For example, Bell and McShane-Caluzi (1984) found that 55% of patrol effort occurred in only 17% of the Kasungu National Park in Malawi. Developed along similar patrol management models to that of uMkhuze, patrol effort in pre-1980s Kasungu represents a magnified view of the potential that heavily focused law enforcement patrolling strategies can have on the creation of information gaps. Knowledge of whether enforcement-driven planning strategies adversely affect the spatial deployment of patrols can provide important insight into the formation of information gaps, and how to mitigate them (see sections 1.4.1 and 1.4.2).

This knowledge will help to synthesize the spatial dynamics of patrolling, policing and data collection, which will enhance the ability to assess the effectiveness of the patrol system as a whole (see Morgan, 2005).

Field ranger-based monitoring programs have shown to be highly effective in the collection of information for the monitoring of environmental indicators in protected areas in Africa and Asia (Gray and Kalpers, 2005; Schmitt, 2006; Jachmann, 2008a, b), and were considered as priorities for implementation in key conservation areas in Tanzania (Arcese *et al*., 1995). The use of field ranger-based patrol systems as a tool for the management of wildlife crime in KwaZulu-Natal is a concept grown from years of application in the field (Ellis, 1994; Draper, 1998; see section 2.2). Patrol strategies that have combined law enforcement with biological monitoring have shown benefits to the conservation of focal species such as the black rhinoceros, *Diceros bicornis minor* (Emslie and Brooks, 1999).

uMkhuze's patrol effort is relatively well resourced by South African standards, and considerable investment into motivational capacity-building, in terms of manpower, training and equipment, has been made over the last decade (Conway and Thusi, 2002; Ransom, 2005). Complemented by a healthy 1.6 field rangers per 10 square kilometers, uMkhuze's patrol effort is comfortably in excess of the recommended effective minimum of 1 field ranger per 10 square kilometers (Emslie and Brooks, 1999; Conway, *et al.*, 2010). The potential to maximize the collection of information pertaining to a wider range of threats in uMkhuze, therefore, seems feasible within the existing patrol management framework. A better understanding of the spatial deployment of patrols in uMkuze and how they affect information outputs pertaining to threats (see sections 1.4.1 and 1.4.2) will provide insight into whether this is feasible without compromising the achieving of key law enforcement objectives.

2.4 Defining a metric for the evaluation of patrol area coverage

It is difficult to understand the limitations of any conservation management system without a mechanism that can measure its effectiveness (Margoluis and Salafsky, 1998; see also section 1.2). Current metrics used to measure the effectiveness of uMkhuze's patrol effort are based largely on law enforcement-related events and encounters such as arrests, illegal incidents and animal mortalities incurred by poaching (Conway and Thusi, 2002; EKZNW, 2010; see also van der Westhuizen, 2007; Jachmann, 2008b). Although providing an indicator of poaching threats to the park, these metrics do not necessarily reflect park wide poaching pressures, whether information gaps exist in the system and, subsequently, the efficacy of the patrol effort as a whole. The direction of patrol effort into poaching hotspots is a common practice used to decrease the threat of poaching (Jachmann, 1998). However, although focused patrolling can be effective in the decreasing of illegal activities in poaching hotspots (Arcese *et al.*, 1995; Jachmann and Billiouw, 1997), poaching efforts may switch from heavily to more marginally patrolled areas in response. This could result, for example, in an incorrect inference that poaching was being reduced when it had actually shifted to a different area. Inferences about the benefits of different patrolling strategies, therefore, need to be focused on an evaluation of information that is representative at the landscape level, where the extent of information gaps can be better assessed and understood (discussed in section 2.5). In addition, information about threats that do not account for differences or shortfalls in area coverage can lead to false impressions as to the spatial distribution of different threats to biodiversity. For instance, information on the occurrence of alien plant invasions could be biased by higher levels of patrolling occurring in poaching hotspots.

Managers often do not have the information that is needed to evaluate the trade-offs between the application of different patrol strategies. For instance, the focus of patrol effort into poaching hotspots has a clear objective, although how this focus affects other areas is not fully understood. An understanding of the consequences of that focus presents an alternative upon which managers can build an objective. If a consequence of focused patrolling was the creation of information gaps, for example, an objective could be to fill those gaps within an appropriate timeframe. Understanding the trade-offs of the different patrol strategies employed in the park first requires a metric to weigh the consequences of different patrol strategies. In addition, the acceptability of these trade-offs will depend on the temporal scale considered, and the tolerance levels of certain risks to biodiversity that may be incurred in areas that are marginally patrolled. From this, more clearly defined objectives, which are instrumental in the evaluation of patrol alternatives, can be established (Hammond *et al*., 1999; see also section 1.4.3).

2.5 A systems approach to patrol planning

An adaptive management approach is prescribed as key to achieving biodiversity conservation objectives in uMkhuze (EKZNW, 2004 and 2007; iSimangaliso, 2010). The adaptive management construct is central to effective conservation management practice and failure to modify decisions through learning could severely compromise the realizing of management objectives (Parma, 1998; Danielsen *et al*., 2003). There are several essential components of the adaptive management process and the omission of any one could result in a failure to meet core objectives (Nyberg, 1999). These components include the definition of clear and measurable objectives (see section 1.4.3) and the design of a monitoring system that will provide relevant feedback, precluding the implementation of a management plan. The monitoring of performance indicators enables an evaluation of the consequences of actions taken to carry out the management plan. Adjustments to management actions, or to the objective itself, can be made based on the understanding that is learned from this process (Hammond, *et al*., 1999; Nyberg, 1999). Understanding the functioning of a system in its entirety, however, is dependent on what knowledge exists of the dynamics between all components of it (Morgan, 2005). Analyses that focus on any particular component of a system, although divulging knowledge of those components, may overlook those emerging properties that replicate the synergy of the system as a whole. Morgan (2005) cautions that failure to recognize the emerging properties of a system will fragment any understanding of the whole. This paradigm is relevant to uMkhuze's patrol system which is lacking in an understanding of the spatial attributes of current information outputs (Figure 2.1.).

Typical of most African models, effective and efficient law enforcement is the multi-faceted primary objective overlying patrol effort in EKZNW's protected areas (EKZNW, 2007). Supported by extensive investigations, judiciary liaison and community outreach programs (EKZNW, 2010), patrol objectives tend to be built largely around the maximizing of population growth of species that are commonly targeted by poachers (see section 1.2; see also Conway, 1981; Bell, 1985; Leader-Williams *et al*., 1990; Leader-Williams and Milner-Gulland, 1993; Jachmann, 2008a, b). In iSimangaliso, a generic wildlife protection management strategy (hereafter the Strategy) was developed from the uMkhuze model and currently serves as a guideline for best patrol management practice. The definition of poaching thresholds for certain threatened or key species targeted by poachers is one of a few key objectives that are able to gauge patrol effectiveness (Conway and Thusi, 2002). However, objectives relating to the patrol system are not clearly defined by the Strategy, and the means for evaluating its effectiveness are undermined as a consequence. The 'maximizing of patrol effectiveness', for example, exists as a somewhat ambiguous part of an objective relating to the use of GIS as a patrol monitoring tool (EKZNW, 2010, page 13).

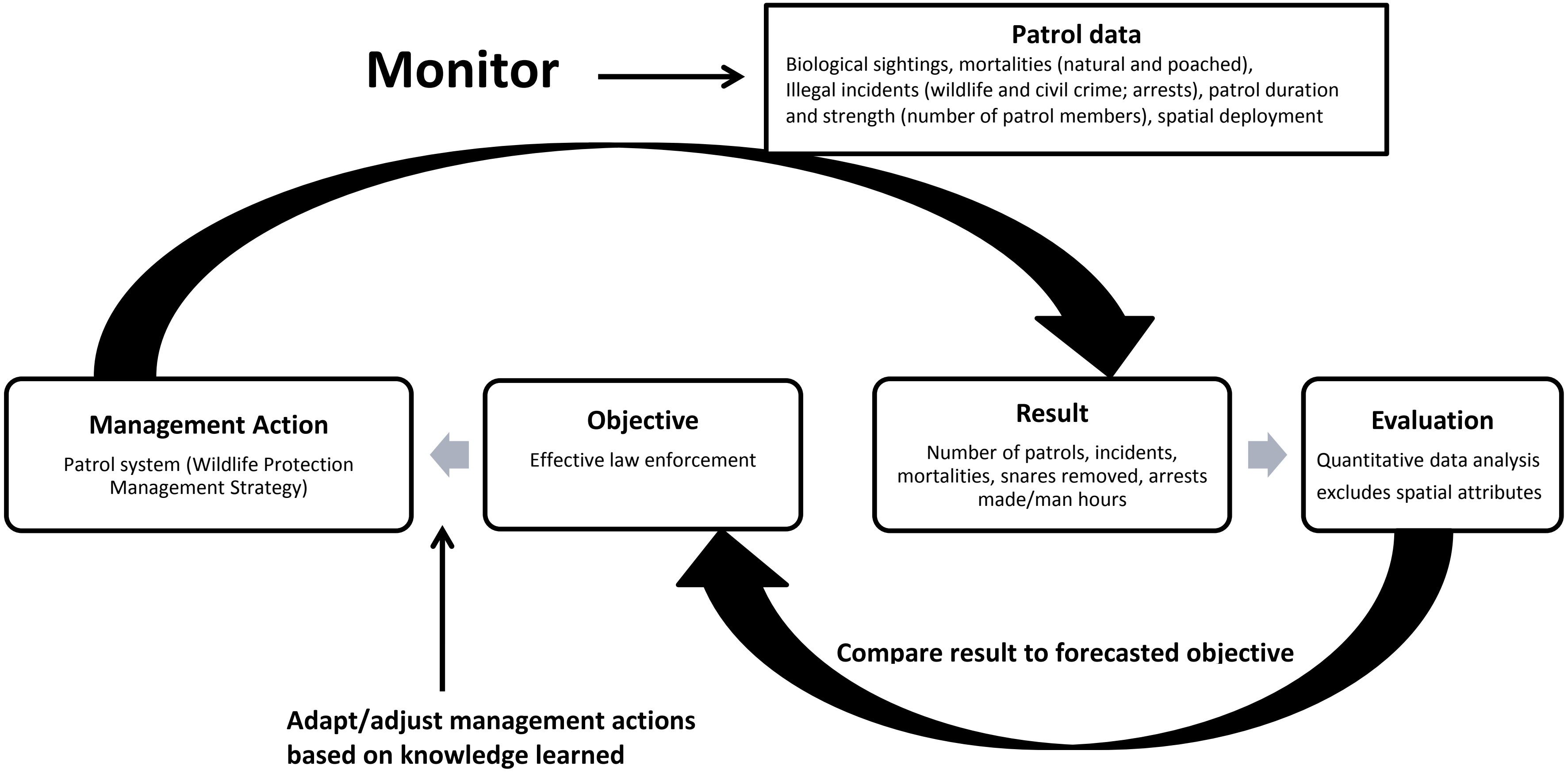

Figure 2.1. Current framework for the evaluation of the uMkhuze patrol system

To a large degree, patrol effectiveness comprises the overlying objective of the Strategy. Effectiveness is evaluated primarily by the assessment of law enforcement-related indices relating to the number of animal mortalities, incidents and snares reported in the field (refer to sections 1.2 and 2.3; see also Figure 2.1. above). In addition, pre-determined key performance indicators assess whether the number of patrols conducted, and arrests made in relation to man hours in the field, meet a minimum standard (EKZNW, 2010). However, the omission of an evaluation of the spatial attributes of the system undermines the ability to attain a more universal understanding of its results (see Morgan, 2005). In its current form, results pertaining to whether the patrol system is achieving effective law enforcement are evaluated regardless of shortfalls in the knowledge of the spatial attributes of it. Therefore, better defined objectives (see section 1.4.3) that synthesize the law enforcement and spatial components of the patrol system would increase the understanding of it, and better serve the evaluation of the system as a whole.

The patrol system also provides the means of addressing information needs for the assessment of other core management actions, such as the monitoring of the state of biodiversity. However, it would not necessarily be prudent to expand the patrol effort to address the evaluation of other management actions prior to establishing the limits of its own efficacy. Nyberg (1999, p 8) aptly contextualizes the adaptive management construct when he states that, “information must be used in order to have value”. Extensive spatially referenced data is collected by patrol units in the field. The inclusion of analyses of the spatial attributes of these data would broaden the understanding of the patrol effort greatly by provisioning a qualitative indicator of patrol effectiveness that was independent of data collection bias.

Chapter 3 – METHODS

The purpose of uMkhuze's patrol system is to implement effective and efficient law enforcement in the park (EKZNW, 2007), and to collect enforcement and biological data. Most of these data are also used to evaluate the effectiveness of the patrol system. However, evaluation metrics are largely dependent on the ability of individual patrol units to detect illegal incidents which may spatially bias the outcomes of evaluations (see section 1.2). Spatially referenced data points collected by the park's thirteen routine patrol units in 2009 and 2010 were analysed, and an investigation into how existing patrol management strategies translated into temporal and spatial patrol area coverage of the park was conducted.

3.1 Field patrol data collection procedures

uMkhuze's patrol system functions along the principles of picket patrolling, a wartime system of soldiering designed in the late 19^{th} century (Wagner, 1896). Picket systems adapted to suit modern day patrolling needs in uMkhuze rely on the deployment of patrol units from a number of strategically placed permanent patrol base camps (see Figure 1.2.). Thirteen patrol base camps in operation during the study period housed single patrol units comprising of from two to four field rangers in each. Each patrol unit was responsible for the conducting of daily (or routine) foot patrols in a patrol area designated to them by park managers. Data relating to illegal activities and biological monitoring was collected each day from within each designated patrol area.

Garmen E-trex Geographic Positioning System (GPS) models used during the study period were lacking the technology to automatically time stamp spatial locations, so locations were recorded manually by patrol units at approximately 30 minute intervals throughout the duration of every patrol (EKZNW, 2010). As per standard operating procedures information pertaining to the number of patrol members, date, departure and arrival times, and a description of the patrol objective (e.g., black rhino monitoring, anti-poaching) were recorded for each patrol (Appendix 2). Spatial locations of certain rare and/or important species of plants and animals, game mortalities and illegal activities or incidents were recorded as encountered in the field (Appendix 3). Field data was recorded onto a monthly patrol sheet by patrol leaders and submitted to section managers for the compilation of monthly status reports. All data was downloaded to a comprehensive digital spreadsheet on a monthly basis (van Tichelin, 2008; Appendix 4).

3.2 Data preparation

Several shortcomings and inconsistencies in the way in which data were collected by patrol units required that data be standardized to allow for comparisons across the different patrol units. To gain a better understanding of the spatial deployment of patrol units in the field, it was necessary to minimize these biases prior to carrying out analyses. Each bias is discussed below with the methodology used to standardize the data.

3.2.1 Sampling error

Spatial locations were saved to the GPS unit by depressing an ‘Enter’ button on the unit. However, if the button was pressed and held rather than released, the same spatial location would be recorded multiple times. If not removed from the data set prior to analysis, this sampling error would be incorrectly interpreted as multiple visits to the same spatial location. To address this, identical data points recorded sequentially during any patrol were removed. Although this correction may have removed certain data points that correctly depicted multiple spatial locations ‘visited’ by a patrol unit on the same day (e.g., when at a location for longer than the sampling interval, such as when attending a crime scene). It is unlikely, given the lack of absolute precision of the GPS unit, that a location would be identically duplicated.

3.2.2 Inconsistent sampling periods

Although recently rectified with the upgrading of GPS units (see section 6.3.2), there was no hard rule or mechanism during the study period which stipulated the temporal frequency at which patrol locations were recorded during any given patrol. This resulted in certain patrol units recording higher numbers of spatial locations than others regardless of whether there was variation in patrol length or duration. Although this difference in the frequency at which data was recorded does not affect comparisons over time for any given patrol unit, it can confound inferences made between patrol units resulting from different sample sizes. To reduce the effects of these sampling differences, distances between sequential waypoints in each dataset for each patrol unit were calculated. Any point within 100 meters of another was removed in order to make the data more comparable across patrol units.

3.2.3 Visits outside of routine patrol areas

Designated patrol areas served primarily as boundary guidelines for patrol units, and it was important to ascertain whether they were, in fact, being routinely patrolled to better understand the dynamics of deployment in the field. Patrol units infrequently conducted patrols outside of their designated patrol areas to lend support to operations in other areas, such as when reacting to poaching incidents in other designated patrol areas, parks or regions. As the focus of this study was on routine patrol strategies and deployment within the park, all data points recorded outside of the park boundary were removed. To remove data that was more likely to reflect patrol effort occurring within the park but outside of routinely patrolled areas, spatial outliers were objectively removed from the dataset using a Jennrich-Turner Bivariate Analysis. This analysis is a simple, uncomplicated model that is not biased by sample size (Jennrich and Turner, 1969). A Jennrich-Turner analysis essentially draws an ellipse around the data in which a specified percentage of the data is encompassed. For this analysis, a 95% occurrence probability ellipse was chosen to depict spatial locations that were considered to be representative of a patrol unit's routine patrol area. Any spatial data points falling outside of the probability ellipse were therefore removed from further analysis. By using all data collected over a two year period, this method removed a conservative number of data points. Jennrich-Turner Bivariate Normal Home Range analyses were performed using ArcView 3.3's Geoprocessing extension.

3.2.4 Data clustering

Patrol units often recorded data points when leaving and entering their respective patrol base camps (see Figure 1.2. and section 3.1) which caused an accumulation of high densities of data within close proximity to them. Although this data accurately reflected their spatial location, it could confound the interpretation of results in several analyses. To reduce this effect a 100 meter radius was drawn around each base camp and any data points recorded within this circle were removed.

3.3 Monthly patrol area coverage

The area covered by each patrol unit every month was an essential starting point to understanding the spatial deployment of patrols in the field (see section 1.4.1). By operating from permanent base camps, patrol units make repeated visits to areas surrounding this fixed location. The concept of the home range, designed for the purpose of investigating how an animal utilizes the area in which it exists (Burt, 1943; White and Garrot, 1990; Selkirk and Bishop, 2002), was a suitable approach to understanding patrol unit movements.

Several methods are available for calculating home range sizes. These include grid cell counts, minimum convex polygon estimates, bivariate ellipse and fixed and adaptive kernel density estimators (Mohr, 1947; Kenward, 2001; Worton, 1987; Worton, 1989, White and Garrot, 1990). Kernel home range estimators are among the most widely used home range estimators in ecology (Barg *et al.*, 2005; Hines *et al.*, 2005; Borger *et al*., 2006; Katajisto and Moilanen, 2006) and this approach was used to quantify patrol area coverage. Kernel home range models are often preferred because it is recognized that most mobile organisms do not utilize their entire home range equally. A fixed kernel home range estimator, with least squares cross-validation of smoothing parameter, was used to estimate the size of routine patrol areas (i.e. the home range) of each patrol unit for each month (Worton, 1989). Kernel home range estimators calculate probability density distributions (isopleths) that quantify areas within which an animal/individual has a higher probability of being found. Based on recommendations of Borger *et al.* (2006), a 90% probability isopleth was used to estimate the monthly area coverage of patrol units (Figure 3.1.).

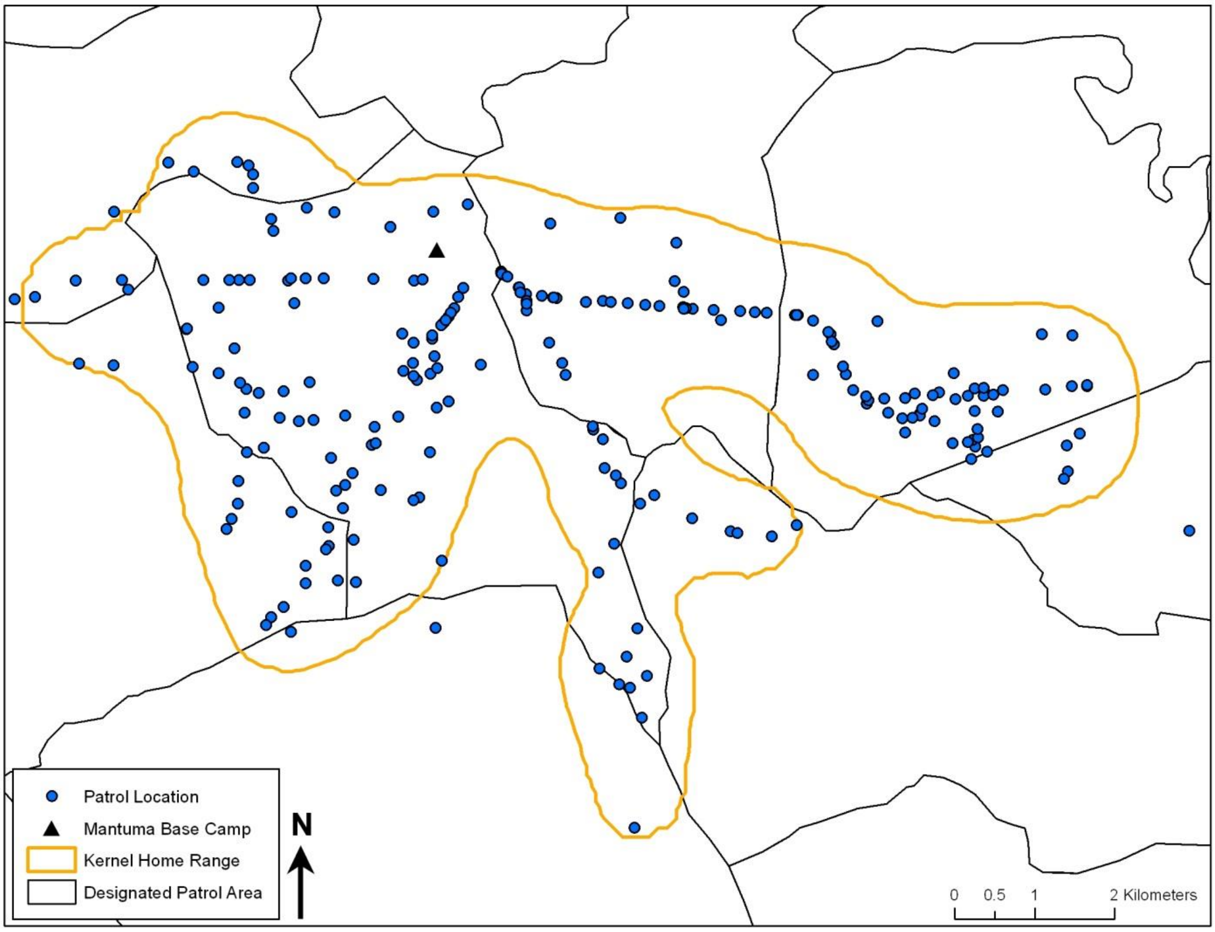

Figure 3.1. Example of a kernel home range analysis with 90% probability isopleth

All kernel home range analyses were performed using ArcView's Spatial Analyst extension (Rodgers and Carr, 2001).

As most patrol units commonly patrolled the park boundary, and areas in proximity to it, home range polygons would sometimes extend to beyond the perimeter of the park. In these cases areas of the home range polygon that extended beyond the park boundary were removed to maintain the focus of the study to area coverage within the protected area only. These monthly area coverage polygons and estimates were used as the basis for analyses, and intended to expand the understanding of any temporal variation in area coverage by individual patrol units, and park wide patrol area coverage achieved each month. Knowledge of temporal variation would help to more clearly define temporal patrol objectives relating to the achievement of total park wide area coverage.

3.4 Distribution of patrol effort within routine patrol areas

Although the previous analysis provides information on the extent of areas covered by patrols (routinely patrolled areas), it does not increase our understanding of the factors that may influence patrol units to visit or avoid certain areas within these areas. Selection bias resulting from disproportionately more visits to certain areas over others can lead to incorrect inferences about where threats or biological events are occurring in the landscape. For example, the assumption that snaring occurs more commonly in thickets may result in patrol units visiting these habitats more frequently in search of them. This can additionally confound inferences when preferences, or the distribution of threats, are linked to habitats that patrol units visit more or less frequently. Different habitats are known to influence animal distributions (Krebs, 1985) and animal movement (Mader, 1984; Fahrig, j. An understanding of the spatial deployment of patrols across different habitat types will help to define patrol objectives that serve to achieve an even distribution across the landscape.

Although kernel home range estimators provide a better estimate of area coverage this method, by design, excludes areas that are underutilized (see section 3.3). For this reason if a goal was to understand whether habitat selection bias was occurring, and whether certain areas were being visited less frequently than expected given their availability, then the use of kernel estimators to delineate patrolled areas would not be useful. Therefore, to gain a better understanding of the spatial deployment of patrols in terms of differential utilization of areas within a routine patrol area, a minimum convex polygon approach was used (Mohr 1947). The minimum convex polygon method creates a home range boundary by connecting the outer most spatial locations to form a convex polygon (Figure 3.2.).

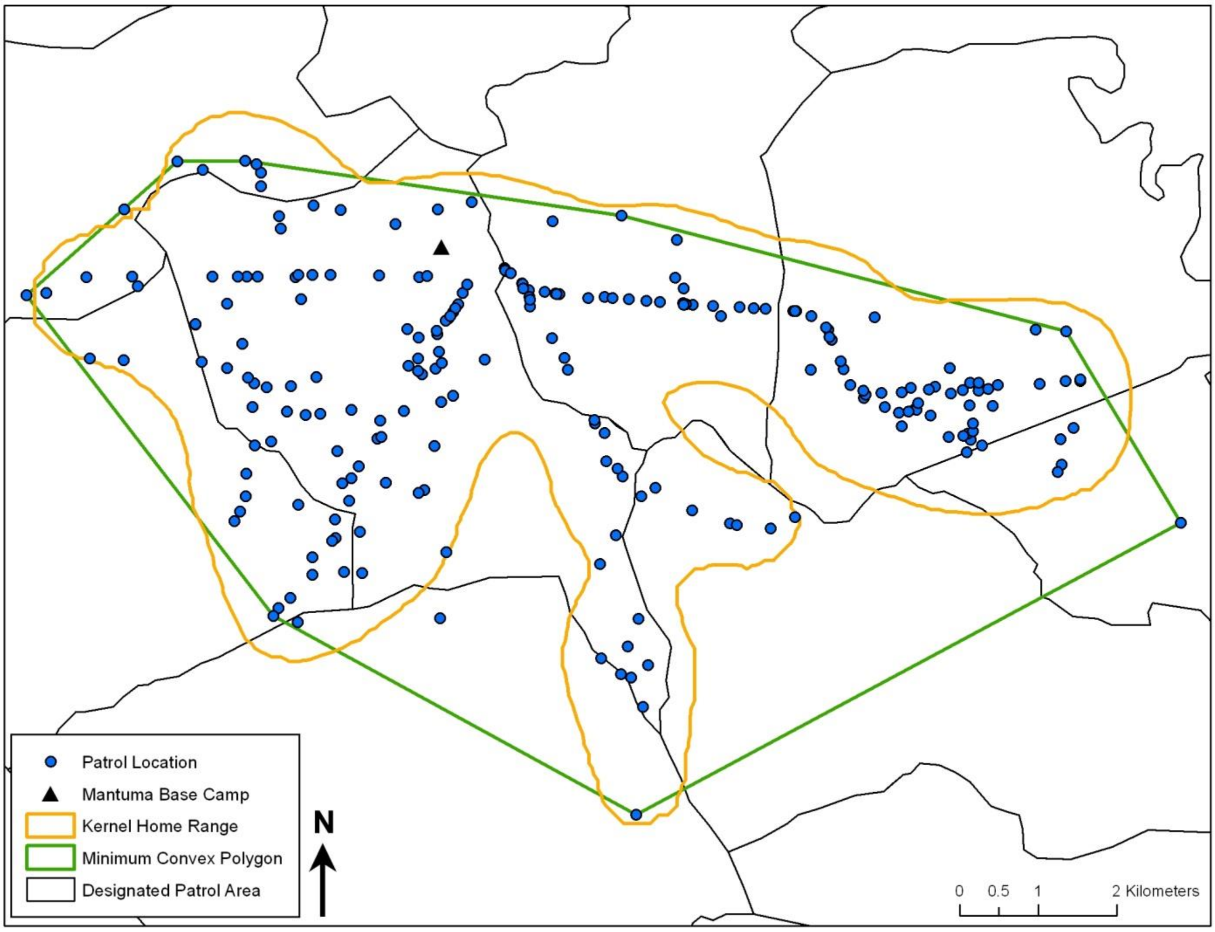

Figure 3.2. Comparison between kernel and minimum convex polygon home range estimators

The minimum convex polygon method produces an overestimate when used to calculate home range size, as it does not account for areas that are marginally or not visited (Powell *et al*., 1997; Burgman and Fox, 2003). However, it was used here to delineate an area within which it was reasonable to assume was accessible by the patrol unit. Habitat types were based on a comprehensive digital vegetation map (van Rooyen, 2004a; Appendix 6), which was over laid by a minimum convex polygon estimate for each year for each patrol unit (Figure 3.3.).

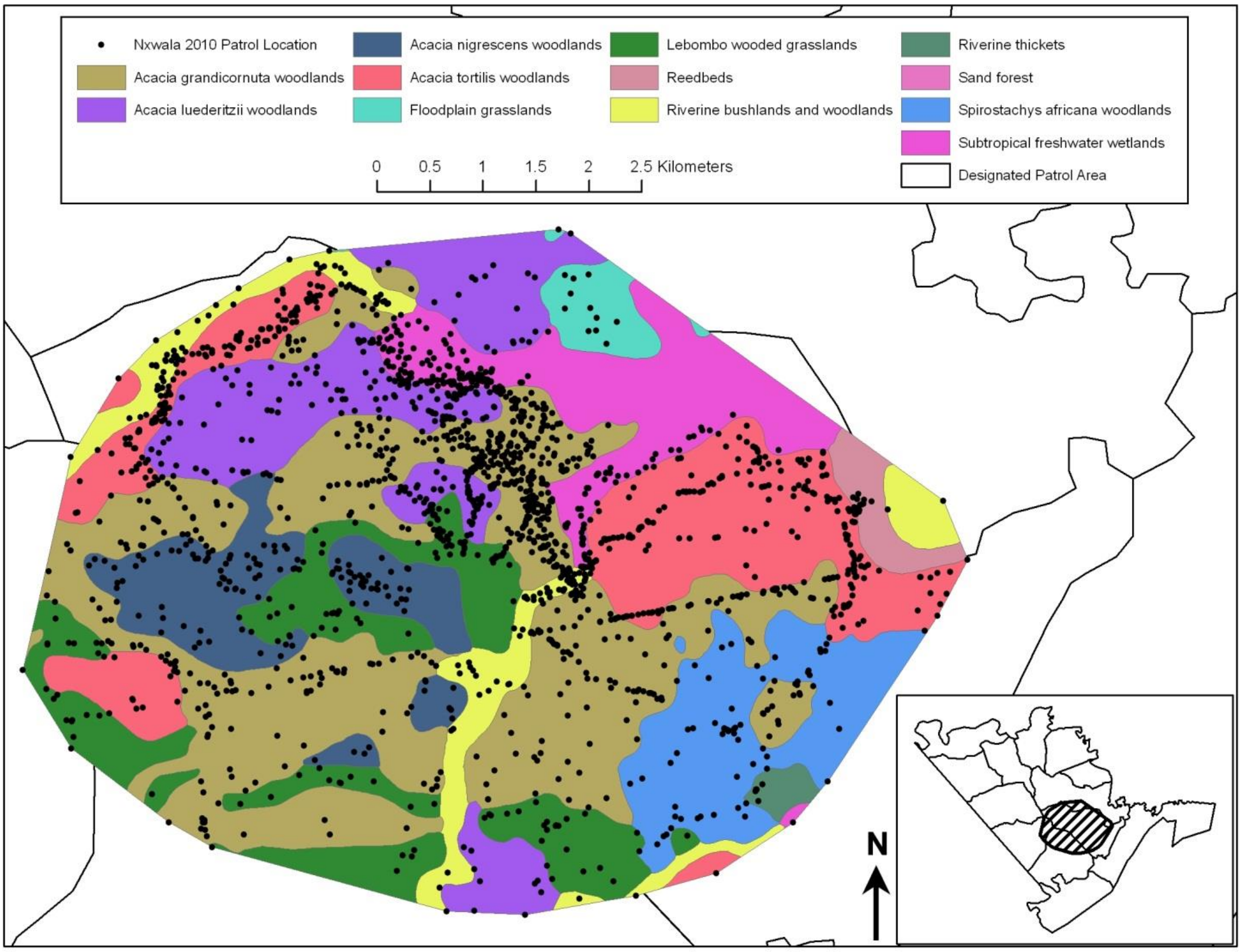

Figure 3.3. A habitat use-availability analysis for the Nxwala Patrol Unit in 2010

The number of patrol visits to different habitat types found in the park was used to investigate whether patrol units were biasing their patrolling efforts in favor of certain habitats. Each spatial location was assigned to a habitat type to determine the number of visitations to each habitat (Table 1).

Table 1. Example of Actual vs Expected number of visits to habitats by the Nxwala Patrol Unit in 2010 (see Table 2 section 4.5)

Nxwala 2010	Total	Expected	Area (Ha)	Ratio
Acacia grandicornuta woodlands	682	578	995	0.58
Acacia luederitzii woodlands	225	228	392	0.58
Acacia nigrescens woodlands	117	127	218	0.58
Acacia tortilis woodlands	364	281	484	0.58
Floodplain grasslands	13	35	6	5.81
Lebombo wooded grassland	133	197	34	5.81
Reedbeds	17	28	48	0.58
Riverine woodlands and forests	119	113	195	0.58
Riverine thickets	7	11	19	0.58
Spirostachys africana woodlands	56	156	268	0.58
Subtropical freshwater wetlands	180	160	275	0.58
Total	1913	1913	3,294	

If patrols were being conducted without the influence of particular habitat preferences or events such as poaching, it would be expected that habitats visited by patrol units should be proportional to the area of that habitat occurring within the patrol area. In other words, a habitat that comprises one half of a patrol area should be visited twice as frequently as all other habitat types combined (the 'expected' proportion of visits). Since patrols commenced and ended at a base camp, habitats and visits occurring within a 500 meter radius of each patrol base camp were excluded from the analysis to diminish the portrayal of more frequent visitation by patrol units to nearby areas as a result of logistics.

Expected visits to each habitat were calculated as the total number of visits (spatial location points) recorded by each patrol unit during the period of analysis, multiplied by the proportion of the given habitat within the minimum convex polygon (i.e. a use-availability analysis; Johnson, 1980; Aebischer *et al*., 1993). The ratio of the observed number of visits and the expected number of visits to each habitat type was then calculated. High observed values relative to expected values (i.e. ratios >1) would indicate a preferred or more frequented habitat, whereas low observed values relative to expected values (i.e. ratios <1) would indicate an avoided or less frequented habitat. Log likelihood G-tests were used to statistically evaluate disproportionate habitat use by each patrol unit (Sokal and Rolff 1995).

3.5 Information outputs

Information outputs pertaining to law enforcement effort and biological monitoring are important outcomes of the patrol effort in uMkhuze. However, the benefits of larger to smaller spatial scale patrolling to the output of information from the field can be ambiguous. For instance, at the larger spatial scale, the practice of directed patrolling into poaching hotspots may result in the coverage of smaller areas which could adversely affect information yields. Viewed from the perspective of the smaller spatial scale, however, area coverage is likely to be more intense which would likely yield more information than would be expected at the larger spatial scale. To determine how patrol area coverage influenced information outputs pertaining to threats to biodiversity (see section 1.4.2), the number of biological sightings, illegal activities and snares recorded, and the habitat type in which the information was collected, were attributed to the patrol unit that collected the information.

As the number of events recorded each month was minimal, the number of events recorded by each patrol unit each year was compared to total annual area coverage to determine whether there were trade-offs in the size of area covered. The number of events recorded was used to determine whether information outputs were related to habitat type or to the proportional use of habitats by patrol units.

Chapter 4 – ANALYSIS of RESULTS

The purpose of this study was to investigate the deployment of patrols in the field, and to identify options that would capacitate a more effective approach to patrol planning (see sections 1.3 and 1.4).

Analyses were conducted to estimate monthly area covered by patrol units, to investigate temporal and park wide patrol area coverage, and to examine whether information outputs were affected by the extent of area coverage. These analyses were intended to complement existing patrol evaluation metrics, and to advocate a patrol planning approach that would enhance the ability of managers to more effectively monitor, manage and evaluate patrol deployment in the field.

4.1 Monthly area coverage

The size of areas covered monthly and variation between patrol units is important to gaining a better understanding of the spatial deployment of patrols in the field (see section 1.4.1). Kernel home range estimators with 90% probability isopleths (see section 3.3) showed that the average area covered by patrol units every month varied (Figure 4.1.). Despite this variability, the average monthly area covered by each patrol unit was relatively consistent over the two years of this study (Paired t-test, N=13, t=0.007, P=0.99). The Mantuma patrol unit covered nearly double the area achieved by other patrol units (2009: 49.29 ± 9.91km^2; 2010: 52.12 ± 12.95km^2). This difference can be attributed to this unit's operation as a mobile unit outside of its designated patrol area.

Differences in the size of monthly area coverage due to seasonal variations, such as the physical challenges of patrolling in extreme temperatures and humidity, or the difficulty of moving through thicker wet season habitats, were investigated. Differences in the average sizes of area coverage in the wet season (October – March) and dry season (April – September) were not significant (Paired t-test, 2009: N=13, t=1.13, P=0.28; 2010: N=13, t=0.44, P=0.67). It does not seem pertinent, therefore, to consider seasonality in the definition of a monthly area coverage objective that will provide a foundation for the evaluation of patrol effort.

4.2 Management designated patrol areas

Designated patrol areas are allocated to each patrol unit and define the area that each unit is primarily responsible for patrolling (see Figure 1.2. section 1.6). The spatial deployment of patrols in relation to the designated patrol areas provides important insight into how effectively area was being covered at the park wide level (see section 1.4.1). Designated patrol areas range in size from 10.46 km^2 to 32.87 km^2 and, given that the average monthly area covered by patrol units is approximately 16 km^2, suggests that patrol units with larger designated patrol areas would not be able to cover their entire area within a month (Figure 4.1.). However, when viewed in the context of the proportion of patrolling that is taking place outside of designated patrol areas (see Figure 4.2. below), the feasibility of mitigating information gaps becomes more apparent. The Mantuma patrol unit, which also operated as a mobile unit, was the exception to the rule. The area coverage by this unit was not considered in future analyses because it did not represent the typical capabilities of patrol units.

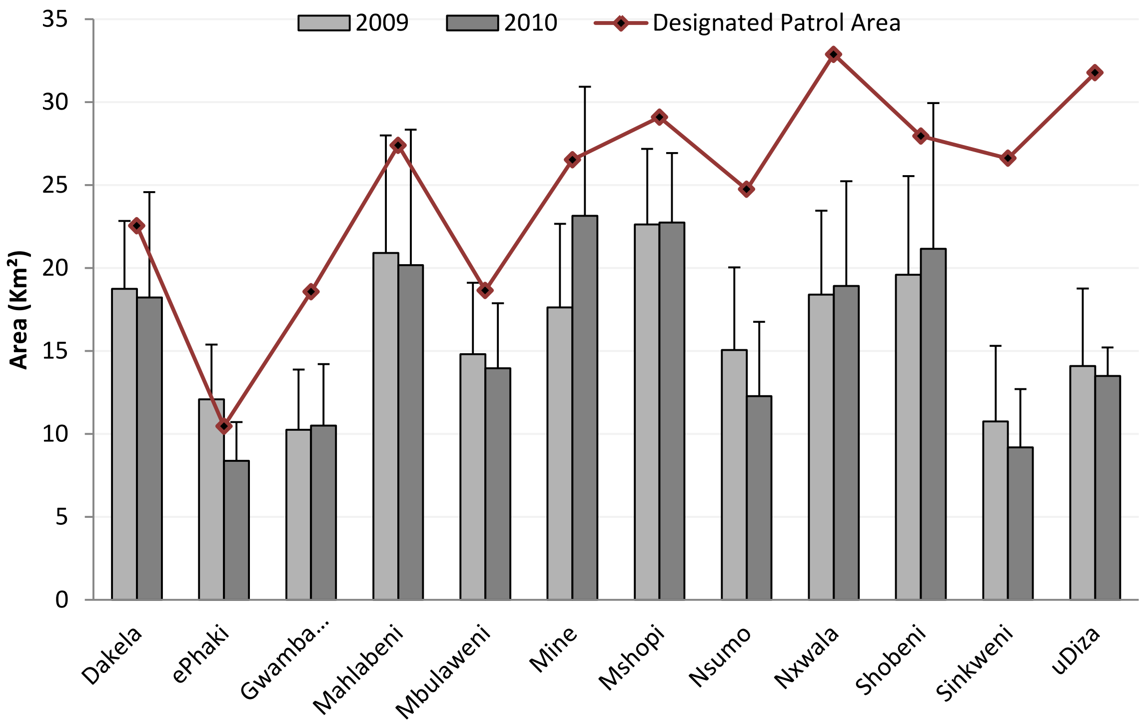

Figure 4.1. Average monthly area covered in relation to the size of designated patrol areas

The size of the average monthly area covered was unrelated to the size of the designated patrol area (Pearson Correlation, N=12, t=0.331, P=0.29) suggesting that differences in the size of the designated patrol area did not explain the differences in the actual area covered. Although the average area covered each month suggested that patrol units could cover at least 70% of their designated patrol area, they covered significantly less (Paired t-test, 2009: 53% vs 70%, N=12, t=4.75, P<0.0001; 2010: 50% vs 69%, N=12, t=6.06, P<0.0001). Taken together, this indicates that although patrol units were not able to cover their entire designated patrol area in a month, they were nonetheless spending large proportions of their time outside of their designated patrol areas (Figure 4.2.).

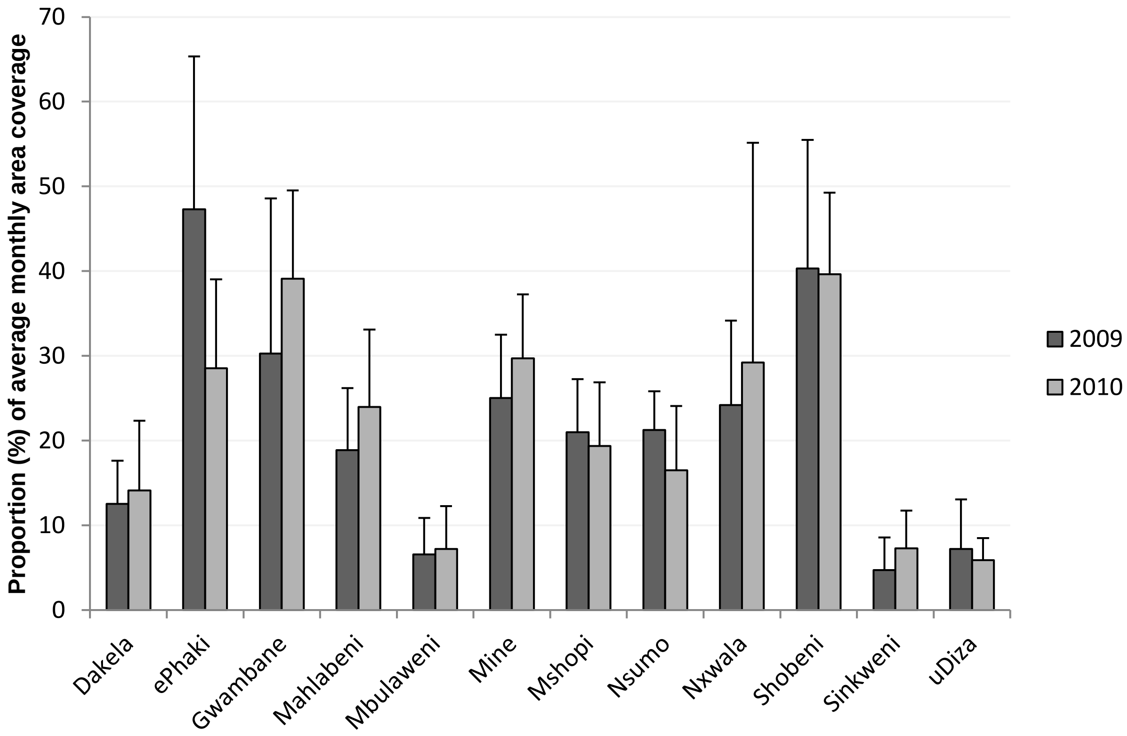

Figure 4.2. Proportion of monthly area coverage occurring outside of designated patrol areas

These shortcomings may be attributed, in part, to differing perceptions between managers and patrol units of where patrol boundaries lie. A more clearly defined patrol objective relating to designated patrol area boundaries is an important foundation from which to evaluate landscape level patrol effort.

4.3 Temporal coverage of routine patrol areas

Area coverage analyses suggest that, given the current capacity of the patrol system, there will be areas of the park left unpatrolled each month. If managers better understood how the spatial deployment of patrols affected the formation of information gaps, they could more clearly define patrol objectives to focus future patrol efforts on previously uncovered areas. To understand whether patrol strategies were addressing the occurrence of information gaps, the percentage of overlap for each sequential month of area coverage was calculated for each patrol unit (Figure 4.3.).

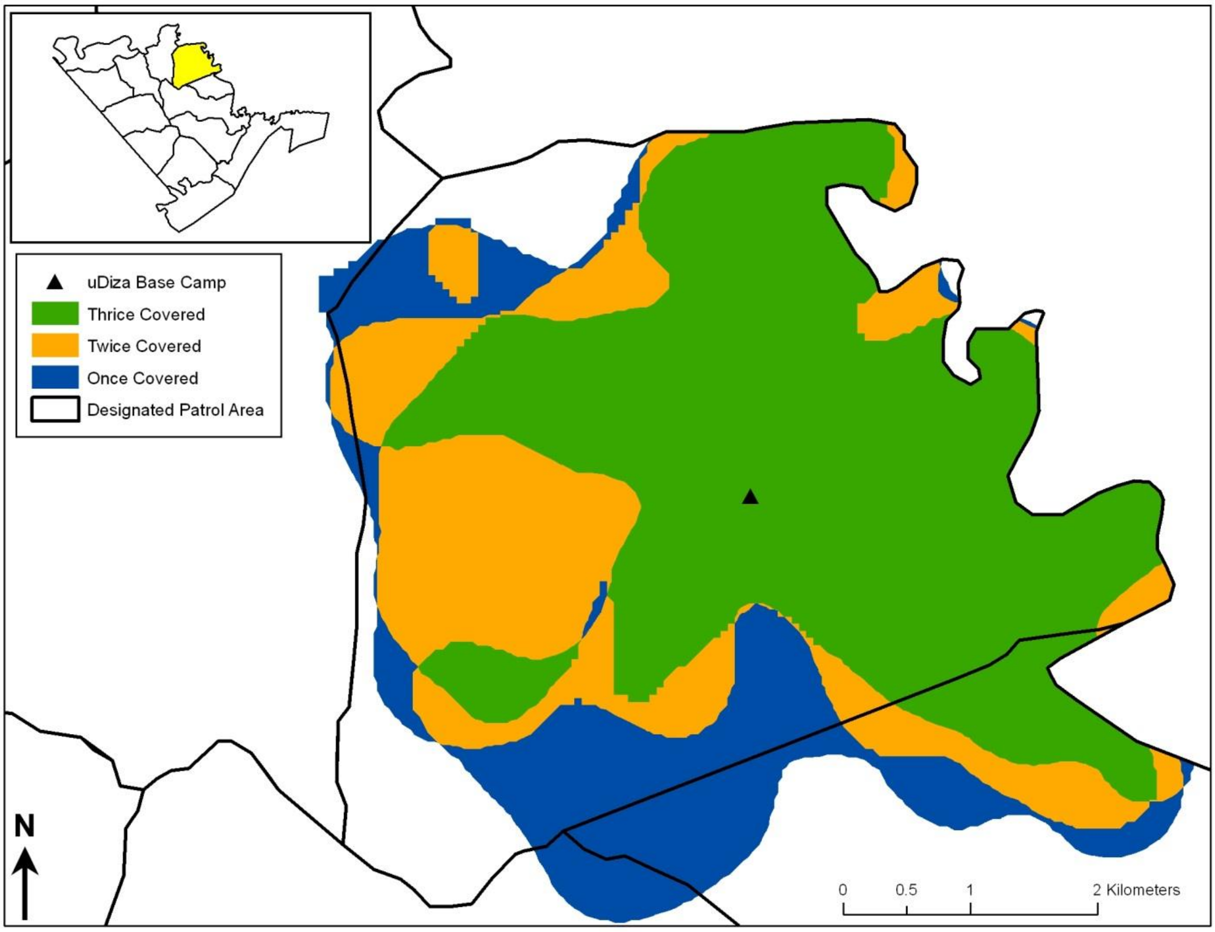

Figure 4.3. Analysis of three sequential months of area coverage overlap for the uDiza Patrol Unit in 2010

This analysis suggests that patrol units repeatedly covered core areas each month and that the minimal amount of new area covered each additional month is not structured around any particular patrol objective (Figure 4.4.).

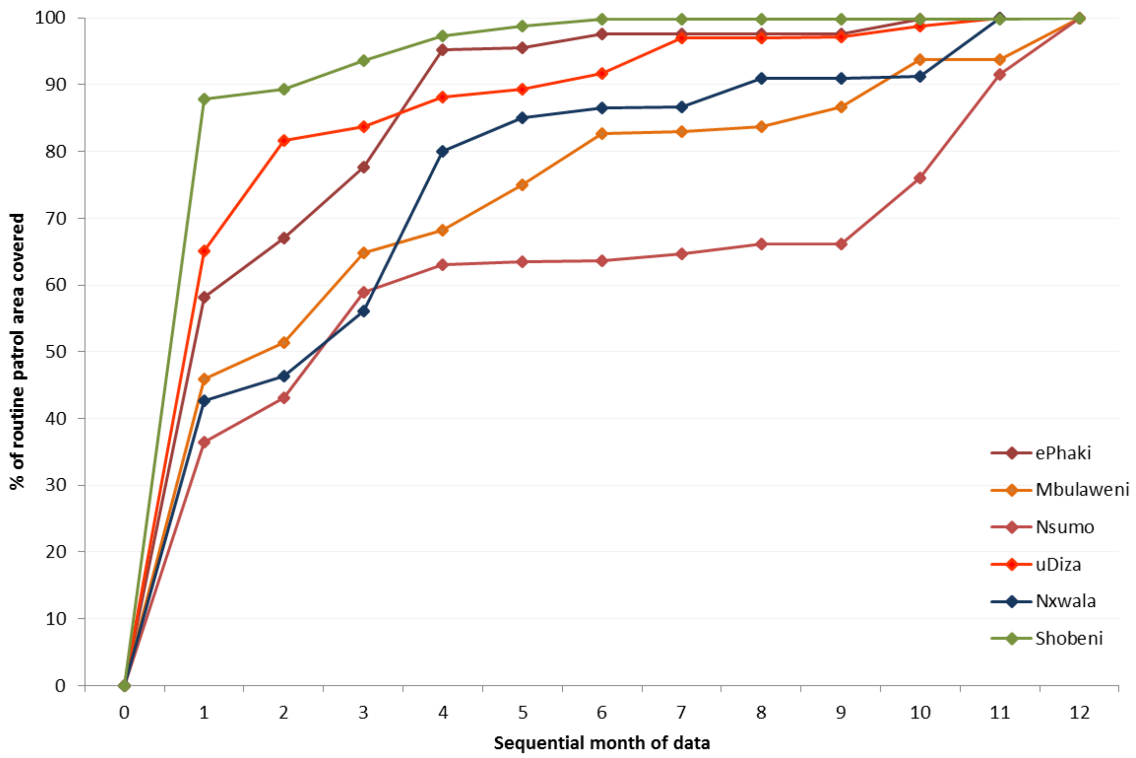

Figure 4.4. Depiction of incremental area coverage of six patrol units in 2010

The amount of new area covered each month suggests that information regarding how individual patrol units interact spatially with each other at the park wide level is needed to understand where information gaps are occurring. Extremes depicted in Figure 4.4., for example, shows how a patrol strategy (Shobeni) can minimize the temporal extent of information gaps whilst another (Nsumo) left upwards of 40% uncovered until the final quarter of the year. More clearly defined patrol objectives pertaining to time frames within which to cover designated patrol areas will provide a suitable foundation from which to evaluate temporal area coverage of the park.

4.4 Park wide area coverage

Although patrol units were spending a significant proportion of their time outside of their designated patrol areas (Figure 4.2.), this would not necessarily result in gaps in information if the areas covered between patrol units were complementary at the park level. For instance, two adjacent patrol units' combined area coverage may cover both designated patrol areas. To better understand the spatial deployment of patrols in the field, it was necessary to fathom how spatial overlap between patrol units translated into park-level coverage. To this end, the percentage of the park covered by all patrol units each month, and the degree to which overlap between patrol units occurred was investigated.

To obtain insight into how the area coverage of individual patrol units translated into park-level coverage, monthly patrol area coverage for each patrol unit was combined. Determining the percentage of the park covered each month was only possible when data had been submitted for all thirteen patrol units, and missing months of patrol data precluded most park level analyses (Appendix 1). For this analysis, data was available for six months in 2009 and five months in 2010.

The average percentage of patrol area coverage overlap each month was relatively low (15% in 2009 and 12% in 2010; Figure 4.5.). The minimal amount of overlap between patrol units provides evidence that there are differing perceptions, between managers and patrol units, of where patrol boundaries lie. However, this suggests that patrol units are nonetheless operating within a patrol area boundary and within the context of the designated patrol area strategy, which was designed with the intent of ensuring that all areas of the park are covered.

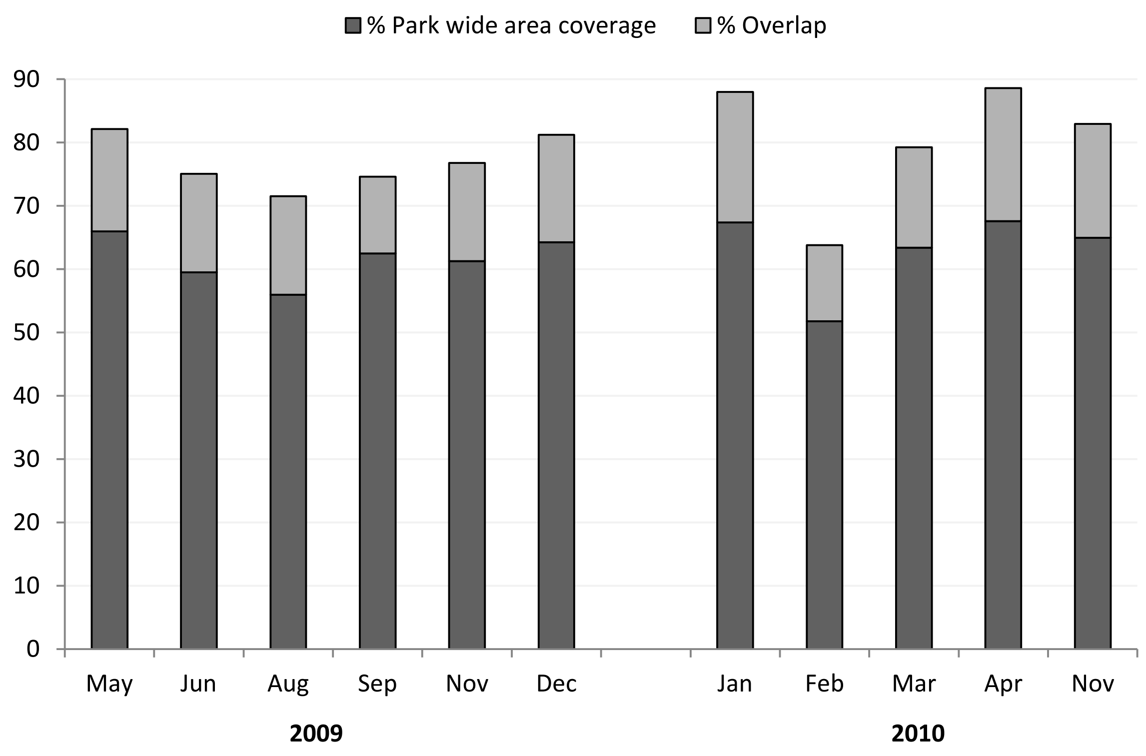

Figure 4.5. Proportion of overlap between patrol units

Although in some cases overlap in patrol areas may be desirable, there is a trade-off in the reduction of total area coverage and, subsequently, the potential for the creation of information gaps. Combining all available data across each year indicated that certain areas remained unpatrolled (Figure 4.6.).

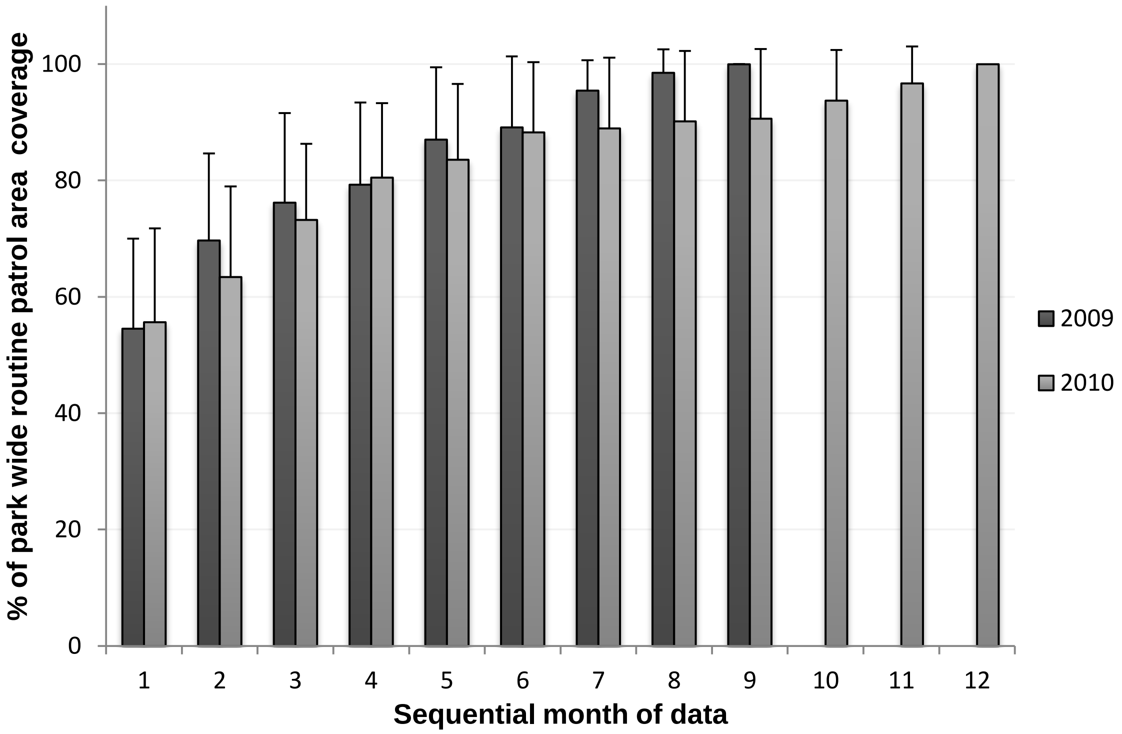

Figure 4.6. A temporal perspective of park wide routine patrol area coverage

An average of 62% and 63% of the park was covered each month in 2009 and 2010 respectively. However, the analysis showed consistently small increases in the percentage of total area covered each month, indicating that patrol effort remained largely focused in much the same areas every month. Figure 4.7. presents a visual overview of the formation of information gaps over a six month period. Routine patrol areas covered 89.2% of the park in 2009 and 92.2% of the park in 2010, indicating that approximately 10% of the park was left unmonitored on an annual basis.

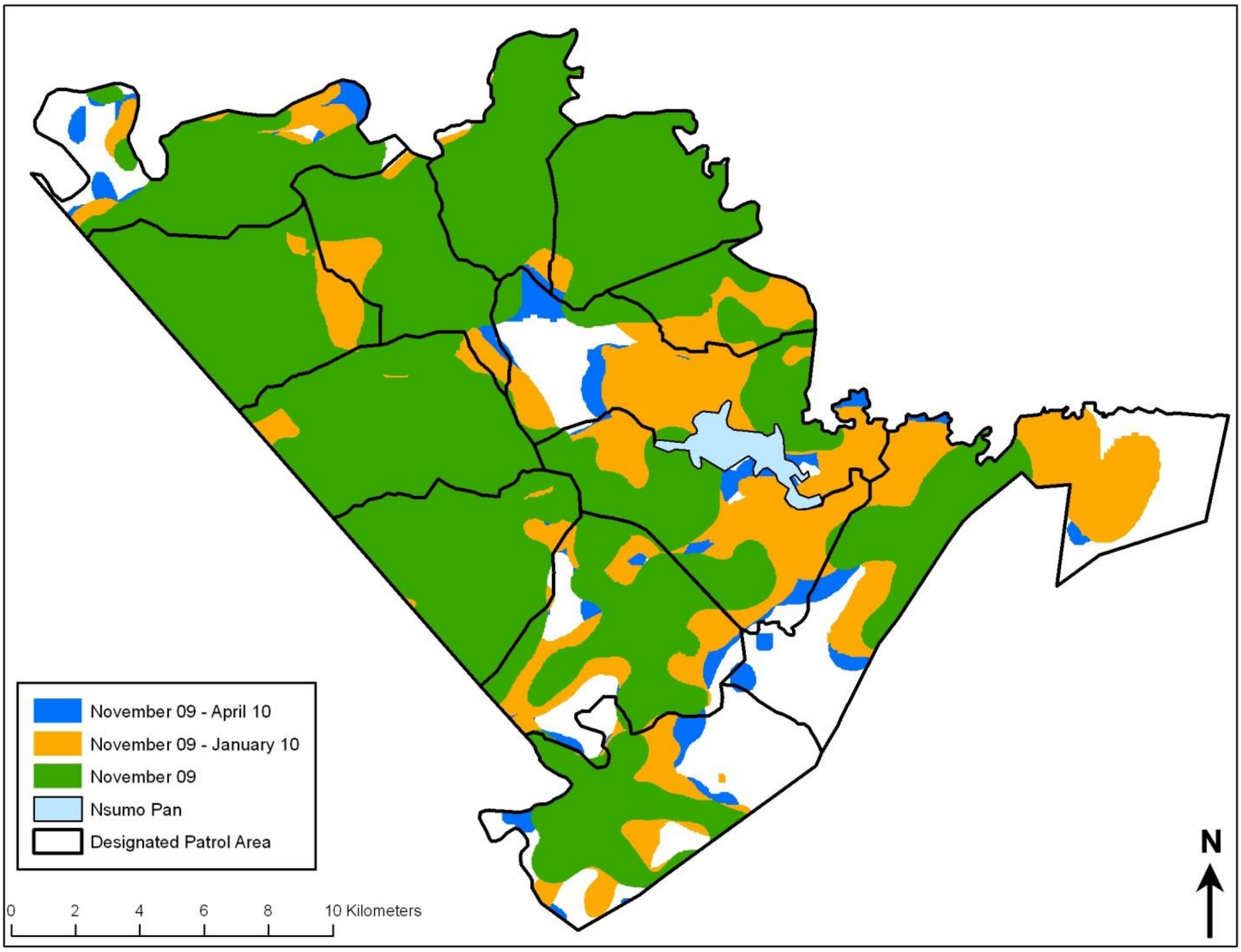

Figure 4.7. An overview of park wide area coverage at one, three and six month intervals

Although the establishment of routine patrol areas using the Jennrich-Turner analysis excluded certain patrol data (see section 3.2.3), visual inspection of all of the original patrol data verifies that these areas may have been patrolled, at best, once during the annual data period. Additionally, plotting of the field patrol data also displayed areas that were poorly covered, despite their being depicted as covered.

4.5 Distribution of patrol effort within routine patrol areas

To understand patrol deployment in the field (see section 1.4.1), it was important to recognize that physiological, topographical and cognizant influences will affect the distribution of patrols across the landscape. Regardless, the preferential use of habitat types could result in incorrect inferences being made about monitoring outcomes or information outputs that are correlated with certain habitats. For example inferences that poaching does not occur in the *Acacia* broadleaved and the *Terminalia sericea* woodlands (see Figure 4.8. below), may be as a consequence of these habitats being inadequately patrolled.

To investigate the distribution of patrol units within their routine patrol areas, and to ascertain whether they showed any preference for patrolling in certain habitats over others, an examination of how they were visiting habitats in proportion to the occurrence of them in their patrol areas was conducted. All patrol units, in both 2009 and 2010, visited habitats differently than expected (see section 3.4), based on the availability of habitat types that were available to them. However, these differences show that preferences were inconsistent between patrol units, although fairly consistent within individual patrol units (Table 2). This suggests that although the type of habitat, per se, was not influencing spatial choices of patrol units in general, consistencies in habitat choice by individual patrol units were observed.

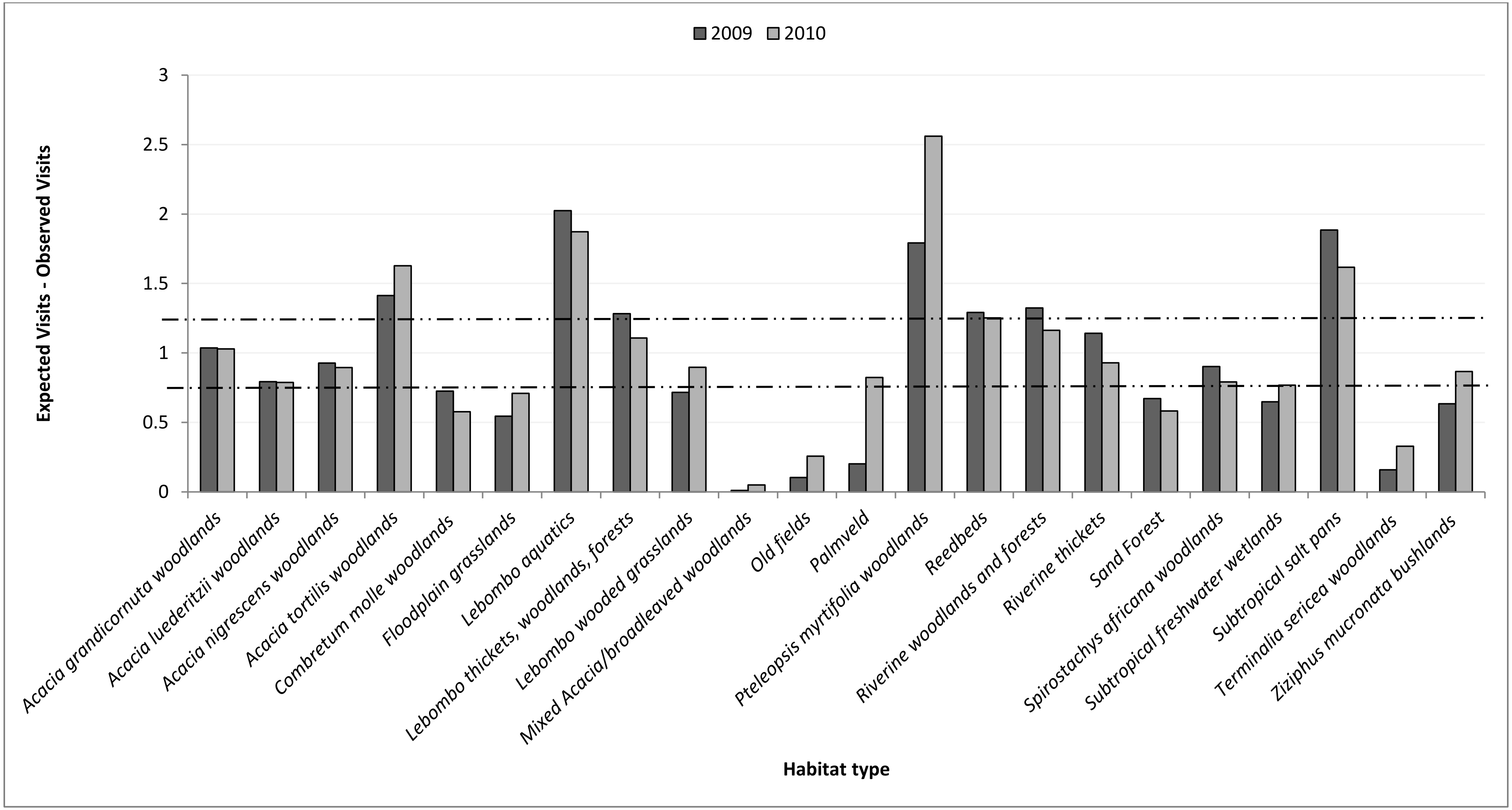

Figure 4.8. The ratio of expected visits to each habitat type in uMkhuze Game Reserve to the observed number of visits. Values >1 indicate habitats visited more frequently, and values <1 indicate habitats visited less frequently than expected based on their total area (see section 3.4). The dashed lines indicate a suggested range within which to maintain habitat use ratios.

At both the level of patrol unit and the park certain habitats were visited significantly more or less than expected based on their availability. This metric was used to establish a more clearly defined patrol objective that would provide a suitable platform from which to evaluate patrol effort. Although a value of >1 suggests that the habitat is being visited more frequently than expected based on its availability (see section 3.4), a value of 1 (observed=expected) will rarely, if ever, be achieved. Therefore, a guideline should be established that specifies an acceptable deviation from 1. For instance, a reasonable guideline could be that to avoid incorrect inferences based on habitat, each habitat value should be a minimum of 0.75 (indicating that the habitat was visited at least 75% of the time that would be expected given the prevalence of the habitat). Alternatively, an upper limit may be that a habitat should not be visited more than 25% more than expected based on its prevalence. In 2009 for instance, 63% of the ratios of habitat use depicted in Figure 4.8. were outside of the suggested range of suitable distribution, represented here by the dashed lines.

Table 2. Habitat use ratios for each patrol unit for each habitat type found within uMkhuze. Values >1 indicate habitats visited more than expected based on their total area and values <1 indicate habitats visited less than expected based on their total area. Values in bold indicate habitat use ratios that are outside of suggested ratio guidelines.

	Dakela		ePhaki		Gwambane		Mahlabeni		Mantuma		Mbulaweni		Mine		Mshopi		Nsumo		Nxwala		Shobeni		Sinkweni		uDiza		Park	
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
Acacia grandicornuta woodlands	0.88	**0.70**	1.05	**0.47**	0.87	0.98	1.07	1.25	**0.39**	0.91	**1.38**	1.26	**0.35**	**0.72**	**1.40**	**1.58**	**0.36**	**0.16**	1.22	1.18	**0.27**	**0.46**	**0.46**	**0.64**	**0.59**	**0.44**	1.04	1.03
Acacia luederitzii woodlands	0.85	**0.67**	**0.55**	**0.34**	-	-	**1.57**	0.98	**0.52**	**0.63**	-	-	**1.93**	**1.78**	-	-	**0.55**	**0.63**	0.94	0.99	**0.27**	-	0.76	**0.49**	**0.67**	**0.58**	0.79	0.79
Acacia nigrescens woodlands	**0.51**	**0.32**	1.16	0.77	0.89	**0.46**	0.84	**0.74**	**0.45**	**1.39**	**0.19**	**0.21**	**0.64**	**0.51**	**0.57**	**0.57**	**5.22**	**6.43**	0.96	0.92	**0.02**	**0.01**	-	-	1.13	1.27	0.93	0.90
Acacia tortilis woodlands	0.95	0.76	1.10	**1.53**	0.76	0.95	**0.18**	**0.40**	**0.62**	**0.73**	**0.44**	**0.46**	1.14	1.02	**0.22**	**0.34**	1.01	1.08	1.17	1.29	**1.53**	**1.65**	-	-	1.14	**1.37**	**1.41**	**1.63**
Combretum molle woodlands	-	-	-	-	0.96	0.82	-	-	**0.36**	0.80	-	-	-	-	-	-	**0.00**	**0.21**	-	-	-	-	-	-	**0.00**	**0.00**	**0.72**	**0.58**
Floodplain grasslands	-	-	-	**0.01**	-	-	-	-	-	-	**1.86**	**2.35**	**0.69**	**0.54**	**0.00**	**0.02**	1.13	**1.40**	**0.34**	**0.37**	1.22	0.92	-	-	-	-	**0.54**	**0.71**
Lebombo aquatics	**1.65**	**2.20**	-	-	-	-	**1.46**	**1.67**	-	**0.01**	**0.00**	**0.00**	-	-	1.90	**1.63**	-	-	-	-	-	-	-	-	-	-	**2.02**	**1.87**
Lebombo thickets, woodlands, forests	1.22	**1.41**	-	-	-	-	1.08	1.11	**1.28**	1.24	1.06	1.07	**0.34**	**0.27**	1.26	1.03	-	-	-	-	-	-	**0.41**	**0.26**	-	-	1.28	1.11
Lebombo wooded grasslands	**0.61**	**0.66**	-	-	-	-	**1.76**	-	-	-	**0.40**	**0.69**	1.02	0.98	1.06	1.14	-	-	**0.63**	**0.67**	**0.00**	-	1.41	**1.59**	-	-	**0.72**	0.90
Mixed *Acacia* /broadleaved woodlands	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**0.01**	**0.05**
Old fields	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.87	**0.30**	-	-	-	-	**0.10**	**0.26**
Palmveld	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**1.75**	**2.73**	-	-	-	-	**0.20**	0.82
Pteleopsis myrtifolia woodlands	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**9.90**	**6.70**	-	-	-	-	**1.79**	**2.56**
Reedbeds	-	-	**0.00**	**0.12**	-	-	-	-	-	-	-	-	-	-	-	-	**1.77**	1.20	0.95	**0.61**	**1.80**	1.05	-	-	-	-	1.29	1.25
Riverine woodlands and forests	1.16	**0.62**	**2.04**	**2.69**	**1.49**	**1.35**	1.14	1.12	**0.02**	1.02	**0.40**	**0.36**	**1.44**	**1.46**	1.27	**1.63**	**1.92**	**1.37**	1.12	1.05	**0.46**	**0.65**	**0.72**	0.90	**1.56**	**1.36**	1.32	1.16
Riverine thickets	-	-	-	-	-	-	-	-	0.67	**0.00**	**2.58**	**2.13**	**1.96**	**2.64**	**0.00**	**0.00**	-	-	**0.37**	**0.63**	**0.68**	**0.36**	-	-	-	-	1.14	0.93
Sand Forest	-	-	-	-	**0.68**	**0.45**	-	-	**0.34**	0.95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**0.01**	-	**0.67**	**0.58**
Spirostachys africana woodlands	-	-	-	-	-	-	0.79	0.80	**0.15**	**1.40**	0.94	1.05	**1.42**	**1.73**	**0.70**	0.87	-	-	**0.36**	**0.36**	**0.75**	**0.52**	-	-	-	-	0.90	0.79
Subtropical freshwater wetlands	-	-	0.87	0.82	1.16	1.29	-	-	0.95	1.13	**2.20**	**0.58**	**2.83**	**2.55**	-	-	**0.40**	**0.43**	1.00	1.13	**0.41**	**0.74**	**0.02**	**0.02**	1.02	0.90	**0.65**	0.77
Subtropical salt pans	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**5.56**	**2.98**	-	-	-	-	**1.88**	**1.62**
Terminalia sericea woodlands	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**0.56**	1.01	**0.36**	**0.54**	-	-	**0.16**	**0.33**
Ziziphus mucronata bushlands	0.89	**1.61**	-	-	-	-	-	-	-	-	-	-	**0.22**	**0.16**	-	-	-	-	-	-	-	-	1.36	1.10	-	-	**0.63**	0.87

4.6 Information outputs relating to patrol area coverage

To determine how patrol area coverage influences information outputs pertaining to threats to biodiversity, 299 biological and law enforcement-related events reported in 2009 and 489 reported in 2010 were examined (see section 4.6). The doubling in the number of events reported can be attributed to an increase in the number of monthly data returns available for analysis, from 118 in 2009 to 184 in 2010 (Appendix 1). In addition an increase in the average number of events reported per month by each patrol unit in 2010 (Table 3) coincides with the implementation of more efficient data management systems in 2008/2009 (van Tichelin, 2008).

Table 3. Average number of events reported monthly by patrol units

	Biological		Illegal		Snares	
Patrol Unit	2009	2010	2009	2010	2009	2010
Dakela	0.33	2.11	0.33	1.11	0.44	1.00
ePhaki	0.22	0.56	0.33	0.33	0.78	1.11
Gwambane	0.56	1.33	0.67	1.44	1.11	1.00
Mahlabeni	0.44	2.67	0.44	1.22	0.44	0.00
Mantuma	4.44	7.22	0.00	0.00	0.00	0.00
Mbulaweni	1.56	3.78	1.67	0.67	0.22	0.67
Mine	1.00	1.11	0.89	1.00	0.33	0.33
Mshopi	0.22	1.00	0.44	0.22	0.22	0.22
Nsumo	0.22	0.11	1.78	1.44	0.33	0.22
Nxwala	1.44	5.00	2.22	1.11	0.56	0.44
Shobeni	1.78	2.67	2.11	2.44	1.78	1.22
Sinkweni	0.11	0.89	0.67	0.67	1.00	0.11
uDiza	0.78	0.78	0.56	2.89	0.78	1.33

In general, the number of events reported was not related to the size of areas covered by patrol units (Table 4). In other words, information from the field was not directly related to the size of the area covered by patrol units. However, the number of biological sightings was significantly correlated with area coverage. The significance of this correlation was driven, in a large part, by the inclusion of Mantuma in the analysis, which reported consistently higher than average biological events due to its ability to cover larger areas (see section 4.1).

Table 4. Results of Pearson's Correlation between the total annual area covered per patrol unit and the average number of incidences reported per year.

All patrol units	2009	2010
Biological Sightings	t_{11}=5.34, P<0.001, R^2=0.85	t_{11}=3.91, P=0.002, R^2=0.76
Illegal Incidents	t_{11}=1.05, P=0.32	t_{11}=1.19, P=0.26
Snares	t_{11}=1.70, P=0.12	t_{11}=1.56, P=0.15
Excluding Mantuma	**2009**	**2010**
Biological Sightings	t_{10}=0.70, P=0.50	t_{10}=1.22, P=0.25
Illegal Incidents	t_{10}=0.40, P=0.70	t_{10}=0.19, P=0.85
Snares	t_{10}=0.91, P=0.39	t_{10}=0.78, P=0.45

Specialized patrol strategies that are able to cover significantly larger areas, such as those employed by the mobile Mantuma patrol unit, can have an effect on information outputs. The exclusion of Mantuma from the analysis suggests that within the range of typical annual area coverage, there are no trade-offs in the size of patrol areas and information outputs. The number of events reported per square kilometer of habitat generally varied by year and habitat type (Table 5).

Table 5. Average number of events reported per square kilometer of habitat

	Biological		Illegal		Snares	
Habitat type	2009	2010	2009	2010	2009	2010
Acacia grandicornuta woodlands	4.07	10.96	4.38	3.45	3.13	1.88
Acacia luederitzii woodlands	7.99	4.72	0.73	3.27	2.91	1.09
Acacia nigrescens woodlands	0.99	10.93	1.99	6.63	0.66	0.33
Acacia tortilis woodlands	3.31	11.04	5.25	6.90	2.76	2.21
Combretum molle woodlands	0.00	1.72	1.14	4.57	0.57	0.00
Floodplain grasslands	4.38	14.38	5.00	0.00	3.13	3.13
Lebombo aquatics	3.07	15.34	1.53	7.67	1.53	7.67
Lebombo thickets, woodlands, forests	2.92	2.92	2.44	3.90	1.22	0.49
Lebombo wooded grasslands	3.46	5.53	2.77	1.73	2.42	1.38
Old fields	0.00	12.35	0.00	0.00	0.00	0.00
Palmveld	0.00	7.12	0.00	0.00	0.00	3.56
Pteleopsis myrtifolia woodlands	0.00	46.73	46.73	0.00	18.69	18.69
Reedbeds	0.00	13.89	9.26	0.00	4.63	0.00
Riverine woodlands and forests	2.85	7.12	3.13	4.27	0.57	2.56
Riverine thickets	15.04	13.16	7.52	0.00	3.76	11.28
Sand Forest	0.00	6.33	0.00	0.00	0.00	0.00
Spirostachys africana woodlands	4.86	6.18	3.53	3.09	2.65	3.53
Subtropical freshwater wetlands	4.31	10.78	3.23	1.08	6.47	2.16
Subtropical salt pans	0.00	0.00	47.62	0.00	0.00	47.62
Terminalia sericea woodlands	0.00	1.90	0.00	0.00	0.00	0.00
Ziziphus mucronata bushlands	1.62	3.23	1.62	8.08	0.00	4.85

The total area of each habitat was strongly correlated with the number of events reported (Table 6) suggesting that field data was linked to the total area of a habitat, and not the habitat type per se. The park-wide habitat use ratio for each habitat, in contrast, did not relate to the number of incidents reported suggesting that preferential use of certain habitats was not yielding great information outputs.

Table 6. Results of Pearson's Correlation testing relationship between habitat type (total area and park-wide use ratio) and the total number of biological sightings, illegal incidents and snaring events reported.

Total area	2009	2010
Biological Sightings	t_{19}=5.22, P<0.001, R^2=0.77	t_{19}=5.62, P<0.001, R^2=0.79
Illegal Incidences	t_{19}=5.83, P<0.001, R^2=0.80	t_{19}=7.49, P<0.001, R^2=0.86
Snares	t_{19}=4.48, P<0.001, R^2=0.72	t_{19}=2.79, P=0.01, R^2=0.54
Use ratio	**2009**	**2010**
Biological Sightings	t_{19}=0.38, P=0.71	t_{19}=0.65, P=0.52
Illegal Incidences	t_{19}=1.31, P=0.21	t_{19}=0.64, P=0.53
Snares	t_{19}=0.39, P=0.70	t_{19}=1.12, P=0.28

Therefore, the total area of habitat is a better predictor of information outputs than is the proportion of times that each habitat type is visited compared to its availability in the landscape. This suggests that a more clearly defined patrol objective (see section 1.4.3) that considers a more even distribution of patrols across habitat types would maximize information outputs from the field.

Chapter 5 – DISCUSSION and CONCLUSIONS

The evaluation of area coverage is crucial to the addressing of rapidly changing threats to biodiversity in uMkhuze, and could not be more clearly illustrated than by the continuing surge in rhino poaching currently being experienced in the region (Kew, 2011; Blaine, 2012). Analyses of uMkhuze's 2009 and 2010 patrol data gives useful perspective to the spatial deployment of patrols in the field, and how this can benefit biodiversity (see section 2.3 Emslie and Brooks, 1999; Arcese *et al*., 1995). Analyses suggest that patrolling techniques and strategies, and the number of patrol units operating in the park, allows for at least two thirds of the park to be covered every month. Furthermore, the capacity exists to achieve park wide area coverage within two months, which is significant when considering the information gaps pointed out by Bell and McShane-Caluzi (1984) that occurred in Kasungu (see section 2.3). Provided that managers in uMkhuze are addressing previously uncovered areas timeously, a two month time frame of achieving park wide area coverage would be more than adequate to monitor a wider range of threats. However, for threats that are more dynamic, such as snaring, smaller time frames may be more appropriate. Therefore, the inclusion of time frames should be an important consideration when determining objectives by which patrol effectiveness can be evaluated (see section 1.4.2; see also Margoluis and Salaksky, 1998 in section 2.4).

Measurable, timeous and diligent area coverage that will minimize information gaps in the landscape is key to the effective management of poaching in KwaZulu-Natal's protected areas (Conway *et al*., 2010). Effective area coverage of the park is an important strategic outcome of the patrol effort (Conway *et al*., 2010; EKZNW, 2010), and the designated patrol area lattice is, in part, a tool that was developed as a means to mitigating the creation of information gaps. However, routine patrol area boundaries have deviated from designated patrol boundaries with the result that part of designated patrol areas are being left unpatrolled, which contributes substantially to the creation of information gaps. The amount of overlap between patrol units does suggest that patrol units are adhering to a patrol boundary, however, but differing ideas of where boundaries occur between managers and patrol leaders undermines the ability to evaluate coverage. Patrol planners need to be cognizant of the fact that subtle influences inherent within patrol units will continue to change the shape of patrol boundaries if left unmanaged. For example, an unsupervised patrol unit of ageing field rangers operating in mountainous terrain would develop a more homogenous routine patrol area shaped around easier, less physically taxing patrol routes. It may not necessarily be important to understand why the re-alignment of patrol boundaries has occurred per se. However, failure to halt these changes is likely to perpetuate the existence of information gaps and information that is used to evaluate patrol effectiveness (see Conway and Thusi, 2002; EKZNW, 2010; van der Westhuizen, 2007; Jachmann, 2008b) will continue to be biased (see Gray and Kalpers, 2005).

The spatial analysis of patrol overlap between patrol units is important where the management of information gaps is concerned. Taking the amount of overlap currently occurring between patrol units into account, an average of 60% of the park was covered each month leaving 40% unmonitored. It is important to understand the trade-offs of patrol overlap strategies, and whether the practice benefits the primary objectives of the patrol effort. For instance, minimizing patrol overlap between patrol units would have resulted in an average 80% of the park being covered each month, without affecting a change in current information outputs (see section 4.3). It is significant that approximately 40 km^2 of the park remained unpatrolled each year, when viewed in this context and considering that it is feasible to systematically fill information gaps within a two month period. The philosophy of reducing the threat of internal poaching through patrol overlap relies on the common knowledge shared by patrol units that areas of their respective designated patrol areas will, at some point, be patrolled by a different patrol unit. However, the effectiveness of this strategy is largely hypothetical. The advantage of managers being able to identify the merits of patrol overlap relative to specific designated patrol areas would negate the unproductive duplication of area coverage between patrol units.

Considering that the management of patrol overlap could free up significant patrol resources for re-allocation, it would be prudent for managers to define the criterion that drives the need for patrol overlap. The establishment of more clearly defined patrol objectives that can evaluate patrol effort (see section 1.4.2) should move beyond the objective of providing a hypothetical watchdog effect on adjacent patrol units. The value of patrol overlap would be enhanced if patrol planning included detailed motives for overlap such as enhanced security, biological monitoring and the omission of information gaps. For instance, it would be pertinent to provide greater patrol overlap support to a large designated patrol area experiencing high levels of poaching from an adjacent patrol (or mobile) unit from a designated patrol area subject to low levels of poaching. Similarly, it would be appropriate to increase patrol overlap in peripheral areas that contained high densities of priority species in an adjacent designated patrol area whose patrol unit was neglecting biological monitoring responsibilities due to poaching pressures. The potential for maximizing information outputs is evident in the mobile Mantuma patrol unit which has far exceeded all other ranges of area coverage, as well as the quantity of biological data collected (see Table 3 section 4.6)

The habitat-use analyses provide valuable insight into how patrols are being distributed in the field (see section 1.4.1). They present an important planning tool that can be used by managers to make correct inferences about the preferential use of habitats within routinely patrolled areas, and about the quality of the information output from them. For instance, the considerable preference shown for habitats such as *Acacia tortilis* could be an important flag for managers. *A. tortilis* habitats are generally subjected to high levels of poaching, and analyses revealed a higher incidence of illegal activities in this habitat. However, as patrol units focused more effort in this habitat, it is unclear whether the higher number of illegal incidents was due to high levels of poaching or to the frequency of visitations by patrol units. Where inclinations for patrolling in certain habitats may be learned as a result of conducting continuous law enforcement operations, it is possible that these preferences may perpetuate as they are passed between patrol units and patrol members, or from manager to manager. Managers should take cognisance of the fact that consistent directed patrolling does not necessarily result in greater information outputs (see section 4.6), and that the trade-offs associated with having a preference for one habitat over another means that another is being neglected. Understanding the spatial extent of patrol area coverage within designated patrol areas will reinforce the ability to build patrol objectives that aim to reduce the occurrence of information gaps. Achieved as a systematic outcome, this knowledge will bolster typical patrol evaluation methodologies such as those described by Conway, 1981; Leader-Williams *et al*., 1990; and EKZNW, 2010.

Alternatively, habitat distribution analyses present opportunities for managers to define patrol monitoring objectives that are specific to a wider or more specialized range of threats linked to particular habitats. For example, the monitoring of threats to the critically endangered sand forest biome in uMkhuze (Lagendijk *et al*., 2011) is given high priority due to the potential for over-utilization by elephants during the dry seasons (Mulqueeny, 2005; EKZNW, 2008). However, the sand forest habitat is consistently less favoured by patrol units (see section 4.5 Figure 4.8.) which suggests that decisions regarding its management could be better informed. Habitat-use analyses also pose important questions around the capacity of the patrol system to collect more specialized data, and whether it would be appropriate to do so. Elevated minimum qualifications for field rangers, for example, means a more educated field force, and their inclusion into the system creates the potential to collect more specialized data. Notwithstanding the considerable drawbacks of losing the experience and skills typically associated with an older generation of field ranger, the systematic analysis of patrol data will allow managers to monitor baseline patrol effectiveness regardless of the ability to collect data, and in terms of a defined spatial objective for any given patrol unit.

The need to inform the current patrol management system in uMkhuze with additional, non-biased evaluation metrics is clear. The incorporation of spatial and temporal analyses with the current evaluation process is the logical progression to understanding how best to improve reliability and confidence in patrol-related outputs. Regardless of what the primary objectives of the patrol system may be (law enforcement vs. environmental monitoring); information outputs generated by it will be profoundly influenced by the manner in which patrol operations are being conducted on the ground. This study provides valuable insight into the spatial deployment of patrols in the field, and to the effects that different patrol management strategies have on critical information outputs pertaining to threats to biodiversity in the park (see sections 1.4.1 and 1.4.2). Most importantly, knowledge learned from this insight builds on the capacity to establish more clearly defined landscape level patrol objectives that will provide a suitable foundation from which to evaluate patrol effort (see section 1.4.3). This study demonstrates that the integration of a spatial evaluation metric will strengthen the current patrol management framework in uMkhuze by improving the capacity to plan more effectively. Timeous and spatially comprehensive outputs from the patrol system not only elevate the integrity of patrol related decision-making processes, but hold patrol units, protected area managers and institutions to a higher level of accountability.

Chapter 6 - RECOMMENDATIONS

Knowledge learned from this study suggests that the integration of spatial analyses with current patrol evaluation and planning approaches would strengthen the patrol management framework of uMkhuze (see Figure 2.1., section 2.4). The patrol system is a powerful management tool that is effective within the current operational deployment structure. However, patrol effectiveness that is gauged almost exclusively on data generated by law enforcement operations inhibits the ability to evaluate the efficiency of the system as a whole (see Morgan, 2005). Fundamentally, there is a need to synthesize the evaluation of data that is derived from law enforcement operations and biological monitoring with a landscape level metric. This will enable managers to define tangible landscape level patrol objectives that are centered on the mitigation of information gaps. Consequently, a stronger foundation from which to evaluate park wide patrol effectiveness will be established.

6.1 An expanded framework for patrol planning

The uMkhuze Wildlife Management Strategy (hereafter the Strategy) is a living framework that is reviewed annually by park managers, and serves to guide the management of the law enforcement effort in the park. It is strongly recommended that managers consider that guidelines for the management of the patrol system in the Strategy is re-compiled into a comprehensive Patrol Management Plan that provides the means to monitor, evaluate and adjust the patrol effort in the field. In this way, objectives specifically addressing patrol-related outcomes can be established in terms of the Strategy's own goals and objectives. For example, an objective aiming 'to ensure satisfactory area coverage' in the Strategy (EKZNW, 2010 page 12) would translate, in the Patrol Management Plan, into a clearer definition of what comprised satisfactory area coverage, and the means and methods to obtaining and evaluating it. In addition, it is recommended that the objectives of the Strategy be more clearly defined in terms of achieving 'effective and efficient law enforcement' (EKZNW, 2007 page 34), and how that relates to the patrol system's ability to address information needs on a wider range of threats to the park.

6.2 Defining measurable landscape level patrol objectives

Understanding the trade-offs of the different patrol strategies that are being employed in the field provides the basis for the establishment of fundamental patrol area coverage objectives (see section 2.5). For instance, the benefits of covering an area more extensively over more intensively may be difficult to discern unless a clear objective has been stated. The intensive sweeping of a habitat to locate snare lines, for example, is one of many standard patrol objectives that have very specific outcomes and understandable benefits. However, at the larger spatial scale, where numerous patrol strategies are enacted simultaneously, it becomes more difficult to recognize any particular benefit. For example, an area with low biodiversity may be intensively covered through the unwitting overlap of three different patrol units, which may not be beneficial in terms of wasting limited patrol resources. These patrol loopholes can be mitigated through a clearer definition of patrol objectives for each patrol unit or designated patrol area. The provision of insight into how information outputs are affected by different patrol strategies gives some perspective on how managers could define the different objectives for these strategies. In terms of laying a foundation for the evaluation of the patrol effort, it is recommended that the following objectives be considered as a prescriptive standard of patrol planning:

6.2.1 Designated patrol areas

The closing of information gaps is a key consideration for managers, and the re-integration of designated patrol areas into the patrol planning process is crucial. Designated patrol areas are fundamental to the definition of landscape level patrol objectives that will provide a foundation from which metrics for the evaluation of patrol effort can be developed.

6.2.2 Area coverage time frames

It is important that area coverage time frames be established to ensure that information gaps are filled as quickly as the system will allow without compromising core law enforcement operations. Managers should consider that total area coverage of the park can be achieved every two months under the current patrol regimen. Through the adoption of an objective planning approach, it is feasible to achieve this goal whilst simultaneously boosting information outputs from the system as a whole.

6.2.3 Patrol distribution

Once area coverage and time frame objectives have been established for a particular patrol unit or designated patrol area, it is necessary to ensure that the distribution of patrols across habitat types is maintained at as even a level as is possible (see section 4.6). Implementation of habitat-use analyses will undoubtedly negate the perpetuation of information gaps at park wide and routine patrol area levels, and will considerably maximize information outputs in general without impacting negatively on the current patrol management framework.

6.3 General

6.3.1 Mobile patrol units

Results from the analysis of data collected by the mobile Mantuma Patrol Unit showed outstanding potential for significantly maximizing information outputs whilst simultaneously increasing patrol area coverage. It is recommended that managers consider the greater value of sustained (mobile) patrolling strategies when viewing alternatives in the context of section 6.1 above. The inclusion of more aptly designed data management systems and objectives that can better serve the evaluation of the effectiveness and potential of mobile patrolling strategies (such as those employed by the specialized Anti-poaching Unit) is likely to bolster the effectiveness of the patrol management framework considerably.

6.3.2 Staying informed

Since the inception of this study, the management of data collected by patrol units in the field has been significantly improved upon with the implementation of the CyberTracker patrol monitoring system. Most notable is the ability that managers have, not only to time-stamp spatial locations, but to be able to pre-program GPS units to automatically record spatial locations. This will have a significant impact on the capacity to perform higher quality analyses that will tighten the knowledge cycle considerably, and within smaller timeframes. The value of capacitating managers to be timeously and consistently informed of the performance of the field patrol effort is a goal that should be strongly pursued by policy makers and managers alike.

In conclusion; experienced managers will tell you that there is no substitute for effective patrolling than patrolling. Objectivity is an important component of learning from the analyses conducted in this study, and the integration of local knowledge and experience remains crucial to their validation. Outcomes from this work have achieved a better understanding of the spatial distribution of patrols in the field, which broadens the understanding of patrol deployment. Consequently, the capacity to recognize the trade-offs associated with different patrol deployment strategies capacitates a more effective approach to patrol planning where the interrelatedness of law enforcement activities and the spatial distribution of patrols strengthen the patrol management framework in uMkhuze.

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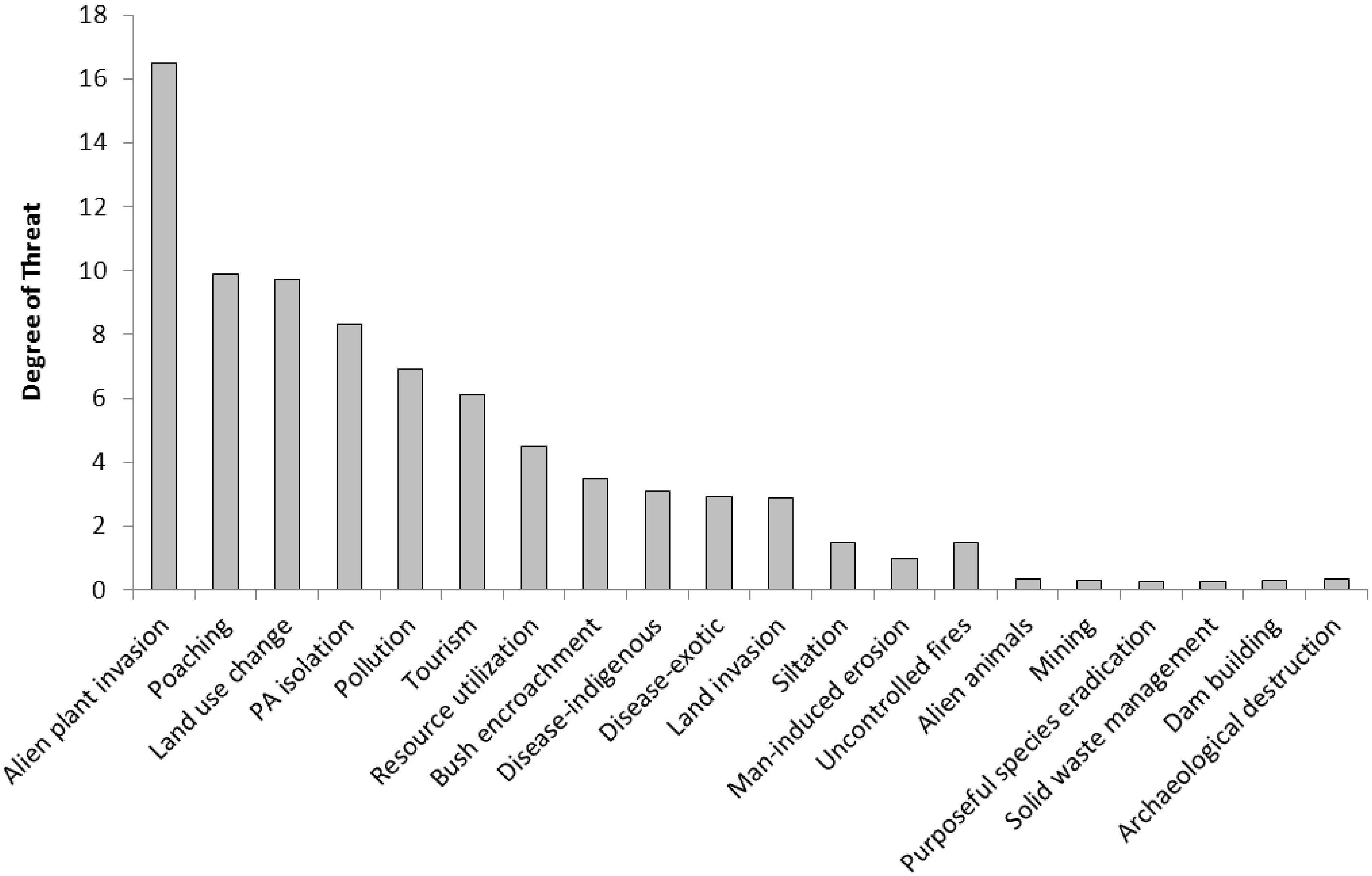
APPENDIX I. Future threats to protected areas in EKZNW's Coastal Region (Goodman, 2003)



APPENDIX II. Monthly patrol data sets

						2009							No. of
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Months
Dakela	x	x	x	√	√	√	√	√	√	√	√	√	9
ePhaki	x	x	x	√	√	√	√	√	√	√	√	√	9
Gwambane	x	x	x	√	√	√	√	√	√	√	√	√	9
Mahlabeni	x	x	x	√	√	√	√	√	√	√	√	√	9
Mantuma	x	x	x	√	√	√	x	√	√	√	√	√	8
Mbulaweni	x	x	x	√	√	√	√	√	√	√	√	√	9
Mine	√	√	x	x	√	√	√	√	√	√	√	√	10
Mshopi	x	x	x	√	√	√	√	√	√	√	√	√	9
Nsumo	x	x	x	√	√	√	√	√	√	x	√	√	8
Nxwala	x	√	x	x	√	√	√	√	√	√	√	√	9
Shobeni	√	√	x	x	√	√	√	√	√	√	√	√	10
Sinkweni	x	√	x	x	√	√	√	√	√	√	√	√	10
uDiza	x	x	x	√	√	√	√	√	√	√	√	√	9

						2010							No. of
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Months
Dakela	√	√	√	√	√	√	√	√	√	√	√	√	12
ePhaki	√	√	√	√	√	x	√	√	√	√	√	√	11
Gwambane	√	√	√	√	√	√	√	√	√	√	√	√	12
Mahlabeni	√	√	√	√	√	√	√	√	√	x	√	√	11
Mantuma	√	√	√	√	√	√	√	x	√	√	√	√	11
Mbulaweni	√	√	√	√	√	√	√	√	√	√	√	√	12
Mine	√	√	√	√	x	√	x	√	x	√	√	√	9
Mshopi	√	√	√	√	√	√	√	√	√	√	√	√	12
Nsumo	√	√	√	√	√	√	√	√	x	√	√	√	11
Nxwala	√	√	√	√	√	√	√	√	√	√	√	x	11
Shobeni	√	√	√	√	√	√	√	√	√	√	√	√	12
Sinkweni	√	√	√	√	√	√	√	√	√	√	√	√	12
uDiza	√	√	√	√	√	√	√	√	√	√	√	√	12

APPENDIX III. Translated monthly patrol information sheet

Patrol Unit: ______________________________
Month: ________________________ Year:______________________
Patrol Leader:_____________________________
Patrol Members: ____

Date	Time Out	Time In	Waypoint start	Waypoint end	Type of Patrol	Field Ranger initials	Observations
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							
27							
28							
29							
30							
31							
1							
2							
3							
4							
5							
6							

APPENDIX IV. Translated monthly patrol events information sheet

Patrol unit: ________________________ **Month and year: ____________________**

Rare sightings

Date	GPS No.	Animal code	Area name	No. of ♂	Age			No. of ♀	Age			No. of ?	Age			Comment
					A	S/A	J		A	S/A	J		A	S/A	J	

Illegal incidents

Date	GPS No.	Incident code	Time	No. of poachers	Dogs	Area name	Animal killed	Dogs shot

APPENDIX **IV** (continued).

Game mortalities

Date	GPS No.	Animal code	Area name	Time of death	Sex	Age	Cause of death

Alien plants

Date	GPS No.	Area name	Code	Species

Raptor nesting sites

Date	GPS No.	Area name	Code	Active/inactive

APPENDIX V. Sample of monthly patrol data management spreadsheet (van Tichelin, 2008)

Field Rang	Way point	Date	Time Out	Time In	Lat	Long	Type of Pa	No. of staff	Illegal Acti	Mortality	Time since	Detailed O	No's	Details (ie	Patrol dura	Month
Dakela	001	7-Jan-10	12:00	18:30	-27.65923	32.19845	Foot Patro	2							6:30	2010-Jan
Dakela	002				-27.66462	32.18936									0:00	2010-Jan
Dakela	003				-27.66511	32.18807									0:00	2010-Jan
Dakela	004				-27.66927	32.17935									0:00	2010-Jan
Dakela	005				-27.65883	32.17736									0:00	2010-Jan
Dakela	006				-27.65743	32.18962									0:00	2010-Jan
Dakela	007				-27.65929	32.19821									0:00	2010-Jan
Dakela	008	8-Jan-10	10:30	15:00	-27.60104	32.28852	Foot Patro	2	D-Animal k	PO- poach	1 - Less than or = one day				4:30	2010-Jan
Dakela	009				-27.58518	32.25757	Observatio	2							0:00	2010-Jan
Dakela	010				-27.58750	32.25613									0:00	2010-Jan
Dakela	011	9-Jan-10	16:00	19:00	-27.59407	32.28047	Foot Patro	2							3:00	2010-Jan
Dakela	012				-27.58485	32.28181	Ambush	2							0:00	2010-Jan
Dakela	013				-27.59428	32.28098									0:00	2010-Jan
Dakela	014	10-Jan-10	12:00	19:15	-27.57297	32.25156	Foot Patro	2							7:15	2010-Jan
Dakela	015				-27.58269	32.24921									0:00	2010-Jan
Dakela	016				-27.60367	32.25410									0:00	2010-Jan
Dakela	017				-27.60659	32.26005	Observatio	2							0:00	2010-Jan
Dakela	018				-27.59924	32.26038	Foot Patro	2							0:00	2010-Jan
Dakela	019				-27.58930	32.26065									0:00	2010-Jan
Dakela	020				-27.58133	32.25337									0:00	2010-Jan
Dakela	021				-27.57299	32.25157									0:00	2010-Jan
Dakela	022	15-Jan-10	5:30	11:00	-27.58686	32.15052	Foot Patro	2							5:30	2010-Jan
Dakela	023				-27.58609	32.16228									0:00	2010-Jan
Dakela	024				-27.58024	32.16849									0:00	2010-Jan
Dakela	025				-27.57880	32.17716									0:00	2010-Jan
Dakela	026				-27.57093	32.19375									0:00	2010-Jan
Dakela	027				-27.57357	32.20125									0:00	2010-Jan
Dakela	028				-27.57658	32.20088									0:00	2010-Jan
Dakela	029				-27.58277	32.19786									0:00	2010-Jan
Dakela	030				-27.58305	32.19234									0:00	2010-Jan
Dakela	031				-27.58206	32.18455									0:00	2010-Jan

APPENDIX VI. Habitat types of the uMkhuze Game Reserve (van Rooyen, 2004; van Rooyen and Morgan, 2007)

Habitat Classification	***Habitat Characteristics***	***Area (Ha)***
Acacia grandicornuta woodlands	Sandy loam and clay soil plains dominated by *Acacia grandicornuta; A. tortilis; A. nilotica; Ziziphus mucronata; Sclerocarya birrea; Dichrostachys cinerea; Themeda triandra; Heteropogon contortus; Digitaria eriantha; Cenchrus ciliaris; Bothriochloa insculpta; Eragrostis heteromera*	3,193
Acacia luederitzii woodlands	Flat, poorly drained clay soils dominated by *Acacia luederitzii var. retinens; A. grandicornuta; A. nilotica; Euclea undulata and E. divinorum.* Other species include *Berchemia zeyheri; Ziziphus mucronata; Dombeya rotundifolia; Acacia nilotica, Spirostachys africana; Balanites maughamii; Euphorbia cooperi; Schotia brachypetala; Galpinia transvaalica; Olea europaea subsp. africana; Strychnos spinosa and Sideroxylon inerme.* Dominant grasses include *Dactyloctenium australe; Enteropogon monostachyos; Panicum maximum and P. deustum.* The noxious weed*, Chromolaena odorata,* occurs at high densities in this habitat	2,752
Acacia nigrescens woodlands	Open woodlands on vertic and ferruginous clay soils dominated by *Acacia nigrescens* and *Sclerocarya birrea* and associated with *Acacia gerrardii, A. tortilis* and *Dichrostachys cinerea* and *Acacia nilotica* thickets. Dominant grass species are *Themeda triandra, Panicum coloratum, Panicum maximum, Urochloa mosambicensis, Bothriochloa insculpta, Digitaria eriantha, Aristida spp., Heteropogon contortus and Eragrostis spp.*	3,018
Acacia tortilis woodlands	Open to closed woodlands occurring on low-lying drainage lines on flat, alluvial soils. Dominated by *Acacia tortilis* and associated with *Spirostachys Africana; Schotia brachypetala; Acacia nilotica; Heteropogon contortus; Eragrostis rigidior; Themeda triandra; Bothriochloa insculpta; Dactyloctenium austral*	3,622

Combretum molle woodlands	Mixed, simple-leafed woodlands and grasslands ocurring on deep mesotrophic soils. Woody component is characterized by *Combretum molle; C. zeyheri; Sclerocarya caffra; Strychnos spinosa; S. madagascariensis; Acacia burkei; Lannea schweinfurthii; Ziziphus mucronata; Terminalia sericea and Sterculia rogersii; Catunaregam obovata and Coddia rudis.*The largely unpalatable grass component is characterized by *Aristida spp.; Sporobolus fimbriatus; Eragrostis rigidior; Eragrostis pallens; Pogonarthria squarrosa and Hyperthelia dissoluta.* More palatable species such a*s Panicum maximum, Digitaria eriantha and Dactyloctenium australe* also occur in places.	1,749
Floodplain grasslands	Soils exposed to seasonal flooding. Dominated by large tree specimens such as Acacia xanthophloea and Ficus sycomorus; small patches of Phragmites australis reed beds; grasses and sedges such as Echinochloa pyramidalis; Hemarthria altissima; Cyperus fastigiatus and Cynodon dactylon	1,599
Lebombo aquatics	Vegetation found along the pans; streams; marshes; springs and gorges of the Lebombo Mountains (Smith, 2001).	652
Lebombo thickets, woodlands, forests	Open to closed woodlands on rocky rhyolitic slopes of the Lebombo Mountains, with or without well-developed herbaceous layer. *Cussonia natalensis; Themeda triandra; Digitaria eriantha; Panicum maximum; Heteropogon contortus; Olea europaea; Aloe marlothii; A. sessiliflora; Euphorbia cooperi; E. tirucalli; Ficus abutilifolia; F. glumosa; Ptaeroxylon obliquum; Combretum apiculatum; Acacia nigrescens; A. burkei; A. caffra; Combretum molle; C. zeyheri; Lannea discolor* and *Pterocarpus rotundifolius* (Smith, 2001).	4,104
Lebombo wooded grasslands	Shallow, sandy rhyolitic soils with *Terminalia phanerophlebia; Combretum apiculatum; Acacia nigrescens* and *Lannea discolor* being the common tree species. Common grasses include *Elionurus muticus; Andropogon gayanus; Schizachyrium sanguineum; Tristachya biseriata; Brachiaria serrata* and *Themeda triandra* (Smith, 2001; Van Rooyen, 2004)	2,892

Mixed *Acacia*/broadleaved woodlands	Open to dense shrub and woodlands occurring on flat drainage lines adjacent to sandy plains and in old fields. Fine sandy loam to dark clay soils dominated by *Ziziphus mucronata; Spirostachys africana; Sideroxylon inerme; Sclerocarya birrea; Berchemia zeyheri; Acacia robusta; A. nilotica; A. tortilis; A. burkei and A. luederitzi*i in woodland component. Shrub layer dominated by *Dichrostachys cinerea; Gymnosporia senegalensis; Acacia borleae; A. karroo; Euclea divinorum; E. natalensis; E. racemosa Rhus quenzii; Coddia rudis; Gymnosporia buxifolia; Croton steenkampianus and Kraussia floribunda.* Predominant grasses are *Themeda triandra; Sporobolus africanus; Bothriochloa insculpta; Ischaemum afrum; Digitaria eriantha; Eustachys paspaloides and Setaria incrassata.*	201
Old fields	Ocurring on the lower uMkhuze river, old fields are dominated by *Hyperthelia dissoluta; Sclerocarya birrea; Dichrostachys cinerea; Acacia nilotica; Strychnos spinescens and Gymnosporia senegalensis.* The alien *Syringa spp*. occurs at relatively high densities.	81
Palmveld	Pallid sands with predominantly *Hyphaene coriacea* and *Phoenix reclinata* palms, and large tree species such as *Garcinia livingstonei; Trichilia emetica; Syzygium cordatum; Sclerocarya birrea; Albizia adianthifolia; Strelitzia Nicolai; Strychnos madagascariensis; Strychnos spinosa; Ekebergia capensis and Acacia robusta*. Common grasses and herbs include *Themeda triandra; Andropogon gayanus; Trachypogon spicatus; Digitaria eriantha; Dactyloctenium geminatum; Eragrostis gummiflua; Cymbopogon pospischilii and Helichrysum kraussii*	281
Pteleopsis myrtifolia woodlands	Dense woodlands on well drained sandy loam soils surrounding dense stands of sand forest. Dominant tree species include *Pteleopsis myrtifolia; Strychnos spinosa; Balanites maughamii; Combretum molle; Dialium schlechteri; Mystroxylon aethiopicum; Commiphora neglecta; Strychnos spinosa; Brachylaena discolor; Acacia burkei; Maerua cafra* and *Strychnos madagascariensis*. Other diagnostic species include *Hymenocardia ulmoides; Tricalysia capensis; Landolphia kirkii and Tricalysia lanceolata.* The shrub layer is characterized by *Hymenocardia ulmoides; Salacia leptoclada; Hypericum revolutum; Tricalysia capensis; Tricalysia lanceolata; Rhus guenzii; Landolphia kirkii; Euclea divinorum; Uvaria caffra; Vitex ferruginea; Carissa tetramera; Ochna arborea; Dalbergia nitidula; Canthium setiflorum; Croton steenkampianus; Zanthoxylum capense and Catunaregam obovata.*	107
Reedbeds	Subtropical freshwater wetland reedbeds dominated by *Phragmites mauritianus and P. australis* (Mucina *et al*., 2006)	216

Riverine woodlands and forests	Important river stabilizers dominated by *Ficus sycomorus; Acacia xanthophloea; Phoenix reclinata; Trichilia emetica; Ekebergia capensis; Acacia schweinfurthii; Azima tetracantha and Rauvolfia caffra*	3,509
Riverine thickets	Dominated by important river bank stabilizer species including *Acacia schweinfurthii and Azima tetracantha; Grewia caffra, Ficus capreifolia and Phoenix reclinata* (Smith, 2001)	532
Sand Forest	Semi-decidious forest on dystrophic acidic soils characterized by *Cola greenwayi; Salacia leptoclada; Drypetes arguta; Newtonia hildebrandtii; Toddaliopsis bremekampii; Uvaria caffra; Erythrophleum lasianthum; Drypetes natalensis; Croton sylvaticus and Tricalysia sonderiana; Balanites maughamii; Strychnos henningsii; Wrightia natalensis; Cassipourea mossambicensis; Craibia zimmermannii; Croton gratissimus; Drypetes natalensis; Erythrophleum lasianthum; Cryptocarya woodii and Strychnos decussata.* The shrub layer is characterized by *Cola greenwayi; Psydrax locuples; Croton sylvaticus; Tricalysia sonderiana; Toddaliopsis bremekampii; Dovyalis caffra; Uvaria caffra; Cola greenwayii; Croton steenkampianus; Hyperacanthus amoenus; Vitex ferruginea; Grewia caffra and Blighia unijugata*. (Brooks *et al.,* 1982; Goodman, 1990; Smith, 2001; Van Rooyen, 2004; Mucina *et al.,* 2006)	158
Spirostachys africana woodlands	Low lying poorly drained soils with high clay content dominated by *Spirostachys Africana; Berchemia zeyheri; Apodytes dimidiate; Sideroxylon inerme; Schotia brachypetala; Acacia grandicornuta; Acacia luederitzii; Strychnos decussate; Maytenus undata; Dovyalis caffra; Dalbergia obovata; Asparagus natalensis and A. falcatus*	2,265
Subtropical freshwater wetlands	Aeolian depressions in flat areas adjacent to seasonal pools, alluvial pans, lakes and marshes. Dominated by grasses such as *Leersia hexandra* and *Eriochloa meyeriana,* and reeds and sedges such as *Phragmites spp.; Scirpus littoralis; Caldium spp.; Cyperus papyrus; C. immensus and Typha latifolia*	928
Subtropical salt pans	Shallow alluvial depressions surrounded by *Phragmites sp*.or herbaceous layers ocurring on sand, calcrete or Cretaceous sediments	21
Terminalia sericea woodlands	Open to closed deciduous woodlands found on dystrophic sandy soils. Characterized by *Terminalia sericea; Sclerocarya birrea; Acacia burkei; A. robusta; Strychnos madagascariensis; S. spinosa; Antidesma venosum; Dichrostachys cinerea; Vangueria infausta; Panicum maximum; Diheteropogon amplectens; Hyperthelia dissolute; Andropogon gayanus*	525
Woody grasslands on sand	Coastal grasslands characterized by high ocurrance of shrubby woody plants (Smith, 2001)	216

Ziziphus mucronata bushlands	Predominantly *dense Ziziphus mucronata* and *Euclea divinorum* woodlands ocurring on rhyolitic soils	619
Total Area		**33,240**