# Operation Wallacea and WEI Field Research Report: Welgevonden Game Reserve, South Africa

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## Executive Summary

Welgevonden Game Reserve is a privately owned reserve that covers 37,500 hectares of South Africa's Waterberg Biosphere. The predominating vegetation in the reserve is tall grass with low nutritional value that can only support small numbers of herbivores. Lions were introduced into the reserve in 1998 and as their population grew, the herbivore population decreased to the extent that additional herbivore stocking had to be undertaken annually. For the benefit of tourism revenue, the ideal situation for the reserve would be to maximize herbivore stocks so to allow a reasonably sized lion population. One possible mechanism for maximizing herbivore stocks is to increase the level of deliberate burning of savannah to encourage growth of primary grasses (the preferred food of grazing herbivores). However, before introducing a new burning regime, a number of factors must be established. Firstly, it is important to understand the habitat preferences of herbivores so to ensure that areas designated for burning will actually be used by them. Secondly, it is important to quantify the existing level of fire and elephant damage to vegetation to determine that additional burning is appropriate. Finally, it is important to investigate how fire and elephant impact to vegetation affects other species in addition to herbivores as a means of ensuring that biodiversity is conserved.

Operation Wallacea and Wildlife & Ecological Investments have been monitoring herbivores, habitat and birds (as an indicator group) at Welgevonden Game Reserve since 2009. The purpose of this report is to relay the findings of this study and use the empirical data in conjunction with information from published literature to make a series of management recommendations for the herbivores and vegetation in the reserve. In Section A of this report, a comparison of herbivore abundance estimates from line-transect sampling and aerial surveys indicated that both methods produced similar abundance estimates. With a year or two of subsequent data collection to improve the accuracy of abundance models produced using line-transect data, it should be possible to replace the expensive aerial surveys with vehicle based surveys.

Investigation of herbivore habitat preferences indicated that these species avoided hill crests and slopes and showed a preference for old lands, plateaus and riparian habitat. Investigation of elephant ranging patterns based on data obtained from GPS collars indicated that elephants utilize all the space available to them. As such, it was predicted that elephant impact to vegetation would not be cause for concern. Section B of this report investigated elephant and fire impact on vegetation in the reserve. As predicted, elephant impact to vegetation was of low intensity throughout the reserve. Fire has also occurred at a low intensity suggesting that a new higher intensity burning regime could be implemented in the reserve. Section C of the report investigated changes to bird distribution and abundance. As predicted based on the low levels of fire and elephant impact to vegetation, bird abundance has remained relatively unchanged since 2009.

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## Section A: Herbivore Abundance, Ranging and Habitat Use

**A1: Factors affecting herbivore ranging and habitat use**

With the development of private game reserves, intensive land and livestock management is required to maximize animal carrying capacity for the purpose of tourism, while at the same time, preventing habitat degradation. High numbers of lion and elephant are preferable for tourism purposes, but problematic to maintain. Lions require large numbers of prey species, which can lead to over-utilisation of vegetation by herbivores (Bothma et al., 2004) and elephants can cause serious and irreversible damage to habitat if kept at high densities (Cumming et al., 1997; Lombard et al., 2001; Birkett, 2002; O'Connor et al., 2007; Ribeiro et al., 2008).

Understanding animal habitat requirements can enable game reserve managers to predict animal distribution patterns (Dörgeloh, 2001) and consequently their impact on vegetation (van Aarde et al., 2006). Habitat selection is the process whereby animals decide which areas to utilise based on the supply of resources (Morris, 2003). A preferred habitat type is one that is used more than expected from its availability (Aebischer *et al*. 1993; Alldredge & Griswold, 2006). For example, in the African savannahs, grazing ungulates preferentially select beneath-canopy grassland rather than open grassland despite the wider availability of open grassland (Treydte et al., 2010; 2011). Habitat selection may be influenced by vegetation type (Shannon et al., 2006; Allred et al., 2011), the presence of water (Smit et al., 2007; Loarie et al., 2009; Crosmary et al., 2012), topographical features (e.g. crest summit or sloped terrain: Redfern et al., 2003) and predator avoidance (Cowlishaw, 1997; Crosmary et al., 2012). As there is often conflict between the pros and cons of different habitat types (e.g. if a habitat has a plentiful food supply but is associated with high risk of predation), habitat selection is the result of cost-benefit assessment (Cowlishaw, 1997; Crosmary et al., 2012).

Many studies have indicated that elephant habitat use is heavily constrained by access to water (Redfren et al., 2003; de Beer & van Aarde, 2008; Gaugris & van Rooyen, 2010). Data from GPS collars on 73 elephants in reserves across southern Africa indicated that during dry season elephant ranging patterns average no more than 4km from water during the day and significantly closer to water at night (Loarie et al., 2009). If access to water in fenced reserves is limited, during dry season, elephants will preferentially browse on vegetation close to these few water sources (Harris et al., 2008; Chamaille-Jammes et al., 2009; Loarie et al., 2009; Roux & Bernard, 2009), suggesting that access to water rather than vegetation type is the key driver behind elephant habitat preferences. Elephant ranging patterns can, however, be modified by the addition of artificial water sources (e.g. Smit et al., 2007). Artificial water sources allow elephants to use vegetation in dry season that they could not normally use. For example, in Kaudom Game Reserve in Namibia, a series of small artificial water sources were introduced during dry season and as a result, the elephants ranged throughout the reserve (Loarie et al., 2009).

Herbivores may also show preference of avoidance for areas that are heavily used by similar species due to a reduction in food availability (Birkett, 2002; O'Connor et al., 2007) or reduction in protective vegetation cover causing an increased risk of predation. For example, giraffe, black rhino and kudu are reported to avoid areas that have been heavily impacted by elephant (du Toit & Cumming, 1990; Birkett, 2002). However, elephant browsing can encourage new growth in woody plants (Kohi et al., 2011) causing smaller species such as impala and steenbock to preferentially forage in elephant impacted areas (Valeix et al., 2011). Moreover, many ungulates preferentially forage in areas where elephants have increased visibility by breaking or uprooting plants (Valeix et al., 2011), presumably because it is easier to detect approaching predators.

**A2: Estimating herbivore abundance**

Estimating livestock abundance is an important part of game reserve management. The balance of predator and prey species must be monitored closely because too many predators can lead to a population crash in herbivores and insufficient numbers of predators can cause herbivore numbers to increase to the point of causing over exploitation of vegetation (Bothma et al., 2004). Ungulate abundance can also be affected by environmental variables, particularly rainfall (Georgiadis et al., 2003; Ogutu, 2008). One method for monitoring large game stocks is via aerial surveys in which all visible game are counted. However, this method is extremely costly. An alternative method is to monitor game using line- transect sampling. Line-transect sampling, has been a popular and widely used technique for estimating abundance of biological populations in a variety of habitats and situations (Buckland *et al.* 2001). Animals can be surveyed from game vehicles and, provided that habitat is recorded along with each animal sighting, population density models can be corrected for variation in detectability according to habitat type. Consequently, the line-transect method may be a more cost-effective method for monitoring game than aerial surveys.

**A3: Objectives for herbivore monitoring at Welgevonden**

Lions were introduced in 1998 into Welgevonden in response to pressure from the landowners to increase the tourism value of the site. The low nutrient grasslands of Welgevonden result in a low carrying capacity of the reserve for large herbivores (Fritz & Duncan, 1994; Walgren et al., 2009) and this, coupled with an increasing lion population, significantly reduced the herbivore population to the extent that additional herbivore stocking had to be undertaken annually. The lion population has now been reduced but annual restocking of herbivores is still being undertaken until the system can be brought into balance. It is therefore necessary to gather more information about the abundance, ranging and habitat preferences of the herbivores in the reserve as a means of ascertaining the correct balance of predator and prey species. The aim of this study was, therefore, twofold: to investigate ranging and habitat preferences of 10 key ungulate species and to compare ungulate abundance estimates calculated from line-transect sampling versus aerial surveys.

**A4: Methods for monitoring elephant ranging, activity and habitat use**

<u>A4.1: Herbivore monitoring research design and study site</u>

Welgevonden is a privately owned reserve that covers 37,500 hectares of South Africa's Waterberg Biosphere between the towns of Vaalwater and Lephalale. Welgevonden was formed using a novel funding mechanism. The 37,500ha reserve, some of which was game ranch and some farmland, was bought by a developer, fenced and stocked with game. 61 blocks of 500ha each were then sold off to private investors who had the rights to build a lodge on the land and to traverse with a single vehicle across the whole reserve. Monthly payments are then made by each of the landowners to manage the reserve. This form of private but joint ownership has succeeded in creating a substantial reserve without the problems normally encountered with separate landowners having separately fenced areas, and may provide a model for private investment to create substantial new areas of land under conservation.

The reserve is home to over 50 different mammals, including the big 5 (lion, leopard, elephant, rhino and buffalo). There are 8 herds of elephant in the reserve and the matriarchs of two of these herds were fitted with GPS collars in 2004. Some of the terrain in the reserve is mountainous, with plateaus and open plains in the higher lying regions. Due to the acidic nature of the soil, the predominating vegetation in these areas is tall grass with low nutritional value that can only support small numbers of herbivores (Andrews & O'Brien, 2000; Walgren et al., 2009). Some areas of the reserve have dense thickets of shrubs and trees and other areas of the reserve which were previously used for farming, have more nutrient rich soil and host other grassland species. The land areas of Welgevonden have been classified into nine different types; riparian, plateau, valley bottom, hill slope, saddle, crest/summit, marsh, old farmlands and old overnight cattle storage lands (Figure 1). There are three rivers which transect the reserve and combine at the Limpopo River.

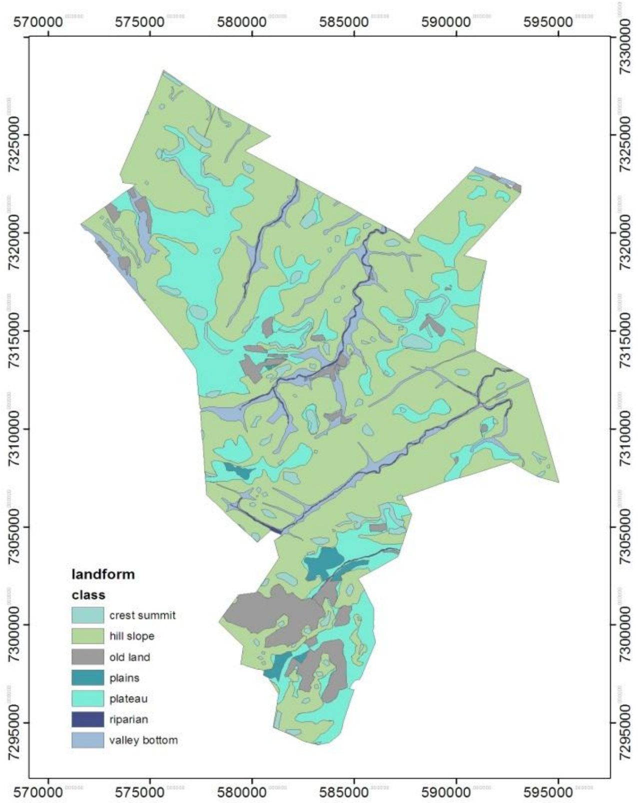


Figure 1: Landform classes in Welgevonden Game Reserve

During the Operation Wallacea field season, large mammal populations were monitored via game vehicle using distance sampling (Buckland et al., 2001) along six 10km long line transects that coincide with reserve road network (300km in total). The transect lines in total incorporated all of the nine different habitat types (some transects covered only one habitat type while others covered multiple habitat types). Transect lines also incorporated areas close to human activity (tourist lodges) and more remote areas of the park. Each transect was sampled a minimum of four times during the data collection season. These data were added to monthly game counts that incorporated the entire road network in the reserve (see Figure 2). In addition annual game count data were collected via helicopter by flying over three separate blocks of the reserve over three separate days (see Figure 2).

A4.2: Herbivore monitoring data collection

Researchers travelled along the transect lines and road systems and a steady pace and recorded their encounters with herbivores. Each time an animal was seen, the species was identified, the number of individuals recorded, the distance along the transect line, the GPS location of the animals (calculated from the GPS location of the vehicle and the distance and direction of the animals to the vehicle), and the habitat type was recorded in addition to the perpendicular distance of the animal from the observer when first encountered. The large mammal species commonly encountered during surveys include elephant, eland, red hartebeest, impala, kudu, reedbuck, rhino, waterbuck, wildebeest and zebra. GPS and habitat data can be combined with existing GIS maps of the reserve and used to investigate ranging and habitat use of specific species. Distance sampling may be used to create population estimates of specific species.

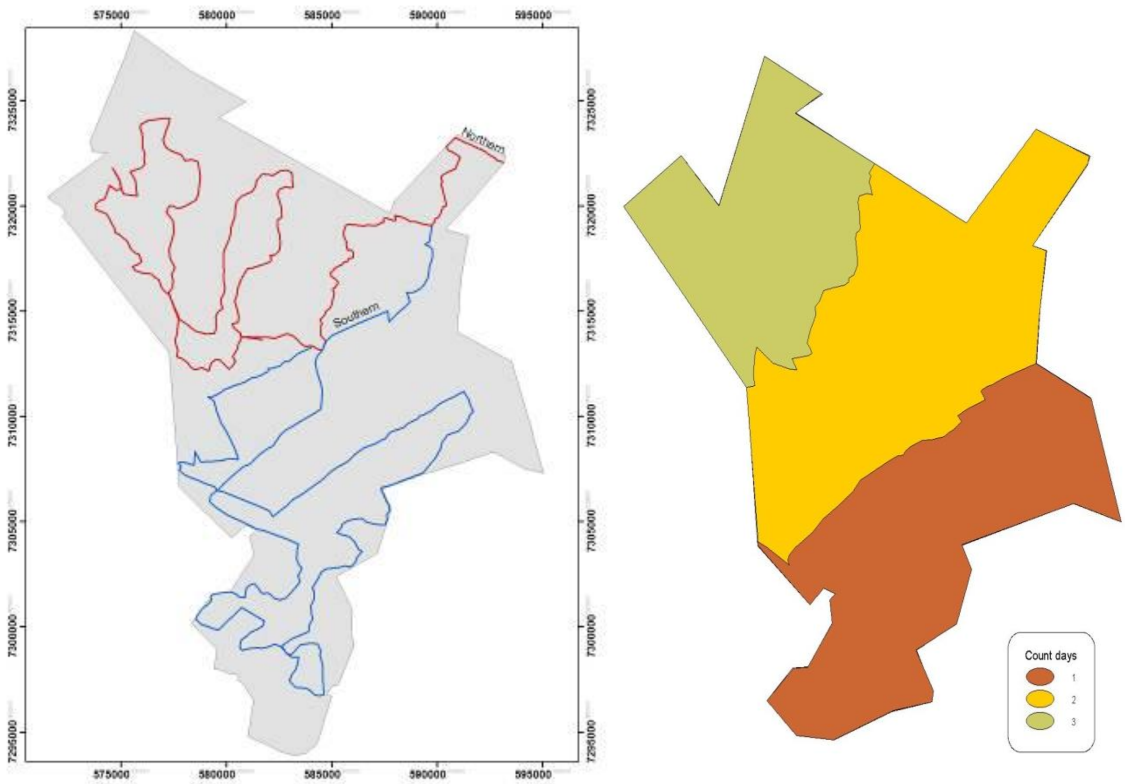

Figure 2: Road network in Welgevonden Game Reserve used for vehicle game counts (left) and blocks of the reserve used for helicopter game counts (right).

A4.3: Herbivore monitoring data analyses

Data from nine key herbivore species (elephant, white rhino, blue wildebeest, burchell's zebra, giraffe, impala, warthog, kudu, waterbuck and red hartebeest) were used to determine habitat preferences with respect to land classes. We used Jacobs' (1974) modification of the Ivlev selection index to determine significant preference and avoidance for each land class. This index measures numbers of individuals of a species selecting each habitat class relative to the availability of the habitat class in the environment. Confidence intervals were formed by constructing an expected hypergeometric distribution among the classes, taking account of cluster sizes.

To monitor elephant distribution and habitat selection, data was taken from GPS collars on two individual elephants, each the matriarch of a different herd. A two-year time series of daily records of elephant locations was obtained from the two elephants. 95% and 50% kernel polygons were constructed for each elephant such that the 95% kernel polygon contained 95% of records of the focal elephant and the 50% kernel contained 50% of records of the focal elephant. Since the reserve is fenced and elephants can't cross the fence, the kernels were intersected with the reserve boundary polygon.

In order to investigate differences in herbivore abundance estimates from vehicle surveys, we combined the sample route shape files (Figure 2), park boundary polygons (Figure 2), and shape file of land classes (Figure 1) to allow the sample routes to be split into segments by land class such that the sampling effort per land class could be known. Additionally, the records of each herbivore cluster were intersected with the land classes shapes so that the observations were marked with their land cover class. This dataset permitted distance models to be used to estimate the density of each species in each land class in each year. This approach of allocating different detection functions to different land classes allowed us to account for the variation in detectability of species between land classes and for the markedly differing densities of herbivores in different land classes due to their habitat selection preferences. In order to fit robust models, all records were truncated beyond 500m. Finally, the densities of each species in each class were multiplied by the areas of each land cover class to produce population estimates for each land cover class. These were summed, and errors propagated to produce a total estimate for Welgevonden game reserve. Density estimates from distance sampling were then presented alongside abundance estimates from helicopter surveys for means of comparison.

**A5: Herbivore abundance, habitat references and ranging results**
Habitat preferences of the nine key herbivore species are presented in Table 1. All species avoided crest summits and hill slopes. All species for which significance could be assessed prefer old land and plateau, with white rhino showing a particularly strong preference for old land. Most species selected toward plains except impala and warthog. Blue wildebeest, red hartebeest and white rhino showed notable preferences for plains. With the exception of impala, most species prefer riparian areas and as predicted, elephant showed an extremely strong preference for riparian habitat. Finally most species, except wildebeest, prefer valley bottom. These selection and avoidance relationships may reflect grazing quality, perhaps mediated by drainage, and predation risk. Further investigation of elephant ranging patterns from the GPS collars of the matriarchs of two separate herds indicated that both elephant herds are ubiquitously present across the whole reserve, except the furthest southern section (Figure 3). There is strong correspondence between the 50% kernels of both herds in the central section of the reserve.

Table 1: Ivlev selection indexes for key herbivore species in relation to land classes. Negative index values indicate significant avoidance. Positive index values indicate significant selection.

| Species | Crest Summit | Hill slope | Old Land | Plains | Plateau | Riparian | Valley Bottom |
|---|---|---|---|---|---|---|---|
| Blue wildebeest | -0.43 | -0.52 | 0.47 | 0.69 | 0.42 | - | -0.13 |
| Burchell's zebra | -0.28 | -0.53 | 0.26 | 0.54 | 0.38 | 0.29 | 0.45 |
| Elephant | -0.39 | -0.4 | 0.22 | - | - | 0.96 | 0.3 |
| Giraffe | -0.24 | -0.74 | 0.33 | 0.38 | 0.48 | - | 0.37 |
| Impala | -0.71 | -0.36 | 0.57 | -0.89 | 0.21 | -0.58 | 0.46 |
| Kudu | -0.63 | -0.37 | - | 0.45 | 0.22 | 0.56 | 0.61 |
| Red hartebeest | -0.9 | -0.38 | - | 0.62 | - | - | - |
| Warthog | -0.18 | -0.7 | 0.69 | -0.58 | 0.31 | 0.34 | 0.32 |
| Waterbuck | - | -0.47 | 0.58 | 0.32 | - | 0.6 | 0.69 |
| White rhino | -0.61 | -0.68 | 0.75 | 0.68 | 0.2 | - | 0.17 |

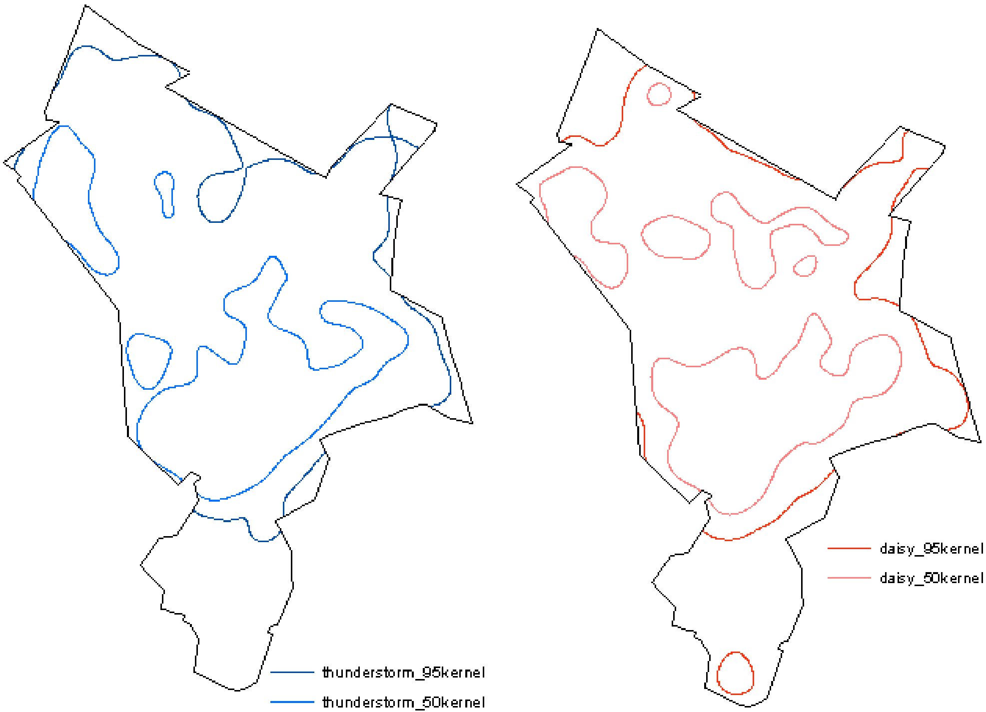

Figure 3: 50% and 95% kernel density analyses of elephant home ranges calculated from data received from GPS collars (blue = Thunderstorm from elephant herd A, red = Daisy from elephant herd B).

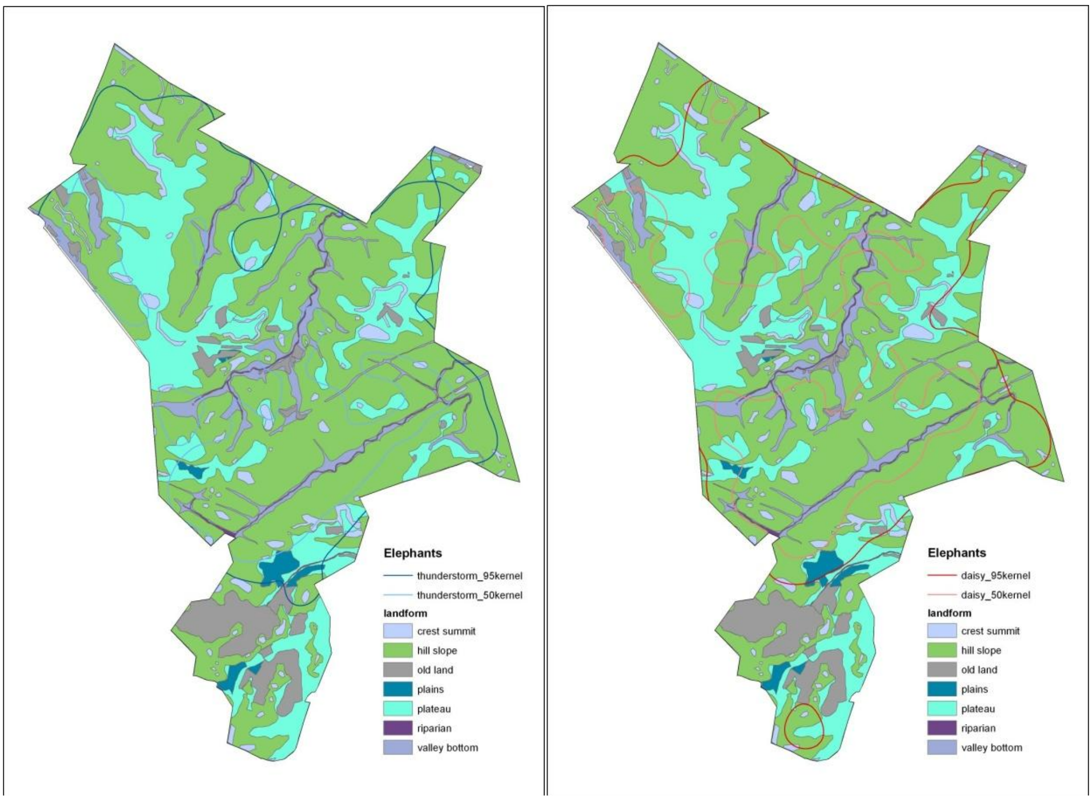

Figure 4: 50% and 95% kernel density analyses of elephant home ranges calculated from data received from GPS collars (blue = Thunderstorm from elephant herd A, red = Daisy from elephant herd B) in relation to land class.

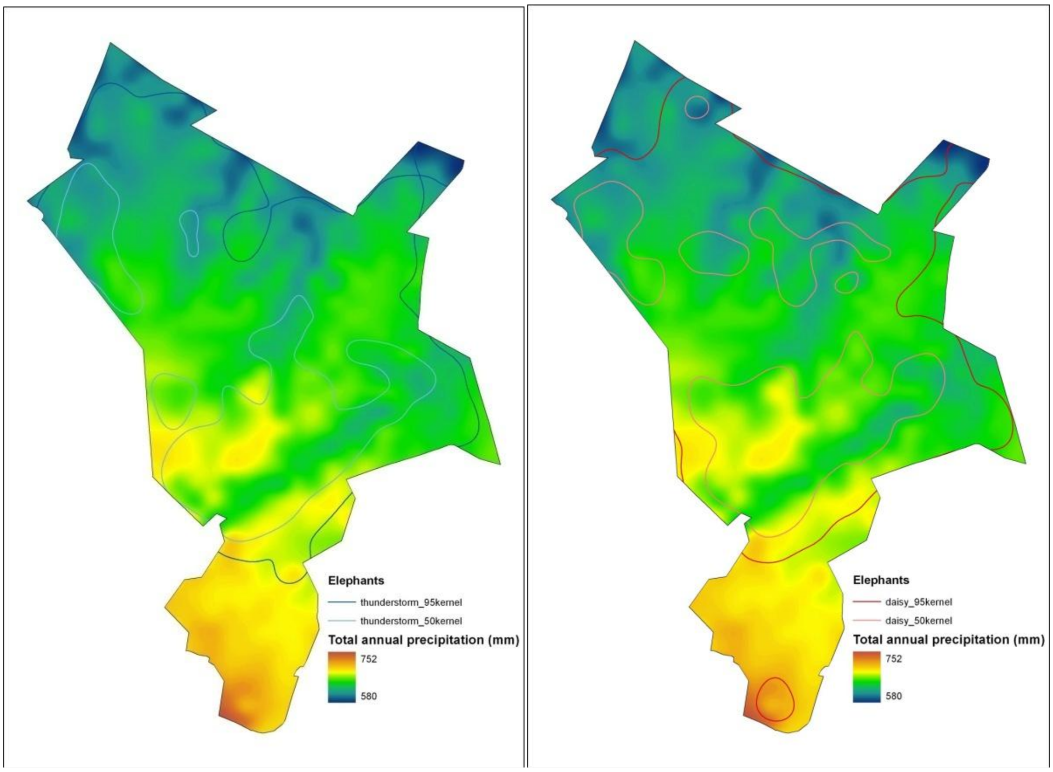


Figure 5: 50% and 95% kernel density analyses of elephant home ranges calculated from data received from GPS collars (blue = Thunderstorm from elephant herd A, red = Daisy from elephant herd B) in relation to mean annual precipitation.

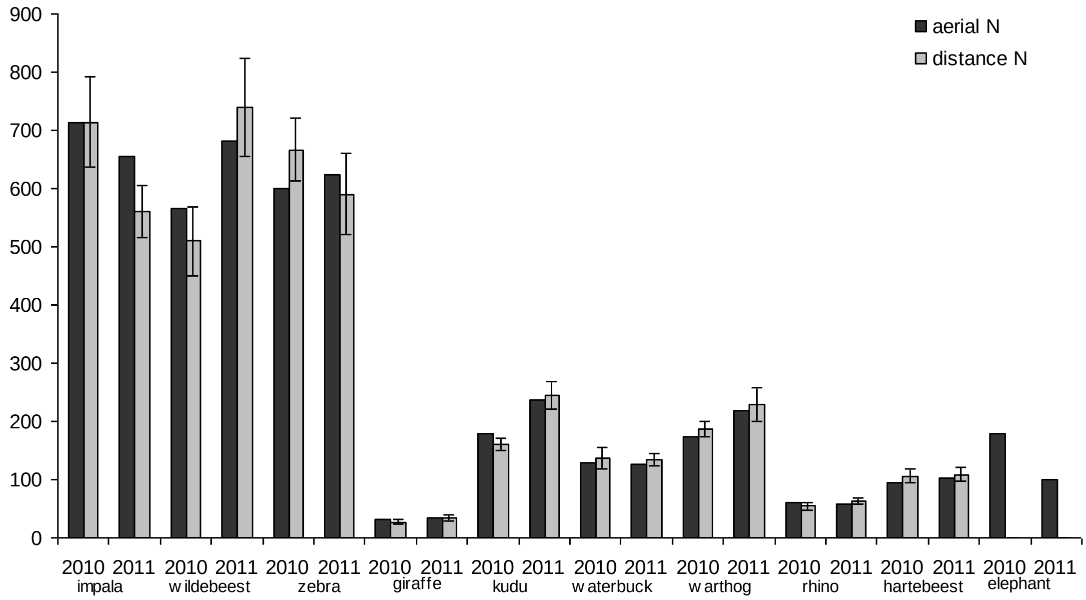


Figure 6: Population size estimates for key herbivores of Welgevonden in 2010 and 2011 by aerial count and distance sampling by land class strata.

Herbivore abundance estimates calculated from distance sampling were compared to abundance estimates calculated from aerial game counts (Figure 6). Although a naïve distance model produces poor estimates of population sizes, when data are correctly stratified, with appropriate truncation and appropriate selection of detection functions, the resulting estimates can be very close to the aerial counts. In almost all cases the aerial count estimate falls within the errors of the distance estimate.

**A6: Discussion of herbivore monitoring results**

Investigation of habitat preferences of 10 key ungulate species indicated that all species avoided crest summits and hill slopes, and preferred old land and plateaus. Most species, particularly elephant, showed a preference for riparian habitat. Further investigation of elephant ranging patterns based on GPS collars fitted to the matriarchs of two separate herds indicated that the elephants ranged throughout the reserve rather than focussing in certain areas although they did tend to avoid the southernmost and driest section of the reserve. This is most likely because water is readily available and widely distributed throughout the reserve. Elephant association with water has been well documented in reserves throughout Africa (Redfren et al., 2003; de Beer & van Aarde, 2008; Loarie et al., 2009; Gaugris & van Rooyen, 2010). As the distribution of water in Welgevonden allows elephant to utilize all the space available to them, one would expect elephant impact on vegetation to be of low intensity and to be evenly distributed throughout the reserve. As such, the presence of elephants in the reserve should have no adverse effect on other ungulate species. This information regarding ungulate habitat preferences can be used to determine the most suitable locations in the reserve for maximising grazing potential with a new burning regime (see Section B of this report).

Comparison of herbivore abundance estimates from line-transect sampling versus aerial surveys indicated that when data from line-transect surveys were correctly modified to account for detectability in different habitat types, the resulting estimates were very close to the aerial counts. These results suggest that after perhaps one or two more years of aerial count data collection it may be possible to discontinue the aerial surveys if distance estimates continue to perform satisfactorily when compared with aerial data.

## Section B: Habitat Monitoring

**B1: The effects of elephant and fire on African vegetation**

A large proportion of South African wildlifeis confined within physical barriers, usually in the form of electrified fences. These fenced enclosures are characteristic of conservation areas, tourism oriented game reserves, private and state owned properties. Successful management of fenced reserves requires a balance between maintaining high densities of large animals that are popular with tourists and the protection of vegetation and habitat heterogeneity. Landscape heterogeneity is extremely important for maintaining biodiversity as it provides variation in shelter and food resources. The African elephant (*Loxodonta africana)* is the largest herbivore species in the savannah ecosystem and, therefore, has a significant impact on vegetation (Guldemond & van Aarde, 2008). Elephant impact on vegetation has been cited as the cause of the conversion of woodland to grassland (Cumming et al., 1997; O'Connor et al., 2007; Ribeiro et al., 2008), increasing the intensity and frequency of fires (Ribeiro et al., 2008; Moncrieff et al., 2008), loss of large trees from the landscape (Kalwij et al., 2010), homogenization of the habitat and loss of diversity in plant and animal species (Cumming et al., 1997; Lombard et al., 2001; Birkett, 2002). African elephants preferentially browse on woody vegetation such as baobabs (*Adansonia digitata*) and acacia trees (*Acacia spp*) by stripping the bark, removing foliage, uprooting the tree and breaking branches. This foraging behaviour has been linked to the decline of woody vegetation in African game reserves (Edkins et al., 2007; O'Connor et al., 2007; Moncrieff et al., 2008) and local extinction of certain species, particularly baobabs (Edkins et al., 2007) and acacia (Gandiwa et al., 2011). Where elephant impact has been considered to be severe, "exclosure plots" have successfully been used to protect plants from elephants (Grant et al., 2007; Lombard et al., 2001; Levick & Rogers, 2008).

In contrast, recent evidence from game reserves where the elephant population is within the recommended carrying capacity has shown that elephant impact on vegetation is distributed evenly across the landscape and thus the impact to any given vegetation type is not sufficient to cause permanent damage to the plants (Boundja & Midgley, 2010; White et al., 2010). In some cases, elephant impact on vegetation was found to increase browse heterogeneity by facilitating the availability and redistribution of browse and encouraging new growth which is particularly important for small browsing herbivores (Kohi et al., 2011). These findings suggest that unless elephant density is unusually high, elephant impact on vegetation remains a natural part of the ecosystem rather than causing widespread vegetation extinction.

To ensure evenly distributed elephant impact on vegetation, fenced reserves must encourage elephants to utilize all the space available to them. Many studies have indicated that elephant habitat use is heavily constrained by access to water (Redfren et al., 2003; de Beer & van Aarde, 2008; Loarie et al., 2009; Gaugris & van Rooyen, 2010). If access to water in fenced reserves is limited, during dry season, elephants will preferentially browse on vegetation close to these few water sources rather than utilizing all available browse within the reserve (Harris et al., 2008; Chamaille-Jammes et al., 2009; Loarie et al., 2009; Roux & Bernard, 2009). Consequently, vegetation in the near vicinity of water becomes heavily impacted by the elephants to the extent of plant extinction (Chamaille-Jammes et al., 2009; Smit et al., 2010). One possible solution to this problem is the addition of artificial water sources to fenced reserves as a means of modifying elephant ranging and habitat use (e.g. Smit et al., 2007; Loarie et al., 2009).

One of the most common forms of natural disturbance is fire, driving diversity in biomes such as grassland, savannas and boreal forests (Bond, 1997; Keeley & Fotheringham, 2001). Bush fires are a common occurrence in South Africa, traditionally occurring in the latter part of the dry season as a result of lightning strikes (van Wilgen 2008). In addition to these natural fires there are many fire management strategies in effect which aim to create and manage biodiversity. Many African reserves use the patch mosaic model (Brockett et al. 2001) where fires are manipulated to create patches of land representative of a range of fire histories, thus creating structural and species heterogeneity (Parr & Brockett, 1999). This method is based on the key assumption that diversity of fire, and hence diversity of patches, will increase biodiversity; in other words, pyrodiversity begets biodiversity. In addition, deliberate burning encourages young grasses to grow, which have a higher nutrient content and are more palatable than successional grasses. Consequently, deliberate burning increases the potential food supply for herbivores and can enable reserves to maintain larger herbivore stocks that would be possible if no burning regime was applied (Brockett et al. 2001).

There is evidence to suggest that herbivores show a preference for recently burned vegetation (Vinton et al. 1993; Sensenig et al. 2010; Allred et al., 2011), but the benefits of patch mosaic burning are still debated (Parr & Anderson). There has been little research into the effects of pyrodiversity on species composition but a number have found that species composition is largely unaffected by fire (Parr et al., 2004; Mills, 2004). Parr et al., (2004) found that over a 50-year natural experiment of extremely varied pyrodiversity, ant assemblages were unchanged or only resulted in differentiation between burned and unburned sites. This implies that species are accustomed to commonly occurring fires in Southern Africa and are largely unaffected by them. However, new concerns have arisen regarding the potential deleterious combination of elephant impact on vegetation and deliberate burning where woody plants that have already been impacted by elephant browsing become more vulnerable to damage from fire (Ribeiro et al., 2008). With this in mind, the decision to apply patch mosaic burning to vegetation should be made in conjunction with close monitoring of elephant impact on vegetation.

**B2: Objectives for habitat monitoring at Welgevonden**

Lions were introduced in 1998 into Welgevonden in response to pressure from the landowners to increase the tourism value of the site. The reserve suffers from a low herbivore carrying capacity due to the low nutrient grasslands (Fritz & Duncan, 1994; Walgren et al., 2009). This, coupled with an increasing lion population, significantly reduced the herbivore population to the extent that additional herbivore stocking had to be undertaken annually. The lion population has subsequently been reduced but annual restocking of herbivores is still being undertaken until the system can be brought into balance. One possible mechanism for maximizing herbivore stocks is to increase the level of deliberate burning of savannah to encourage growth of primary grasses (the preferred food of grazing herbivores). However, before implementing a new burning regime, it is important to investigate the severity and distribution of elephant impact to woody vegetation because woody plants that have been damaged by elephants are more vulnerable to additional damage from fire (Ribeiro et al., 2008). Thus, areas of the reserve with notable elephant impact to vegetation should not be included in the new burning regime. Moreover, if investigation of elephant impact on vegetation reveals severe damage to woody plants then reserve management may consider using exclosure plots to protect plants from further damage.

The aim of this current study was, therefore, to monitor habitat in the Welgevonden Game Reserve to determine the level of fire and elephant impact with the view to use the results of the study to help design a new burning regime. Elephant impact on vegetation was investigated in two ways: by measuring changes to woody plant biomass over time and by measuring the intensity of elephant damage to woody vegetation using a 7-point Walker scale. The frequency and distribution of fires was investigated using satellite data. As the elephant population at Welgevonden is carefully managed using contraceptive intervention and data from elephant GPS collars indicate that they range throughout the reserve rather than focussing on certain areas (see Section A of this report), it was predicted that elephant impact on vegetation would be low and that woody plant biomass would remain relatively constant over time. As the reserve management do not burn extensively through the reserve, it was also predicted that the fire satellite data would identify areas in the reserve suitable for inclusion in a new higher intensity burning regime.

**B3: Methods for habitat monitoring**

<u>B3.1: Habitat monitoring research design and study site</u>

A description of the study site can be found in section A4.1 of this report. A stratified sample of 40 100m x 100m survey sites have been designated in the Welgevonden Private Game Reserve for the purpose of habitat monitoring and bird point counts (Figure 7). Collectively, the survey locations include all major habitat types in the reserve. The large plot size incorporates the full area used for bird point counts, but as measuring vegetation in a 100m x 100m plot would be extremely time consuming, 5m x 5m squares within the plot were used for habitat data collection. The locations of these smaller squares were kept uniform across all of the sites and the distribution was designed as to maximise coverage of the site (see Figure 7). To lay out these 5m x 5m squares, the survey team started at the South-western corner of each the sites, which was accessed by walking 70.7m (hypotenuse of 50m x 50m square) in a south-westerly direction from the centre of the 1 ha block. This point was referred to as the Main Site Marker. From the main site marker, the 5m x 5m square was marked out by laying out a rope 5m directly north, and from this point, 5m east, followed by 5m south and finally 5m west. This 5m x 5m square was labelled Square 1 (see Figure 7). Care was taken to ensure that no one walked inside the square during the marking period as this would influence the veld before the data was collected.

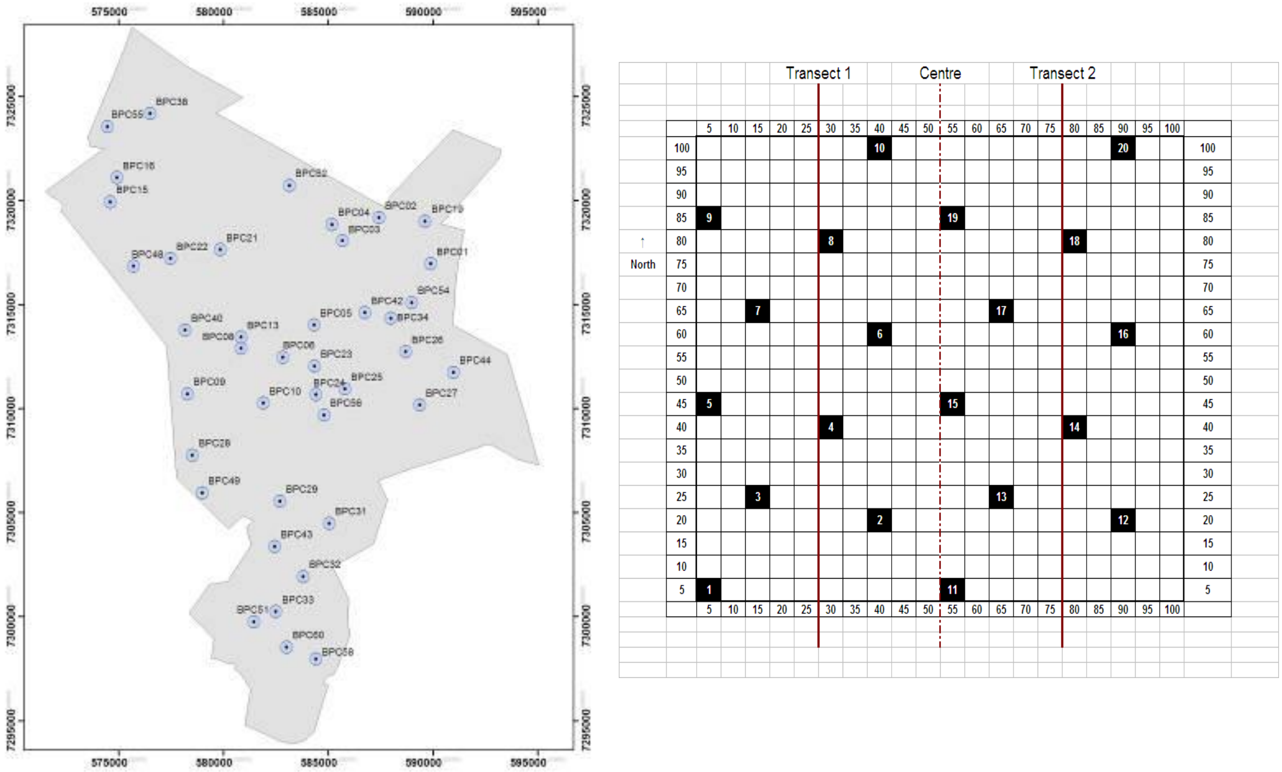


Figure 7: Distribution of the 40 survey sites for habitat monitoring in Welgevonden Game Reserve and lay-out of the 5m x 5m squares within each 1 hectare survey site

<u>B3.2: Habitat data collection</u>

Habitat surveys were completed once a year at the time of the winter bird surveys from 2009 to 2011. In each 5m x 5m square all woody plants >1m were identified to species level and the width of the plant at the widest point and the height of the widest point were recorded. The basal stem (or bush) diameter, and average diameter of stems for bushy species were also be recorded. Woody vegetation was then placed into one of six height categories:

- 1 – 2 meters
- 2 – 4 meters
- 4 – 6 meters
- 6 – 10 meters
- 10 – 20 meters
- >20 meters

The amount of woody vegetation at different heights was measured using a 3m pole with 0.5m markings along transect 1 and transect 2 of the 1ha plot (see Figure 7). The pole was placed on each 1m marking of the 100m tape and the number of branches touching the pole was counted in each 0.5m category up to 20. More touches than this were counted as >20. If a 1m sample point is occupied by a woody plant species then >20 touches should be recorded in each 0.5m category up to 3m or to the height of the bush if it is less than 3m. A second person followed to measure the volume of the grass at each of the 1m points using a veld monitoring device called a Disc Pasture Meter, which consists of an aluminium disc of standard weight and size that is dropped down the pole to squash the grass. The height of the disc was then read off the pole to give an estimate of grass volume at that point. Both of the people walking up this diagonal transect walked on the right of the line and conducted the data collection to the left of the tape, again, so that the veld was not altered prior to data collection. In addition, the height of the tallest tuft of grass within a 0.5m radius circle around that point was measured.

The level of grazing in the entire 5m x 5m square was estimated in the following categories:

1- no indication of use
2- very few grass tufts show any signs of being removed by larger herbivores (clear cut leaving stalks at the same height)
3- more than10 % but less than 30% of tufts show signs of utilisation by larger herbivores
4- more than 30 % but less than 50% of tufts show signs of utilisation by larger herbivores
5- more than 50 % of tufts show signs of utilisation by larger herbivores

A qualitative and quantitative evaluation of impact by herbivores (especially elephant), as well as other herbivores or due to other causes such as wind was made on each woody plant. Impact was quantified according to the Walker 7-point scale.

| TYPE: | CODE: |
|---|---|
| Pulled or kicked out | A |
| Pushed over and dead or apparently dead | B |
| Main trunk broken, is or appears to be, dead | C |
| Main trunk broken but resprouting or likely to resprout | D |
| Pushed over but still alive | E |
| Main trunk tusk-slashed | F |
| Main trunk debarked (% of the circumference) | *G |
| Roots exposed and eaten (% of the circumference) | *H |
| Primary branches broken | *J |
| Secondary and/or smaller branches broken | *K |
| None: | Z |

*These parameters are quantified (‘Amount’)

Impact types G, H, J and K were quantified according to the percentage classes given below. The percentage classes refer to the percentage of the total canopy volume and are estimated. In the case of exposed roots and debarking of the main trunk (types G and H respectively), the percentage of the root base or trunk's perimeter (i.e. a circle) so affected was estimated and coded accordingly.

| | |
|---|---|
| 1-10% | 1 |
| 11-25% | 2 |
| 26-50% | 3 |

| | |
|---|---|
| 51-75% | 4 |
| 76-90% | 5 |
| 91-100% | 6 |
| None: | Z |

Fire impact was quantified as follows:

| | |
|---|---|
| Main stem(s) killed, entire plant dead, or apparently so | A |
| Main stem(s) killed but coppicing from ground level | B |
| Main stem(s) alive, re-sprouting | C |
| Only debarked area of main stem burnt | D |
| Primary stems killed, no signs of re-sprouting | E |
| Primary stems killed, re-sprouting off main stems | F |
| Secondary and/or smaller branches killed, re-sprouting | G |
| None – no signs of fire impact | Z |

Where a plant was impacted by something other than elephant or fire, the impact was recorded, regardless of whether the cause was known or not. Impact was quantified, where possible or applicable, using the same classes as for elephant impact amount.

| | | | |
|---|---|---|---|
| Buffalo | B | Wind | W |
| Eland | E | Hail | H |
| Kudu | K | Lightning | L |
| Giraffe | G | Other | O (If known, the cause must be recorded) |
| Porcupine | P | Unknown | X |
| Black rhino | R | | |

B3.3: Habitat data analyses

The biodiversity monitoring database for Welgevonden allows data to be processed to calculate basal area of woody plants in each plot each year, and also to evaluate the Walker damage scale and estimate grass biomass. In order to investigate changes to these three variables over time, all estimates of each variable were combined across the plots in the reserve in a given year to find a mean value and a standard error of woody plant basal area, elephant impact, and grass biomass. The time series were then converted to index numbers.

Satellite remote sensing offered the opportunity to characterize the fire regime of Welgevonden Game Reserve. We exploited the monthly time series of MODIS burned areas MOD45 (Roy et al., 2002) at 500m resolution. This product was produced by an algorithm that detects sudden and persistent changes in reflectance of vegetated areas associated with burning events. The time series can be manipulated to derive maps of fire frequency and interval since the last fire. Fire history was censored at 140 months. When interpreting burned areas maps it is important to note the limitations of burned area detection with MODIS.

**B4: Habitat monitoring results**

Mean basal area of woody plants in habitat plots remained relatively unchanged from 2009 to 2011, (mean 2009 = 0.142 +/- 0.053, mean 2011 = 0.154 +/- 0.052: Figure 8). The mean level of elephant impact on woody vegetation (indicated using the 7-point walker scale) has steadily increased from 2009 to 2011, (mean 2009 = 3.21 +/- 0.41, mean 2011 = 3.85 +/- 0.38: Figure 9). However, the mean score for elephant damage remained relatively low indicating that there is no immediately risk of localized woody plant extinction or widespread irreversible damage to woody vegetation in the reserve. Grass biomass (indicated by mean sward length) remained relatively constant from 2009 to 2011 (mean 2009 = 62.5 +/- 16.2, mean 2011 = 56.25 +/- 25.92: Figure 10).

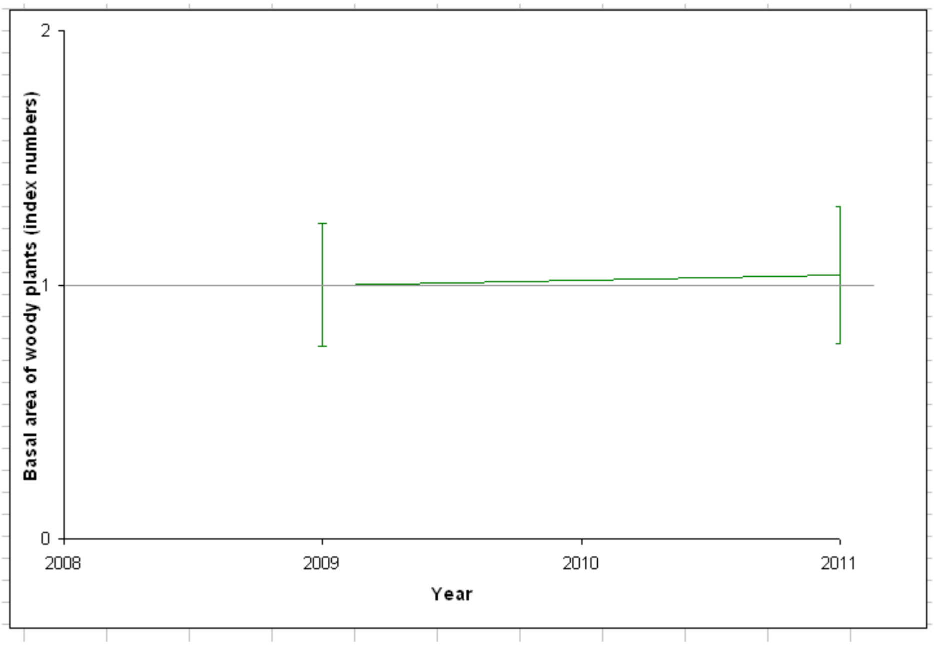


Figure 8: Basal area of woody plants index calculated from habitat surveys in 2009, 2010 and 2011

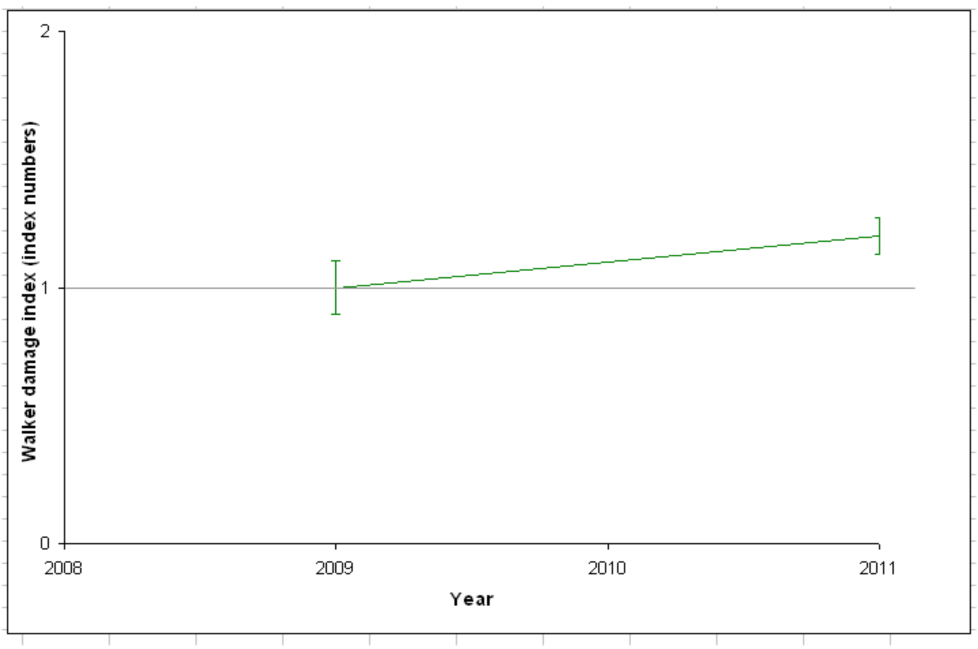


Figure 9: Walker elephant impact index for woody plants calculated from habitat surveys in 2009, 2010 and 2011

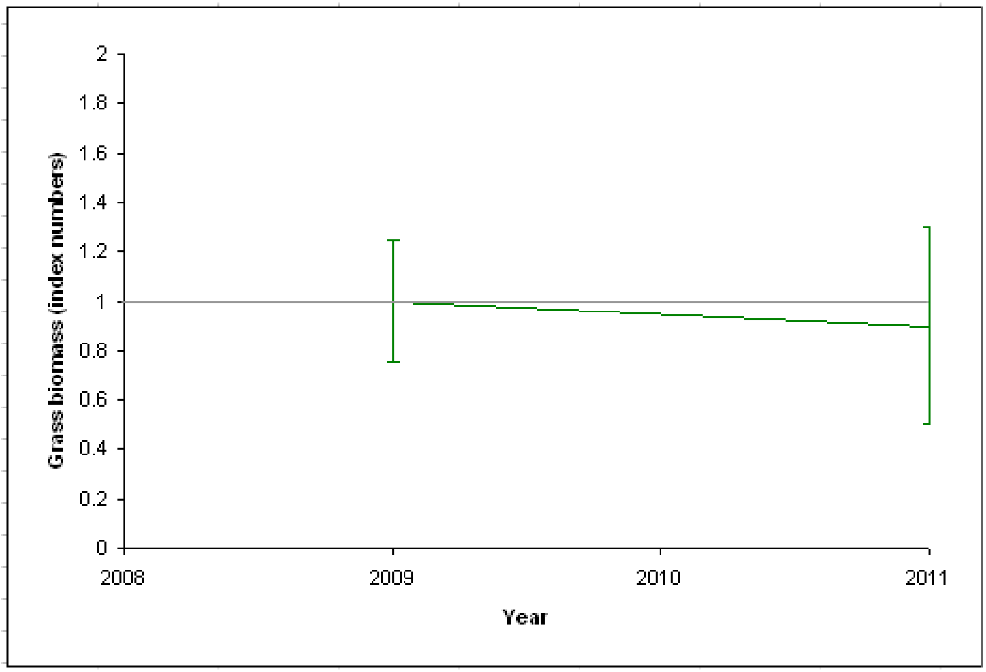


Figure 10: Grass biomass index calculated from habitat surveys in 2009, 2010 and 2011

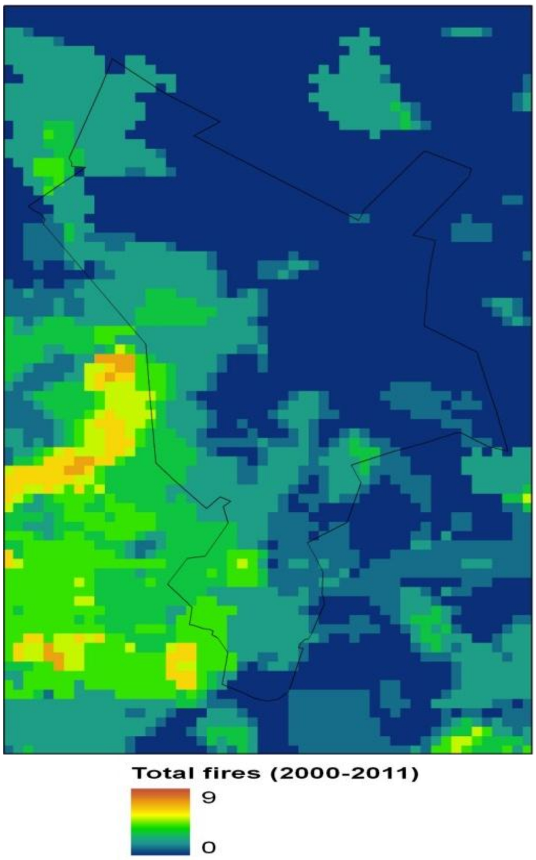


Figure 11: Fire frequency in Welgevonden

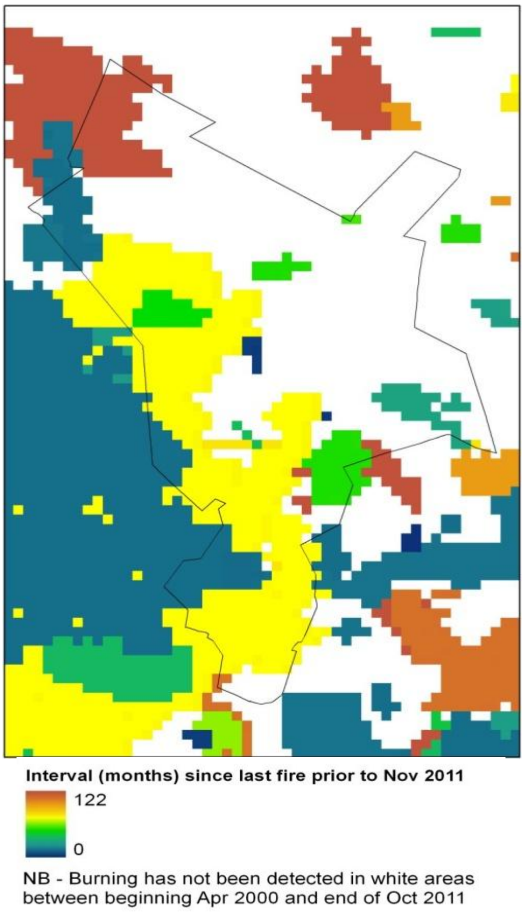


Figure 12: Fire interval since last burning occurred in Welgevonden

The frequency of fire and fire interval since last burning in the Welgevonden Game Reserve are presented in Figures 11 and 12 respectively. Where burning has occurred, the total number of fires averages around 3 fires since 2000 and the interval since fire prior to November 2011 was over 100 months. No burning of any kind since April 2000 has been detected in the Eastern side of the reserve. The most significant effect is associated with the scale of the instantaneous field of view of the sensor and the relative contrasts of a mixture of land cover classes. Very small burned areas may not be detected. Similarly very mild burns from which rapid recovery occurs may also not be detected. Nonetheless these results suggest a gradient of burn severity from West to East across the reserve.

**B5: Discussion of habitat monitoring results**

Investigation of elephant impact on habitat at Welgevonden Game Reserve indicated that intensity of elephant damage to woody vegetation was consistently low throughout the reserve. Moreover, there was no significant change to woody plant biomass from 2009 to 2011. The low levels of elephant impact on vegetation are most likely due to the even distribution of water throughout the reserve that enables elephants to utilze all the space available to them (e.g. Smit et al., 2007; Loarie et al., 2009), and a successful contraceptive management plan that has prevented the elephant population from growing too large for the space available to them. Moreover, these findings support the view that elephant impact on vegetation is only a cause for concern when elephant density exceeds the carrying capacity of the reserve (Boundja & Midgley, 2010; White et al., 2010). Collectively, these data suggest current level of elephant impact on vegetation would not interfere with plans to increase the burning regime in the reserve.

Investigation of fire frequency and distribution using satellite data indicated that the overall intensity of fire is very low and the entire Eastern side of the reserve appears to have never been burned. Burning intensity is notably higher in the adjacent reserve to the west of Welgevonden suggesting that there is potential to increase the burning regime within Welgevonden. If the burning regime in the reserve is increased, then the news areas to be burned should be chosen carefully so as to maximize available grazing for herbivores. Investigation of habitat preferences of 10 key herbivore species in the reserve indicated that all species deliberately avoid hill crests and hill slopes (see Section A of this report). Consequently, burning in these areas is unlikely to benefit herbivore stocks. All species showed a preference for old lands and plateaus, and all species with the exception of blue wildebeest showed a preference for valley bottoms. These three land classes are therefore the most suitable areas for burning. In terms of the distribution of these land classes and current fire intensity, the majority of the old lands are located in the Southern section of the reserve where burning intensity is highest (along with the western side of the reserve). As the Southern section of the reserve is also the driest (see Figures 5 and 13), deliberate burning in this area should proceed with extreme caution.

The best options for the new burning regime may therefore be to focus on the plateaus and valley bottoms. These two habitat types are distributed throughout the reserve, and the plateaus in particular represent a large proportion of the total area of the reserve. As a result, if grazing could be maximized throughout the plateaus then this could lead to a significant increase in the carrying capacity of herbivores. Nevertheless, widespread burning throughout the reserve could have a negative impact on the ecosystem in general. With this in mind, it would be pertinent to investigate the possible benefits of different burning regimes using an experimental paradigm before implementing a reserve-wide strategy.

**B6: Recommendations for investigating the effect of burn regimes on herbivores**

Should the Welgevonden reserve management wish to experimentally test the effect of burn regime on herbivore density, there are two possible strategies that could be used. The first approach is to establish a set of large, reasonably homogeneous land units and allocate planned burning activities in a randomized replicated manner to these units. Herbivore community attributes should be measured on every land unit before and after the prescribed burns, and a record should be kept of which burn treatments were applied to each land unit. Analytical approaches such as ANOVA could then be used to test for an effect of burning on herbivores in a robust experimental design which controls for site effects. This approach requires careful record-keeping of management actions and some work to design the burn schedule, but analysis of the data produced by such a study is very simple.

The second approach is a historical natural experiment. This method involves using satellite remote sensing to characterize the burn regime at fine spatial scale and short time scales. This method could make use of the MOD45 burned areas products described above, or more sophisticated custom products such as monthly delta Normalised Burn Ratio (dNBR) derived from MODIS or Landsat like sensors to characterize the burn regime. Additional gridded time series of environmental covariates relevant to sward condition will also be required (such as satellite measured precipitation). The standard monthly herbivore surveys (see Section A of this report) could then continue as normal in order to spatially join the herbivore records with the environmental records to build a statistical model of the herbivores community attribute of interest such as local density as a function of environmental conditions. This would permit prediction of the impact of burning savannah in a particular condition on the herbivore community. This approach requires no special management actions; however, the analytical procedure is more complex.

## Section C: Bird Abundance and Diversity

**C1: Factors affecting African bird populations**

Savannah grasslands are periodically burned in a mosaic pattern to improve the grazing value and also to reduce the fire load of dead grass (Parr & Anderson, 2006). Savannah habitat is also heavily impacted by elephants (Edkins et al., 2007; O'Connor et al., 2007; Landman et al., 2008; Levick & Rogers, 2008) and the combination of fire management strategies and high densities of elephants has lead to major changes to the savannah ecosystem (Ribeiro et al., 2008; Mapaure & Moe, 2009). Consequently, close monitoring of the effects of environmental variables and human intervention on species distributions and species richness is a prerequisite for the successful management of African reserves. Many studies have monitored the effect of human intervention (e.g. burning) and browsers on vegetation, but fewer studies have investigated the effect of these variables on faunal biodiversity. Herpetofauna (Nasseri et al., 2011), invertebrates (Parr, 2004; Haddad et al., 2010) and particularly birds (Davis et al., 2000; Mills, 2004; Valentine et al., 2007; Wilson et al., 2008) are excellent indicators of faunal responses to changes in vegetation and are therefore the ideal taxa to monitor when investigating the effect of environmental variables and human activity on savannah biodiversity.

African bird assemblages are reportedly affected by environmental variables, human activity and browsers (van Rensburg et al., 2002; Chown et al., 2003; Fairbanks, 2004; Valentine et al., 2007; Wilson et al., 2008). Environmental variables such as net primary productivity; precipitation (which is also strongly correlated with net primary productivity); absolute minimum temperature; and, at coarser resolutions, habitat heterogeneity are reportedly significant positive correlates of avian species richness in South Africa (van Rensburg et al., 2002; Wilson et al., 2008). Bird species richness is also known to be affected by topography (Patterson et al., 1998).

Investigation of pyrodiversity on bird diversity have indicated that species composition is largely unaffected by fire (Parr et al., 2004; Mills, 2004). Mills (2004) studied medium term responses of birds to mild/cool and severe/hot sections of burned sites in comparison to unburned sites. Bird species richness did not differ significantly between treatments, although species count was slightly higher in mild burn sites than in control sites. Bird species composition, sorted by dietary preference, displayed minor changes. Some changes were linked to habitat change as a result of fire. Granivores and ground-feeding species were less common on severe burns where there was the least grass cover. However, no species was entirely absent (Mills, 2004). In a similar study (Bouwman & Hoffman, 2007) bird species richness and species composition was monitored over a 5-month period following two controlled burns and an accidental fire. Species richness and density increased immediately in the burned areas and most of the species that moved into the burned areas were larger, more opportunistic birds. After five months, however, bird communities returned to their pre-burn composition and density (Bouwman & Hoffman, 2007).

Similar studies have been conducted in the grassland of Australia, which grows in sub-tropical conditions similar to that of Southern Africa. Reilly (1991) observed three responses to fire in bird populations after a severe wildfire and found that 60% of bird species had returned after one year and 86% by two years, although bird population sizes took longer to recover. This indicates that whilst fires do not threaten the existence of bird species, the intensity of fires can affect their abundance. Bain et al., (2008) investigated the effect of fire on eastern bristlebirds (*Dasyornis brachypterus*) and found that their numbers decreased in burned areas and increased in unburned areas. This pattern remained for up to 9 months before numbers returned to pre-burn levels in both areas. This suggests that bristlebirds move to unburned areas before returning when conditions are more suitable. Valentine et al., (2007) used replicated, experimental fire treatments (unburnt, dry season burnt and wet season burnt), spanning two habitats (riparian and adjacent open woodland), to examine the short- (within 12 months of fire) and longer-term (within four years of fire) changes of bird assemblages. With the exception of a few species, higher abundances of birds in the burnt treatments were observed in the short-term. Dry season burnt sites contained higher abundances of insectivores and granivores, while wet season burnt sites had more carnivores. In the long-term, dry season burnt sites were characterized by lower abundances, especially of nectarivores and granivores. These findings were particularly pronounced in riparian habitat (Valentine et al., 2007).

Recent studies in African reserves have suggested and mosaic burning strategies combined with elephant impacted habitat can have a significant effect on vegetation (Ribeiro et al., 2008). As there is significant evidence to suggest that bird density and species richness is heavily affected by habitat (van Rensburg et al., 2002; Mills, 2004; Bouwman & Hoffman, 2007; Valentine et al., 2007; Wilson et al., 2008) it is likely that the combined effect on elephant and fire damage to vegetation, in turn, affects bird biodiversity. The short-term and long-term combined effects of elephant and fire damage to vegetation on bird diversity is yet to be investigated.

**C2: Objectives for bird monitoring at Welgevonden**

The objectives for bird monitoring at Welgevonden Game Reserve were twofold. The first aim was to establish the distribution of bird species richness in relation to environmental variables. Following van Rensburg et al., (2002) and Wilson et al., (2008) this study aimed to model bird species richness using vegetation variables in addition to precipitation, temperature and elevation. The second objective of the bird monitoring project at Welgevonden was to investigate long-term changes to bird guild abundance as a means of determining whether elephant and fire damage to vegetation has had a general effect on the bird population. The information obtained may then be used to assist with plans for a new fire management strategy in the reserve.

**C3: Methods for bird monitoring**

C3.1: Bird monitoring research design and study site

A description of the study site can be found in section A2.1 of this report. A stratified sample of 40 survey sites have been designated for the purpose of bird point counts and habitat surveys. Surveys were conducted twice per year, during the summer and winter seasons. Each of the 40 sample sites were surveyed for birds using point counts to obtain 3 replicate counts per season.

C3.2: Bird data collection

Bird surveys were conducted from just after dawn until a period up to 3 hours after dawn. The survey team with supporting Field Guide / Ranger gathered around the central point of the 100m X 100m square, facing outwards in a circle from the centre of the square so birds over all 360 degrees can be recorded. Any birds disturbed during that period were recorded. One person was designated to record all birds identified by the team and to note the time from the beginning of the 10-minute period that each bird was observed. The survey team then identified all birds seen or heard over the 10-minute period, their approximate distance (in 10m bands to 50m), their compass bearing (the distance and compass bearing data enable the distribution of the records within the 100m square to be plotted) and their height (ground, low, mid, canopy and flying). A digital recorder was used to record the whole 10-minute point count so that any reported observations or data accompanying those observations missed by the recorder in the heat of the 10 minute count (observations can come very rapidly at some sites) could be detected.

C3.3: Bird data analyses

In order to describe the environment of Welgevonden we prepared seven maps of environmental variables which were used as covariates in species distribution models. All maps were of the same resolution and spatial extent and perfectly geocoded to each other such that they are 'overlayable' in subsequent map algebra operations. We used three Landsat 7 scenes collected in the summers of 2006 and 2009 to characterise land cover in the park (Table 2). The scenes were downloaded from the USGS, and the metadata was used to write macros to first correct all bands of all scenes to at-sensor radiance and then normalise this radiance in all bands of all scenes to top of atmosphere reflectance. These scenes were then overlaid in the sequence given in Table 3 to simultaneously gapfill the SLC_off gaps in the Landsat 7 scenes and mosaic all scenes together to produce a complete coverage of Welgevonden. The six bands produced were then clipped to the outline of the reserve. We then performed a tasselled cap (TC) transformation using ETM coefficients to reduce the dimensionality of this multispectral data set and produce three statistically orthogonal layers which are biologically meaningful: TC greenness represents the amount of healthy green vegetation, TC brightness represents the amount of bare soil, and TC moistness represents soil moisture (Figure 13). We used a 30m digital elevation model derived by minimum curvature spline interpolation of 90m data from the shuttle radar tomography mission. We used three spatially interpolated climate surfaces (Hijmans et al, 2005): Mean annual temperature, total annual precipitation and precipitation in the driest quarter (Figure 13). The distribution of each species was modelled independently and then used to create a map of relative species richness.

Table 2: Landsat scenes used to derive environmental variables for Welgevonden Game Reserve

| WRS path row | Date | Satellite | Sensor | Solar elevation (°) | Scene ID | Gapfill order |
|---|---|---|---|---|---|---|
| WRS-2 p171r077 | 13 August 2009 | Landsat 7 | ETM | 38.4726340 | LE71710772009225ASN00 | 1 |
| WRS-2 p171r077 | 29 August 2009 | Landsat 7 | ETM | 43.0598742 | LE71710772009241ASN00 | 2 |
| WRS-2 p171r077 | 18 June 2006 | Landsat 7 | ETM | 32.0286457 | LE71710772006169ASN00 | 3 |

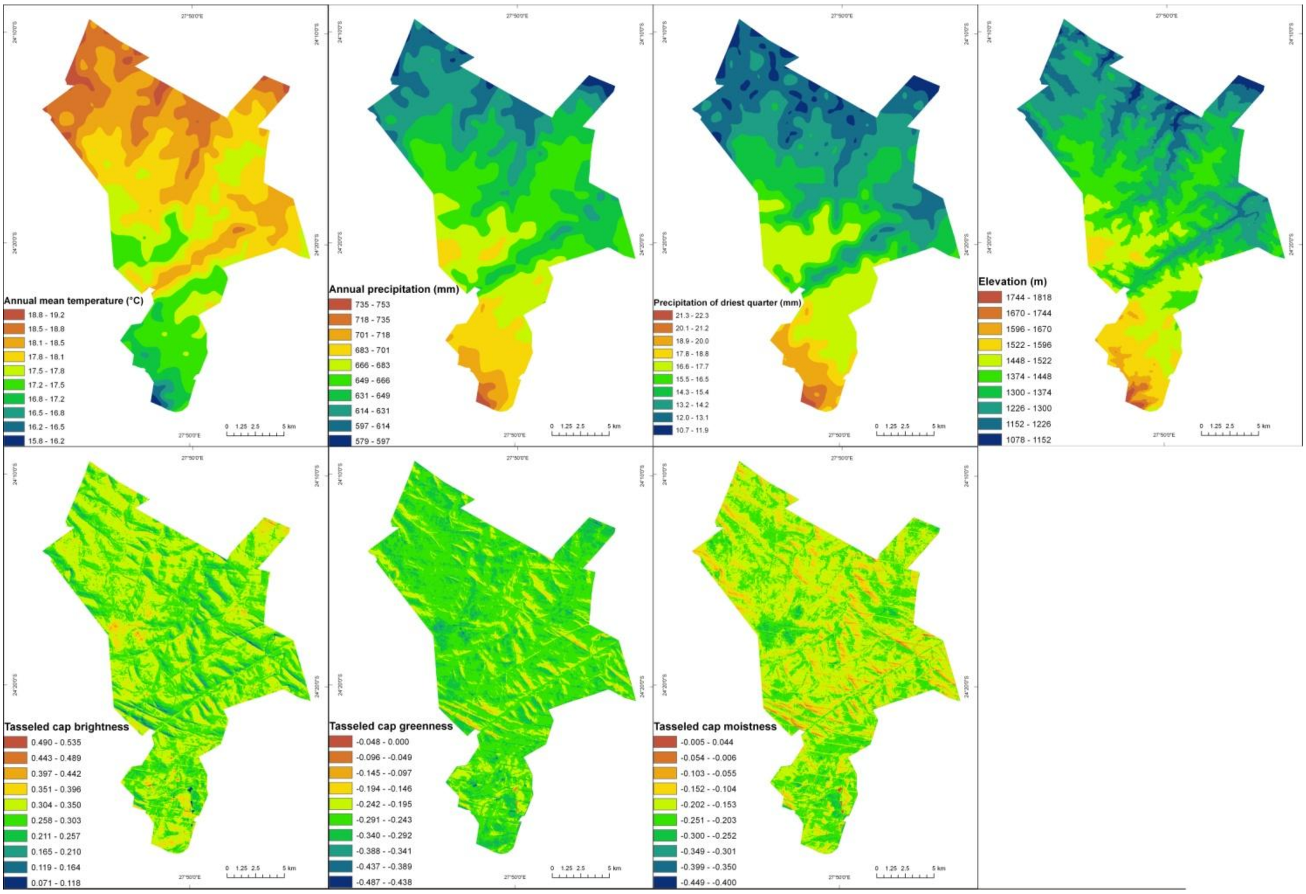

Figure 13: Environmental variables used to model bird distribution patterns and species richness

The bird community in Welgevonden is dominated by a small number of common species, yet there are also many species which are relatively rare. It is not possible to detect annual trends in the relative abundance of the rarest species using a relatively small data set. However by grouping species into guilds it was possible to derive an indicator which has some power, in the long-term, to detect significant trends in bird populations. Birds were allocated to guild following Hockey et al (2005), relative abundances were calculated for all species, summed within guilds and standard errors calculated. Finally the data were converted to index numbers.

**C4: Bird monitoring results**

Figure 14 depicts the distribution of bird species richness in Welgevonden Game Reserve. The environmental variables had differing effects on each individual bird species and not all variables were relevant for each bird species. However, as all variables were relevant to some species, it is fair to say that all variables affected the distribution of bird species richness. Bird guild population trends are depicted in Figure 15. Abundance of aerial insectivores, raptors and ground birds has remained relatively constant from 2009 to 2011. There has however been a significant increase in the abundance of frugivorous birds from 2009 to 2011.

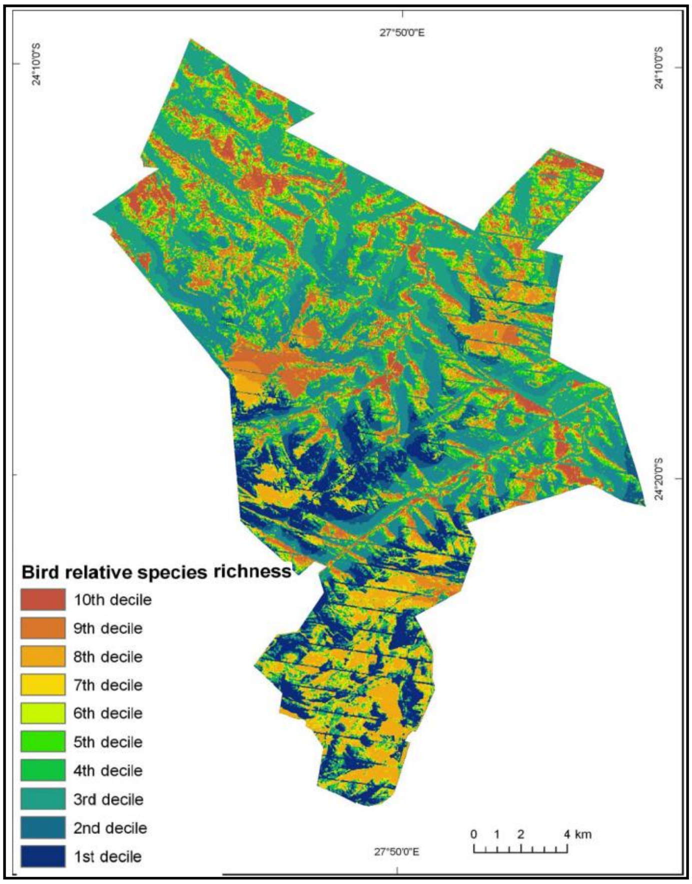


Figure 14: Relative species richness of birds in Welgevonden Game Reserve

**C5: Discussion of bird monitoring results**

As predicted, annual precipitation, mean annual temperature, elevation, and vegetation characteristics (tasselled capped greenness, brightness and moistness) significantly affected the distribution of bird species richness in the reserve. In general, bird species richness appears to be lower in the southern section of the reserve, which is also the driest part of the reserve (Figure 13). The southern and western sections of the reserve have also been subjected to a higher intensity of burning than the remainder of the reserve (see Figures 11 and 12), suggesting that there may be a long-term effect of burning on bird distribution patterns.

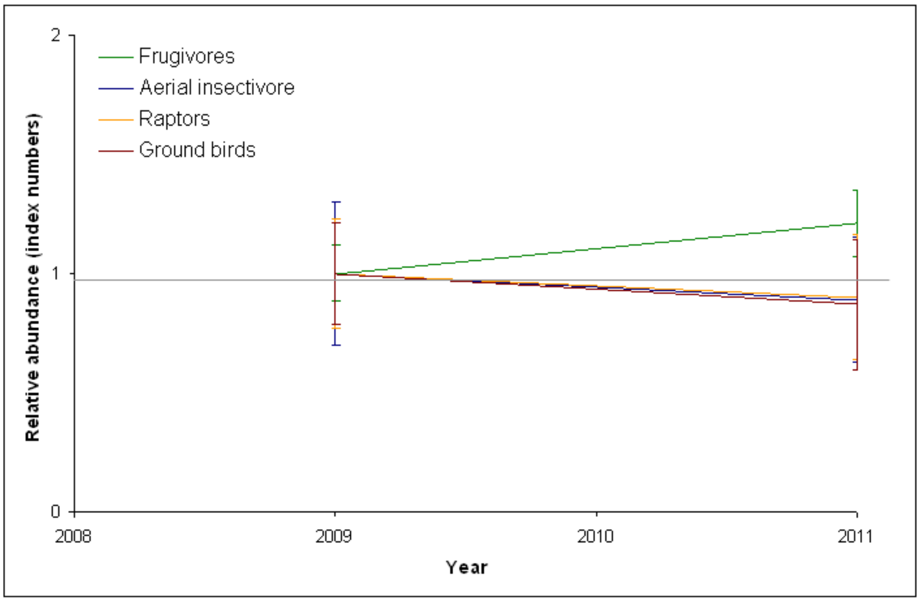

Figure 15: Trends in relative abundance of bird guilds between 2009 and 2011.

However, further analyses are required to tease out the relative importance of environmental variables and historical fire patterns on bird diversity.

In terms of long-term changes to relative bird guild abundance at Welgevonden, only frugivorous birds showed any notable change in abundance. That ground bird, aerial insectivore and raptor abundance has remained unchanged from 2009 to 2011 is to be expected considering that the intensity of elephant impact on vegetation and burning at Welgevonden are very low (see Section B of this report). For the same reason, it is difficult to interpret the increase in frugivorous bird abundance. Even if the low intensity of fire at Welgevonden had a long-term affect on birds, one would expect ground dwelling birds and insectivores rather than frugivores to be the effected guilds (Mills, 2004; Valentine et al., 2007; Bain et al., 2008). Similarly, one would expect elephant damage to woody vegetation to cause a decrease rather than an increase in frugivorous birds. Consequently, it seems most likely that the increase in frugivorous bird abundance in 2011 compared to 2009 was most likely due to differences in annual rainfall causing a change in fruit abundance in the reserve.

Published literature indicates that unless burning is severe (Reilly, 1991) changes to bird assemblage as a result of fire are generally only relevant in the short-term (Mills, 2004; Bouwman & Hoffman, 2007; Bain et al., 2008). Consequently, it is not possible to investigate the immediate effects of burning on bird diversity at Welgevonden using the existing data set. If the reserve management intends to increase the burning regime in the reserve so to maximize grazing potential for herbivore stocks, then it would be pertinent to investigate the possible effects of different burning regimes on bird density and species richness using an experimental paradigm before implementing a reserve-wide strategy (see Section B6 of this report for examples of burning experiments). Reserve management may also want to consider burning during the wet season rather than during the dry season because wet season burns do not appear to have a long-term affect on bird populations (Valentine et al., 2008).

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