Exploring the breeding diet of the Black Sparrowhawk (*Accipiter Melanoleucus*) on the Cape Peninsula

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Abstract

This study investigates the diet of breeding Black Sparrowhawks (*Accipiter melanoleucus*) on the Cape Peninsula of South Africa. Macro-remains of prey were collected from below and around the vicinity of nests throughout the breeding seasons of 2012 and 2013. These prey items were then identified down to species where possible through the use of a museum reference collection. In both years 85.9% of the individual remains were those of *Columbidae,* which corresponds with the only other diet study on Black Sparrowhawks. Red-eyed Doves were the most common prey species, accounting for around 35% of the diet's biomass and 45% of the prey items. Helmeted Guineafowl were also an important component of the diet for certain nests, making up on average 26.4% biomass of the diet. I found very little difference in diet between the different stages of breeding (pre-lay, incubation and nestling), despite the fact that females only contribute significantly during the nestling state and are considerably larger than the males. I also found little difference in the diet composition between pairs which bred either earlier or later in the year, despite productivity being significantly higher for earlier breeding pairs. However, a crude analysis of the overall diet per month revealed increased diet breadth in the early lay months as opposed to the later months. This was a result of fluctuations in the presence of Laughing Doves, Feral Pigeons and Helmeted Guineafowl, probably driven by those species breeding behaviour. Lastly, I also found no difference in the diet composition between pairs with either pure or mixed plumage morph compositions in this polymorphic species. This study provides further evidence to the claim that Black Sparrowhawks on the Cape Peninsula are benefitting from man-altered environments that provide perfect habitat for suitable prey.

Introduction

The Black Sparrowhawk, *Accipiter melanoleucus,* breeds throughout much of Sub-Saharan Africa's forested regions, (Malan & Robinson 1999; Allan et al. 2005). However individuals were not recorded on the Cape Peninsula until 1993 (Ottle 1994). This followed a two-decade rapid westward expansion of the South African population. Their success in this region is highlighted by the roughly 40 breeding pairs that exist there today (Amar et al. 2013). This success in numbers and increased distribution has been attributed to a number of factors, most of them anthropogenic. Climate is often thought to be a key influence in avian range shifts, and is believed to have been important for birds in Europe (Walther et al. 2002). However, as yet we have no indication that this has been important in this species' expansion in South Africa (Hockey & Midgely 2009). Rather human induced habitat alteration is thought to be the main driving factor for the Black Sparrowhawk and many other avian species that have expanded westward (Hockey et al. 2011). Since natural woodlands in the west of South Africa are rare, the mass artificial creation of them in the form of exotic plantations are likely to be a key factor in this species expansion (Hockey et al. 2011). The large alien Pine (*Pinus* spp.) and Eucalyptus (*Eucalyptus* spp.) plantations on the Peninsula are the preferred nesting sites of this species, so long as those trees are at least 18m in height (Malan & Robinson 2001). This is one such new advantage that has allowed Black Sparrowhawks to colonise the winter-rainfall season for breeding. That breeding occurs during the rainy season in this region is a potentially important feature of this population as it differs from the rest of South Africa's populations, which also breed in winter, but this coincides with the dry period (Allan et al. 2005). However use of these artificial woodlands as nest sites may be just one component driving Black Sparrowhawk's current success, as the other surrounding man-altered environment has provided other previously non-existent advantages to other birds which are prey of the Black Sparrowhawk.

Many accipiters such as the Black Sparrowhawk attack from cover, whether from a perch or in flight (Newton 1986; Allan et al. 2005). This is because accipiters are often slower than their usual prey in straight flight and thus they typically rely on concealment to get as close to their prey as possible before making a short attack (Newton 1986). This is the preferred hunting method; however there have been a few cases of Black Sparrowhawks chasing prey for up to 1.5km (Allan et al. 2005). Human-driven modification of the landscape has changed historical Fynbos shrubland towards a mosaic of tree-filled and open sub-urban areas (Hockey et al. 2011). This has almost certainly resulted in hunting benefits for Sparrowhawks by providing new sources of concealment on the edge of open areas, the ideal habitat for catching avian prey (Malan & Robinson 1999; Curtis et al. 2007). Many other Accipiters are bird specialists, for example, the Eurasian Sparrowhawk (*Accipiter nisus*) preys almost exclusively on birds, making up 97% of their diet in Europe (Newton 1986), while previous research in South African found that 98% of the Black Sparrowhawks diet was also birds (Malan & Robinson 1999). This preference for avian prey is linked to the Sparrowhawk's talon morphology. The talons are specifically adapted to capture aerial prey, as unlike other raptors, certain toes are greatly elongated for grasping prey and pulling it into the shorter but stronger back toes (Newton 1986). A previous study of the Tokai-Stellenbosch region (a similar area to this study) found that Red-eyed Doves (*Streptopelia semitorquata*) were the most preferred prey species along with other *columbidae* (pigeons and doves), which together accounted for 72.6% of the biomass and 86.8% by numbers of the sparrowhawk's diet (Malan & Robinson 1999). The sub-urban 'garden' habitat is most likely supplying the vast majority of the bird's prey as *Streptopelia* doves and other columbidae are all commonly found in such habitats (Dean 2005). While *columbidae* were less prominent in the diet of Eurasian Sparrowhawks (*Accipiter nisus*); they still formed the largest component at 24.4% (Newton 1986). Like the Black Sparrowhawk, Cooper Hawks (*Accipiter cooperii*) in Indiana nest in and around urban areas (Roth & Lima 2003). They also favour *columbidae* in their diet where in one study two *columbidae* species made up 43% of their diet (Roth & Lima 2003).

As one of the largest accipiters in Southern Africa, Black Sparrowhawks are able to kill a large variety of prey, including large game species over 1kg in weight such as the Helmeted Guineafowl (Guineafowl; *Numida meleagris*) and the Hadeda Ibis (*Bostrychia hagedash*) (Malan & Robinson 1999; Allan et al. 2005). Other prey species in South Africa include ducks, thick-knees, egrets and even smaller accipiters (Malan & Robinson 1999; Allan et al. 2005). Larger prey is believed to be usually taken by females as the sexes are extremely dimorphic in size with males typically weighing around 450g, half as much as females who can reach close to one kilogram (Tarboton & Allan 1984; Allan et al. 2005). Some studies have found that this sexual dimorphism in raptors results in marked changes in the size distribution of prey items during breeding. For example, during the incubation period of Eurasian Sparrowhawks (*Accipiter nisus*), the average size of prey items is significantly smaller due to the male doing almost all the hunting (Newton 1986). Fluctuations in the diet composition are also regulated by the activities of prey species themselves (Newton 1979) and raptors are generally believed to frequently time their breeding decisions around this (Sebele 2012).

Black Sparrowhawks exhibit widespread discrete plumage polymorphism between either predominately black (dark) or pied (light) morphs (Amar et al. 2013). Throughout Southern Africa the dark morph is considered rare (Allen et al. 2005), however in the Cape Peninsula population over 75% of the birds are dark morphs (Amar et al. 2013). The complete reversal in this morph ratio has yet to be explained, however various hypotheses exist. Amar et al. (2013) showed that the adult morph type follows a typical Mendelian inheritance pattern, indicating that the morph is passed down to offspring. The dominance of the dark morph could thus simply be explained by the founder effect, whereby the initial colonising individuals were predominately dark. However another hypothesis is that the dark morph results in increased reproductive success through some environmental advantage. The obvious environmental difference between this population and the rest of South Africa (where the white morph predominates) is the higher levels rainfall during the breeding season in the Cape Peninsula. Recent reviews have further highlighted a strong link between light and polymorphism, suggesting crypsis plays a key role (Galeotti et al. 2003). Light conditions may be lower for the Cape population due to winter rainfall, and so it's likely that the dark morphs' crypsis may be of benefit via background matching (Amar et al. 2013). With increased crypsis, the dark birds may well have a hunting advantage, and can acquire more or better quality prey, especially during the breeding season. This explanation has received further support where Amar et al. (2013b) have shown that high frequencies of dark morphs throughout the South African population are strongly associated with a higher proportion of rainfall occurring during the winter breeding months. This suggests that the high frequency of dark morphs in the Cape Peninsula may well be an adaptive trait, rather than simply the result of the founder effect. However the white morph plumage is not necessarily a disadvantage as it is thought to not cripplingly reduce crypsis and in fact may benefit certain hunting strategies (Louette 2012). The stark contrast created by the white patches on the birds is thought to assist in flushing and confusing groups of prey during open chases. The idea that both morph's have specific advantages over the other is supported by data from Amar et al. (2013c). No significant difference in productivity was found between nesting pairs of purely dark or white morphs, however significantly higher productivity was found for mixed pairs (pairs comprising of both a dark and a light morph) over those which were pure (i.e. contained only one morph) (Amar et al. 2013c). One hypothesised mechanism for these differences is thought to be the mixed pair's ability to exploit a wider range of conditions, habitats or prey species, thereby expanding their foraging niche and the resources available during the chick rearing period (when both parents hunt) (Amar et al. 2013c).

The colonisation of the Cape Peninsula has resulted in a portion of this population altering their breeding phenology. In doing so, these individuals have increased their productivity (Martin et al. 2013; Sebele 2012). The population has been shown to have a bimodal distribution of laying dates; with the later mode corresponding to the distribution of the other populations in South Africa (Sebele 2012). This earlier mode indicates significant plasticity among the population, which has clearly helped them more easily colonise new areas such as the Cape Peninsula (Martin et al. 2013). However the hypothesis that this shift in lay dates is due to rainfall has received little support (Martin et al. 2013) and the role of diet has not yet been explored. The supposed increase in prey availability due to the sub-urban/urban environment may reduce feeding pressure and account for the early laying period as was the case for Northern Goshawks (*Accipiter gentilis*) in North America (Kenward 2006). Such food availability is also implicated as an explanation for the cases of Black Sparrowhawks double brooding (Curtis et al. 2005). Furthermore in Curtis et al.'s (2005) study, all the successful double-brooding pairs on the Cape Peninsula initially layed in the early mode, suggesting either sufficient prey availability, high-quality prey, or both, throughout the year.

In this study, I focus on the diet of Black Sparrowhawks on the Cape Peninsula. I will examine prey data throughout the breeding seasons of two adjacent years. Various questions will be investigated, including the overall composition of their diet in terms of species numbers and their biomass. I will test the hypothesis that the diet composition will fluctuate for breeding pair throughout the various stages of their breeding season. On this issue I will also test whether the diet composition changes throughout the different months of the breeding season. I will also test whether the laying dates of breeding pairs result in different diet compositions. Finally I'll test the hypothesis that the composition of plumage morphs of breeding pairs affects their diet composition.

Methods

Study Site

All data were collected on the Cape Peninsula during the Black Sparrowhawk breeding seasons (March – November) of 2012 and 2013. The majority of nest sites were situated around the eastern slopes of the Table Mountain Chain (34°00′S, 18°26′E) in an area of roughly 150km^2, while other extended south towards Cape Point and east towards the Cape Flats. The area consists of various habitat types, including urban areas, sub-urban areas (houses and greenspaces), exotic plantations, vineyards and patches of Fynbos and indigenous Afromontane forest (Amar et al. 2013). The region experiences a temperate Mediterranean climate with locally variable winter rainfall (Cowling et al. 1996) which has an annual average of approximately 1250mm (South African Weather Services). Average minimum and maximum temperatures are 12°C and 21°C respectively (South African Weather Services).

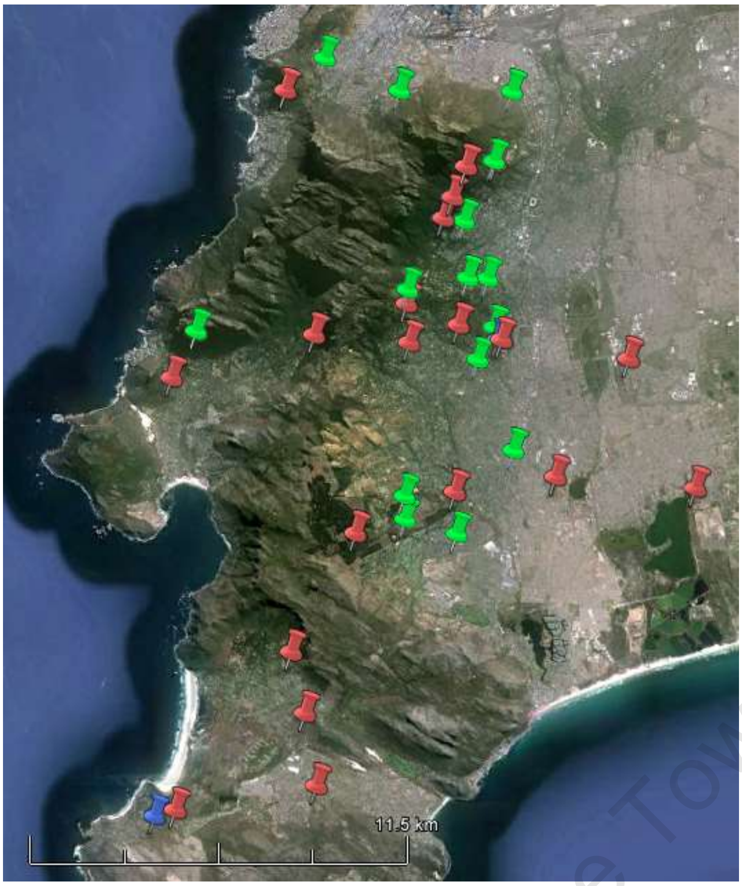

Figure 1 – Satellite image of the Cape Peninsula with Black Sparrowhawk nests marked at their locations. Red nests are those that were only sampled in 2012, blue only in 2013, and Green during both years.

The breeding altitudes of the birds range from sea level to about 300 m (Amar et al. 2013). A total of 53 nesting attempts were visited over the entire study period, 36 and 17 nests in 2012 and in 2013 respectively. However certain territories of 2012 were revisited in 2013, and data were collected from 38 individual nesting territories in total across the two years (Fig 1).

Prey collection

Prey items were collected by members of the Cape Peninsula Black Sparrowhawk Project during their monitoring visits. Remains included feathers and bones, while pellets were excluded from the analysis. Nest site samples were taken throughout the breeding season at regular two week intervals. All remains in a nest’s vicinity were collected during each collection to ensure that remains found during subsequent visits were produced between the last visit and that date of collection (Amar & Redpath 2005). An attempt was made to place remains from one prey item into individual bags; with multiple remains that were clearly from one individual were placed into a single bag. This was not always possible, and in some cases multiple prey items were clearly included in the same sample bag. The name of the nest and the date of collection were recorded on the bag. A reference collection of the prey species skins and skeletons was obtained from Ditsong National Museum of Natural History and was used to ensure that prey items were correctly identified (Figs. 3 & 4). Prey remains were identified down to species level through feathers and skeletal remains except for raptor prey as no reference material was available. However the elongated middle digits indicated they were *accipitrinae* (Goshawks and Sparrowhawks), making it highly probable that they were either Rufous-breasted Sparrowhawks (*Accipiter rufiventris*) or African Goshawks (*Accipiter tachiro*), the only other *accipirtinae* in the region (Hockey et al. 2005). When necessary (i.e. when multiple prey items were included in the same bag), the most commonly represented element was used to calculate the minimum number of individuals represented in each sample.

Figure 2 - Six humerus bones from the reference collection. Starting from the left, the bones belong to a: Laughing Dove, Turtle Dove, Red-eyed Dove, Speckled Pigeon, Feral Pigeon and Guineafowl. Humerus bones were the most commonly found bone, and they differed markedly in size throughout the common species making for easier identification.

Figure 3 – Skin of speckled pigeon from the reference collection. Species skins were used to identify the feather remains.

Overall composition of the diet

Data across all nests for each species was pooled together for each study year. Column charts were created based on the number of individuals for each species as well as their contribution toward biomass. The weights for biomass were taken from Hockey et al. (2005) and where two weights were offered for a species, usually due to sexual dimorphism, a midpoint was used (Appendix 3). Only the seven most preferred species were shown as well as the pooled contribution of all other species, either those identified to species or those which were only identified down to family or genus.

Breeding period and Morph data

The prey remains were classified as taken during three different breeding stages. These stage were the: ‘prelay’ stage, ‘incubation’ stage, and ‘nestling’ stage. The prelay stage accounted for the time breeding pairs spent building the nest, as well as the females improving body condition in preparation for laying and incubation, during this time the male will often bring food to the female for courtship feeding and during the time the female is in egg laying lethargy where she will rarely hunt, during this time therefore we would expect any prey remains to have been prey caught by the male. The incubation stage accounted for the time between the laying and hatching of eggs, during which the male does the vast majority of hunting while the female incubates the eggs at the nest (Newton 1986). The nestling stage accounts for the time after hatching through to the juvenile leaving the nest site, during the first 2 weeks the female spends the vast majority of her time brooding the chicks before starting to hunt herself from 2-3 weeks onwards. The dates of these stages for each nest were verified through field notes taken by volunteers during each sample collection.

During visits to nests fieldworkers also recorded the morph type of both the male and the female attending the nest. The morphs were determined using recommendations by Amar et al. (2013) where birds with less than 40% white plumage on their throat, chin, breast, and flanks were considered ‘dark’ and those with more than 65% ‘light’. Pairs in which both birds were either ‘dark’ or ‘white’ were considered of a ‘pure pairs while those which had one of each were considered as a ‘mixed pairs. Because of the dominance of dark morphs, only two out of 15 pure morphs were purely white. However, previous research suggested that both pure dark and pure light pairs had similarly lower breeding success as compared with mixed morphs.

Calculating Diet breadth

Diet breadth was calculated to analyse the diversity in the diet of Black Sparrowhawk pairs. Fifteen nests that had a sample size of ten items or more were considered. Diet breadth was calculated using Levin’s index of niche breadth (Levin 1968) which is calculated as follows:

$$B = \frac{1}{\sum p_i^2}$$

$$where\ B = Levin's\ measure\ of\ niche\ breadth$$

$$and\ \ p_i = proportion\ of\ individuals\ recorded\ from\ a\ species$$

Diet breadth was then standardised on a scale of 0 to 1 according the Levin’s Standarised index as follows:

$$B_A = \frac{(B-1)}{(n-1)}$$

$$where\ B_A = Levin's\ standardised\ measure\ of\ niche\ breadth$$

$and\ n = the\ number\ of\ species\ in\ the\ nest\ sample$

This standardisation accounted for the varying samples sizes between nests.

Statistical Analysis

The effect of breeding period on diet composition

Generalised linear mixed models (GLMM) were conducted on the top five most important species (numerically), to test whether their frequency in the diet changed according to different breeding stages (prelay/incubation/nestling). Separate models were run for each of the prey species. A binomial proportional response variable was used of prey items found of the species, over total items found, for each breeding stage. Each model used breeding stage (Prelay; incubation; Nestling) as the explanatory factor and included nest site as a random term to account for the fact that for many (but not all) nests we had information on the proportion of each prey species in the different breeding periods. Although, potentially not strictly true, we assumed that remains from the same nest site over both years were considered independent.

Does diet composition differ between early and late breeders?

A Principal Components Analysis (PCA) was conducted to describe diet composition and variability. This reduced multiple variables into the most important components which described variation between nests. A covariance matrix of six variables (p) was used including the five most present species, and an ‘other’ category. Only nests which had at least 7 or more prey items delivered were used in this analysis, which provided a total of 22 nests over the two years. The PCA created PCA scores for each nest, and only values from the two most explanatory dimensions were considered, Dimensions 1 and 2. These data were then used to test whether diet composition, based on the six species variables, affected whether a breeding pair layed during the ‘early’ (March-May; n=7) or the ‘late’ (June-October; n=15) period (Martin et al. 2013). Two GLMs (General Linear Models) were conducted, each using one of the two sets of PCA Scores as a response variable. Lay period (Early; Late) was used as the explanatory factor. The PCA scores for Dimension 2 all underwent a translation of 2 to create only positive values, before undergoing a $\log^{10}$ transformation. Both sets of scores were tested for normality using a Shapiro-Wilks test. The nests' PCA scores were correlated with their sample size to make sure there was no correlation bias.

I created another PCA to further explore diet differences over time (within a year). A covariance matrix of six variables (p) was used including the five most present species, and an 'other' species category. The eight months of the breeding season were used as individuals. A standardised diet breadth score for each month was also calculated. I then tested whether there were any statistical differences between samples collected in the 'early' months (March-May) and the 'late' months (June-Oct). A linear regression was used to test whether diet variability changed throughout the eight months. PCA scores of the first two dimensions for each month were regressed against their standardised diet breadths.

Does diet composition differ between the plumage morph of breeding pairs?

To test whether the plumage morph compositions of breeding pairs' affects their diet composition, a GLM in combination with data from the PCA scores (described above) was used. The morph of the breeding pair (Pure, n=15; Mixed, n=7) was used as the explanatory factor. Another GLM was conducted to test whether plumage morph affected the variability of pairs' diet. The GLM used the diet breadth scores of 15 nests as the response variable. Diet breadth underwent a square-root transformation and was tested for normality using a Shapiro-Wilks test. The morph of the breeding pair (Pure, n=9; Mixed, n=6) was again used as the explanatory factor. The smaller sample size reflected the difference in the minimum number of samples required for each text (10 for diet diversity, and 7 for the PCA composition measure).

All analyses were conducted using RStudio coupled with R (Version 3.0.1 [R Development Core Team]). GLMMs were undertaken with package lme4 (Version 1.0) (Bates et al. 2013). Principal Components Analyses (PCAs) were undertaken with package FactoMineR (Version 1.25) (Husson et al. 2013). The package lsmeans (Version 1.10) (Lenth 2013) was used to undertake post-hoc Tukey tests to check for significant differences between factor levels as well as outputting so-called least-squares means for factor combinations.

Results

Overall diet composition

Based on their minimum numbers, a total of 315 and 101 prey items were collected during 2012 and 2013 respectively. Fifteen prey species were identified in 2012 and nine in 2013. The seven raptor remains were only identified down to sub-family levels, while one lapwing remain was identified down to genus (Appendix 3). Each nest site had an average of 7.9 ± 1.3 prey remains (mean ± 1 SE; min - max = 1 - 42; n = 53) collected during both years. The six most frequently encountered prey species in the diet were the same in both 2012 and 2013 and the presence of smaller raptors in the diet was also consistent (Table 1; Fig. 4). In both years Red-eyed Doves and Feral Pigeons were the two most common species and four of the top five were always *columbidae* (Table 1; Fig 4). In 2012 Red-eyed Doves and Feral Pigeons equally contributed the most to the biomass of the diet, however in 2013 Guineafowl were the largest contributor to biomass in the diet with a 4.70% increase from 2012 (Table 1; Fig. 4). However Guineafowl remains were only found at 12 nest sites and over 50% of them at just three. Speckled Pigeons were also much more common in the diet in 2013, almost doubling their contribution in numbers.

Table 1 – Table of the most common prey species in the Black Sparrowhawk diet in 2012 and 2013. Contribution by number of items and biomass are shown.

Species	**2012**		**2013**	
Common names (*Scientific names*)	**% by numbers**	**% by biomass**	**% by numbers**	**% by biomass**
Red-eyed Dove (*Streptopelia semitorquata*)	43.2	29.7	45.5	28.5
Feral Pigeon (*Columba livia*)	27.0	29.7	24.8	24.8
Laughing Dove (*Spilopelia senegalensis*)	7.3	2.0	4.0	1.0
Speckled Pigeon (*Columba guinea*)	6.3	6.1	11.9	10.4
Helmeted Guineafowl (*Numida meleagris*)	6.0	24.1	7.9	28.8
Spotted Thick-Knee (*Burhinus capensis*)	2.9	3.9	3.0	3.7
Cape Turtle Dove (*Streptopelia capicola*)	1.9	0.8	0.0	0.0
Raptor (Accipitridae)	1.6	1.2	1.0	0.7
Other	3.8	2.5	2.0	2.1

Turtle Doves on the other hand were absent from the diet in 2013. Species that were considered 'Other' included: four Red-Winged Starlings (*Onychognathus morio*); three Olive Thrushes (*Turdus olivaceus*); an African Olive Pigeon (*Columba arquatrix*); a Hadeda Ibis (*Bostrychia hagedash*); a domestic budgie (*Melopsittacus undulatus*); a domestic chicken; a domestic cockatiel (Nymphicus hollandicus); and an unknown species of lapwing, most likely either a Crowned (*Vanellus coronatus*) or Blacksmith Lapwing (*Vanellus armatus*) which are the most common lapwing species in the region (Hockey et al. 2005). An unknown species of mole was the only mammalian remain found.

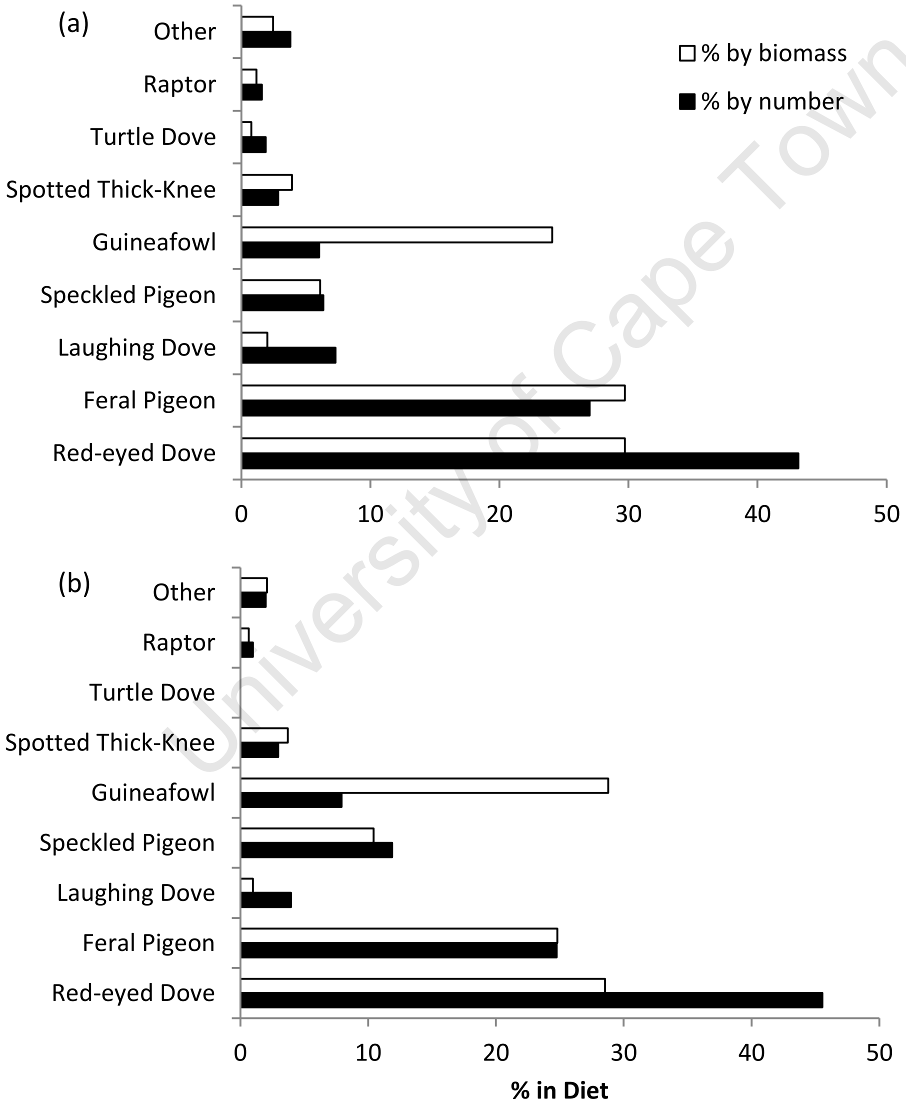

Figure 4 - Overall species composition of Black Sparrowhawk Diet in (a) 2012 and (b) 2013. Both the numbers of individuals (Black bars) and biomass (Open bars) contribution for each species are shown.

GLMM: Breeding stage

Each breeding stage had an average of 140 ± 13 prey remains (mean ± 1 SE; min - max = 162 - 117; n = 3) collected during both years. No model was found to be significant when testing the effect of the lay period on the diet composition (Table 2). Thus the proportions of the five most common species in the diet did not fluctuate significantly throughout the breeding season (Table 2; Fig 5).

Table 2 – GLMM's of the effect of the breeding stage on the composition of the five most common species in the Black Sparrowhawk diet. The untransformed parameter effects ±1 SE; the parameter Z values; and the p values of the models are shown. No model was found to be significant.

Model	Model term		Effect ± S.E.	*Z*	*P*
	Intercept		-0.14 ± 0.22		
Red-eyed Dove		Prelay	0.00 ± 0.00		
	Nest period	Incubation	0.26 ± 0.29	-0.90	0.368
		Nestling	0.23 ± 0.29	-0.79	
	Intercept		-1.13 ± 0.26		
Feral Pigeon		Prelay	0.00 ± 0.00		
	Nest period	Incubation	-0.21 ± 0.32	-0.65	0.518
		Nestling	-0.26 ± 0.32	-0.80	
	Intercept		-3.18 ± 0.51		
Guineafowl		Prelay	0.00 ± 0.00		
	Nest period	Incubation	0.32 ± 0.64	-0.50	0.618
		Nestling	-0.02 ± 0.59	-0.03	
	Intercept		-3.14 ± 0.58		
Speckled Pigeon		Prelay	0.00 ± 0.00		
	Nest period	Incubation	0.51 ± 0.67	0.78	0.438
		Nestling	0.13 ± 0.57	0.23	
	Intercept		-3.35 ± 0.57		
Laughing Dove		Prelay	0.00 ± 0.00		
	Nest period	Incubation	-0.10 ± 0.70	-0.14	0.888
		Nestling	-0.06 ± 0.59	-0.11	

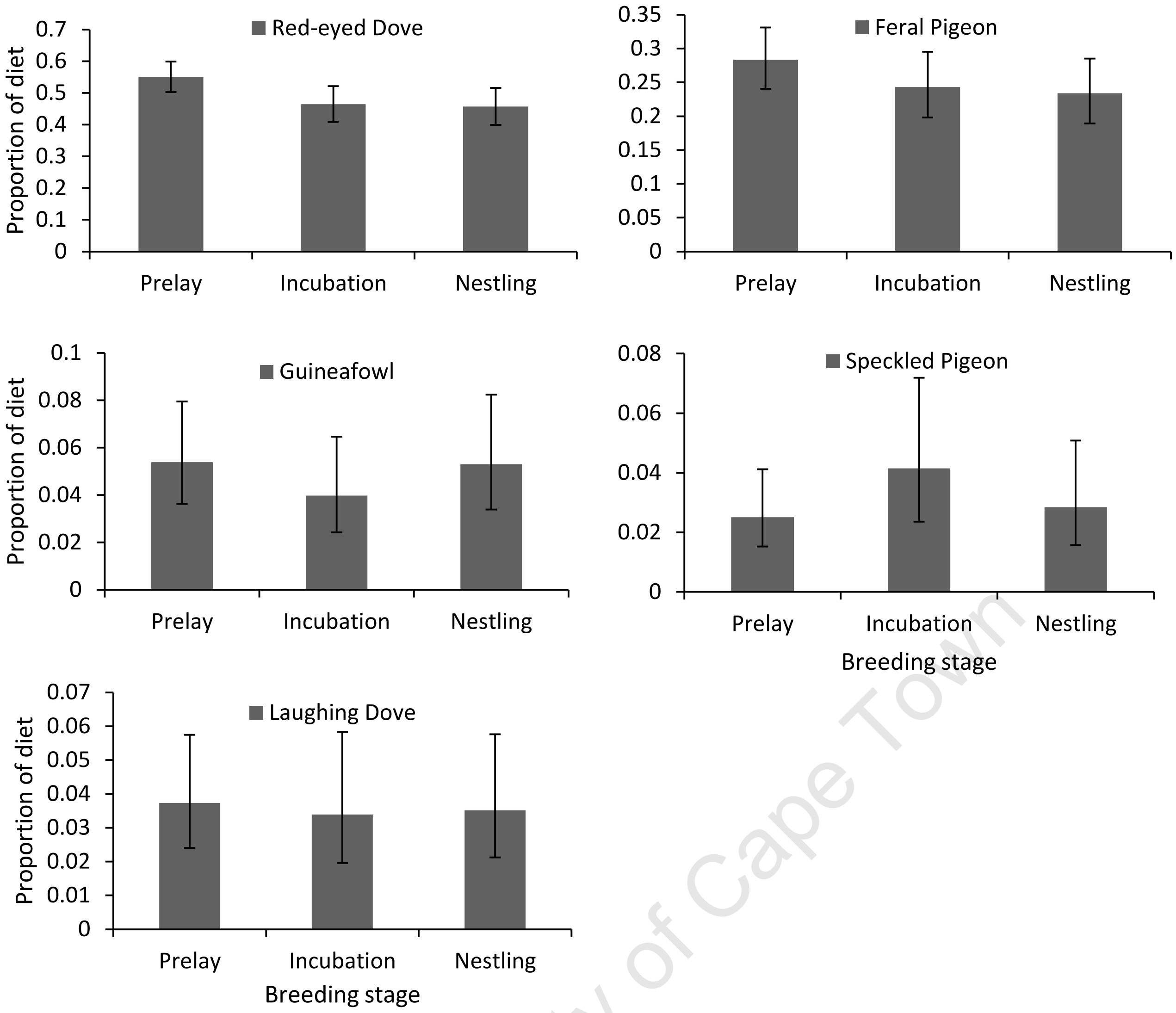

Figure 6 – The species' proportion in the Black Sparrowhawk diet during the three different breeding stages (Prelay; Incubation; Nestling). Proportions for the five most preferred species the: Red-eyed Dove; Feral Pigeon; Guineafowl; Speckled Pigeon; and Laughing Dove are shown. Predicted means ± 1 SE back-transformed to the original scale are shown.

PCA analyses

The first two dimensions of the PCA analysis explained 59.11% of the total variance in the data (Figs. 2 & 3). Along Dimension 1 there was a strong separation between nests with many Red-eyed Dove remains (PCA score = -0.89) and those with many Feral Pigeons and 'Other' species (PCA score = 0.69 & 0.70) (Fig 2; Table 3). Along Dimension 2 the strongest separation is between those nests with many Laughing Doves (PCA score = 0.91) and those with lots of Guineafowl (PCA score = -0.41) (Fig 2; Table 3; Appendix 1).

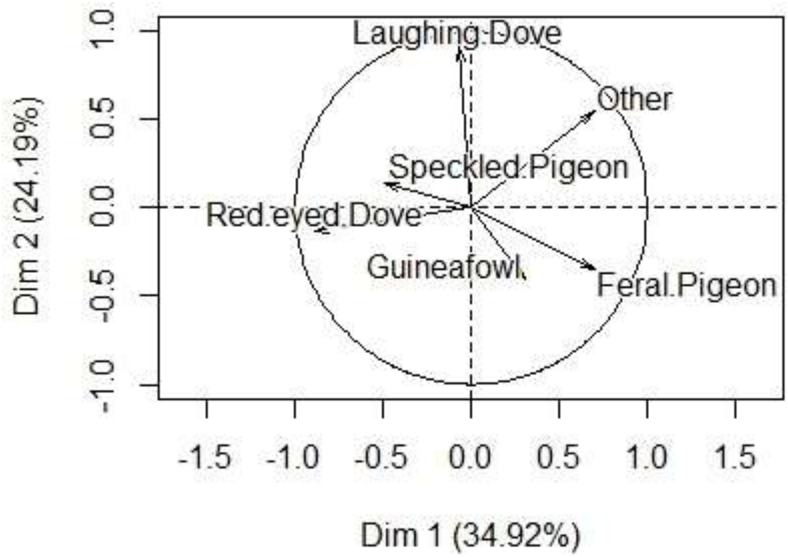

Figure 7 – PCA of species variables. The five most common species in the diet, as well as the rest clumped as ‘Other’, are shown. Together Dimensions 1 and 2 explain almost 60% of the PCA’s variance.

The majority of nests sites seem to be evenly split among favouring Red Eyed Doves and Speckled Pigeon in their diet or Feral Pigeons (Fig. 7). Barring nests 11, 20 and 17; nests fell below the origin of Dimension 2 indicating a stronger presence of Guineafowl and Feral Pigeon in their diet over Laughing Doves and Other species (Fig. 7). Using the PCA scores as a proxy for species composition, I found no significant difference between either PCA axes scores and lay period. Thus there did not appear to be large differences in prey composition between those birds which bred during the early or late lay periods.

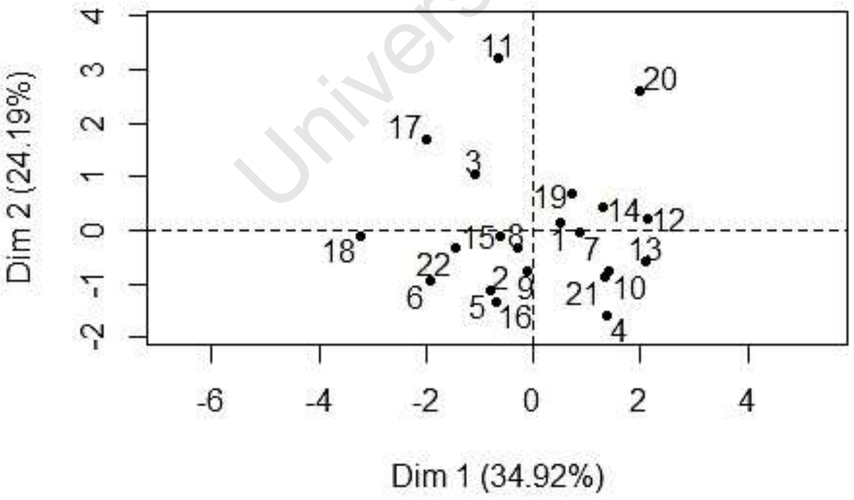

Figure 8 – PCA of individual nest sites in relation to variables. Individual numbers correlate to nest numbers in Appendix 1. Together Dimensions 1 and 2 explain almost 60% of the PCA’s variance.

Table 4 - GLM of the effect of lay period (Early; Late) of 22 Black Sparrowhawk pairs on their subsequent PCA scores in both dimensions 1 and 2. The parameter effects ±1 SE; the parameter t values; and the p values of the models are shown. Neither model was found to be significant.

Model	Model term		Effect ± S.E.	*t*	*P*
PCA Dimension 1	Intercept		0.22 ± 0.57		
		Early	0.00 ± 0.00		
	Lay period	Late	-0.42 ± 0.69	-0.46	0.549
PCA Dimension 2	Intercept		0.30 ± 0.10		
		Early	0.00 ± 0.00		
	Lay period	Late	-0.02 ± 0.13	-0.13	0.898

The second PCA analysis indicates different diet compositions for individual months (Figs. 9 & 10). As with Figure 7, a strong separation exists between Laughing Doves and Feral Pigeons along Dimension 2 (Fig. 9). It further indicates that during certain months the overall composition of the diet favoured more Red-eyed Doves or more Speckled Pigeon (Fig. 9). June (No. 4) showed a strong increase of Laughing Doves in the diet, while May (No. 3) had a majority Guineafowl and Feral Pigeon composition (Fig. 10). March (No.1) and July (No.5), both had compositions dominated by Red-eyed Doves and Feral Pigeons (Fig. 10). The marked differences along Dimension 2 between certain months show a slight chronological trend (Fig. 10). This is illustrated by the breeding months' PCA scores along Dimension 2 almost significantly differing based on the months' lay period (GLM PCA Dimension 2: *P* = 0.055; Table 5; Fig. 10). Those months during the early lay period score much lower along Dimension 2 than those who lay during the lay period (Table 5; Fig. 10). The overall diet composition favoured more Feral Pigeons and Guineafowl over Laughing Doves during the early lay period, before favouring less of these species and more Laughing Doves as well as 'Other' species during the late lay period (Figs. 9 & 10).

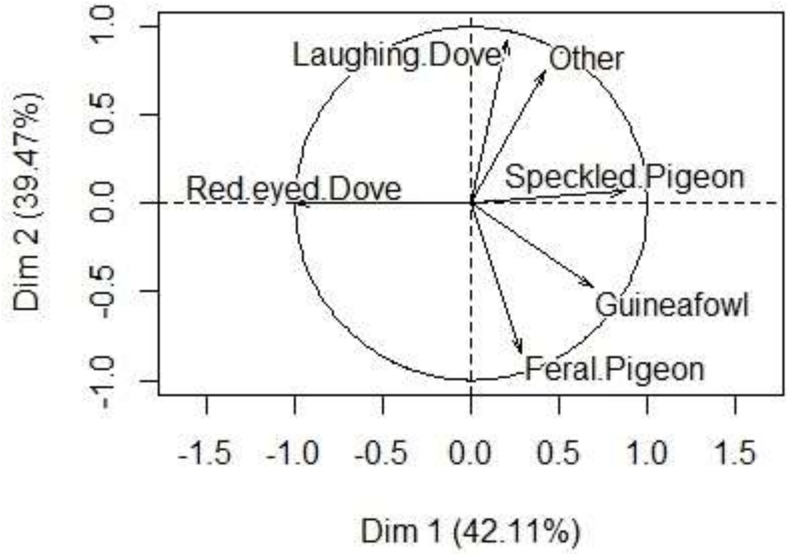

Figure 9 – PCA of Months during the breeding season. The variables of the five most common species in diet, as well the rest clumped as 'Other' are shown. Together Dimensions 1 and 2 explain over 80% of the PCA's variance.

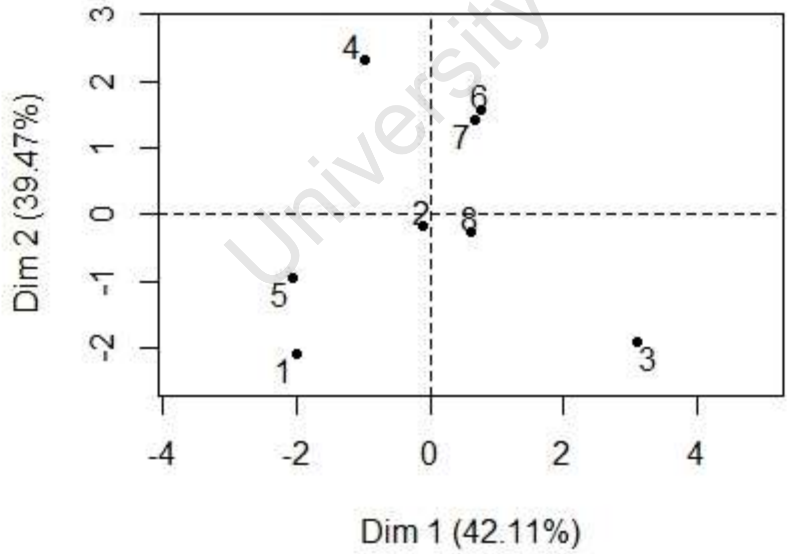

Figure 10 – PCA of individual months in relation to variables. Individual numbers correlate to month numbers in Appendix 1. Together Dimensions 1 and 2 explain over 80% of the PCA's variance.

Table 5 - GLM of the effect of the lay period (Early; Late) of eight months on their subsequent PCA scores in both dimensions 1 and 2 from Figures 9 and 10. The parameter effects ±1 SE; the parameter t values; and the p values of the models are shown. Neither model was found to be significant.

Model	Model term		Effect ± S.E.	*t*	*P*
	Intercept		0.33 ± 1.05		
PCA Dimension 1		Early	0.00 ± 0.00		
	Lay period	Late	-0.53 ± 1.32	-0.40	0.704
	Intercept		-1.39 ± 0.73		
PCA Dimension 2		Early	0.00 ± 0.00		
	Lay period	Late	2.22 ± 0.93	2.38	0.055

A strong negative linear relationship (R^2=0.74) was found between the breeding months' PCA Dimension 2 and their subsequent diet breadths (Fig. 11). The lower a month scored along Dimension 2, the higher its standardised diet breadth score (niche breadth) was (Fig. 11).

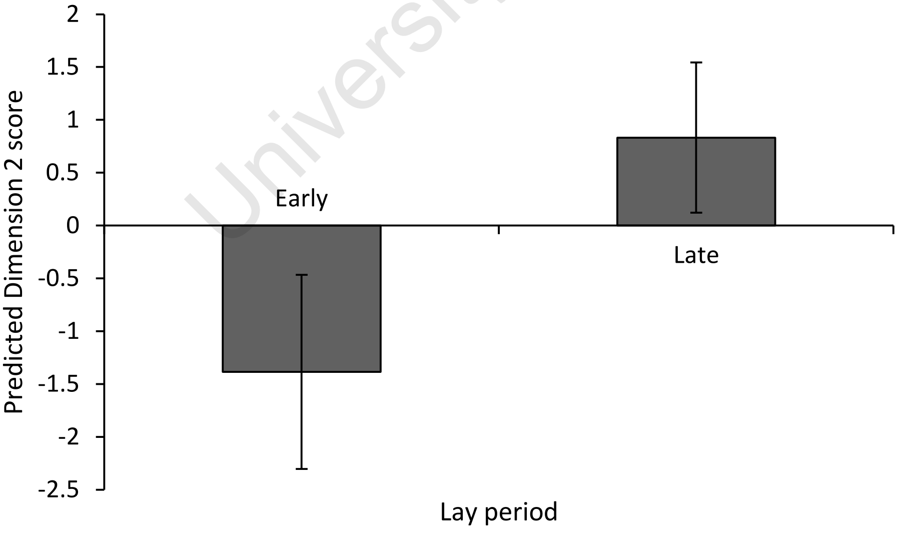

Figure 10 - Mean PCA score along Dimension 2 for month during the early and late lay period. Predicted means ± 1 SE are shown.

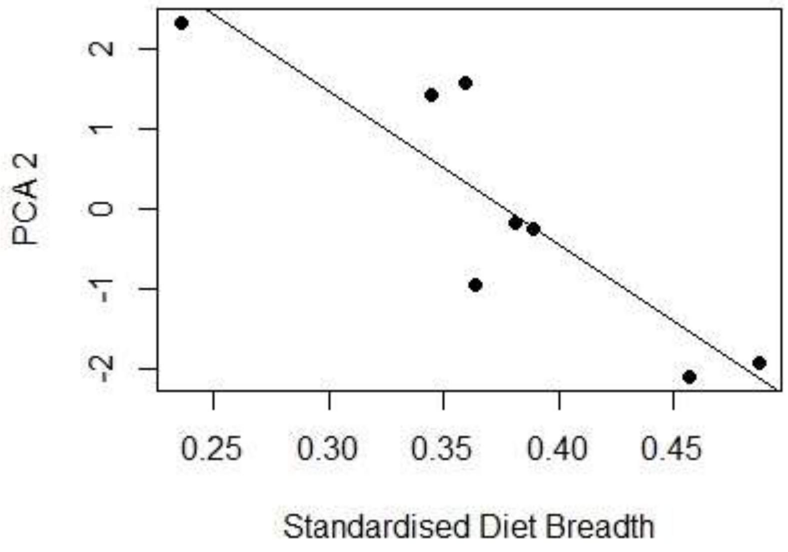

Figure 11 – Linear regression of the PCA dimension 2 score versus the standardised diet breadth for the eight months of the breeding season (*F*=21.23; *df*=6; *P*=0.003). The equation for the regression is: $y_i = -19.2x_i + 7.2$ with an adjusted R-squared of 0.74 (where y_i.= PCA Dimension 2 score and x_i = Standardised diet breadth).

Each nest site used in the GLM analysis of Table 6 had an average standardised diet breadth index of 0.56 ± 0.05 (mean ± 1 SE; min - max = 0.85 – 0.42; n = 15).The plumage morph composition of breeding pairs did not significantly affect those pairs diet breadth (GLM Diet Breadth: *P* = 0.621; Table 6). While those pairs that had mixed plumage morphs had on average a larger standardised diet breadth, they were not deemed significantly so (Fig. 12). The breeding pairs' PCA scores in Dimension 1 or 2 were also not significantly affected by their plumage morph composition either (GLM PCA Dimension1: *P* = 0.651; GLM PCA Dimension 2: P = 0.380; Table 7).

Table 6 – GLM of the effect of the morph of 15 Black Sparrowhawk pairs diet breadths.

Model term		Effect ± S.E.	*t*	*P*
Intercept		0.59 ± 0.08		
Morph	Mixed	0.00 ± 0.00		
	Pure	-0.05 ± 0.10	-0.51	0.621

Table 7 – GLM of the effect of the morph (Mixed; Pure) of 22 Black Sparrowhawk pairs on their subsequent PCA scores in both dimensions 1 and 2 from Figures 7 and 8.

Model	Model term		Effect ± S.E.	*t*	*P*
PCA Dimension 1	Intercept		0.22 ± 0.57		
		Mixed	0.00 ± 0.00		
	Morph	Pure	-0.32 ± 0.69	-0.46	0.651
PCA Dimension 2	Intercept		0.30 ± 0.10		
		Mixed	0.00 ± 0.00		
	Morph	Pure	-0.11 ± 0.12	-0.89	0.380

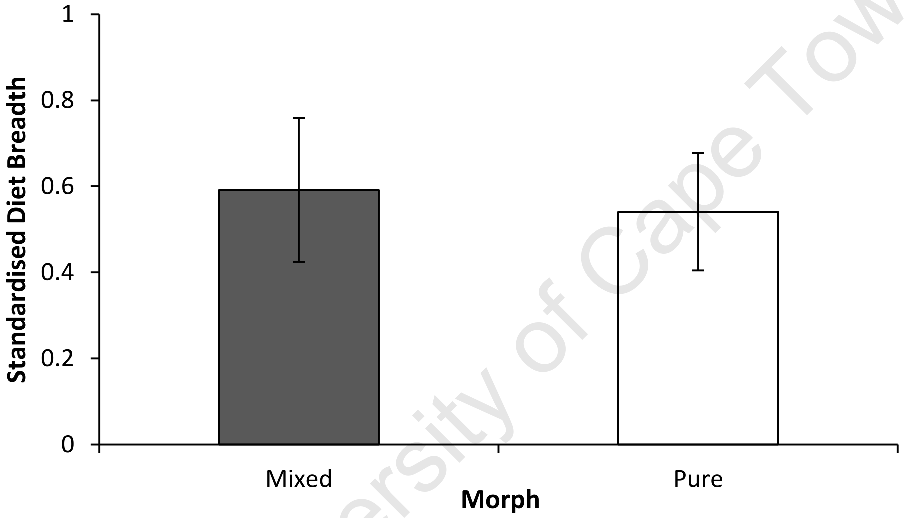

Figure 12 – Mean standardised diet breadths for breeding pairs with mixed versus pure plumage morph compositions. Predicted means ± 1 SE are shown.

Discussion

Results from this study show that Black Sparrowhawks on the Cape Peninsula prey predominately on *columbidae*. The *columbidae* identified in this study range in size from 100 to 400g which makes them an ideal prey size for the slightly larger and much larger, male and female Black Sparrowhawk. All of these species were fairly common and it's thus unsurprising that they form the bulk of the diet. The PCA of the diet split some nest sites into those whose diet was dominated by Feral Pigeons and those dominated by Red-eyed Doves. Nests that were dominated by Feral Pigeons also had fewer Laughing Doves. Feral Pigeons are abundant in urban as opposed to sub-urban environments where the *streptopelia* doves are more common (Dean 2005). The pattern of composition observed in the results could thus be explained by whether a pair's territory is predominately urban or sub-urban.

Other than columbids, the much larger Guineafowl formed a large component of the diet in terms of biomass, if not numerically. The fact that they were mostly limited to a few nests indicates that those Sparrowhawk individuals are likely specialist Guineafowl hunters. Guineafowl were not taken at certain nests where they do occur, indicating it is not simply a matter of availability. On average they weigh much more than even female sparrowhawks making them a high risk, but high reward prey item. I predicted that Guineafowl would be significantly reduced in the diet during the incubation period of the breeding season since a Sparrowhawk male is on average a third of their weight (Hockey et al. 2005). During this period the male is doing the vast majority of hunting, and during this period even if the female does hunt for herself she is unlikely to bring any prey she catches back to nest (Newton 1986). Regardless of this, the results showed no significant indication of Guineafowl proportions in the diet fluctuating throughout the different breeding stages. A possible reason could include that younger and smaller Guineafowl were killed by the male. A more convincing explanation is that females killed them opportunistically when they entered the vicinity of their nests. Field observations confirm that Guineafowl are often present near nests, and it's possible that since they are largely foraging on the ground, they are less vigilant to the arboreal threat posed by the incubating females.

The diet composition of breeding pairs didn't significantly change throughout the three different breeding stages for all five of the most common prey species. However the overall diet composition fluctuated significantly between different breeding months, as well as whether those months were during the early or late lay periods. These changes were largely the result of fluctuations for three species; the Guineafowl and Feral Pigeon which were favoured in the diet earlier in the breeding season, and the Laughing Dove which was favoured later in the breeding season. It's likely that the abundance of these prey species or their breeding behaviour resulted in this. Little is known about the breeding of Feral Pigeons and it's assumed that they lay throughout the year (Dean 2005). Their decrease in the diet during the later months is thus likely to be due to increased availability of other species such as the Laughing Dove. The Laughing Dove laying dates peak during the later months of the year (Dean 2005). The incubation period may make them more vulnerable to Black Sparrowhawks, particularly the males who may be more food stressed from feeding the females as well as themselves. The first heavy rains of the year trigger Guineafowl to start leaving their flocks and pair up for breeding (Ratcliffe 2005). Thus the relative drop of Guineafowl in the diet during the later months of the Black Sparrowhawk lay period correlates to the start of the Guineafowl breeding season. Black Sparrowhawks may find it much easier to locate Guineafowl when they are in large groups as opposed to breeding pairs. Another advantage is that younger juvenile Guineafowl are present in the flocks and are likely to be easier prey (Ratcliffe 2005).

The timing of breeding in Black Sparrowhawks has been found to be extremely variable between individuals (Sebele 2012; Martin et al. 2013). However, whether a pair layed during the early or late period of the year had no significant effect on the composition of their diet. Despite improved conditioning thought to be a possible explanation, my results indicate it's unlikely that these birds are laying early due to a better diet composition (Martin et al. 2013). However the increased diet breadths of the early laying months suggest that the feeding conditions may be better during this time, and the lack of a result for the pairs used in my analysis may be down to sample size. It's also possible that earlier breeders have been residents at a nest site for longer than later breeders, and are thus more used to other environmental conditions of their territories besides prey availability and while Martin et al. (2013) found no evidence of this; they cautioned there relatively small sample size.

The plumage morphs of pairs had no significant effect on the composition or the variability of their diet (diet breadth). This result therefore provides little support for the hypothesis that improved diet through niche expansion is the explanation to account for the increased productivity of mixed pairs (Amar et al. 2013c). However, the lack of a significant result may be due to a lack of power in sample size of both remains and nest sites with different morph combinations.

The occurrence rates of *columbidae* and *phasianids* in the overall diet composition of this study are almost identical to those found by Malan & Robinson (1999). They also found that these two families contributed the bulk of both the numbers and biomass of the Black Sparrowhawk diet. As with Malan & Robinson (1999), this study also found negligible amounts of mammals and small passerines in the diet. Interestingly starlings (*Sturnidae*) form a trivial component of the Black Sparrowhawk diet, despite their similar weights to Cape Turtle Doves and Laughing Doves, and the fact that they are abundant throughout the country where Black Sparrowhawks occur (Hockey et al. 2005). Unless they are just very poor quality food, it's possible this family largely avoids predation through its gregarious behaviour that is not as strongly exhibited by most *columbidae* (Dean 2005; Craig 2005). Red-winged Starlings are known to be particularly aggressive and often use their numbers to mob predators, another potential deterrent (Craig 2005). Since Malan & Robinson's (1999) study was on populations throughout the whole of South Africa, our similar results indicate that the bulk of the Black Sparrowhawk's diet is consistent throughout the country. It also suggests that the diet has not significantly changed over the last decade.

None of the main prey species identified in this study are forest birds (Hockey et al. 2005). This is provides further evidence to the notion that Black Sparrowhawks dependence on exotic forests is mainly limited to nesting sites (Malan & Robinson 2001; Allen et al. 2005). It's thus likely the other man-altered areas are supplying them with the majority of their diet and probably as previously thought, providing them with preferable hunting habitat (Malan & Robinson 1999; Curtis et al. 2005; Allan et al. 2005).

This method used for assessing the diet in this study relied purely on macro-remains, and thus had a likely bias against small prey items (Simmons et al. 1991; Redpath et al. 2001). The method further biases against very small items as well as very large items, as these are less likely to be taken back to the nest. By not including pellets, it not only biases against small prey items, but also mammalian prey (Simmons et al. 1991; Redpath et al. 2001). Previous studies have found Black Sparrowhawks to principally feed on large prey (>200g) and have trivial numbers of mammals in their diet (Simmons 1986; Malan & Robinson 1999; Curtis et al. 2005); although they followed similar methods to this study. However a long term on-going study (Tate unpublished data) has found no cases of mammalian prey being brought back to the nests of 24 different breeding pairs during roughly 15 months of camera footage. Roth & Lima (2003) found that despite their abundance, small birds well seldom taken by Coopers Hawks in urban areas where *columbidae* were present. Furthermore, even by combining pellet and marco-remain data, a diet study will still retain some bias (Redpath et al. 2001). A final bias would be against those remains preferred by scavengers and thus be more at risk from being removed from the vicinity of the nest and not collected.

In summary this study further confirms the notion that the Black Sparrowhawk, like other Sparrowhawk species, feeds predominately on *columbidae*. It also highlights the significance of Guineafowl as a prey species for certain Black Sparrowhawk pairs on the Cape Peninsula. Black Sparrowhawks seem to not change their diet throughout the breeding season, despite the dimorphism in size between sexes. The combination of the plumage morphs of breeding pairs seems to have no effect on diet, while diet seems to have no effect on whether pairs breed earlier or later in the year. This is despite more favourable diet conditions during the earlier months, likely due to certain prey species breeding behaviours. The variability in diet compositions between nests indicates that the habitat makeup of territories is likely playing a significant role, and could possibly be very revealing for further insights into the Black Sparrowhawk diet.

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Appendix 1 – Scores for PCA dimensions 1 and 2 for the Nest sites used in the first PCA analysis. Only values for dimensions 1 (32.92%) and 2 (24.19%) are shown which explained over 50% of the variance.

Nest	Nest Number	Dimension 1	Dimension 2
Alphen Common 2012	1	0.511258	0.152208
Audrey's Nest 2012	2	-0.80674	-1.13413
Bergvliet 2012	3	-1.10593	1.043396
Bergvliet 2013	4	1.383099	-1.57557
Bishops Court East	5	-0.80674	-1.13413
Bishops Court East13	6	-1.93848	-0.95476
Chart Farm 2012	7	0.871072	-0.02821
Chart Farm 2013	8	-0.27696	-0.31109
Deer Park 2012	9	-0.11194	-0.77846
Glen Dirk 2012	10	1.423899	-0.77396
Newlands 2012	11	-0.64465	3.208013
Newlands Picnic 2012	12	2.12605	0.216951
Oakley Avenue 2012	13	2.100655	-0.58869
Orange Kloof 2012	14	1.290011	0.415763
Stone Church 2012	15	-0.61925	-0.09982
Stone Church 2013	16	-0.70818	-1.32342
Tamboerskloof 2012	17	-2.00895	1.694083
Tamboerskloof 2013	18	-3.23763	-0.09152
Tokai Picnic 2012	19	0.703022	0.670195
Tokai Picnic 2013	20	1.978645	2.59589
Zonnestraal-2 2012	21	1.340961	-0.86455
Zonnestraal 2013	22	-1.46321	-0.33817

Appendix 2 - Scores for PCA dimensions 1 and 2, the standardised diet breadth, and the lay period for the Months used in the second PCA analysis. Only values for PCA dimensions 1 (42.11%) and 2 (39.47%) are shown which explained over 80% of the variance.

Month	Month Number	PCA.1	PCA.2	BA	Lay Period
March	1	-2.01	-2.08	0.46	Early
April	2	-0.10	-0.17	0.38	Early
May	3	3.09	-1.91	0.49	Early
June	4	-0.97	2.33	0.24	Early
July	5	-2.06	-0.94	0.36	Late
August	6	0.75	1.59	0.36	Late
September	7	0.68	1.43	0.35	Late
October	8	0.61	-0.25	0.39	Late

Appendix 3 – Weights used to calculate biomass of prey items. Species weights were taken from Hockey et al. (2005). * Average weight of the *accipitrinae* in the region. ** Average weight of the *vanellus* species in the region.

Species	
Common names (*Scientific names*)	**Weight (g)**
Red-eyed Dove (*Streptopelia semitorquata*)	250
Feral Pigeon (*Columba livia*)	400
Laughing Dove (*Spilopelia senegalensis*)	100
Speckled Pigeon (*Columba guinea*)	350
Helmeted Guineafowl (*Numida meleagris*)	1450
Spotted Thick-Knee (*Burhinus capensis*)	500
Cape Turtle Dove (*Streptopelia capicola*)	150
Raptor (Accipitridae)	270 *
Budgerigar (*Melopsittacus undulatus*)	40
Cockatiel (Nymphicus hollandicus)	100
Domestic chicken	800
Red-winged Starling (*Onychognathus morio*)	140
Olive Thrush (*Turdus olivaceus*)	66
African Olive Pigeon (*Columba arquatrix*)	450
Lapwing (*Vanellus sp.*)	500**
Hadeda Ibis (*Bostrychia hagedash*)	1250