**Wind-farms threaten Southern Africa's cliff nesting vultures**

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## INTRODUCTION

Throughout Africa there is a need for greater energy production. Wind energy is commonly understood to be a clean and environmentally friendly renewable energy resource (Leung & Yang, 2012), and many African countries are planning or have already constructed wind farms.South Africa is investigating the large-scale exploitation of wind power for electricity generation (Szewczuk & Prinsloo, 2010) and two wind farm developments are currently proposed in the Maluti mountains in the Kingdom of Lesotho. The proposed development area includes the breeding and foraging range of two cliff-nesting vulture species, the Bearded Vulture *Gypaetus barbatus meridionalis* and Cape Vulture *Gyps coprotheres*.

Although the impacts of wind turbines on the environment are not well established (Leung & Yang, 2012), a number of recent studies have confirmed that the effects of wind farms on birds are of conservation concern (Carette *et al.,* 2009; Carette *et al.,* 2012; Telleria, 2009). Large soaring birds are particularly vulnerable to collisions with turbines and are at highest risk when using orographic lift (Barrios & Rodriguez, 2004; Hötker, 2008; Hötker, Thomsen & Jeromin, 2006; Hunt, 2002; Katzner*et al*., 2012). Since wind farms are often placed in areas heavily used by raptors, there is real potential for conflict between vultures and wind turbines in southern Africa. Iin fact, of all bird species in southern Africa, Bearded Vulture and Cape Vulture have been assessed as the two most sensitive to wind turbine impacts (Retief et al., 2012).

Africa has experienced large vulture population declines in recent decades (Ogada, Keesing & Virani, 2012). In southern Africa, vulture populations are threatened primarily by human persecution, poisoning and interactions with powerlines (Brown, 1991; Krüger *et al*., 2006; Mundy *et al,.* 1992; Rushworth 2007). Wind farms therefore present a new threat to birds in addition to all existing impacts. The negative effects of wind farms on birds are those causing avoidance behaviour, disturbance or fatality through collision with rotor blades and associated power line infrastructure (e.g. Carette *et al.,* 2012; de Lucas *et al*., 2012). Mortality through collisions has the potential for high impact on vulture populations because of the species' long life spans and low reproductive rates.

The Bearded Vulture is classified as Endangered in Southern Africa (Anderson 2000a), but is in the process of being uplisted to Critically Endangered (Krüger, pers. comm.), with only about 100 pairs (330 birds) remaining (Krüger, Allan & Jenkins, in prep.). The population is currently declining at -1.1% per annum and its entire range is restricted to the Maluti-Drakensberg mountains of Lesotho and South Africa. The Cape Vulture is a southern African endemic that is classified as vulnerable (Anderson, 2000b). Wolter (2012) estimates the global population to be 2900 pairs (*c*. 8000 birds) of which 1450 birds (20%) occur in the Maluti-Drakensberg region.

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To date no quantitative data exists for Africa as to the extent to which wind-farms will kill vultures. The findings of studies on raptor mortality at turbines vary greatly because the probability of collisions depends on a range of factors such as species, species-specific flight behaviour, weather conditions and topography around the turbines (de Lucas *et al*., 2008; Kuvlesky*et al*., 2007). However, international experience indicates that the *Gyps* species are extremely susceptible to being killed by rotor blades (Ferrer et al., 2011), because of a combination of their lack of forward visual field (Martin, Portugal & Murn, 2012), their foraging behaviour and lack of ability to take rapid avoidance action.

Spain is one of the top two wind power producers in Europe (Leung & Yang, 2012) and the negative impacts of wind farms on vultures has been well documented. Barrios & Rodriguez (2004) and Carette *et al*. (2012) found a positive relationship between the large scale distribution and abundance of griffons and their mortality at wind-farm turbines. Flight altitude was also found to be a key determinant of the risk to birds of turbines which have a rotor swept zone of 50-150 m above ground (Katzner *et al.,* 2012).

Long term monitoring of cliff-nesting vulture populations and information obtained from GPS satellite tags attached to Bearded and Cape Vultures in southern Africa, provides a unique opportunity of having pre-construction population status data as well as data on the ranging behavior and flying height of different age classes. This paper uses Population Viability Analysis models to predict the potential population level impacts of the proposed establishment of wind energy developments on cliff nesting vultures in southern Africa, using existing information on distribution and ranging behaviour, and drawing parallels with studies on similar species elsewhere where required.

## METHODS

### Data collection

We used data from ten Bearded Vultures (BV) and two Cape Vultures (CV) captured in the Maluti-Drakensberg mountains during 2007 – 2010. The BVs were fitted with Argos GPS satellite transmitters (Microwave Telemetry Inc.). One CV was fitted with an Argos satellite transmitter (Microwave Telemetry Inc.) and the second with a GSM cellular transmitter (Africa Wildlife Tracking). The BV ranging data comprised 13.5 bird years, made up of 5.75 juvenile years, 4.75 immature years, 1 sub-adult year and 2 adult years. The CV ranging data comprised 1.6 adult years.

The wind-farms being assessed are proposed for development in Lesotho, therefore data points in South Africa were excluded. Additional reasons for excluding South African data points were because (1) habitat and land use differs between the two countries, and (2) the effect of the Great Escarpment which causes an abrupt 1000 m change in flying height as the birds transition between Lesotho and South Africa which is not representative of the general foraging habitat in Lesotho.

Speed is recorded with each data point; only data points representing foraging behaviour (11-77 kph, Brown 1988) were used in the analysis.

A total of 17 617 data points where BV were flying were collected, 10640 of which were foraging records over Lesotho. A total of 490 CV data points were collected, 93 of which were over

Lesotho. Of the 93 points only 5 had flying speed data, therefore all records across both countries with flying speed >11 kph (n=116) were used for flying height calculations.

The Argos satellite system assigns an estimate of accuracy, the location class (LC), to each location (CLS, 2011). The accuracy for LC-3 is <150 m, for LC-2 it is 150-300 m, for LC-1 it is 350-1000 m and for LC-0 it is >1000 m. Accuracy for LC-A, B or Z locations cannot be calculated by Argos therefore in this study only LCs3,2 and 1 were used for the Cape Vulture fitted with the Argos transmitter.

Ground surface elevation was calculated using a Digital Terrain Model (DTM) (SRTM 90m). The vertical accuracy of the DTM is reported as ±16 m. Error for both the GPS PTT and DTM are of similar magnitude and normally distributed, and for the purposes of this exercise the two error terms were assumed to cancel each other out.

Vulture flight altitude above ground level (AGL) was determined for each data point by subtracting the ground surface elevation from the GPS-determined PTT altitude.

Positions of wind farms were recorded from the wind-farm EIA applications. One application reported the highest point of the blade to be 90 m while the other 100 m; for the purposes of this analysis the highest point of all blades was assumed to be 100 m.

## Data Analysis

### *Foraging behavior*

Adult BV forage predominantly within 15 km radius of the nest site, whereas non-adult birds forage extensively over both the highlands and, to a lesser extent, lowlands and may traverse the entire species range within a few days (>300 km) (unpublished data). Adult CV forage predominantly within 15 km of breeding colonies (unpublished data), but extends up to 40 km (Brown & Piper 1988; Jarvis et al., 1974; Robertson & Boshoff, 1986). The foraging behaviour of juvenile and immature CV in the Drakensberg is not recorded.

### *Flying Height*

Vulture flight altitude AGL was determined for each data point by subtracting the ground surface elevation from the GPS-determined PTT altitude. Error in calculation of flight AGL is the sum of errors in DTM data and in GPS estimated elevation. The published vertical error of the 90 m SRTM data is ±16 m, while the manufacturers reported accuracy of the GPS is ±15 m (Microwave Telemetry Inc.). For the purposes of this study the error around the reported positions was assumed to be normally distributed (confirmed for GPS by sample data[2]), and because the SE is very similar in magnitude it was assumed that the two error terms cancel each other out in calculation of flying height AGL in a large data set. Horizontal error was discounted as the reported horizontal error of the GPS is ±5 m whereas the ground resolution of the DTM is 90 m. Katzner *et al.* (2012) calculated maximum possible error as the sum of the

[2] The reported vertical error was tested by using an Argos GPS unit to compare recorded altitude with known ground elevation. The mean of the altitude recordings was the same as the known elevation, with a SD of 15.5 m (n=80, unpublished data), confirming the manufacturers reported vertical error for this location.

error terms and removed all observations within that distance of the ground, but because they did not remove any apparent high outliers from the data set, their mean results are inherently upward biased meaning that the actual flight altitudes are likely to be slightly less than the estimates they presented. In this study we sought to avoid that bias.

Some negative values were obtained in calculating height AGL, some due to the sum of the error terms, but in most cases were related to the bird flying close to, but below, a cliff face, where the elevation of the 90 x 90 m pixel is recorded as the height of the top of the cliff.

### *Habitat Selection*

For the purposes of this study habitat was classified as one of the following landscape positions: (1) Upper slopes, mountain tops and high ridges; (2) Midslopes and open slopes; (3) Plains; and (4) Canyons, deeply incised streams and U-shaped valleys, using the Topographic Position Index algorithm in ArcGIS 9.3 (ESRI, Redlands, CA) on the DTM. Habitat selection was determined by comparing observed habitat use while foraging (flying 11-77 kph) with expected habitat use based on the proportion of different habitat types in Lesotho.

A Resource Selection Index was used to determine selection or avoidance of habitats using:

$$W_i = O_i / L_i$$

where

$W_i$ = resource selection index for habitat i
$O_i$ = Proportion of habitat i used by the animal
$L_i$ = Proportion of habitat i in the environment

A value > 1 indicates selection and < 1 indicates avoidance.

### *Population Viability Assessment*

Vortex 9.99 (Lacey, Borbat&Pollak 2005) was used to model population level impacts for both BV and CV. Vortex is a model that incorporates population parameters and environmental and demographic stochasticity to predict population size under different scenarios.

Parameters used in the baseline model were derived from a number of predominantly local sources, published and unpublished literature but with some parameters being used from the European literature where local data does not exist (Annexure 1 & 2).

The baseline models for each species were calibrated with actual data on population size changes (Brown 1992 vs. Krüger, Allan & Jenkins, in prep, for BV; Brown & Piper 1988 vs. Allan, Krüger & Jenkins, in prep, for CV), and accordingly incorporate current anthropogenic mortality factors e.g. poisoning, power line collisions.

*Population Size*

Accurate population size information was obtained from repeated ground and aerial surveys over 30 years (Allan, Krüger & Jenkins, in prep; Brown 1992, Brown & Piper 1988; Krüger, Allan

& Jenkins, in prep.; Wolter 2012). Current BV and CV population sizes in the Maluti-Drakensberg are estimated as 368 and 1450 respectively. The precise locations of all breeding sites were recorded using GPS and 1:50 000 scale topographic maps.

*Mortality*

There is no published information on actual wind-farm mortality for either vulture species.

Mortalities as a result of collisions with wind-farm structures were included in the model as a combination of increased age-specific mortality rates (adults) and additional harvest (non-adults) in the case of BV, and as increased age specific mortality rates across all age classes for CV. Mortality is therefore proportional to population size, whilst harvest is constant irrespective of population size.

Acknowledging that actual risk of bird collision is affected by particular features of individual wind farms (e.g. location, number and type of turbines), Telleria (2009) used proximity of *Gyps* colonies as a crude assessment of collision risk with turbines, specifically number and size of vulture colonies located inside buffer areas delimited at increasing distances (5, 10, 20 and 30 km) from wind-farms. We adopted a similar approach for both BV and CV by identifying the number of susceptible adult birds based on proximity of known nesting sites (Krüger, Allan & Jenkins in prep.; Krüger unpublished data) to the proposed wind-farms. Survival rates for each species at each distance class were assumed based on the understanding of foraging behaviour frm tracking data, and the total mortality per year estimated by the sum of the products of number of susceptibles and survival rate per distance class (<10, 10-15, 15-20, >20 km) (Table 1 & 2). A spreadsheet model was used to calculate the likely number of adult mortalities per year, assuming both wind farms became operational simultaneously. The number of individuals likely to die was then converted to a mortality rate, which was added to the baseline adult mortality rate in Vortex for the wind-farm scenario (Annexure 1 & 2).

Whilst there are limitations to estimating mortality in this manner, it is believed that using actual population data and known foraging behaviour produces a more realistic estimate of mortality than simply using published collision rates from other studies.

It was assumed that once a BV territory becomes vacant or CV pair is lost from a colony they are not replaced (current data indicates this; Brown 1991).

**Table 1: Number of susceptible adult Bearded Vultures at different distance classes from both proposed wind-farms; survival probability in parentheses is the product of the estimated survival probability at different distances from each wind-farm, illustrating that birds occupying areas closer to one or both developments are at significantly higher risk (lower survival)**

| | | Oxbow wind-farm | | | |
|---|---|---|---|---|---|
| | Km | <10 km | 10-15 km | 15-20 km | >20 km |
| Letseng wind-farm | <10 km | 0 (0.1) | 4 (0.45) | 2 (0.55) | 0 (0.2) |
| | 10-15 km | 0 (0.45) | 0 (0.35) | 2 (0.8) | 0 (0.7) |
| | 15-20 km | 0 (0.55) | 0 (0.8) | 0 (0.45) | 2 (0.9) |
| | >20 km | 10 (0.2) | 2 (0.7) | 8 (0.9) | 168 (0.98) |

**Table 2: Number of susceptible adult Cape Vultures at different distance classes from both proposed wind-farms; survival probability in parentheses is the product of the estimated survival probability at different**

**distances from each wind-farm, illustrating that birds occupying areas closer to one or both developments are at significantly higher risk (lower survival)**

| | | Oxbow wind-farm | | | |
|---|---|---|---|---|---|
| | Km | <10 km | 10-15 km | 15-20 km | >20 km |
| Letseng wind-farm | <10 km | 30 (0.15) | 0 (0.4) | 0 (0.6) | 0 (0.3) |
| | 10-15 km | 0 (0.4) | 0 (0.25) | 0 (0.7) | 30 (0.5) |
| | 15-20 km | 0 (0.6) | 0 (0.7) | 0 (0.45) | 144 (0.9) |
| | >20 km | 72 (0.3) | 0 (0.5) | 432 (0.9) | 1694 (0.99) |

Adult BV mortality is predicted to start off at 5-10 birds per year, but stabilising at about 3 birds per year over the longer term. This translates into a 1% increase in adult mortality over the baseline rates (Annexure 1).

In the Maluti-Drakensberg mountains there are approximately 130 non-adult BV (Krüger, Allan & Jenkins, in prep) and 1450 CV (Wolter, 2012), a ratio of 0.09:1. Assuming the same collision rate for BV as for CV, and that CV collision rate is the same as published for *Gyps fulvus*, and that collisions are in proportion to abundance, the non-adult BV collision rate is estimated as 0.017 (range 0.070-0.065) collisions/turbine/yr. Based on the estimated population size (130), mean mortality rate (0.017 collisions/turbine/yr) and proposed number of turbines (80), non-adult mortality is predicted to be 1.33 birds/yr. This was entered into Vortex as a harvest of 4 birds every 3 years (Annexure 1).

Non-adult CV are assumed to move widely than adults across the landscape, hence putting all non-adults at risk even if the colony where they were born is far away. The non-adult CV collision rate was estimated using the average mortality rate for *Gyps fulvus* in Spain which is recorded as 0.186 (range 0.078-0.727) collisions/turbine/yr. Based on the estimated population size (240), mean mortality rate (0.186 collisions/turbine/yr) and proposed number of turbines (80), non-adult mortality is predicted to be 14.88 birds/yr. Because all individuals are at risk no matter how small the population, mortality was kept constant over time.

The adult and non-adult CV mortality were summed to estimate total mortality. Initially the number of CV killed per annum is very high (30-90 birds), but stabilizes at 20-25 birds per annum. This mortality was converted into age specific mortality rates and added to the age specific mortality rates in the baseline model, which assumes a stable age distribution (Annexure 2).

## RESULTS

<u>Flying height</u>

BV spend 92% of their flying time at foraging speeds (11-77 kph); the remaining 8% of time is spent in cross country travel (>77 kph), as classified by Brown (1988) (n=10640; Figure 1). More than half of the foraging time (53.5%, n=9791) is spent ≤100m AGL i.e. below maximum expected rotor height and hence at risk of collision (Figure 2).

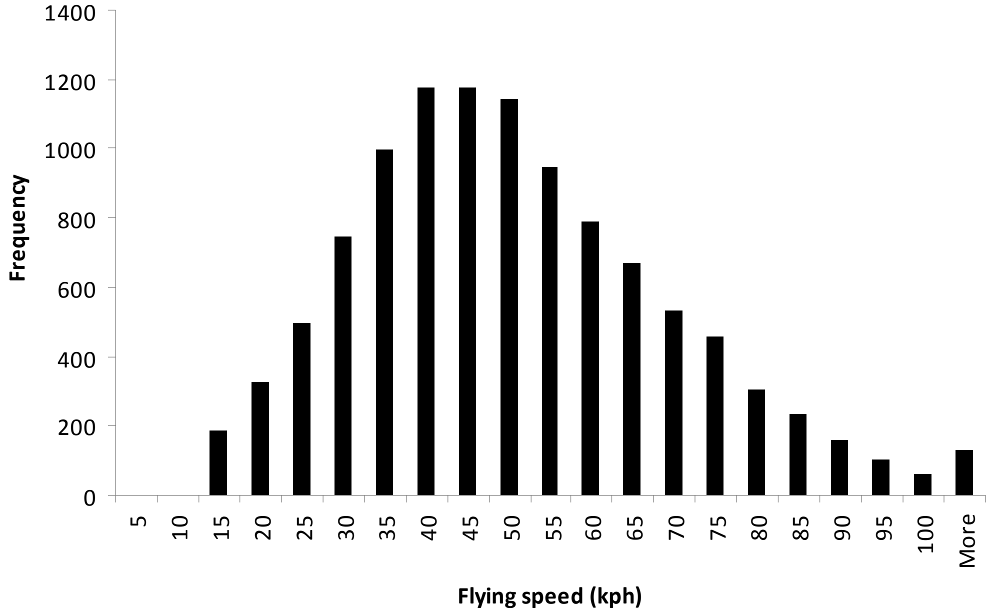



**Figure 1: Bearded vulture flying speed (kph); records <11kph assumed to be roosting or walking and excluded (n=10640).**

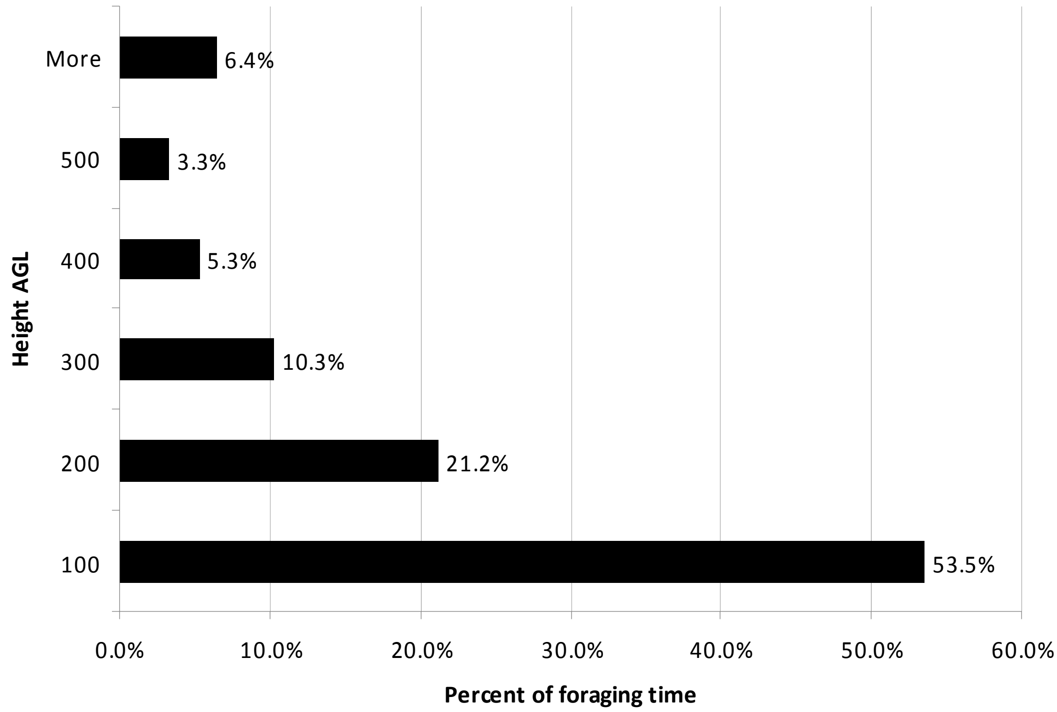



**Figure 2: Proportion of Bearded Vulture foraging time spent in different height classes above ground level (n=9791).**

A large proportion of CV flying time (61.7%, n=379) is spent ≤100m AGL i.e. below maximum expected rotor height and hence at risk of collision (Figure 3).

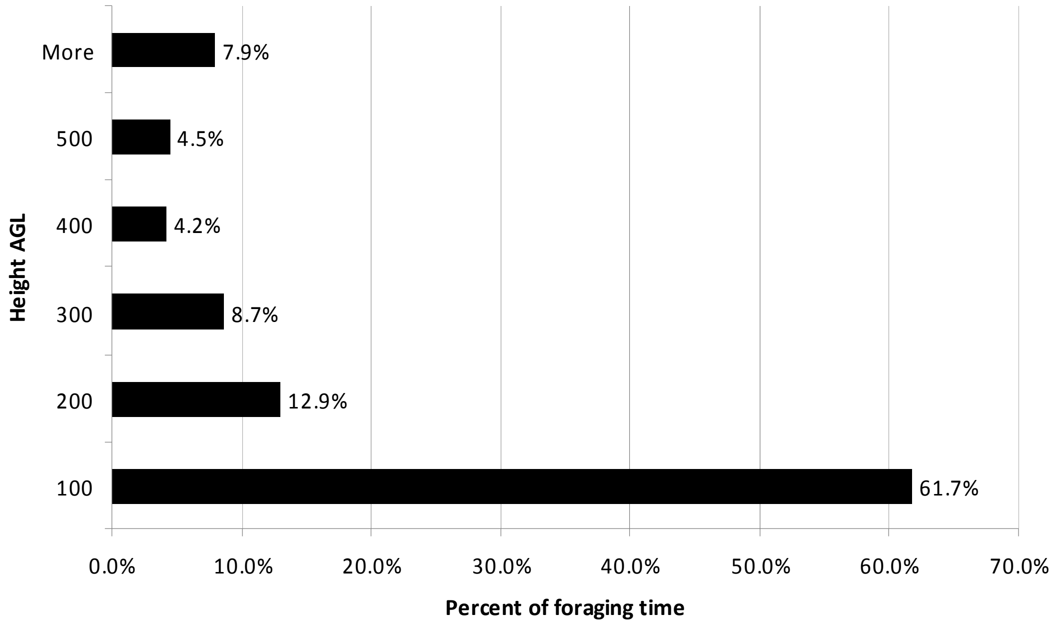



**Figure 3: Proportion of Cape Vulture foraging time spent in different height classes above ground level (n=397).**

## Habitat selection

Bearded Vultures of all age classes actively select upper slopes, mountain tops and high ridges where they spend 44% of their time, and use valley bottoms, canyons and plains less than expected (n=10201, Table 2, Figure 4).

**Table 2: Resource Selection Index for Bearded Vulture in Lesotho; RSI > 1 indicates selection, RSI < 1 indicates avoidance**

| Habitat type | Proportion of habitat in environment | Proportion of habitat used | RSI ($w_i$) |
|---|---|---|---|
| Canyons, deeply incised streams and valleys | 0.316 | 0.235 | 0.744 |
| Plains | 0.038 | 0.010 | 0.255 |
| Midslopes and open slopes | 0.350 | 0.314 | 0.896 |
| Upper slopes, mountain tops and high ridges | 0.296 | 0.441 | 1.491 |

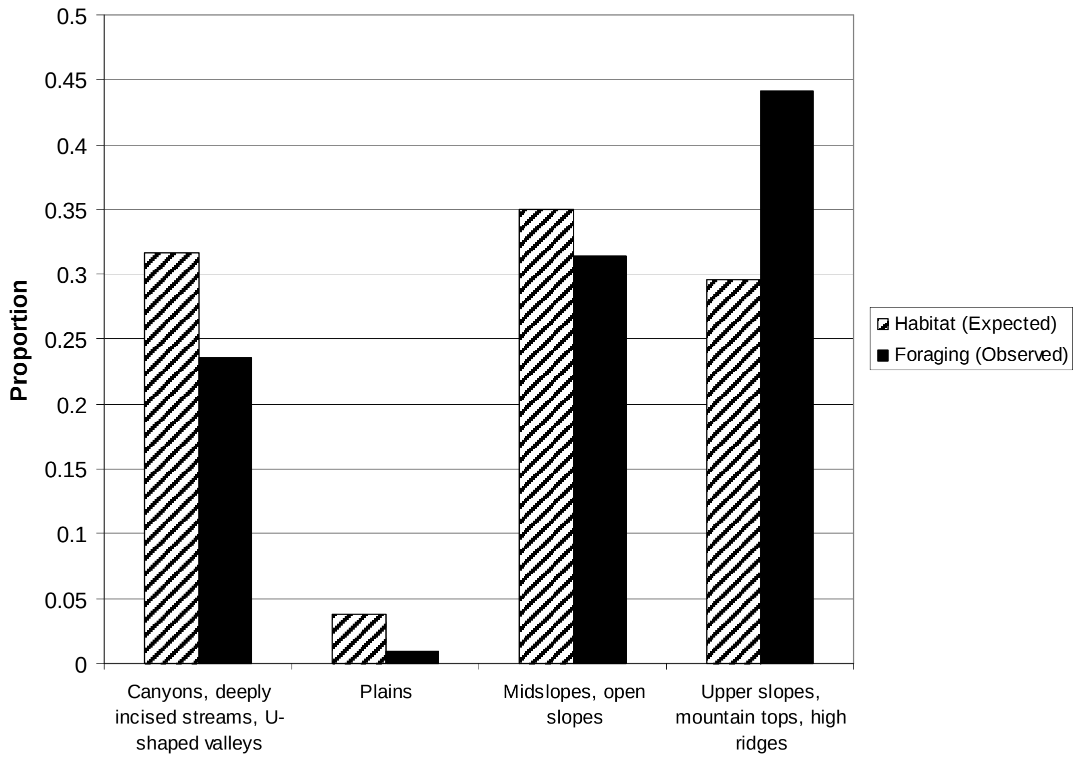



**Figure 4: Habitat selection by Bearded Vultures (all age classes combined) in Lesotho.**

The majority of BV flying time below 100 m AGL is at foraging speeds (<77 kmh), but a proportion of 'cross country' flying (>77 kph) takes place below 100 m AGL; conversely, most BV high speed flying takes place above 100 m AGL (Figure 5). There is no significant relationship between flying speed and height above ground level ($r^2$=0.0889). Preliminary GIS analysis indicates that most flight over valleys is both high speed and higher above ground level than flight over ridge tops and upper slopes i.e. the upper right portion of Figure 5..

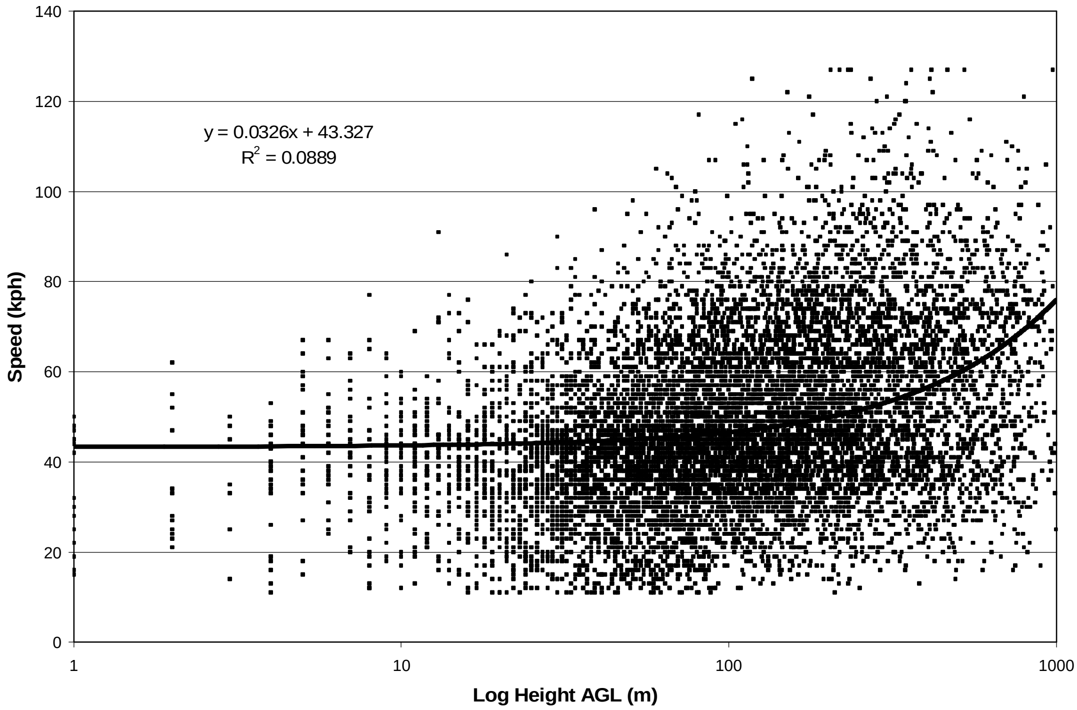


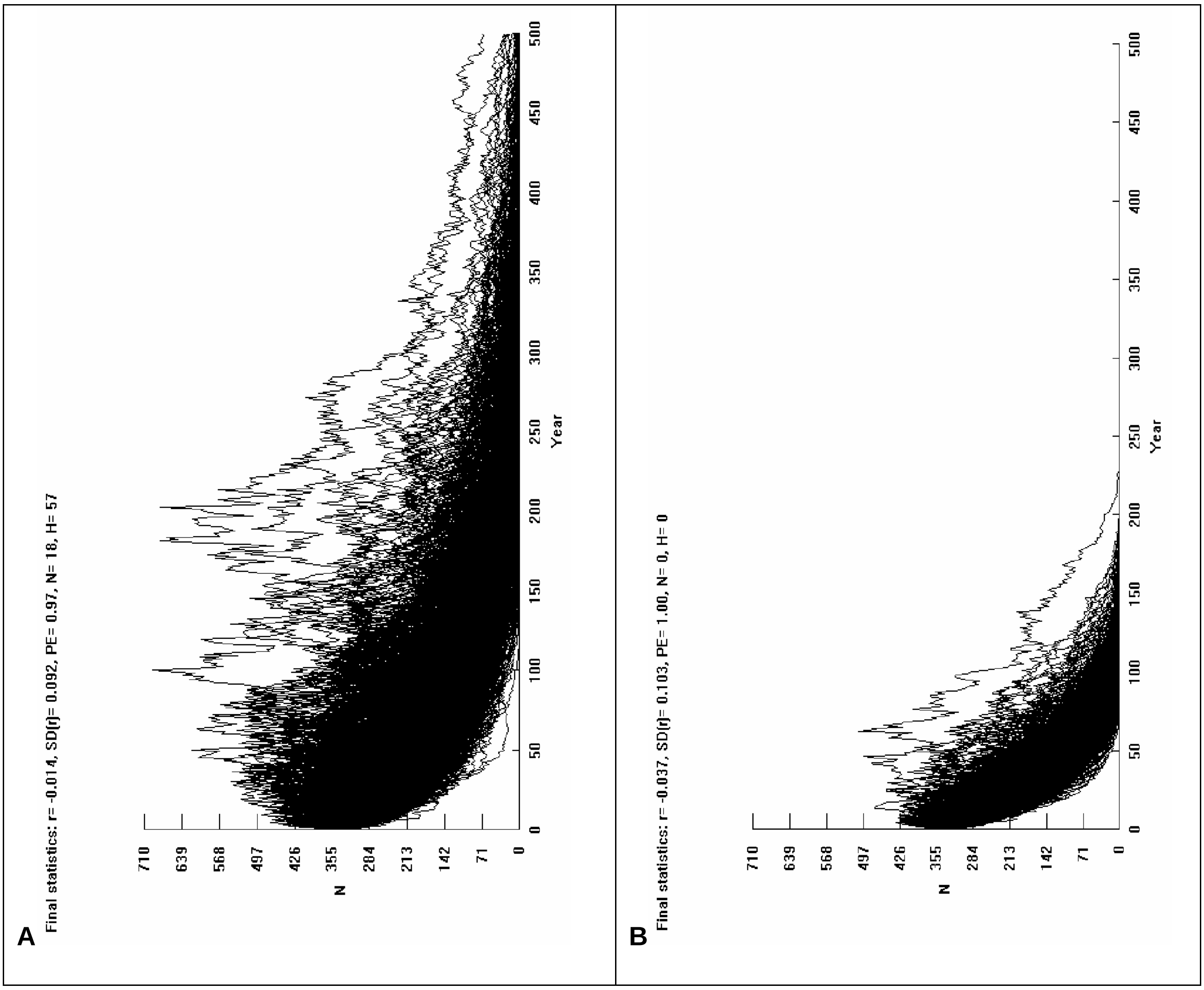

**Figure 5: Relationship between Bearded Vulture flying speed (kmh) and Log height above ground level (m).**

## Population Viability Analysis

The predicted impacts of mortalities caused by wind-farms are extreme for both BV and CV, with BV population rate of decline increasing from the current -1.4% per annum (baseline model) to -3.7% per annum, and CV populations rate of decline increasing from the current -2.2% per annum (baseline model) to -3.4% per annum (Table 3; Figure 6).

**Table 3: Stochastic growth rate of Bearded and Cape Vulture populations in the Maluti-Drakensberg pre- and post-wind-farm construction**

| Species | Population growth rate pre-wind-farm (% per annum) | Population growth rate post-wind-farm (% per annum) |
|---|---|---|
| BV | -1.4 | -3.7 |
| CV | -2.2 | -3.4 |


A
Final statistics: r= -0.014, SD(r)= 0.092, PE= 0.97, N= 18, H= 57
N
Year
B
Final statistics: r= -0.037, SD(r)= 0.103, PE= 1.00, N= 0, H= 0
N
Year

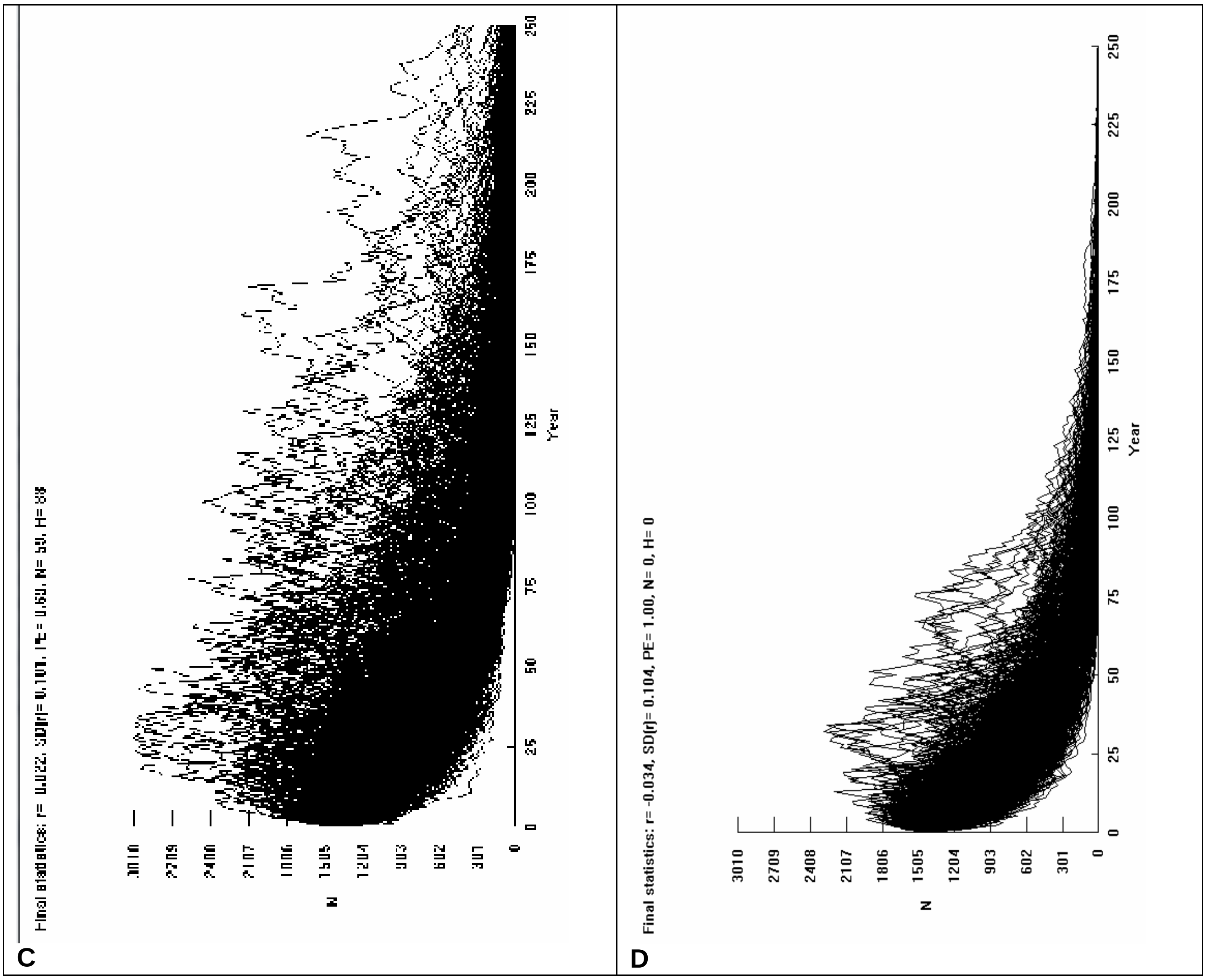



**Figure 6: Population trajectories for Bearded and Cape Vultures in the Maluti-Drakensberg; A. BV pre-wind-farm, B. BV post-wind-farm, C. CV pre-wind-farm, D. CV post-wind-farm**

The median time to extinction will be brought forward significantly for both species with the addition the two proposed wind-farms. For BV the median time to extinction will be brought forward by 150 years from 260 years based on current impacts to 110 years, whilst that for CV will be brought forward by 80 years from 220 years based on current impacts to 140 years (Table 4).

**Table 4: Median time to extinction (MTE) for Bearded and Cape Vultures in the Maluti-Drakensberg pre- and post-wind-farm impacts (units = years)**

| Species | MTE pre-wind-farm | MTE post-wind-farm | Difference |
|---|---|---|---|
| BV | 260 | 110 | 150 |
| CV | 220 | 140 | 80 |

**DISCUSSION**

Bearded Vultures actively select ridge tops and upper slopes and fly predominantly less than 100 m above ground level, therefore putting them at risk both in terms of the areas they select and the height at which they fly. This coupled with a small and declining population means that wind-farm development in the Lesotho highlands, even at a modest scale, will have a catastrophic impact on this species, with the population declining rapidly and predicted to go extinct in a little over 100 years. Whilst there is insufficient data to make statements about habitat use for Cape Vultures, this species spends a large proportion of its flying time (62%) below 100 m and is also at high risk, and is also predicted to go extinct in the presence of wind-farms.

In addition to the area and flying height conflict, recent findings that vultures are blind in the direction of travel because their visual field does not allow them to see forward when they are looking down for food (Martin, Portugal &Murn, 2012), and that large birds a less able to take avoidance action if an obstacle is detected at last moment, further make them susceptible to collisions with turbines and the associated electrical infrastructure. Because of their low reproductive rate and long life spans this population will be unable to replace an accumulative loss of individuals. Quite simply: 'Wind farms and vultures need to be kept apart' (University of Birmingham 2012).

Genetically, the southern African population of *Gypaetusbarbatusmeridionalis* is different to the 'same' subspecies in the Ethiopian highlands (Krüger& van Vuuren in prep.) and therefore should be considered a separate Evolutionary Significant Unit. This population is already considered Critically Endangered (Krüger 2013) and wind-farms will undoubtedly hasten its demise. Given that this population is genetically distinct, there are no options for supplementation with genetic stock from elsewhere in the world.

It must be noted that the model predictions are conservative because they assume constant level of mortality from other anthropogenic causes such as power line collisions, electrocutions and poisoning. Electricity supply companies in both Lesotho and South Africa are already embarking on additional large scale electrification projects both for residential and industrial purposes, and there are indications that poisoning is increasing due to an increase in jackal populations and for harvesting of vultures for the muthi trade. Additional power lines will be required for taking electricity from the wind-farms to the national grid. The anticipated increase in mortality associated with an expanded electricity grid is not taken into account in the models. In order to capture more wind power and reduce costs of generating renewable energy, the size of turbines, including blade length and generation capacity keeps increasing. Given that both species of vulture forage close to the ground the threat posed by longer blades is likely to increase in the future if additional new projects and retrofitting of existing wind-farms with larger blades takes place.

Wind-farms, even at a modest scale (two wind-farms, 80 turbines), pose a *significant threat* to both Bearded Vultures and Cape Vultures in the Maluti-Drakensberg. However, achieving the objectives of the Lesotho government in terms of wind generated electricity will require *severalthousand* towers and associated power line infrastructure, and the impacts of that would be devastating.

Mitigation options for windfarm developments in Lesotho have been reviewed (Jenkins 2013). There is a high degree of risk and a low level of confidence that this risk can be minimised to acceptable levels, especially given the strong winds and frequent misty conditions experienced in the Lesotho highlands. The only real mitigation option would be to locate the wind-farms in areas of low vulture (and other large bird) activity – predominantly the western lowlands or, in the case of vultures, plains, valley bottoms or lower slopes.

The Bearded Vulture is the symbol of the uKhahlamba Drakensberg Park World Heritage Site, and a key focus of the Maloti Drakensberg Transfrontier Programme: loss of this iconic species will be a very public failure of transfrontier conservation efforts. So-called 'clean' energy is not synonymous with 'green' energy.

Annexure 1: Input parameters for Vortex model for Bearded Vulture

| Parameter | Value | References | Notes |
|---|---|---|---|
| Length of simulation | 500 years | | |
| Iterations | 500 | | |
| Extinction definition | <5 individuals | | Population effectively extinct when so few individuals in such a large area; assumed extremely remote possibility of recovery from such low numbers and effective 'genetic extinction' would occur even if recovery in numbers of individuals took place; truncated to avoid unrealistic exaggeration of tail of time to extinction |
| Inbreeding depression | None | | |
| Age first reproduction | Females 7 years; Males 7 years | Brown 1988; Krüger unpublished data | Tracking data from one juvenile indicates that reproduction may be initiated at 6 years, but this may also be an indication of a declining population |
| Maximum breeding age | 30 years | | Assumed, no data for Maluti-Drakensberg population |
| Sex ratio at birth | 50:50 | | Assumed |
| Breeding strategy | Monogamous | | |
| % of adult males in the breeding pool | 97% | Krüger pers. comm. | A few nest sites observed with trios, assumed to be 2 males and one female |
| % adult females breeding | 70% | Brown 1988; Krüger unpublished data | Pairs do not breed every year |
| Distribution of number of separately sired broods produced by a | 100% of females produce a single clutch; maximum of 1 chick produced per | Brown 1988 | |

| | | | |
|---|---|---|---|
| female in a year | nesting attempt | | |
| Initial population size | 336 | Krüger, Allan & Jenkins in prep. | |
| Carrying capacity | 700, assumed to remain constant over time with 5% EV | | Although the original population was substantially larger, it is unlikely that given food and habitat constraints whether the population could ever recover to above 700 birds; nest sites are not limiting; realistically the CC is likely to continue decreasing because of habitat change and livestock practices, but there will be an increased food provisioning to offset these reductions in food availability |
| Mortality | Age specific mortality assumed equal in males and females; EV in reproduction and mortality concordant. | | See below for mortality rates used in baseline and wind-farm scenarios |
| Harvest | 0.0167 birds/tower/yr or 4 birds every 3 yrs; biased to younger birds assuming they are less experienced, equal risk to males and females; arbitrarily broken down to: females 2 years old: 1, females 4 years old: 1, males 1 years old: 1, males 3 years old: 1 | | See Methods section; assuming 130 juveniles at risk and that absolute mortality remains constant over time given the wide ranging behaviour of juveniles |

| Age class (years) | Mortality %: Baseline (SD) | Mortality %: Wind-farm (SD) |
|---|---|---|
| 0-1 | 48 (10) | 48 (10) |
| 1-2 | 40 (8) | 40 (8) |

| | | |
|---|---|---|
| 2-3 | 27 (5) | 27 (5) |
| 3-4 | 20 (5) | 20 (5) |
| 4-5 | 15 (4) | 15 (4) |
| 5-6 | 5 (3) | 5 (3) |
| 6-7 | 5 (3) | 5 (3) |
| Adult (7-30) | 3 (2) | 4 (2) |

Annexure 2: Input parameters for Vortex model for Cape Vulture

| Parameter | Value | References | Notes |
|---|---|---|---|
| Length of simulation | 250 years | | |
| Iterations | 500 | | |
| Extinction definition | <10 individuals | | Population effectively extinct when so few individuals in such a large area; assumed extremely remote possibility of recovery from such low numbers and effective 'genetic extinction' would occur even if recovery in numbers of individuals took place; truncated to avoid unrealistic exaggeration of tail of time to extinction |
| Inbreeding depression | None | | The decline is so rapid that inbreeding is unlikely to be a factor |
| Age first reproduction | 5 years for males and females | | Although younger birds have been observed breeding at four or five years, it is assumed that the majority of birds breed once full adult plumage is obtained |
| Maximum breeding age | 30 years | | Assumed, no data. Vortex assumes that animals can reproduce throughout their adult life and does not model reproductive senescence. Individuals are removed from the model after they pass the maximum age of reproduction. |
| Sex ratio at birth | 50:50 | | Assumed |

| | | | |
|---|---|---|---|
| Breeding strategy | Monogamous | | Mundy et al. (1992) assume that paired birds remain together for life |
| % of adult males in the breeding pool | 70% | | There are adults that do not breed |
| % adult females breeding | 70% | | There are adults that do not breed |
| Distribution of number of separately sired broods produced by a female in a year | 100% of females produce a single clutch; maximum of 1 chick produced per nesting attempt | | |
| Initial population size | 1450 | Wolter 2012 | |
| Carrying capacity | 3000, assumed to remain constant over time with 5% EV | | Although the original population was substantially larger, it is unlikely that given food and habitat constraints whether the population could ever recover to above 3000 birds; nest sites are not limiting; realistically the CC is likely to continue decreasing because of habitat change and livestock practices, but there will be an increased food provisioning to offset these reductions in food availability |
| Mortality | Age specific mortality assumed equal in males and females | | See below for mortality rates used in baseline and wind-farm scenarios |
| Harvest | None | | Wind-farm impact modelled through increases in age specific mortality rates |

| Age class (years) | Mortality %: Baseline (SD) | Mortality %: Wind-farm (SD) |
|---|---|---|
| 0-1 | 60 (10) | 61 (10) |
| 1-2 | 37 (10) | 38 (10) |
| 2-3 | 20 (5) | 21 (5) |
| 3-4 | 15 (5) | 16 (5) |
| 4-5 | 10 (5) | 11 (5) |
| Adult (5-30) | 5 (5) | 6 (5) |

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