LONG TERM PROSPECTS FOR THE PERSISTENCE OF BREEDING VERREAUX'S EAGLES (*AQUILA VERREAUXII*) AT THE WALTER SISULU NATIONAL BOTANICAL GARDEN, JOHANNESBURG

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A research report submitted to the
Faculty of Science,
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DECLARATION

I hereby declare that this research report is my own, unaided work except where acknowledged. It is being submitted in partial fulfilment of the requirements for the degree of Master of Science in Environmental Science at the University of the Witwatersrand, Johannesburg. It has not been submitted for any degree or examination in any other University.

Tamara Lauren Kruger

At ...*JHB*... on the …*31st*…. day of …*May*……. 2010

ABSTRACT

Verreaux's Eagles (*Aquila verreauxii)* have been sighted in the Walter Sisulu National Botanical Garden since the 1940s. The natural habitat surrounding the Botanical Garden, which is utilised for hunting purposes, has undergone extensive urbanisation and subsequently the habitat required by typical prey species, such as Rock Hyrax (*Procavia capensis*), has decreased. As a result food supplementation during the breeding season was initiated by the Black Eagle Project Roodekrans (BEPR); a non-profit organisation dedicated to the preservation of these urban raptors. With further proposed urban development, the aim of this research was to deduce the long term prospects for breeding Verreaux's Eagles at the Botanical Garden. Analyses were carried out on historical aerial photographs to illustrate the decreasing natural habitat available for prey species within a 10 km radius of the eagle's nest site. The feeding data collected by the BEPR over a 16 year period (1993 - 2008) were analysed to investigate changes in prey species and breeding data were analysed to detect possible changes in breeding success over the 16 year period. The aerial photograph analysis indicated that prey suitable habitat within a 10 km radius of the nest diminished by approximately 29.7 km^2 (9.5 %) from 1984 to 2007. In 2007 approximately 116.7 km^2 (37.2 %) of suitable prey habitat remained within this radius, with a further reduction predicted to decrease suitable habitat within this radius, in the following three years, by an additional 1.03 km^2 (1.3 %). The feeding data suggested that there has been a switch from Rock Hyrax to other prey species such as Helmeted Guineafowl (*Numida melagris*) and francolin (*Francolinus* spp.). The breeding data revealed few inconsistencies with respect to the incubation period, nestling period and post fledging dispersal period which were similar to established studies on Verreaux's Eagles. Despite a reduction in the suitable prey habitat and change in prey, breeding has persisted over the 16 year period. Therefore the prospects of these Verreaux's Eagles to continue to breed and hunt at the Botanical Gardens will depend on the, as yet unknown, threshold of prey abundance and habitat disturbance.

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ACRONYMS

BEMP	Black Eagle Monitoring Project
BEPR	Black Eagle Project Roodekrans
DEA	Department of Environmental Affairs
DLA	Department of Land Affairs
GDACE	Gauteng Department of Agriculture, Conservation and Environment
GIS	Geographic Information System
NEMA	National Environmental Management Act (No. 107 of 1998)

GLOSSARY

Cainism	Also referred to as siblicide or fratricide, it is the struggle observed in certain raptor species such as Verreaux's Eagles involving the death of the second hatchling (Abel) caused by the first hatchling (Cain)
Chick	A young bird or nestling prior to fledging
Clip	To clip or crop a photograph is to remove any unwanted features that distract from the focus of the photograph; for example a border/frame as well as the feducials of an aerial photograph
Clutch	A group of eggs that have been laid
Feducial	The reference markings of an aerial photograph
Fledge	A juvenile bird's initial flight
Fledgling	A young bird or juvenile that has fledged following the nestling period
Fratricide	See cainism and siblicide
Raptor	Birds of prey, including eagles (Accipitridae), hawks (Accipitrinae), falcons (Falconidae) and owls (Strigidae and Tytonidae) characterised by strong talons for capturing prey and a predominantly carnivorous diet
Siblicide	See cainism and fratricide
Territory	An animal's home range that is used for hunting and breeding activities which it defends against intrusion by other members of the same species

1. INTRODUCTION

1.1 Verreaux's Eagle

Verreaux's Eagle (*Aquila verreauxii*) of the Order Falconiformes and the Family Accipitridae, commonly known as the Black Eagle, was named in the 19th century after the French collectors Jules and Edouard Verreaux (Hockey *et al*. 2005). As one of the larger members of the genus *Aquila*, Verreaux's Eagles weigh approximately 4.3 kg and have a wingspan of up to 2.2 m (Gargett, 1990; Figure 1). They are sexually dimorphic with females being larger and heavier (Gargett, 1990). Juveniles are a mottled light brown colour whereas adults are predominately black apart from a white v-shaped section on the back and rump (Gargett, 1990). Verreaux's Eagles form monogamous pair bonds, are highly territorial and their longevity may extend for a period of up to 40 years (Vernon, 1972; Steyn, 1982).

Figure 1: Verreaux's Eagles: (*A*) Juvenile; (*B*) Breeding pair on the nest, (*C*) Adult in flight. Photograph credit: Garth Heydenrich.

Verreaux's Eagles have been evaluated as a species of "Least Concern" and are primarily distributed in southern Africa in Zimbabwe, South Africa and Lesotho; however they are scarce in Namibia, Botswana and Mozambique (Gargett, 1990; Hockey *et al*. 2005; (BirdLife International, 2008). In Southern Africa their distribution is widespread along the eastern escarpment in areas characterised by rocky terrain, lightly wooded savannah

and grasslands (Davies & Allan, 1995; Gargett, 1990; Hockey *et al*. 2005; Figure 2). Their distribution strongly overlaps that of the Rock Hyrax (*Procavia capensis*), a small mammal weighing up to 4.3 kg which inhabits vegetated rocky outcrops (Gargett, 1990; Old & Shoshani, 1982). The Verreaux's Eagle's diet consists of 70 - 90 % Rock Hyrax, but may include other prey items such as small mammals (hares), reptiles (snakes and lizards) and birds (guineafowl, francolins and bustards) (Davies & Allan, 1995; Steyn, 1982; Boshoff *et al.* 1991; Chiweshe, 2000). A habitat that supports adequate prey density is critical to the survival of Verreaux's Eagles, particularly with respect to breeding success (Davies, 1994). Breeding occurs annually and each cycle includes several stages including nest building, incubation, nestling and post fledging dispersal (Rowe, 1947; Gargett, 1990).

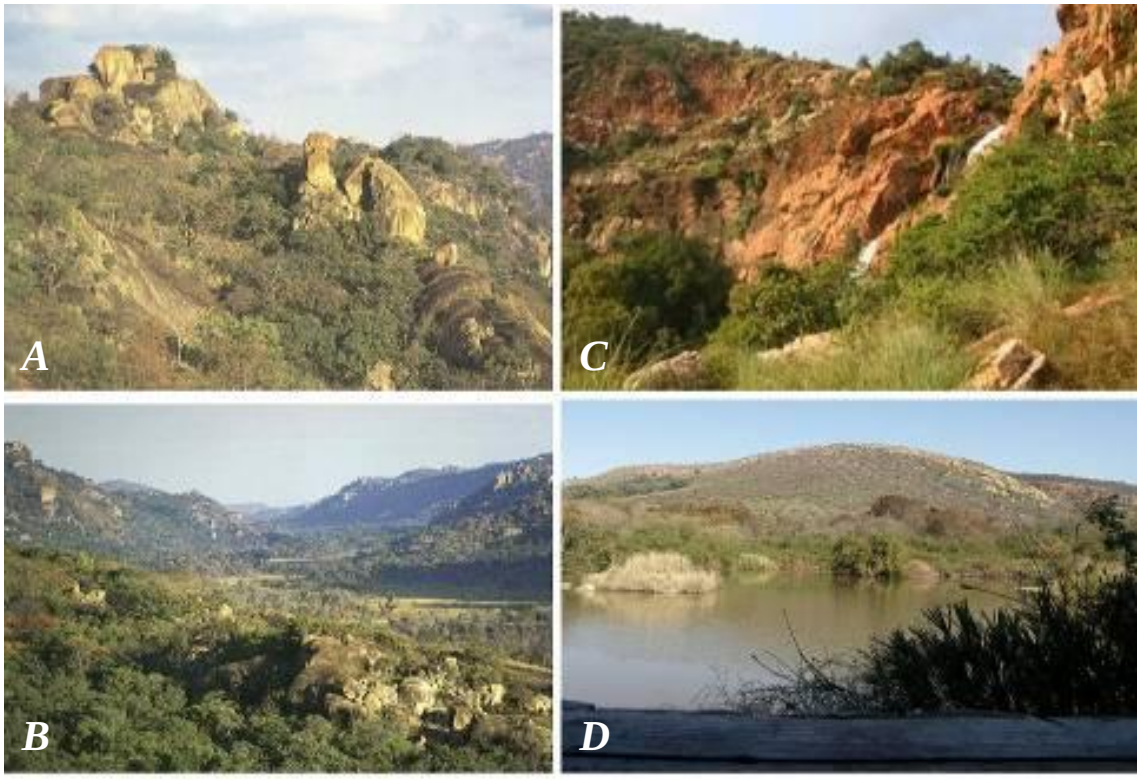

Figure 2: Typical Verreaux's Eagle habitat types. (*A & B*) Motopo Hills, Zimbabwe. Photograph credit: Gargett, 1990. (*C & D*) Walter Sisulu National Botanical Garden, South Africa. Photograph credit: Garth Heydenrich.

A complete breeding cycle takes approximately eight - nine months (Rowe, 1947; Brown, 1952; Gargett, 1990). The first stage involves nest building on rocky cliff ledges or rocky pillars using leafy sprays, sticks and branches (Rowe, 1974; Gargett, 1990). Copulation commences during nest building and continues until nest building has been completed; while feeding may also occur on the nest during this stage (Gargett, 1990).

Each breeding cycle usually yields two eggs followed by incubation which is predominately carried out by the female and takes approximately 44 days (Rowe, 1947; Gargett, 1967). Hatching may take up to three days while the interval between the first and second egg is approximately four days (Rowe, 1947; Gargett, 1967; Steyn, 1982). Although two eggs are commonly laid and hatched, only one nestling survives as the first hatched chick, referred to as Cain, monopolises food resources and physically injures the second hatched chick, referred to as Abel (Rowe, 1947; Gargett, 1967). This is commonly referred to as cainism, siblicide or fratricide. The period from egg laying until fledging of the juvenile takes approximately 140 days (Rowe, 1947). During the post-fledging period, which takes approximately 98 days, the juvenile will remain in the adult's territory, hone its flying skills and learn hunting skills from the adults (Gargett, 1990). Towards the end of the post-fledging period the adults will become increasingly aggressive towards the juvenile encouraging it to leave their territory (Rowe, 1947; Gargett, 1990).

The breeding success of Verreaux's Eagles may be affected by numerous factors including, but not limited to, changing of a mate, prey availability and habitat destruction, of which the latter may influence raptor populations by impacting on prey abundance (Gargett, 1990; Sorely & Anderson, 1994).

1.2 Walter Sisulu National Botanical Garden

The Walter Sisulu National Botanical Garden (hereafter referred to as the Botanical Garden), was founded in 1982 and is located in Gauteng Province of South Africa (Figure 3). The Botanical Garden lies along the Roodekrans and Paardekraal Ridges and is situated within the Rocky Highveld Grassland at an approximate altitude of 1 740 metres above sea level (Rutherford & Westfall, 1994; Bredenkamp & Van Rooyen, 1996). Verreaux's Eagles have been recorded in the Botanical Garden since the 1940s and breeding activities have been recorded at the Witpoortjie Falls which is situated within the Botanical Garden since 1993 (BEPR, unpublished reports).

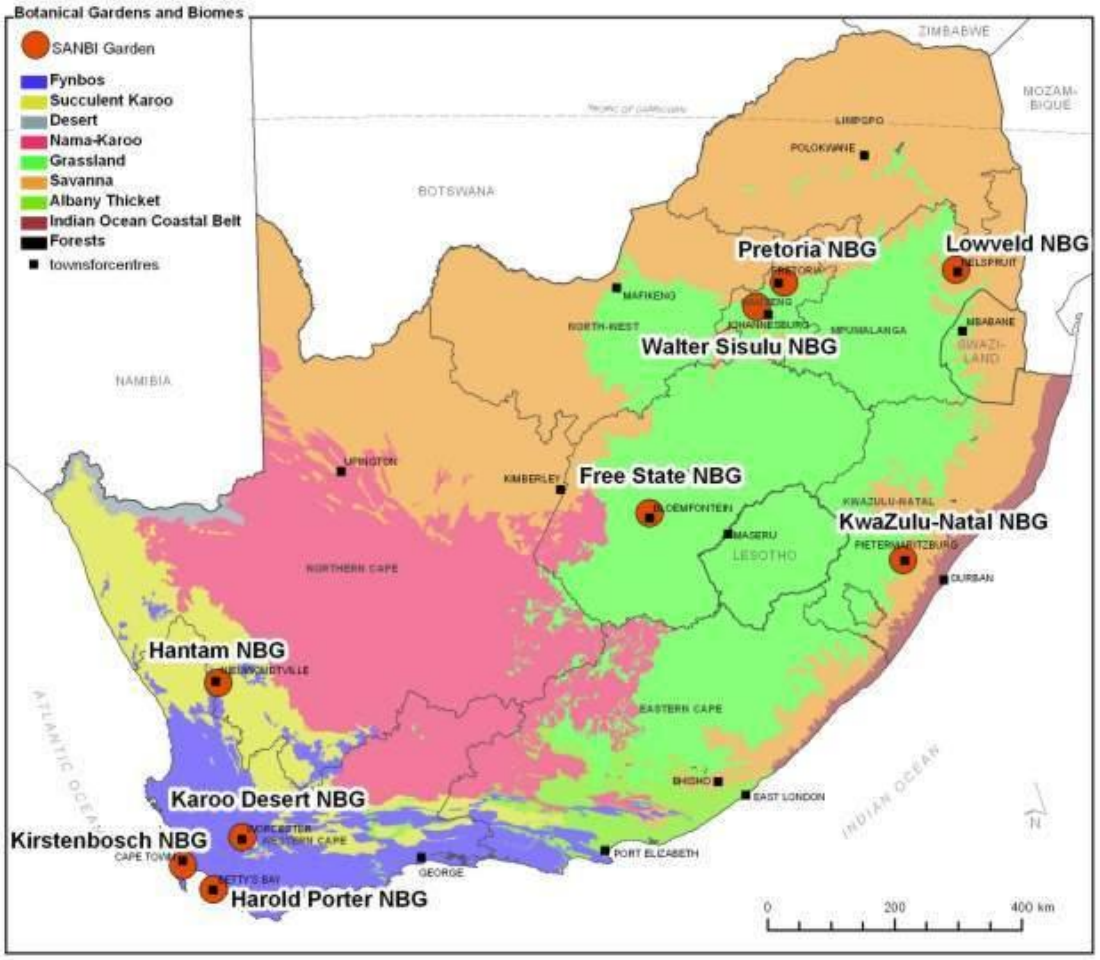

Figure 3: The location of the Walter Sisulu National Botanical Garden (NBG) is indicated among several other Botanical Gardens in South Africa (South African National Biodiversity Institute, 2010).

The Verreaux's Eagles at the Botanical Garden are an iconic attraction for visitors as they are the only pair that breeds within the 'green urban' region of Johannesburg (Simmons *et al.* 2007). Despite extensive urbanisation in the vicinity of the nesting site and hunting grounds, they continue to breed at the Botanical Garden (Cringan & Horak, 1989; Marzluff, 1997; Simmons *et al*. 2007; BEPR, unpublished reports). The Gauteng Province is growing rapidly; the population was > 7.3 million in 1996 and grew to > 8.8 million in 2001 with urbanisation levels falling above 90 % (Statistics South Africa, 2001; Kok & Collinson, 2006). Intense urbanisation, such as through urban sprawl, initiates a change in the landscape's morphology through the fragmentation of natural habitats (Palomino & Carrascal, 2007). Fragmentation occurs when corridors which promote species movement between habitat patches are broken and subsequently affect ecosystem functioning such as faunal movement (Saunders *et al.* 1991; Collinge, 2000; Janes & Bowers, 1998; Andreassen *et al*. 1998). A study on root voles concluded that

habitat destruction and patch isolation through fragmentation were affecting their dispersal patterns within the ecosystem (Andreassen & Ims, 1998). Urbanisation has transformed, disturbed and fragmented the natural habitat surrounding the Botanical Garden and consequently Rock Hyrax, which should be the primary prey species, have diminished in the vicinity of the nest site (Albertson, 2008; Davies & Allan, 1995; BEPR, unpublished reports).

1.3 Black Eagle Project Roodekrans

The recording of information on the Verreaux's Eagles at the Botanical Gardens started on an *ad hoc* basis in 1988 by Dr. Gerhard Verdoorn of the Raptor Conservation Group. In 1992 the Black Eagle Monitoring Project was initiated as a unit of the Raptor Conservation Group; at this stage their aims and objectives included:

1. Educating and informing the public about Verreaux's Eagles and raptors in general.
2. Conserving the Verreaux's Eagles in the Walter Sisulu National Botanical Garden.
3. Monitoring the Verreaux's Eagles' breeding cycle.

In 1998 the group's name was changed to the Black Eagle Project Roodekrans (BEPR); a non-profit organisation which uses volunteers to carry out the abovementioned aims and objectives. The BEPR monitors the Verreaux's Eagles throughout the year, albeit more frequently during the breeding season, and assesses whether any action needs to be taken such as the initiation of the supplementary feeding programme. In the 1990's it was thought that they were suffering a prey shortage as there appeared to be a gradual decline in prey abundance from previous years (BEPR, unpublished reports). In 1993, following the hatching of the first chick, monitors noted the lack of an immediate food supply brought to the nest despite extensive hunting efforts. By comparison, in previous years prey was brought to the nest within four hours of hatching (BEPR, unpublished reports). Lastly, the observed increase in domestic chickens (*Gallus gallus domesticus)* being taken as prey further supported the idea that prey availability was diminishing (BEPR, unpublished reports). Therefore a supplementary feeding programme was initiated whereby a farmed domestic rabbit carcass of approximately 1.5 - 3 kg is placed at several locations within the vicinity of the nest on an 'as needed' basis during the breeding season as decided by the BEPR manager (BEPR, unpublished reports). Supplementary feeding programmes have been used previously as part of raptor conservation strategies in response to insufficient food resources (Bretagnolle *et al.* 2004).

The BEPR has made several advancements towards the conservation of the Verreaux's Eagles in the Botanical Garden. In 1999 a negotiation was made with the South African Microlite Association that the area over the nesting gorge within the Botanical Garden is a no-fly zone so as not to disturb the breeding pair (BEPR, unpublished reports). Furthermore, in association with the Urban Raptor Conservation Project and the Birds of Prey Working Group for the Endangered Wildlife Trust, the BEPR has proposed the conservation of the Verreaux's Eagles through the establishment of the Little Falls Wildlife Reserve (see Appendix 1). The aim of the 2.15 km^2 reserve is to preserve the ridge habitat which will ultimately benefit the Verreaux's Eagles as well as other urban and semi-urban raptor species. The BEPR has also played a significant role in preserving the area within a 5 km radius of the nesting site by opposing urban development such as Sugarbush Estate and Protea Dal development (see Appendix 2). This important area is threatened by proposed developments such as Homes Haven Extension 1, Little Falls Extension 16, Sugarbush Estate and Protea Dal development. Homes Haven Extension 1, which is located approximately 4 km north-west of the nest site, was approved in 2006. In the same year the Gauteng Department of Agriculture, Conservation and Environment (GDACE) approved Phases 1 and 2 of Sugarbush Estate; the remaining portions (Phases 3 - 5) were authorised however the decision is under review; refer to Figure 4 which illustrates areas which have been developed since 2006 and areas proposed for future development. Key undeveloped hunting areas that lie within 10 km include the Botanical Garden; the watershed between the Roodekrans and Paardekraal Ridges; Little Falls; Kloofendaal Nature Reserve and Kingskloof (Albertson, 2008).

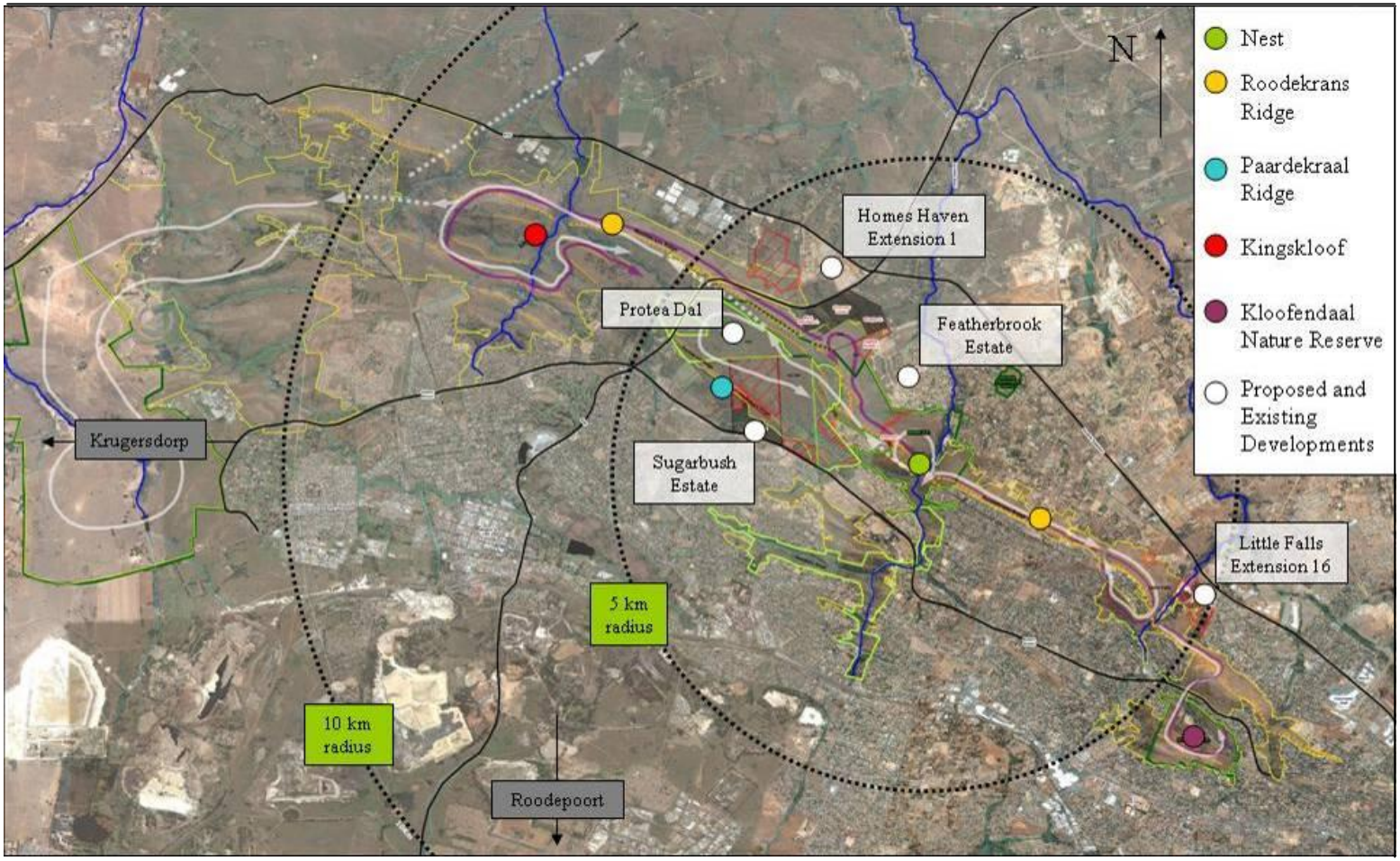

Figure 4: The location of the nest site, including major developments, geographic features, core hunting habitat and observed flight patterns[1] (the purple arrows indicate the hunting patterns prior to 2005; the grey arrows indicate the patterns as of 2008; Albertson, 2008)

[1] It should be noted that insufficient evidence was given as to the construction of the flight patterns; the information has likely been gathered as part of the BEPR monitoring process with insufficient modelling and/or evidence of said flight patterns.

1.4 Aims and Objectives

It was hypothesised that suitable hunting habitat utilised by breeding Verreaux's Eagles at the Botanical Garden is decreasing as a result of urban development and anthropogenic land transformations. As a result, these transformations were predicted to result in dietary composition changes, including a switch to suboptimal prey species and a subsequent decrease in breeding success. Therefore the objectives of this study were to:

1. Assess whether the core habitat, deemed suitable for hunting by the Verreaux's Eagles, has decreased due to increasing urbanisation.
2. Interpret the feeding data and assess whether there has been a switch to different prey resources and/or a decrease in prey provisioning.
3. Interpret the breeding data and identify any changes in breeding variables and breeding success during the observation period.

Using the results of this research, the BEPR will be able to assist the National Department of Environmental Affairs (DEA), the Gauteng Department of Agriculture, Conservation and Environment (GDACE) as well as Non-Governmental Organisations in developing sound policies with respect to future urbanisation and development of the remaining natural habitat surrounding the Botanical Garden.

2. METHODS

The objectives of this research were met through two avenues; the first using aerial photographs to identify a change in the hunting suitable habitat surrounding the Botanical Garden and the second using feeding and breeding data collected by the BEPR from 1993 to 2008. The results were analysed in order to draw final conclusions regarding the long-term prospects for the persistence of the Verreaux's Eagles at the Botanical Garden.

2.1 Aerial Photography Analysis

The effect of increased urbanisation on the Verreaux's Eagle's available hunting range was assessed using historic aerial photographs. The flight plans and a total of 283 aerial photographs were sourced from the Department of Land Affairs (DLA) for the region within the topographical locale of 2627BB for 1984, 1993 and 2007 (see Appendix 4).

Each individual photograph was georeferenced using the Georeferencing Tool in ArcInfo, a Geographic Information System (GIS) designed by ESRI, in combination with a georeferenced 1:50 000 topographical map. Georeferencing is the process whereby an image such as an aerial photograph is assigned spatial coordinates in order to conduct further analyses. For the purpose of this analysis the photographs were not orthorectified as georeferencing was deemed sufficient. The photographs were clipped using Arc Toolbox's Data Management Clip Function, mosaiced into a single image for each year using Arc Toolbox's Data Management Mosaic Function and then assigned a geographic projection of WGS84. A round polygon was created in ArcCatalogue and then used with ArcInfo's Editor Function to delineate the total area situated 0 - 10 km away from the nest. This distance from the nest site was selected as it is inclusive of the eagle's core hunting habitat which ranges from 0 - 5 km from the nest (Albertson, 2008). However, Figure 4 illustrates that the eagle's flight patterns are extending beyond 5 km and in fact beyond 10 km as well. Therefore, why was a radius larger than 10 km away not selected? Hunting closer to the nest site (i.e. 0 - 10 km), is advantageous as it yields a shorter and safer distance over which to carry prey, particularly during the breeding season (Gargett, 1990). Flying excursions further from the nest places "ever-increasing stress on the birds, particularly during the breeding season...[as] excursions to find sufficient prey [expose] them to potentially fatal risk factors as they are forced to fly over urbanised areas and farmland" (Albertson, 2008).

The landscape in each aerial photograph was delineated using polygons assigned with a projection of WGS84 into two categories. These categories included:

A. Undeveloped and therefore potentially suitable and partially suitable for prey species, including continuous and fragmented sections of natural, undisturbed areas and agricultural land, and
B. Developed and therefore presumably unsuitable for prey species, including urbanised and developed areas such as residential developments, shopping complexes, mine tailings dams and any area altered through building or clearing activities.

The cut-off size for undisturbed habitats was approximately 0.005 km^2. The proportion of habitat change was calculated for a distance of 0 - 10 km away from the nest and the results were compared between years and then considered with respect to the feeding and breeding data.

2.2 Black Eagle Project Roodekrans Data

The Verreaux's Eagles at the Botanical Garden have been monitored since 1993; volunteers use binoculars and telescopes during six hour long shifts, primarily on weekends and public holidays. A volunteer remains at the base of the Witpoortjie Falls with the telescope positioned on the nest itself. The volunteer carries a pair of binoculars and record the eagle's behaviour. Should they fly away from the nest, perform aerial displays; behave territorially towards other avifaunal species or towards the fledged juvenile, all this information is recorded in a colloquial manner. During the breeding season, the routine changes slightly, as volunteers will focus their attention on the nest itself and on the video feed from the webcam to record activities on the nest. Annual monitoring awareness workshops and training programmes are supplied in order to ensure consistent, accurate and responsible monitoring (refer to Appendix 3). The observation data are collated and analysed each month by the group manager who generates annual reports for the public's perusal (BEPR, unpublished reports).

2.2.1 Feeding Data

The BEPR collects feeding information for the purpose of assessing provisioning rates and dietary composition, specifically during the breeding season. The dataset includes the date of the feeding episode, the prey species that was caught and any anecdotal behaviour.

The reliability of this dataset was compromised as it is inconsistent and incomplete. Some years are incomplete while other years are missing altogether. Furthermore, the reason for data absence on a day to day basis is unknown (i.e. whether due to lack of prey

or lack of monitoring). The monitoring is not strictly limited to weekends and public holidays as claimed, monitoring during the breeding season is more frequent and unpredictable. Therefore the data could not be extrapolated and provisioning rates could not be calculated. The data available for this study are summarised in Table 1.

Table 1: Availability of feeding data collected by the BEPR.

Year	Data Availabile
1993 - 1995	No data
1996	May & September
1997	January - June
1998	May - February 1999
1999	March - January 2000
2000	No data
2001	March - December; however prey items were not identified to species
2002	March - November; however no records were taken for supplementation
2003	February - November; however no records were taken for supplementation
2004	March - December
2005	March - October
2006	March - October
2007	March - September
2008	March - August

2.2.2 Breeding Data

The BEPR collects breeding data in order to ascertain breeding success for each season. A season appeared to be deemed successful with the fledging of the juveniles. These data include information collected from 1993 - 2008 and includes laying and hatching dates, nestling survival and siblicide events, fledging date, date of post-fledging dispersal and any noteworthy or anecdotal behaviour. These data were used to calculate the duration between laying of the first and second egg, the incubation period, the duration between hatching of the eggs, the nestling period and the duration to fledgling dispersal.

2.2.3 Data Analysis

The feeding dataset was analysed, as far as possible given the nature of the data, to assess the proportion of prey species that were caught by the Verreaux's Eagles per year. A non-parametric test was conducted because the sample size was small and did not conform to normality. The Kruskal-Wallis test, which is a non-parametric test that compares three or more unpaired groups, was used. Also referred to as a Kruskal-Wallis one-way analysis

of variance by ranks, the test yields a P value which answers the following: if the populations really have the same median, what is the chance that random sampling would result in medians as far apart as observed in the research?

The breeding dataset was analysed to assess consistency in breeding patterns, laying and hatching dates, incubation, fledging and post fledging dispersal period, as well as breeding success. The breeding data that were selected for analysis began with the laying of the first egg and ended with either the post fledging dispersal or the final recorded sighting of the juvenile.

3. RESULTS

3.1 Aerial Photograph Analysis

In total, 283 aerial photographs were used for the three years analysed, whereby each year was represented by a single aerial photograph, delineated by a 10 km radius around the nest. The individual photographs were of varying quality and following the mosaic process, the quality of the final photographs was poor. The borders between the individual images often blurred the image or the individual photographs did not align accurately following the mosaic process. This quality issue resulted in the partially subjective selection of Type A (undeveloped) habitat types since what appeared to be suitable may in fact not have been. Furthermore, due to the lack of clarity, continuous suitable habitats may have been incorrectly "fragmented" for ease of delineation which jeopardises possible fragmentation analyses. Table 2 lists the attributes of suitable habitat within 10 km of the nest for 1984, 1993 and 2007. Figure 5 illustrates suitable habitat for Verreaux's Eagle prey at the Botanical Garden.

Table 2: Undeveloped habitat within 10 km of the nest site; including predicted changes in undeveloped habitat due to from proposed developments.

Attribute	1984	1993	2007	2007 - 2010
Total prey habitat area (km^2)	146.4	130.5	116.7	115.7
Percentage of 10 km radius	46.6 %	41.6 %	37.2 %	36.8 %
Number of fragments	264	196	191	*
Minimum fragment size (km^2)	0.01	0.01	0.005	*
Maximum fragment size (km^2)	20.0	16.9	12.8	*
Mean fragment size (km^2)	0.6	0.7	0.6	*
Standard deviation	1.6	1.8	1.5	*

* The fragmentation information could not be inferred for 2007 - 2010 as the aerial photographs were not available.

Between 1984 and 2007 (23 years), the undeveloped natural habitat potentially suitable for prey species within 10 km of the nest decreased by 29.7 km^2. This equates to a loss of 9.5 % of the total 314.2 km^2 within the 10 km radius. In 1984 the total loss of undeveloped potentially suitable prey habitat was already 53.4 %, and by 2007 it was 62.9 %, leaving only 116.7 km^2 (37.2%) of undeveloped potentially suitable prey habitat within 10 km of the nest site. The number of fragments, the minimum fragment size, the maximum fragment size decreased by 27, 50 and 36 % respectively while the mean fragment size remained constant.

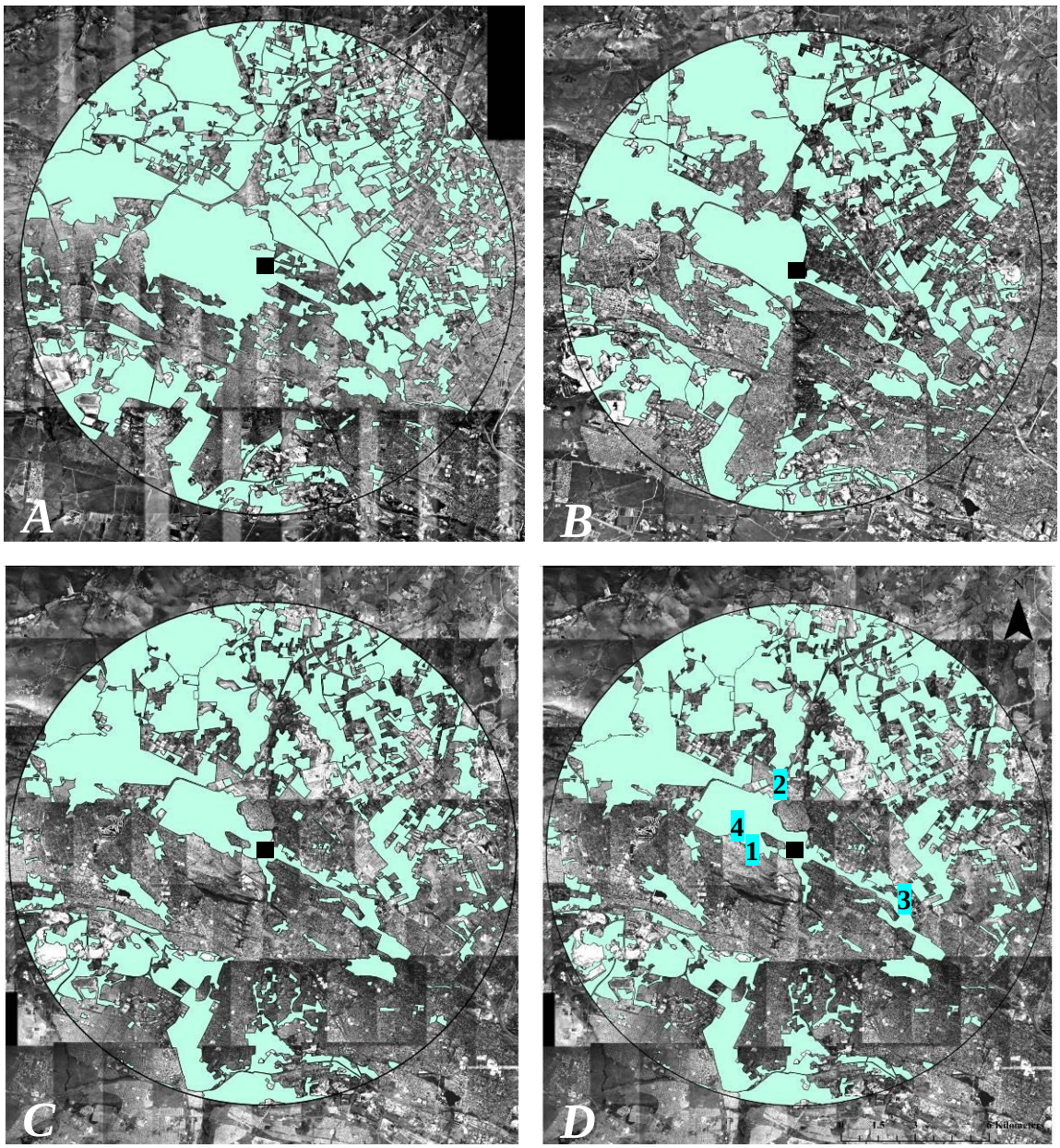

Figure 5: Available prey habitat, indicated by the blue polygons, within a 10 km radius of the nest site which is indicated by the black square in the centre of each image; (A) 1984; (B) 1993; (C) 2007; (D) Post 2007 including proposed developments to be constructed during 2007 - 2010, (1) Sugarbush Estate; (2) Homes Haven Extension 1; (3) Little Falls Extension 16; (4) Protea Dal development.

3.2 Feeding Data

The complete dataset for feeding and supplementation data from 1993 - 2008 has been summarised in Appendix 6. Refer to Table 3 for the proportion of prey species caught by the Verreaux's Eagles from 1996 - 2008 and the results of the Kruskal-Wallis test.

Table 3: Proportion (%) of prey species caught by the Verreaux's Eagles at the Walter Sisulu National Botanical Garden (1996 - 2008)

	Bird[2]	Dassie	Francolin	Guineafowl	Mammal	Rabbit	Rat	Unknown
Mean	5.9	7.5	5.0	23.8	3.7	9.8	1.8	34.4
Std. Deviation	10.3	7.7	10.1	27.3	7.1	11.1	3.7	10.3
Lower 95% c/limit	-0.7	2.7	-1.4	6.4	-0.8	2.7	-0.6	8.5
Upper 95% c/limit	12.4	12.4	11.4	41.1	8.2	16.8	4.1	60.3

Note: No data available for 2000

There was a significant difference in the proportion of different food types in the diet of breeding Verreaux's Eagle during the sampling period (1996 – 2008) (Kruskal-Wallis ANOVA by Ranks, $H_{7, 96} = 17.33690$ $p = .0154$)

3.3 Breeding Data

Breeding data were available for a 16 year period from 1993 - 2008. However, two breeding cycles occurred during the years 1994, 1996 and 1998 following initial failed attempts. In 1997 a third egg was laid, an extremely rare event as Gargett (1990) only recorded a single instance of a third egg being laid. In 1994 both chicks from the first clutch died and subsequently a second clutch was laid. In 1996 the eagles double clutched, reportedly due to bi-weekly supplementation during the nesting stage. Once the second clutch had hatched the unfledged juvenile of the first clutch was chased away by the male to a distance of approximately 1.5 km from the nest. As a result, the adult eagles had to provide prey for the second clutch as well as the juvenile. Although the supplementation continued bi-weekly, the adults were absent during extended hunting trips and, presumably as a result of this, Cain died due to either heat exposure or lack of food and the unfledged juvenile was killed by an unidentified predator. In 1998 the male disappeared and the female abandoned the clutch following several days of solitary incubation; however a second breeding cycle commenced when a new mate appeared. (All breeding data cited above were sourced from BEPR, unpublished reports).

[2] The Verreaux's Eagles were known to catch small bird and mammal species on several occasions which were recorded in the dataset as 'bird' or 'mammal'.

Table 4: Summary of the breeding data collected by the BEPR.

Category	Average (days)	Standard Deviation	N	Other Studies: Average (days)
Duration between laying	4.2	0.8	19	3 [(1)]; 4 [(2&3)]
Incubation period	44	1.2	15	43 - 44 [(1)]; 44 - 45 [(2&3)]
Duration between hatching	3.6	0.8	12	2 [(1)]
Nestling	100.1	5.3	14	90 - 98 [(3)]
Post fledging dispersal	88.1	16.1	12	97 [(1)]; 98 [(3)]

[1] Rowe, 1947; [2] Steyn, 1982; [3] Gargett, 1990

4. DISCUSSION

4.1 Aerial Photograph Analysis

The aerial photograph analysed indicates that the core hunting habitat has diminished significantly over the previous two decades from 1984 - 2007. This decline in natural habitat is mirrored with the increase in developed and subsequently unsuitable habitat, primarily as a result of housing developments (Albertson, 2008). This habitat change may have affected the Verreaux's Eagles as urbanisation is known to affect birds through the spread of urban areas into natural habitats (Chace & Walsh, 2006). The effect of fragmentation and habitat degradation on the abundance, richness and diversity of raptors was illustrated in a study conducted in Spain which concluded that habitat transformation, particularly due to the expansion of urban areas, and the subsequent fragmentation of the natural habitat compromises the conservation of raptors (Carrete *et al.* 2009). One can surmise that due to the subjective selection of undeveloped (i.e. potentially suitable) habitats in this study, the apparent fragmentation is not representative of the change in fragment size and number over time. Even though fragmentation could not be quantitatively assessed, the eagle's flight patterns combined with the aerial photograph analysis, (Figure 4 & Figure 5 respectively), suggest that the Verreaux's Eagle's flight patterns may be moving beyond the 5 km boundary in a north westerly direction of the nest while excluding the highly fragmented north easterly area (Figure 4; Albertson, 2008). Since fragmentation increases as a result of urban development, the apparent decrease in fragment number is nonsensical (Swenson & Franklin, 2000).

The National Environmental Management Biodiversity Act (Act No. 10 of 2004) (NEMA) categorises threatened ecosystems as being critically endangered, endangered, and vulnerable and those in need of protection. The natural habitat surrounding the Botanical Garden is threatened, as it has "undergone degradation of ecological structure, function or composition as a result of human intervention" (NEMA, 2004). This natural habitat is ecologically important, particularly the Roodekrans Ridge which runs the length of the Botanical Garden and fulfils the habitat requirements for Rock Hyraxes (Davies, 1994). Ridges are regarded as biodiversity hotspots; not only does their spatially heterogeneous nature provide a "greater diversity of potential niches for plants and animals than do homogeneous landscapes", but they serve as important corridors for species movement (GDACE, 2006). Examples of rare, endemic or endangered species found along the Roodekrans ridge and in the surrounding natural habitat include Silver Sugarbush (*Protea roupelliae*), Fez Aloe (*Aloe peglerae*), African Hedgehog (*Atelerix frontalis*), Bibron's Blind Snake (*Typhlops bibronii*), Giant Bullfrog (*Pyxicephalus adspersus*), Rock Scorpion (*Hadogenes gunningi*) and the Roodepoort Copper Butterfly

(*Aloeides dentatis*) (Albertson, 2008; BEPR, 2009). According to the GDACE's Ridge Guideline, the Roodekrans Ridge is classified as a Class Three Ridge System and is regarded as having lost between 35 - 65 % of its surface area to activities such as urban development. The aerial photograph analysis confirms this as by 2007 the natural habitat up to 10 km from the Roodekrans Ridge had decreased by 63 %.

4.2 Feeding Data

The feeding data can be analysed from two perspectives, firstly the amount of prey that is needed and secondly the proportion of prey species being caught. Regarding the former, Gargett (1990) states that one Rock Hyrax per day is required for a breeding pair whereas < 1 Rock Hyrax per day is required out of the breeding season (Gargett, 1990). Since it was not possible to extrapolate the BEPR's feeding data, the results could not be compared to Gargett's findings and those from other established studies.

In 1999 there were 29 instances of supplementation and since the BEPR only supplements on an 'as needed' basis this degree of supplementation suggests that prey was scarce during this period. The supplementation for this year started in April, peaked in July and ended in January 2000, which coincides with the increased food requirements during the breeding season (Gargett, 1990).

Regarding the type of prey species, although Verreaux's Eagles are prey specific, the diet of those in the Botanical Garden included numerous other prey items such as guineafowl, francolins, rats, rabbits and several other bird and mammal species. Rock Hyrax is the preferred prey of Verreaux's Eagles (Steyn, 1982); however in this case Rock Hyrax constituted 7.5 % versus guineafowl which proved dominant constituting 23.8 % over the total monitoring period. Therefore, it can be surmised that prey items are taken based on their relative abundance and accessibility rather than species type or preference (Janes, 1984; Ontiveros & Pleguezuelos, 2000).

4.3 Breeding Data

The breeding cycles from 1993 - 2008 appear to have followed a pattern similar to typical Verreaux's Eagle breeding activity elsewhere despite the double clutching episodes and the three egg clutch in 1997 which is considered extremely rare (Rowe, 1947; Steyn, 1982; Gargett, 1990). Supplementation in 1996 and 1997 was high and this may have played a role in the double clutch and the three egg clutch respectively. The incubation period, the duration between laying and hatching, the pre-fledging period and the pre-

dispersal period are all in agreement with Gargett's findings (1990). Furthermore, since raptor breeding output is food limited or that raptors are unlikely to breed at all in times of food shortages, one may assume that a food shortage was not experienced (Brown & Amadon, 1968; Newton, 1979; Tjernberg, 1983; Gonzalez *et al.* 2006). However, the affects of either the supplementation programme or artificial prey populations may be skewing the breeding success and frequency. Therefore since the breeding results appear reasonably successful, and predictable, over the past 16 years it seems that the monitors may be overplaying the possibility that prey availability is limiting breeding.

4.4 Effects of Stress on the Verreaux's Eagles at the Botanical Garden

The Verreaux's Eagles are exposed to an array of stresses related to living in an urbanised area, particularly limited food resources. Prey availability, which is critical in determining the suitability of raptor territories, is determined by the density of and accessibility to prey (Widen, 1994). With the apparent reduction in natural habitat as seen through the aerial photograph analysis, the density of and accessibility to prey may be affected. Prey supply is especially important during the breeding season (Davies, 1994). Verreaux's Eagles in the Motopo Hills of Zimbabwe bring up to 1.2 prey items to the nest per day during the nestling stage and taking, on average, 1.1 prey items per day in the post-fledgling stage (Gargett, 1990). A direct comparison with Gargett's results could not be made and therefore one cannot assume that insufficient prey items are being caught. However, Gargett's results were not prejudiced by supplementary feeding which may be affecting the amount of prey caught by reducing the need. This however is only an assumption as other studies have shown that supplementary feeding does not affect parental provisioning rate (Gonzalez *et al.* 2006).

The influence of stress, due to presumed resource scarcity and habitat disturbances may have caused atypical behaviour of these Verreaux's Eagles (BEPR, unpublished reports; Gargett, 1990). Indicative behaviour included aggression over prey items; extended absences during incubation by the male; and mating episodes which occurred outside the conventional breeding time. Generally only occurring during nest building, mating outside this stage is a displacement activity due to disturbance, such as those experienced in the urbanised environment surrounding the Botanical Garden (Gargett, 1990). Prey consumption on the nest by the female eagle, outside the time frames of the breeding season is also unconventional, as prey is usually eaten close to the kill location (Gargett, 1990).

Continued urbanisation, particularly the Sugarbush Estate and the Protea Dal development, will contribute to this stressful living environment. As previously mentioned, the BEPR is taking legal action against these developments and in order to test the hypothesis that the eagles are unable to catch sufficient prey, they have decided to suspend the supplementation programme in 2009 (L. Woodcock pers. comm.).

5. CONCLUSIONS

Decreased resources have played a role in the decline of raptors in the Northern Cape Province (Anderson, 1996) and therefore successful conservation of the Verreaux's Eagle at the Botanical Garden is also likely to be dependent on the preservation of resources. With the continued destruction of core prey habitat through urban development, the conservation of these eagles will be hampered. In 2008, Homes Haven Extension 1 was under review and investigations into the remaining phases of Sugarbush Estate were still pending. However, should these developments go ahead the expected loss of natural habitat over the next five years within the core 5 km radius around the nest site will be approximately 1.03 km^2 (1.3 %). This will include proposed developments such as Sugarbush Estate (0.6 km^2), Homes Haven Extension 1 (0.1 km^2), Little Falls Extension 16 (0.2 km^2) and Protea Dal development (0.13 km^2). Therefore in order to counteract the reduction in food availability, continued supplementation may be necessary for the eagle's long term persistence (Simmons *et al*. 2007).

Site specific protection, such as the proposed Little Falls Wildlife Reserve may not be successful as this type of reserve would prove too small (Pedrini & Sergio, 2002). Conservation management of the wider environment has been proposed as a more effective tool (Widen, 1994; Tucker & Evans, 1997). Therefore in order to preserve this pair of breeding Verreaux's Eagles, the effects of further development on this sensitive ridge ecosystem must be taken into consideration by GDACE. Furthermore, as an umbrella species, raptors are important for conservation planning at a larger scale as they serve as indicators of urban ecosystem health by identifying changes in habitat structure and the fragmentation thereof (Simberloff, 1988; Thiollay, 1989; Chace & Walsh, 2006). Protection of these indicative species is in line with NEMA's mandate which aims to "provide for the protection of ecosystems that are threatened or in need of protection to ensure the maintenance of their ecological integrity".

The Verreaux's Eagles at the Botanical Garden appear to be breeding successfully despite apparent food shortages. However, the threshold point at which the eagles cease to breed successfully and leave their territory is unknown. It is unlikely they will tolerate further depletion in their prey base and should supplementation cease this threshold may be reached (Simmons *et al*. 2007). The absence of a consistent food source, resulting from the continued destruction of the natural habitat surrounding the nest site, is more likely to lead to a change in territory outside of the Botanical Garden (Gargett, 1990).

6. LIMITATIONS AND FUTURE STUDIES

The analyses of the breeding and feeding data were limited due to the qualitative nature of the data. The monitoring programme was limited due to time and financial constraints. Monitoring occurred inconsistently but primarily on weekends, public holidays and sometimes during the week albeit more frequently during the breeding season. Therefore, any activity occurring outside the monitoring sessions or activity not captured on the webcams could not be analysed as part of the dataset and this may have skewed the results. For example, the ability to deduce hunting success would be limited as the eagles are often out of sight during monitoring periods (Gargett, 1990). The feeding data were collected sporadically from 1993 onwards and a complete dataset was not available. Therefore, there was no comprehensive picture of the eagle's feeding activities throughout the project's duration. These data are often qualitative in nature with no clear scientific goal, therefore it is lacking in consistency and applicability. The BEPR's monitoring regime can be improved though consistency with respect to their monitoring periods. Monitoring sessions where no prey is recorded need to be captured on the database as this "miss" data can be used for extrapolation purposes. Therefore, based on the shortcoming of the BEPR dataset, a guideline for carrying out the monitoring programme has been attached as Appendix 7.

The process of georeferencing a multitude of photographs is open to error which was experienced in this study as the quality resulted in partially subjective delineation of the undeveloped (i.e. potentially suitable) habitat types. These difficulties may be overcome by selecting the unsuitable habitat instead thus accurately representing fragmentation of the suitable habitat over time. Sourcing of photographs with greater clarity may be more suitable for future studies.

Expanding the scope of the aerial photography analysis beyond the 10 km boundary set for this research may prove beneficial as it was noted that the eagles utilise the habitat beyond this boundary (Albertson, 2008). There is little information available on where these eagles hunt as the distance from the nest site increases. This hampers any interpretation on understanding the long term survival of eagles in the area. However, the importance of assessing available habitat within a core range is highlighted.

Following a 21 year study of the Verreaux's Eagles in the Motopo Hills of Zimbabwe, Gargett (1990) deduced that the study of a raptor species in isolation, without studying its prey base, will limit the research's scope (Gargett, 1990). Therefore, additional studies into the eagle's prey population may prove beneficial. Studies of movements of this

breeding pair beyond their core breeding area (e.g. satellite tracking harnesses) may also provide insight into their hunting patterns.

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