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Abstract

Earlier studies done in the north have shown that grazing increases surface albedo by reducing shrub height and abundance, and thus have the potential to cool down the local climate. But what about effect of grazing in other systems? In African savanna grasslands some grazers are able to transform grass swards into a lawn-like state by regular grazing. The grazing excludes tall-grass colonizers and the spread of lawn grasses is thus promoted by grazing. A characteristic of savanna ecosystems is the tree-grass coexistence. Field experiments have indicated that in the absence of herbivory and fire, woody plant encroachment in savannas can be high, but grazing lawns seem to be resistant to shrub invasion. I investigate how the creation of grazing lawns affects the albedo of savanna grasslands. By comparing albedo between grazing lawns, bunch grass and woody shrubs. I also quantify the extent of grazing lawns across the. I show that grazing lawns have a significantly higher albedo than both bunch grass and grass encroached by woody plants and that albedo increased during the growing season. Albedo decreased when the amount of bare soil increased, and albedo increased with more grass. The assessment of grazing lawn distribution in the park showed that lawns in some parts cover 20% of the transect area. This study shows that grazing lawns, and by extension grazers, could affect the local climate on African savannas, through a higher albedo.

1. Introduction

The climate system of the earth is driven via the incoming long- and short wave radiation emitted by the sun. This is either directly reflected or absorbed and reemitted as heat (long-wave radiation) from the earth surface. The climate system is controlled by the energy balance between land surface and the atmosphere, both locally and regionally as well as globally (Bogren et al. 1999). Human activities such as the burning of fossil fuels and degradation of natural forests have caused huge and abnormal amounts of carbon dioxide (CO_2) and other greenhouse gases to be emitted into the atmosphere since the industrial revolution (IPCC 2014). The greenhouse gases trap heat from the sun in the earth's atmosphere. This increases the global temperature and has a negative effect on biodiversity and human life (Kricher 2011, IPCC 2014). CO_2 is the most important forcing gas of climate change (Bogren et al. 1999, Bernes 2007). Plants strongly interact with climate change and do this in three main ways; through chemical feedbacks (photosynthesis), water feedbacks (transpiration) and energy feedbacks (albedo). During photosynthesis plants convert CO_2 to energy and oxygen (O_2), thereby reducing global warming by removing CO_2 from the atmosphere (Bernes 2007, Kricher 2011, Reece et el. 2011). Transpiration is the passage of water through a plant from the roots through the vascular system to the atmosphere (Reece et al. 2011). Deep rooted plants like trees have a higher transpiration than other plants which affects moisture transport to the atmosphere that works as a cooling agent (Bala et al. 2007, Syktus and McAlpine, 2016). Albedo is the fraction of solar radiation reflected from a surface. The energy that is absorbed raises the surface temperature, and promotes the heat exchange between the surface and the lowest layer of the atmosphere. Surface albedo thereby has a major influence on the energy balance of the Earth (Coakley 2003).

The balance among these different climate feedbacks is not well known, although the albedo effects seem to be strongest at high latitudes (Betts 2000, Bala et al. 2007, Chapin et al. 2008, de Wit et al. 2014), while the transpiration and carbon-balance feedbacks are stronger in the tropics (Bala et al. 2007, Chapin et al. 2008). In research on climate change most emphasis has been on the chemical (carbon) feedbacks, but increasing number of studies suggest that water- and energy feedbacks are equally important (Chapin et al. 2000, Foley et al. 2003, Chapin et al. 2008, Naudts et al. 2016, Syktus and McAlpine 2016). The effects of albedo on climate in the North are strongly mediated by snow cover. Climate warming causes snow to melt earlier (by 1–2 days per decade) (Euskirchen et al. 2007). This reduces albedo, which increases energy absorption, and thereby increases the rate of local to regional climate warming. The warmer climate also causes shrub encroachment and tree line advance which further reduces the albedo and increases warming (Chapin et al. 2008). Vegetation transitions also have effects in summer. Modeling results indicate that a change from moist tundra to shrub tundra could reduce albedo by 0.005 and increase net radiation by 0.9 W/m^2 which would result in approximately a 3.4 W/m^2 increase in summertime sensible heat flux. This is comparable to the radiative forcing of 4.4 W/m^2 which is the expected effect of a doubling of the atmospheric CO^2 concentration (Chapin et al. 2000).

Most of what is known about albedo and vegetation is dominated by data from the boreal and temperate zone (Chapin et al. 2000, Beringer et al. 2005, Cohen et al. 2013, te Beest et al. 2016) and only few studies are from (sub)-tropical zones (Allen et al. 1994, Syktus and McAlpine 2016). According to the commonly accepted view, trees and shrubs have a lower albedo than light soil and short grass (Allen et al. 1994, Chapin et al. 2000, Coakley 2003, Thompson et al. 2004, Pearson et al. 2013). Thompson et al. (2004) measured albedo along

a gradient from arctic tundra to boreal forest, and found that albedo decreased dramatically along the vegetation gradient from tundra to forest. This decrease in albedo was closely correlated with the increase in above-ground biomass and leaf area index. Several studies show that the low albedo of shrub and forest tundra can result from the greater trapping of shortwave radiation in the taller, more complex canopy (Chapin et al. 2000, Thompson et al. 2004, Beringer et al. 2005). This means that short grass patches should reflect more radiation, which can reduce the warming of the earth's surface.

Only a few studies have investigated the effects of grazing on albedo and they have been done in high latitudes. Their results have shown that grazing by reindeer both delay snowmelt and increase the surface albedo by reducing shrub height and abundance (Cohen et al. 2013). Therefore reindeer grazing has the potential to help cool down the arctic tundra (te Beest et al. 2016). So what about effect of grazing in other systems? To my knowledge, no one has investigated the effect of grazing on albedo in a (sub)-tropical environment.

African grazing ecosystems have a high diversity of large mammal grazers, often forming dense herds. Short-grass specialist species with relatively broad mouths are able to transform grass swards into a lawn-like state by regular grazing. Grazing lawns are characterized by their short stature and high plant biomass concentration, which allows them to withstand frequent grazing. However, this also imposes a risk to be shaded out by taller bunch grass species (McNaughton 1984, Hempson et al. 2015). Their spread is thus promoted by grazing, which excludes possible tall-grass colonizers. The grazing is favored by the lawns high leaf-stem ratio and high nutrient content which offers the grazers a higher intake per mouthful eaten (McNaughton 1984). Furthermore lawn grasses generally have lower leaf C/N ratio and higher concentrations of other nutrients, such as sodium, than other grassland types (Stock et al. 2010, Hempson et al. 2015).

Lawn and bunch grass communities form mosaics where patches of lawn in the bunch grass matrix can vary in size from some square meters to a few hectares (Owen-Smith 2004, Cromsigt and Olff 2008). The only existing megaherbivores in Africa that subsists on a diet of grass are the white rhino (*Ceratotherium simum*) and the hippo (*Hippopotamus amphibius*), but hippos are restricted to areas within a few kilometers of water (Verweij et al. 2006, Waldram et al. 2008). The large body size of white rhinos allows them to endure a low-quality diet and they crop grass swards unselectively at tuft scale with their broad mouths. These traits make them important drivers of grazing lawn creation and maintenance (Hempson et al. 2015). A study by Stock et al (2010) found that in Hluhluwe-iMfolozi Park (HiP) the spatial distribution of lawn and bunch grassland seems to be non-dependent on specific soil properties but rather an animal-driven phenomenon. Another study from HiP by Waldram et al. (2008) showed that white rhino acts as an influential ecosystem engineer, in creating and maintaining grazing lawns and that other species of grazers were unable to sustain lawn grass patches when white rhino were removed. White rhinos are thus facilitating other short grass specialists such as warthog and impala. A similar study by Cromsigt and te Beest (2014) investigated how white rhinos affect the structure of savanna grasslands after their reintroduction in Kruger National Park. They found that in the low rhino impact landscape the proportion of short grass were 60–80% lower than in the high rhino impact landscape, and grazing lawns were almost nonexistent. Cromsigt and Olff (2008) also studied grazing lawn formation in HiP and argue that lawn formation is promoted by a diverse community of both large and small herbivores, in which megaherbivores (such as rhino and hippo) are responsible for the first initiating disturbance but then smaller species assist in keeping the grass short and thus promote colonization of grazing lawn species. Especially warthog and impala seemed to play an important role in

maintaining and promoting the colonization of lawn grasses. The authors argue that the fact that white rhino is considered to be the main driver behind grazing lawn creation might underestimate the role of smaller grazers.

A defining characteristic of savanna ecosystems is the tree-grass coexistence in the landscape. Though, the mechanisms that support this coexistence and the factors that regulate the relative proportions of trees and grass across different savanna types remain unclear (Scholes and Archer 1997). In a continental scale analysis Sankaran et al. (2005) found strong signs that water is the limiting factor for the maximum cover of woody species in many African savanna systems. However disturbance dynamics such as fire or herbivory control savanna structure below the maximum (Sankaran et al. 2005). Field experiments have indicated that in the absence of grazing, browsing and fire, woody plant encroachment in savannas can be high (Scholes and Archer 1997). Many savannas are experiencing encroachment by shrubs (Stevens et al. 2017), but grazing lawns seem to be quite resistant to shrub invasion (Joris P. G. M Cromsigt, 2017, personal communication, 9 March). Shrub encroachment would probably have a negative effect on the albedo of savannas since it has previously been shown that shrubs have a lower albedo than grasslands (Gatebe et al. 2014).

Purpose

The aim of this study is to investigate if and how the creation of grazing lawns affects the albedo of savanna grasslands. This is done by comparing the albedo between these short-grassed grazing lawns, taller bunch grass and woody shrubs, to see what effect grazing has on albedo, and thus on the local climate. If the grazing lawns differ in albedo they could be able to mediate regional warming by changing the energy balance of savanna grasslands. This could be a valuable ecosystem service, delivered by grazers, depending on how other climate vegetation feedbacks are altered.

I hypothesise that grazing lawns will have a higher albedo than both bunch grass and woody plants. I also hypothesise that the albedo of woody vegetation will be lower than that of both grassland types because of its higher canopy complexity.

Objectives:

1. Quantify albedo of shortly grazed grazing lawns versus tall grassland and woody encroached tall grassland
2. Quantify the extent of grazing lawns across the landscape to assess the relevance of this vegetation type on a landscape scale

2. Methods

2.1 Study Site

The study was performed in the Hluhluwe-iMfolozi Park (HiP) (figure 1) which is situated in southeastern South Africa in the KwaZulu-Natal province, between S 28.0000–28.4300, and E 31.7160–32.0150. The park has an area of 90,000 ha with fenced borders, and is characterized by a high habitat heterogeneity with altitude ranging from 60 to 750 meters (Boundja and Midgley 2010). In Hluhluwe, the northern part, there is a mesic savanna with about 700–1000 mm rain per year. iMfolozi (the southern part) supports a semi-arid savanna with rainfall of about 600 mm/year. There are strict wet and dry seasons and the rain mainly falls during the summer (October to March). The vegetation in the park varies from grasslands, thickets and open Acacia woodlands, to closed woodlands and forests in

the northern section (Owen-Smith 2004, Waldram et al. 2008). Grazing lawns, characterized by stoloniferous grass species whose persistence and spread is facilitated by grazing, occur as patches in the taller bunch-grass matrix (Cromsigt et al. 2009). These short-grassed patches are most common in the semi-arid region in iMfolozi (Archibald et al. 2005). HiP was established in 1895 and is one of the oldest Game Reserves in Africa. It is known worldwide for being the historical home of the southern white rhino (*Ceratotherium simum simum*), following the successful 'Operation Rhino' efforts in the 1950s that brought the white rhino back from the verge of extinction. The Park is the source population of all the world's southern white rhinos, and has the highest density of white rhinos in the wild (Gaisford and Swart 2010). HiP has a high density of herbivores, the total biomass of large herbivores currently exceeds 10 000 kg/km^2 (le Roux et al. 2017). This exceeds the biomass of large herbivores in the Serengeti ecosystem and is double that in Kruger National Park. Almost all of the large herbivores that were historically extant in the region exists
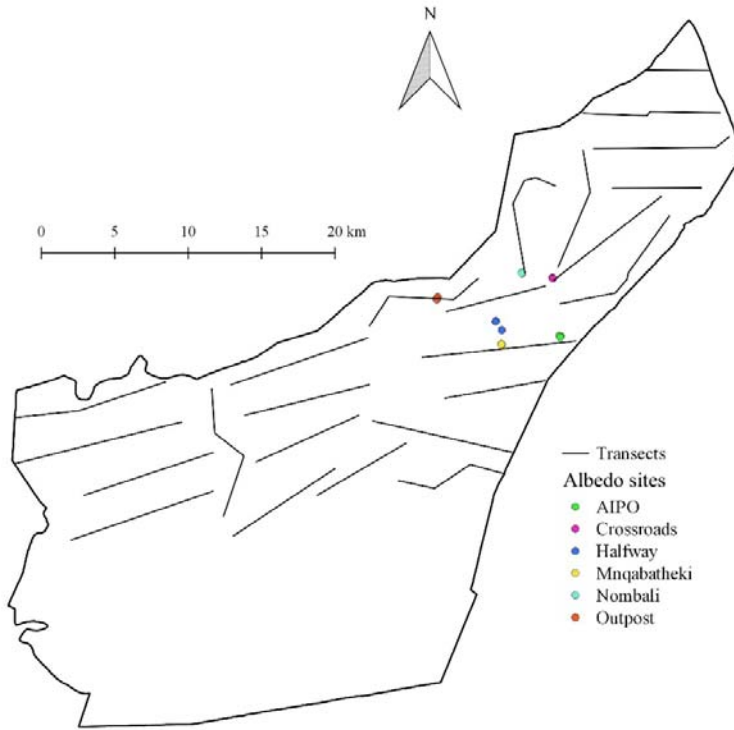

Figure 1. Outline of the Hluhluwe-iMfolozi Park showing the position of the 24 transects and the albedo measurement plots. There are three albedo plots per site. At five of the sites the plots are clustered together, so that it looks like one point. At Halfway the tall plot was about 700m away from the other two plots and therefore shows separately on the map.

in HiP currently. The species assemblage includes five mega herbivores (body mass >1000 kg), five large herbivores (body mass 100-1000 kg), and eleven medium-sized herbivores (body mass 5-100 kg). White rhinos dominate the grazing guild in HiP, contributing nearly half of the grazing biomass and consuming over one third of all grass eaten by large herbivores (Owen-Smith, Cromsigt and Arsenault 2017).

2.2 Data sampling

2.2.1 Field albedo measurements

The albedo measurements were performed at 6 different sites in the northern part of the park (figure 1), with 3 vegetation types measured at each site: grazing lawn, tall bunch grassland and woody encroached tall grassland (figure 2). To capture changes in albedo with the advancing wet season, I measured each site three times 10-13 of October, 9-11 of November and 29-30 November and 1 of December, 2016 (the early wet season) with four and three weeks, respectively, between the measurements. The first measurement was taken just at the beginning of the growing season and the third measurement in the middle of the

season. The measurements were taken during the severest drought in the region in 30-40 years (Joris P. G. M Cromsigt, 2017, personal communication, 9 March). As a result the contrast between lawn and tall grass areas was still minimal at the start of the study, and there was also a large proportion of bare soil, which made it hard to select plots that best represented the vegetation I wanted to study.
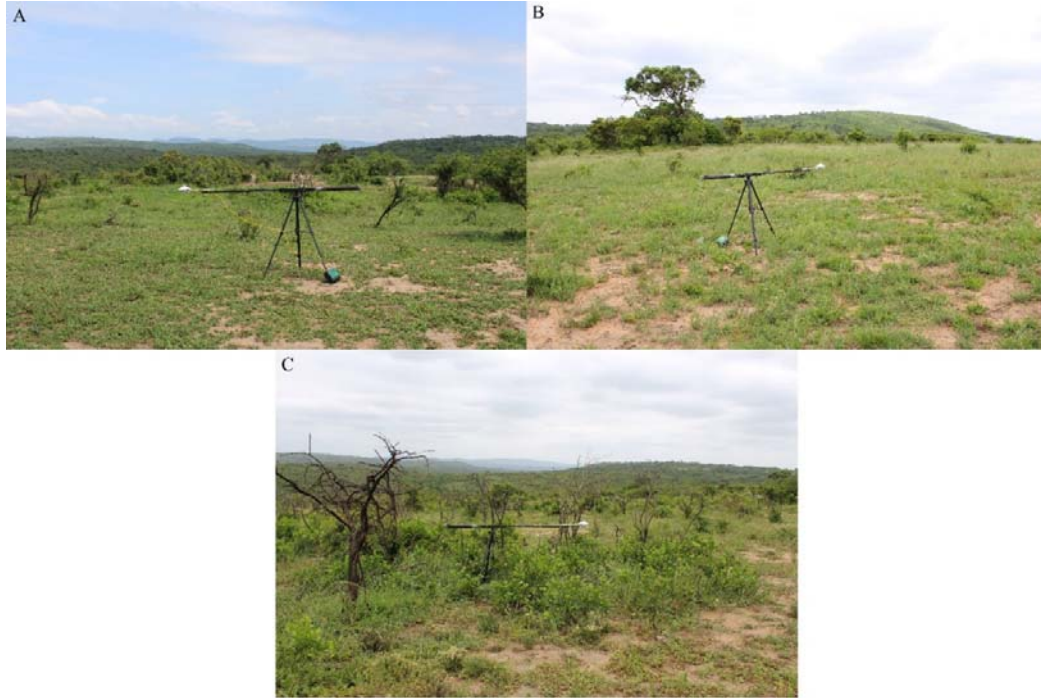

Figure 2. Three of the experiment plots at site AIPO, A shows a lawn, B tall bunch grass and C a woody plot.

The albedo was measured on all three vegetation type plots at each site within one hour of each other, to prevent differences among vegetation types arising from a changing solar angle. The albedometer was mounted on a tripod and levelled one meter above the ground, right above a marked middle point. This method has been successfully used in Arctic tundra by Williamson et al. (2016). Albedo measurements were logged every 30 seconds for 10 minutes. To check if and how albedo changes during the light hours of the day I also
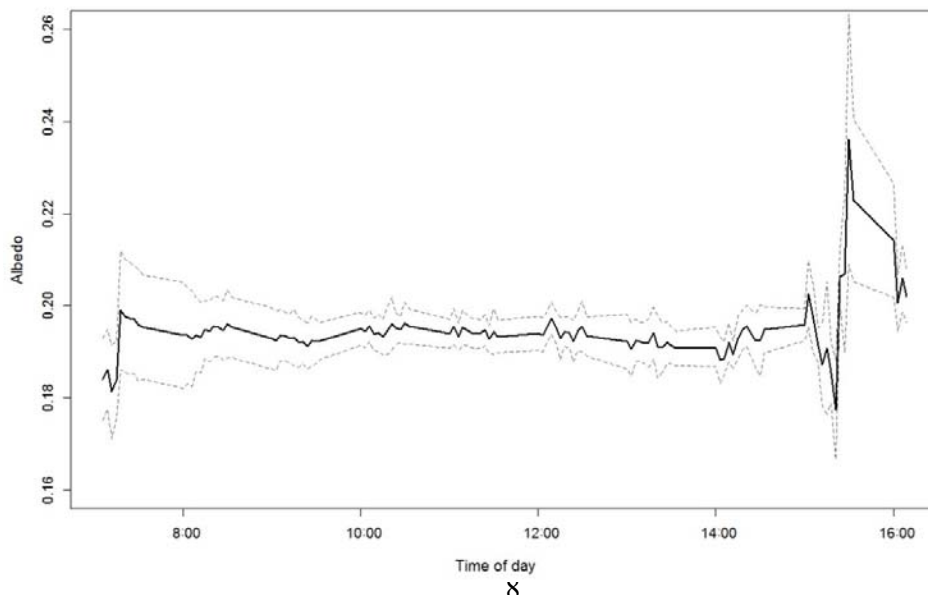

Figure 3. Result from the 5 whole day measurements of albedo. Dashed grey lines show standard error.

performed continuous measurements between 7.00 and 16.00 during 5 separate days. There was in fact little variation in albedo between 8:00 and 15:00 (see figure 3). Therefore, I limited all my albedo measurements to this time period.

In addition to the albedo measurements I measured the vegetation properties of each plot. This was done using a point intercept method in a circular plot, around the marked middle point, with a radius of 2.6 m (figure 4). At 105 points, every 20 cm along eight 2.6 m transects (one in each wind direction), I recorded the number of hits per species (up to a maximum of 5 hits per species per point) and the canopy height at that point. This was done using a thin stick, all living parts of the plant that touched the stick (both leafs and braches) were counted as a hit and the height was measured as the highest point a plant touched. The middle point was only measured once. I always started the measurements from the edge of the plot and worked towards the middle. Although I fixed the middle

Figure 4. Outline of the plot design with the middle point and the eight transects.

point and always laid out transects in the 8 wind directions, I could not be sure that transects were at the exact same place at the different measurement times. This circle plot method results in an over-sampling of the central part of the plot compared to the edges. However, this design reflects the fact that the albedometer also takes the central part of the plot into account more than the edges. Radiation that is reflected by vegetation directly below the sensor has a higher change to be measured than radiation that is reflected further away.
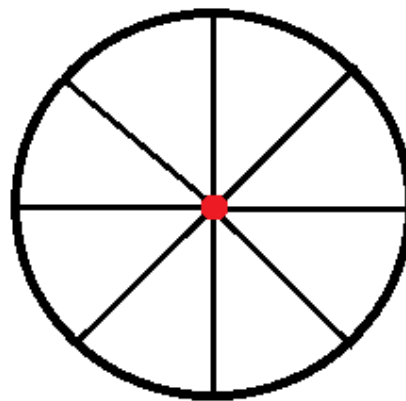
2.2.2 Grazing lawns

Since 1986, the park management has operated a bi-annual ungulate census using 24 line-transects, ranging in lengths of 3.9 to 10.5 km (8 km on average), dispersed throughout the park (figure 1). The transects are cut prior to each game count. In 2004, 2010 and 2014 these transects were walked to monitor the distribution of grazing lawns. I was able to use this data and rewalked the transects during October and November in 2016 to assess current lawn distribution. The southernmost part of the park is managed using a wilderness concept where limited human impact is allowed and transects are not cut. This area is less accessible and has higher restrictions for research and was, therefore, excluded from this study. I used the same protocol as in Cromsigt et al. (2009). Every 5 meter along the transect grazing lawns were recorded as present if lawn grass species dominated (< 75%) a 5-m plot and extended several meters on both sides of the transect. The species recorded as lawn grass were; *Cynodon dactylon, Dactylostenium australe, Digitaria longiflora, Panicum coloratum, Sporobolus nitens* and *Urochloa mosambicensis*.

2.3 Statistical analysis

Prior to the statistical analysis one site (Nombali) had to be excluded because the third measurement could not be performed at that site, due to the presence of two poached rhino. The 20 albedo measurements from each plot were averaged and I tested for differences between the averages.

All data were analysed with the software package R version 3.3.2 for windows (R Core Team 2016). To ease the process of analyzing the data the separate program Rstudio Version 1.0.136 was used (RStudio Team 2016). The effect of vegetation type and progressing wet season on albedo was analyzed using a linear mixed-effects model with vegetation type and measurement time as fixed effects and the site as a random effect to account for the block design. I also compared the effect of vegetation type on the mean vegetation height using the same model design. For this analysis the package nlme (Pinheiro et al 2016) was used.

To investigate how the plot characteristics associate with each other, I performed a PCA analysis with albedo, vegetation height, total number of vegetation hits and hits by grass, forb and woody plants as variables. I performed four PCA analyses, one averaged over all times and then one for each measurement time. I also tested, with linear regression models, how variation in albedo depended on the total number of bare soil, woody plants, and grass hits separately and on the total number of vegetation hits. A multiple regression could not be performed because of collinearity in the data.

3. Results

3.1 Albedo

Vegetation type (residual $F_{2,8}$ = 12.79, p-value = **0.003**) and time period (residual $F_{2,24}$ = 37.84, p-value **< 0.001**) both had an effect on albedo as single factors. However, there was no significant interaction between measurement time and vegetation type ($F_{4,24}$ = 0.14, p-value = 0.967), which indicated that the difference between vegetation types stayed the same over time, this is also illustrated in figure 5C. The measured albedo values varied between 0.11 and 0.21 and the linear mixed-effect model showed that there was a significant difference in albedo between both lawn and tall bunch grass and lawn and woody plants (table 1, figure 5A and B).

Table 1. Results of linear mixed effect model testing the effect of vegetation type and time on albedo, significant values are bold with an asterix, intercept show albedo for lawn at time 1.

	Value	Std. Error	Df	T-value	p-value
Intercept (Lawn)	0.1475	0.0060	28	24.4084	**0.0000***
Tall grass	-0.0166	0.0061	8	-2.7351	**0.0256***
Woody	-0.0306	0.0061	8	-5.0524	**0.0010***
Time 2	0.0225	0.0048	28	4.7039	**0.0001***
Time 3	0.0445	0.0048	28	9.2923	**0.0000***

The albedo increased during the growing season, (figure 5C and D). This increase in albedo between the first measurement time and the two following measurements was shown to be significant (table 1). The same model was also run with tall grass at time 2 as intercept to be able to see differences between tall grass and woody and time 2 and 3. The result is shown in table 2, and demonstrates a significant difference between tall grass and woody and also between the second and third measurement time.

Table 2. Results of linear mixed effect model testing the effect of vegetation type and time on albedo, significant values are bold with an asterix, intercept show albedo for tall at time 2.

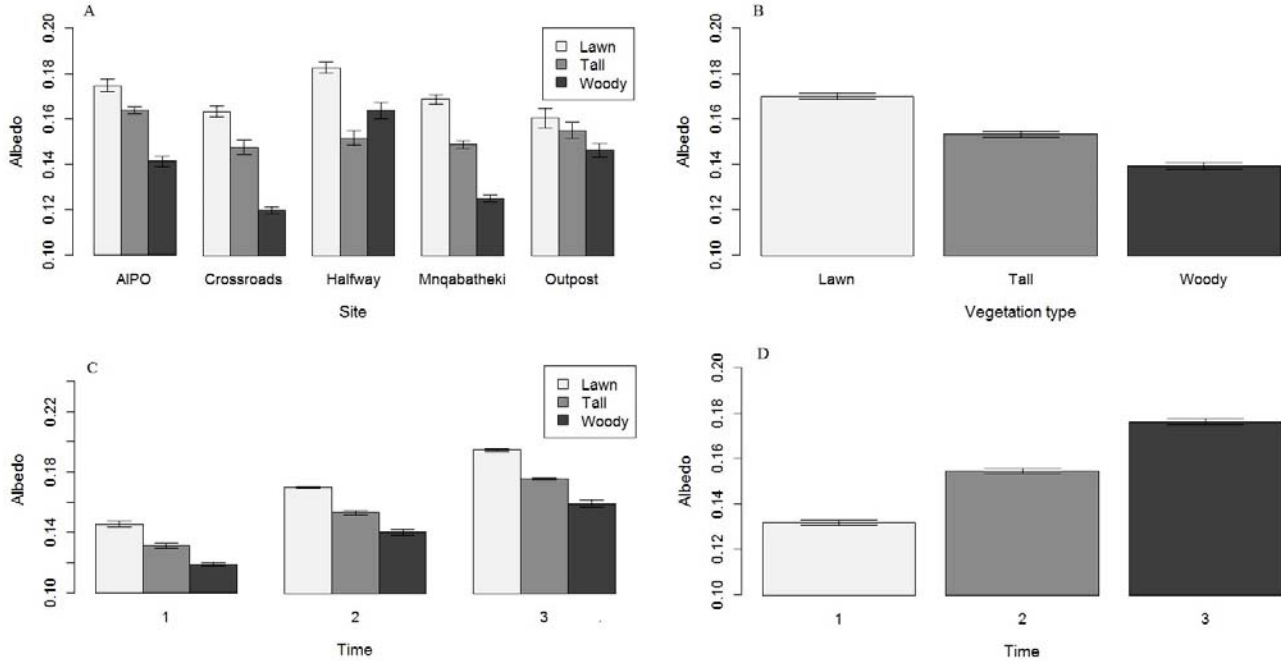|	Value	Std. Error	df	T-value	p-value
Intercept (Tall)	0.1535	0.0060	28	25.3874	**0.0000***
Lawn	0.0166	0.0061	8	2.7351	**0.0256***
Woody	-0.0141	0.0061	8	-2.3173	**0.0419***
Time 1	-0.0225	0.0048	28	-4.7039	**0.0001***
Time 3	0.0220	0.0048	28	4.5884	**0.0001***

Figure 5. A and B show mean albedo for different vegetation types, in A all sites are shown averaged over time, in B albedo is averaged over vegetation type and time. C and D show the mean albedo for the three different measurement times, C shows albedo averaged over measurement time and vegetation type, in D albedo is averaged for each measurement time. Error bars show standard error.

3.2 Vegetation

There was a significant difference in vegetation height between the different vegetation types ($F_{2,8}$ = 15.98, p-value = **0.002**) and over time ($F_{2,24}$ = 21.57, p-value **< 0.001**) (figure 6). The interaction between time and vegetation type was not significant ($F_{4,24}$ = 1.68, p-value = 0.189) which indicates that the observed patterns in vegetation height for the different vegetation types stayed constant over time.
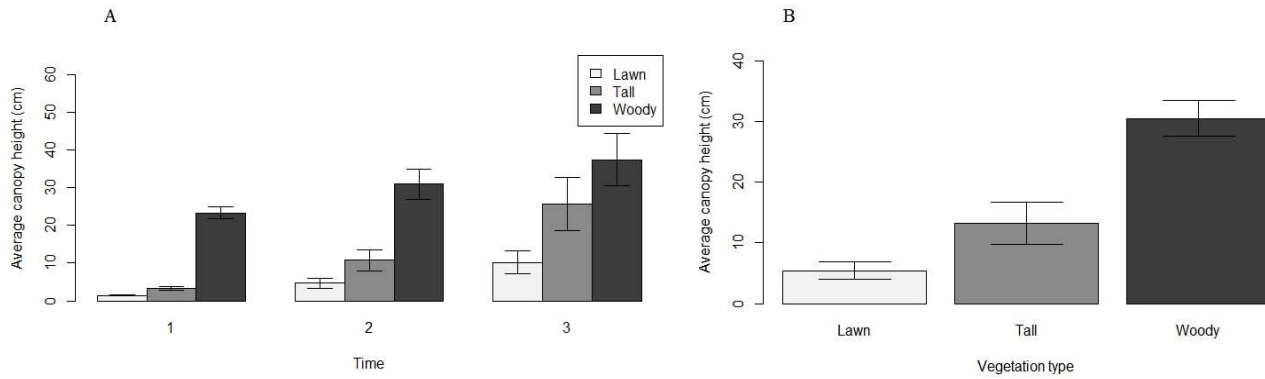
Figure 6. Average canopy height, in A all vegetation types are shown at different times, in B all sites are averaged over each vegetation type and time. Error bars show standard error.

3.3 PCA analysis

In the first PCA analysis, with the variables averaged over all measurement times, the first two principal components explained 76.6 % of the variance in the data set (table 3). Albedo showed a negative correlation with PC 1 and a positive correlation with PC 2 (figure 7A). The number of hits by woody plants are positively correlated with PC 1 (figure 7A), and bare soil is negatively correlated with PC 2- This indicates that an increase in albedo is associated with a reduction in cover of woody plants and bare soil. The number of grass hits, however, was positively correlated with PC 2 (figure 7A) and this suggests that an increase in albedo is associated with an increasing grass cover. The result of the PCA analyses for each measurement time can be seen in table 3 and they show a similar pattern as the averaged one (figure 7B-C), with grass always being opposite to bare soil.

Table 3. Result of PCA analyses, all models explain between 0.75 and 0.8 of the variance in the data using the first two principal components.

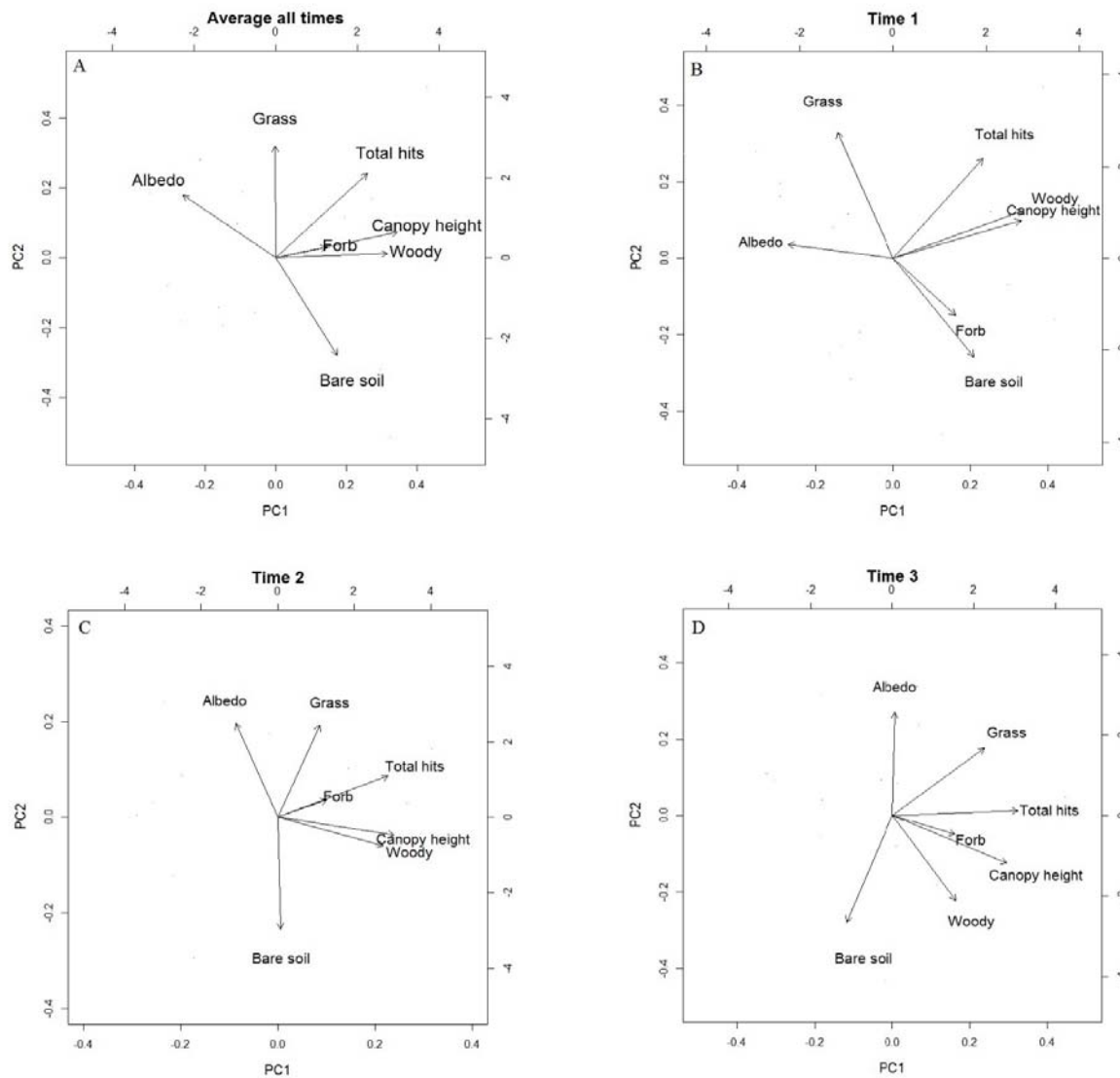|	Average all times		Time 1		Time 2		Time 3	
	PC 1	PC 2	PC 1	PC 2	PC 1	PC 2	PC 1	PC 2
Standard deviation	1.783	1.477	1.780	1.451	1.748	1.554	1.726	1.534
Proportion of Variance	0.454	0.312	0.453	0.301	0.437	0.345	0.426	0.336
Cumulative proportion	0.454	0.766	0.453	0.753	0.437	0.781	0.426	0.762

Figure 7. Biplots for the different PCA analyses, A shows the result when averaged over all times. The pattern is roughly the same for all different times (B-D), with grass and bare soil as opposites.

3.4 Effect of vegetation on albedo

The results of the regressions can be seen in table 4. As already indicated by the PCA analysis, the regression confirmed that albedo strongly declined with increasing bare soil (table 4, figure 8A). The albedo increased when the amount grass increased (table 4, figure 8B) and also when the total number of hits by vegetation increased (table 4, figure 8C). The albedo did, however, not depend on the number of woody plant hits (table 4, figure 8D). Bare soil had the highest r^2 and explained about 55% of the variance in the data, while grass explained about 42% of the variance and total vegetation hits 19% (table 4).

Table 4. The results from the regressions between albedo and bare soil, woody plants, grass and vegetation hits, significant values are written in bold with an asterix.

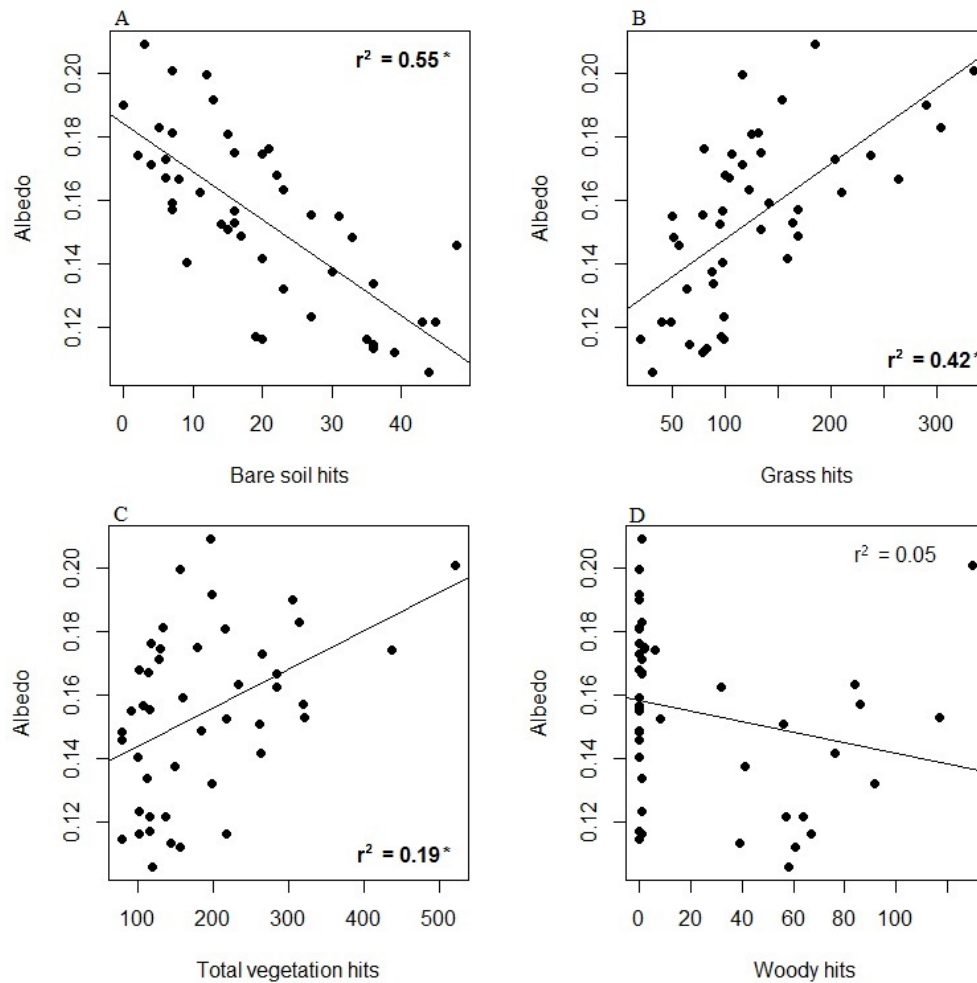|	Intercept	Estimate	T-value	p-value	r^2
Bare soil	**0.1843***	-0.0015	-7.205	**<0.0001***	0.5469
Woody	**0.1581***	-0.0002	-1.524	0.135	0.0513
Grass	**0.1241***	0.0002	5.526	**<0.0001***	0.4152
Total vegetation hits	**0.1314***	0.0001	3.201	**0.0026***	0.1925

Figure 8. The relationship between albedo and bare soil (A), hits by grass (B), hits by woody plants (C) and total vegetation hits (D). Also shown is the abline from the linear regression analyses and the r^2 value, bold and an asterix marks a significant regression.

3.5 Lawn cover

The percentage of lawn cover per transect has varied among years but the spatial pattern remained similar (figure 9). There is a much higher percentage of grazing lawn cover in the

southern, drier, parts of the park. Along some transects lawns cover over 20% of the transect area.
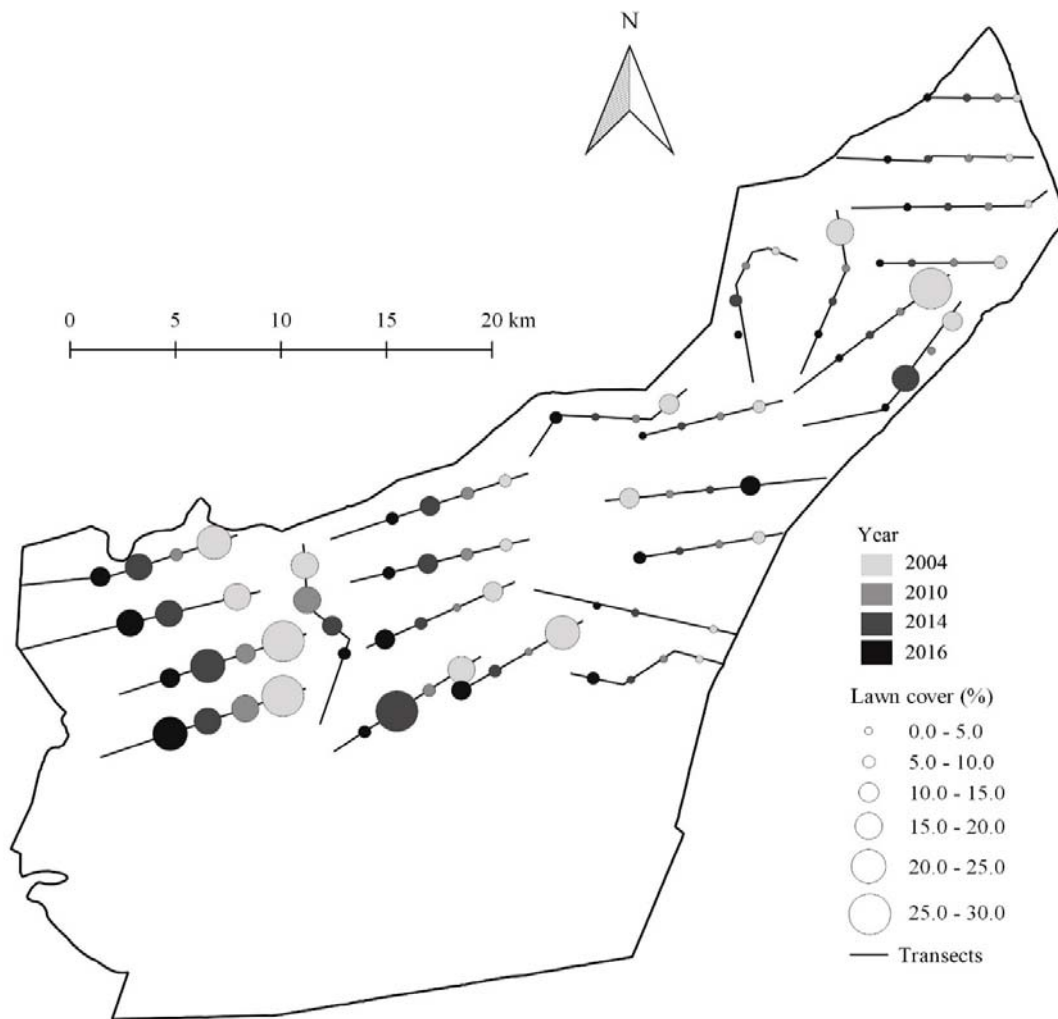

Figure 9. Percentage lawn cover per transect for each measured year. Each circle show the total percentage of lawn cover along a transect for a specific year, the color of the circle denotes what year the lawn cover was estimated.

Discussion

The purpose of this study was to investigate if grazing lawns affect the albedo of savanna grasslands and thus can affect the local climate. I showed that grazing lawns in the Hluhluwe-iMfolozi Park have a significantly higher albedo than both bunch grass and grass encroached by woody plants (table 2), which is as hypothesised. I also show that tall bunch grass also has a significantly higher albedo than woody encroached grassland (table 2) and that albedo increased during the growing season (table 1, figure 5D). In the PCA analyses bare soil and woody were always on opposite ends from albedo, which indicate that they are factors reducing the albedo, while grass was always close to albedo, which would indicate that more grass means higher albedo. Total number plant hits, vegetation height and forb was always in between grass and bare soil in the biplots (figure 7). The regression analyses showed that albedo did indeed decrease when bare soil increased, probably because of the dark soil color, and albedo increased with more grass and total plant hits. Surprisingly the number of hits by woody plants did not affect the albedo (table 4, figure 8). The assessment of grazing lawn distribution in the park showed that the pattern have been the same since 2004 with a high percentage of lawns in iMfolozi, in some parts exceeding 20% (figure 9).

Even though the differences between these vegetation types might seem small (lawn had 0.0166 higher albedo than bunch grass and 0.0306 higher albedo than woody encroached grassland) it has previously been shown that small differences in albedo can have an impact on the local climate (Cohen et al. 2013, Naudts et al. 2016). Cohen et al. (2013) investigated the effect of reindeer summer grazing on the vegetation, snowmelt timing, surface albedo and ground heating by comparing summer and non-summer pastures in the northern tundra areas of Fennoscandia. More shrubs protruding above the snow layer and earlier snowmelt in the area not grazed in summer, lowered the albedo during the snowmelt season, the difference in mean albedo was between 0 and 0.05. This caused higher solar energy absorption of up to 6 W/m^2 in the snowmelt season and contributed up to 0.5 W/m^2 to the yearly energy balance.

These studies, however, were conducted in the boreal/arctic region and other factors such as transpiration also affects the local climate. When looking at the effect of albedo in (sub)-tropical climates the albedo effect seems to be less important (Foley et al. 2003). In Australia Syktus and McAlpine (2016) investigated the effects of restoration of savanna woodlands and found that the effect of evaporative cooling from the trees were stronger than the lower albedo of the trees and thus the restoration resulted in a cooling effect on the local climate despite of the lowered albedo. However leafy tree canopies do in general evaporate more water than any other vegetation type; more than ten times that of herbaceous vegetation (Sheil 2014). Furthermore Syktus and McAlpine (2016) state in their study that shallow-rooted, rainfed crops have a limited ability to maintain an evapotranspiration high enough to uphold the positive feedback between the land surface and the atmosphere that helps to cool the climate. A study by Anderson et al. (2013) compared the transpiration of lawn and bunch grasses collected from Hluhluwe-iMfolozi Park and the Serengeti and found that unclipped bunch grass does not have a significantly different transpiration from unclipped lawn grasses. However when clipped, the bunch grass get a significantly higher transpiration while the transpiration of lawn grasses stay the same. This would indicate that ungrazed lawn and bunch grass do not have a significantly different transpiration, but when grazed, bunch grass get significantly higher transpiration

rates. Since this difference in transpiration only occur when the bunch grass is grazed the difference in transpiration between bunch grass and lawn is probably not big enough to offset the effect of the lowered albedo. Charney et al (1977) compared the effects of albedo change with high or negligible evapotranspiration in semi-arid regions. They found that while an increase in albedo from 0.14 to 0.35 did decrease the surface temperature in both the high and negligible evapotranspiration cases, the ground temperature was much higher with negligible evapotranspiration. This is not directly applicable to this study since they compared one case with too high evaporation and one case with negligible evaporation, while the study by Anderson et al. (2013) shows that there are only slight differences between the lawn- and bunch grass types. But this show the need for further investigation of the effect of transpiration for both grass types and for the low woody shrubs.

From my data the two factors that affect the albedo the most seems to be amount of grass (positive) and amount of bare soil (negative) (figure 7 and figure 8. A and B). I had hypothesised that the woody vegetation would have a stronger negative effect on albedo. Since there was a significant difference between lawn- and woody plots, where woody had a lower albedo (table 1), but also because in the PCA analyses woody seemed to be as far away from albedo as bare soil was (figure 7). The low correlation (figure 8D) might however, in part, be due to the fact that there where so many null values since there were hardly any woody plants in the lawn- or tall plots. There was also one outlier that had the most woody hits but also one of the highest albedo values (figure 8D). But other studies have also found that it is the transition from grass to shrub that lowers the albedo and not so much differences in shrub height or abundance per se (te Beest et al. 2016). For grass on the other hand, there was never a null value since there was grass in all plots. The area was going through a severe drought during the study and a lot of the vegetation had died, which meant there was a high percentage of bare soil especially in the beginning. The soil was also relatively dark and often when I performed the measurements it had been raining the day/days before, which made the soil even darker. This is probably the reason albedo decreased with increasing bare soil (figure 8 A, table 4). Bare soil does however not typically have a negative effect on albedo. Desert areas in Sahara have been found to have albedo values of 0.5 and higher, and the albedo of the soil background in areas with sparse and seasonally changing vegetation cover does not typically exceed 0.35 (Knorr and Schnitzler 2006). Gatebe et al (2014) did also find that for few land cover types (e.g. croplands), albedo increased after fire, possibly because of the exposure of the underlying soils with higher albedo. I measured from the start of the growing season and the amount of bare soil in the plots decreased during the season, which is perhaps a major reason for increased albedo during the growing season (figure 5 C-D, table 1 and 2). However, other studies have also found that albedo increases during the growing season so the decrease in bare soil might not be the only reason for this increase (Juszak et al. 2014, Williamson et al. 2016). This could be explained by the higher leaf to branch ratio during the growing season, because branches are relatively dark and have lower albedo than leafs, a higher leaf area index would give a higher reflection and thus albedo (Juszak et al. 2014). The difference between vegetation types stayed the same over time (figure 5 C), despite the extreme conditions in the beginning of the growing season, which means that the increase in albedo was the same in all vegetation types.

The total number of vegetation hits showed a positive correlation with albedo (figure 8 D, table 4), which was unexpected, since a more complex surface captures more light and thereby should have a lower albedo (Chapin et al. 2000, Coakley 2003, Beringer et al. 2005, Bogren et al. 2008). This could to some extent come from the fact that bare soil had

lower albedo than all vegetation types so a vegetation hit, no matter what functional group, would result in a higher albedo. Another factor can be that if the lawn was flowering, I would get a higher number of hits but the grass flowers are so thin that they do not affect the light capturing in the way as the same number of hits by a low thick bush would. It might also be affected by the fact that I used a maximum of five hits/species during the measurements. A lawn grass would never come over 5 hits/species but woody plants sometimes did. There are also other studies that have found a positive relation between shrubs and albedo. Williamson et al. (2016) found that while *Salix* stands had lower albedo than shrub free vegetated sites, closed-canopy *Betula glandulosa* had summer albedo values similar to sites lacking shrubs. They believe that as leaves expand the shrub canopy surface becomes increasingly impenetrable which increases reflection and thus the albedo. Furthermore Juszak et al (2014) have found that increasing shrub biomass might not lead to a decrease in albedo if the vegetation type is constant. So I could get a high number of vegetation hits but still have a relatively high albedo.

When the selection of the study sites took place the drought was just coming to an end and much of the vegetation was dead. It was therefore difficult to choose sites that best represented the vegetation types I wanted to study. Nonetheless the albedo still differed consistently between the vegetation types (table 1 and 2, figure 5 B) and I expect that the difference between theses vegetation types could have been larger if the plots would have been more representative.

It is difficult to say how widespread in the landscape grazing lawns have to be for their higher albedo to have an effect on the local climate. In the study by Syktus and McAlpine (2016) a 15 % increase in the area of woody savannas would have a considerable impact on the regional climate of Australia. The key difference in land surface characteristics was a higher leaf-area index, decreased surface albedo and increased surface roughness. These changes in surface characteristics were the main drivers of the climate response. I show that in Hluhluwe-iMfolozi Park, particularly in the semi-arid parts of the park, lawns make up more than 20% of the transect area (figure 9). Although this has to be further investigated, this grazing lawn percentage could have a substantial effect on the local climate. The fact that the lawns are most widespread in the semi-arid parts suggest that the evapotranspiration might play an important role. Alkama and Cescatti (2016) found that the strongest effect on air- and land surface temperature from loss of forest and other woody vegetation cover occurred in arid and semi-arid regions, followed by temperate, tropical, and boreal biomes

This study suggests that grazing and the creation of grazing lawns can be important factors affecting the local climate. Especially since I was able to show a significant difference in albedo between not only lawn grass and woody plants but also between lawn and bunch grass. This difference was significant even at the first measurement time in the beginning of the growing season when the difference in height between lawn and bunch grass was minimal (figure 6A). This indicates that lawn grasses have a higher albedo than bunch grass even if they are both grazed short. So the grazers promotes a higher albedo both through the grazing itself but also through the promotion of the spread by the more grazing tolerant lawn grasses. My results also suggest that woody encroachment of previously not wooded tall grasslands may have quite serious effects for the albedo part of climate-vegetation feedbacks, because woody vegetation had lower albedo than both bunch- and lawn grass. If grazing does limit woody encroachment it thus not only increases albedo by creating short grass, but also by keeping woody plants out.

To date most of the literature discussing vegetation impacts of mega herbivores has focused on the impacts of browsing species, such as the African Elephant (*Loxodonta africana*) (Duffy et al. 1999, Asner et al. 2016). Another study by Doughty et al (2010) hypothesized that the extinction of mammoths contributed to a fast increase in dwarf tree cover, which had a warming effect on the climate, partially by the lowered albedo. But grazing megaherbivores could have equally large impacts as browsing. The only existing megaherbivores in Africa that subsists on a diet of grass are the white rhino and the hippo, and both have been shown to create grazing lawns (Verweij et al. 2006, Waldram et al. 2008). However it has been shown that other grazers also help with creating and maintaining these lawns. One of the most important findings of this study is the effect that these grazing lawns, and by extension grazers, can have on the local climate through a higher albedo, although the magnitude of this effect will have to be further investigated.

Acknowledgments

References

Alkama, R., and Cescatti, A. (2016). Biophysical climate impacts of recent changes in global forest cover. Science, 351(6273), 600-604.

Allen, S. J., Gash, J. H. C., Sivakumar, M. V. K. and Wallace, J. S. (1994) 'Measurements of Albedo Variation Over Natural Vegetation in the Sahel', *International Journal of Climatology*, 14(6), 625-636.

Anderson, T. M., Kumordzi, B. B., Fokkema, W., Fox, H. V. and Olff, H. (2013) Distinct physiological responses underlie defoliation tolerance in African lawn and bunch grasses. *International Journal of Plant Sciences*, 174(5), 769-778.

Archibald, S., Bond, W. J., Stock, W. D. and Fairbanks, D. H. K. (2005) 'Shaping the landscape: Fire-grazer interactions in an African savanna', *Ecological Applications*, 15(1), 96-109.

Asner, G. P., Vaughn, N., Smit, I. P. J. and Levick, S. (2016) 'Ecosystem-scale effects of megafauna in African savannas.' *Ecography*, 39(2), 240-252.

Bala, G., Caldeira, K., Wickett, M., Phillips, T. J., Lobell, D. B., Delire, C. and Mirin, A. (2007) 'Combined climate and carbon-cycle effects of large-scale deforestation.' *Proceedings of the National Academy of Sciences of the United States of America*, 104(16), 6550-6555.

Beringer, J., Chapin, F. S., Thompson, C. C. and McGuire, A. D. (2005) 'Surface energy exchanges along a tundra-forest transition and feedbacks to climate.' *Agricultural and Forest Meteorology*, 131(3-4), 143-161.

Bernes, C. (2007). 'En ännu varmare värld: Växthuseffekten och klimatets förändringar.' Naturvårdsverket.

Betts, R. A. (2000) 'Offset of the potential carbon sink from boreal forestation by decreases in surface albedo.' *Nature*, 408(6809), 187-190.

Bogren, J., Gustavsson, T., and Loman, L. (1999). Klimatologi och meteorologi. Studentlitteratur

Bogren, J., Gustavsson, T., and Loman, L. (2008). Klimat och väder. Studentlitteratur

Boundja, R. P. and Midgley, J. J. (2010). 'Patterns of elephant impact on woody plants in the Hluhluwe-Imfolozi park, Kwazulu-Natal, South Africa.' *African Journal of Ecology*, 48(1), pp 206–214

Chapin, F. S., Eugster, W., McFadden, J. P., Lynch, A. H. and Walker, D. A. (2000) 'Summer differences among Arctic ecosystems in regional climate forcing.' *Journal of Climate*, 13(12), 2002-2010.

Chapin, F. S., Randerson, J. T., McGuire, A. D., Foley, J. A. and Field, C. B. (2008) 'Changing feedbacks in the climate–biosphere system.' *Frontiers in Ecology and the Environment*, 6(6), 313-320.

Charney, J., Quirk, W. J., Chow, S. H., and Kornfield, J. (1977). A comparative study of the effects of albedo change on drought in semi–arid regions. Journal of the Atmospheric Sciences, 34(9), 1366-1385.

Coakley, J. A. (2003). 'Reflectance and albedo, surface.' Encyclopedia of the Atmosphere, 1914-1923.

Cohen, J., Pulliainen, J., Ménard, C. B., Johansen, B., Oksanen, L., Luojus, K. and Ikonen, J. (2013) 'Effect of reindeer grazing on snowmelt, albedo and energy balance based on satellite data analyses', *Remote Sensing of Environment*, 135, 107-117.

Cromsigt, J. P. G. M., and te Beest, M. (2014) 'Restoration of a megaherbivore: landscape-level impacts of white rhinoceros in Kruger National Park, South Africa.' *Journal of Ecology*, 102(3), 566-575.

Cromsigt, J. P. G. M., Prins, H. H. T. and Olff, H. (2009) 'Habitat heterogeneity as a driver of ungulate diversity and distribution patterns: interaction of body mass and digestive strategy.' *Diversity and Distributions*, 15(3), 513-522.

Cromsigt, J. P. G. M., and Olff, H. (2008). 'Dynamics of grazing lawn formation: an experimental test of the role of scale dependent processes.' *Oikos*, 117(10), 1444-1452.

de Wit, H. A., Bryn, A., Hofgaard, A., Karstensen, J., Kvalevag, M. M. and Peters, G. P. (2014) 'Climate warming feedback from mountain birch forest expansion: reduced albedo dominates carbon uptake.' *Global Change Biology*, 20(7), 2344-2355.

Doughty, C. E., Wolf, A. and Field, C. B. (2010) 'Biophysical feedbacks between the Pleistocene megafauna extinction and climate: The first human-induced global warming?' *Geophysical Research Letters*, 37(15)

Duffy, K. J., Page, B. R., Swart, J. H. and Bajic, V. B. (1999) 'Realistic parameter assessment for a well known elephant-tree ecosystem model reveals that limit cycles are unlikely.' *Ecological Modelling*, 121(2-3), 115-125.

Euskirchen, E. S., McGuire, A. D. and Chapin, F. S. (2007) 'Energy feedbacks of northern high-latitude ecosystems to the climate system due to reduced snow cover during 20th century warming.' *Global Change Biology*, 13(11), 2425-2438.

Foley, J. A., Costa, M. H., Delire, C., Ramankutty, N. and Snyder, P. (2003) 'Green surprise? How terrestrial ecosystems could affect earth's climate.' *Frontiers in Ecology and the Environment*, 1(1), 38-44.

Gaisford, J., and Swart, D. (2010). The home of rhino conservation. *The horn magazine*

Gatebe, C. K., Ichoku, C. M., Poudyal, R., Román, M. O., and Wilcox, E. (2014). Surface albedo darkening from wildfires in northern sub-Saharan Africa. Environmental Research Letters, 9(6), 065003.

Hempson, G. P., Archibald, S., Bond, W. J., Ellis, R. P., Grant, C. C., Kruger, F. J., Kruger, L. M., Moxley, C., Owen Smith, N. and Peel, M. J. (2015) 'Ecology of grazing lawns in Africa', *Biological Reviews*, 90(3), 979-994.

IPCC, (2014): Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Juszak, I., Erb, A. M., Maximov, T. C. and Schaepman-Strub, G. (2014) 'Arctic shrub effects on NDVI, summer albedo and soil shading.' *Remote Sensing of Environment*, 153, 79-89.

Knorr, W., and Schnitzler, K. G. (2006). Enhanced albedo feedback in North Africa from possible combined vegetation and soil-formation processes. Climate Dynamics, 26(1), 55-63.

Kricher, J., (2011). Tropical ecology. Princeton University Press.

le Roux E, Clinning G, Druce DJ, Owen-Smith N, Graf JA and **Cromsigt JPGM**. (2017). 'Temporal changes in the large herbivore fauna of Hluhluwe-iMfolozi Park.' In: *Conserving Africa's Mega-Diversity in the Anthropocene: the Hluhluwe-iMfolozi Park story* (eds. Cromsigt JPGM, Archibald S & Owen-Smith). Ecology, Biodiversity and Conservation Series, Cambridge University Press.

McNaughton, S. J. (1984) 'Grazing Lawns - Animals in Herds, Plant Form, and Coevolution.' *American Naturalist*, 124(6), 863-886.

Naudts, K., Chen, Y. Y., McGrath, M. J., Ryder, J., Valade, A., Otto, J. and Luyssaert, S. (2016) 'Europe's forest management did not mitigate climate warming.' *Science*, 351(6273), 597-600.

Owen-Smith, N. (2004) 'Functional heterogeneity in resources within landscapes and herbivore population dynamics', *Landscape Ecology*, 19(7), 761-771.

Owen-Smith, N., Cromsigt, J. P. G. M. and Arsenault, R. (2017). ' Megaherbivores, competition and coexistence within the large herbivore guild.' In: *Conserving Africa's Mega-Diversity in the Anthropocene: the Hluhluwe-iMfolozi Park story* (eds. Cromsigt JPGM, Archibald S & Owen-Smith). Ecology, Biodiversity and Conservation Series, Cambridge University Press.

Pearson, R. G., Phillips, S. J., Loranty, M. M., Beck, P. S. A., Damoulas, T., Knight, S. J. and Goetz, S. J. (2013) 'Shifts in Arctic vegetation and associated feedbacks under climate change', *Nature Climate Change*, 3(7), 673-677.

Pinheiro J, Bates D, DebRoy S, Sarkar D and R Core Team (2016). _nlme: Linear and Nonlinear Mixed Effects Models_. R package version 3.1-128, URL: http://CRAN.R-project.org/package=nlme>.

R Core Team (2016). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Reece, J.B., Urry, L.A., Cain, M.L., Wasserman, S.A., Minorsky, P.V. and Jackson, R.B., (2011). Campbell biology. Boston: Pearson.

RStudio Team (2016). RStudio: Integrated Development for R. RStudio, Inc., Boston, MA. URL http://www.rstudio.com/.

Sankaran, M., Hanan, N. P., Scholes, R. J., Ratnam, J., Augustine, D. J., Cade, B. S., Gignoux, J., Higgins, S. I., Le Roux, X., Ludwig, F., Ardo, J., Banyikwa, F., Bronn, A., Bucini, G., Caylor, K. K., Coughenour, M. B., Diouf, A., Ekaya, W., Feral, C. J., February, E. C., Frost, P. G. H., Hiernaux, P., Hrabar, H., Metzger, K. L., Prins, H. H. T., Ringrose, S., Sea, W., Tews, J., Worden, J. and Zambatis, N. (2005) 'Determinants of woody cover in African savannas.' *Nature*, 438(7069), 846-849.

Scholes, R. J. and Archer, S. R. (1997) 'Tree-grass interactions in savannas.' *Annual Review of Ecology and Systematics*, 28, 517-544.

Sheil, D. (2014). 'How plants water our planet: advances and imperatives.' *Trends in Plant Science*, 19(4), 209-211.

Stevens, N., Lehmann, C. E., Murphy, B. P., and Durigan, G. (2017). Savanna woody encroachment is widespread across three continents. Global change biology, 23(1), 235-244.

Stock, W. D., Bond, W. J. and van de Vijver, C. (2010) 'Herbivore and nutrient control of lawn and bunch grass distributions in a southern African savanna', *Plant Ecology*, 206(1), 15-27.

Syktus, J. I. and McAlpine, C. A. (2016) 'More than carbon sequestration: Biophysical climate benefits of restored savanna woodlands', *Scientific Reports*, 6, 29194.

te Beest, M., Sitters, J., Ménard, C. B., and Olofsson, J. (2016). 'Reindeer grazing increases summer albedo by reducing shrub abundance in Arctic tundra.' *Environmental Research Letters*, 11(12), 125013.

Thompson, C., Beringer, J., Chapin, F. S. and McGuire, A. D. (2004) 'Structural complexity and land-surface energy exchange along a gradient from arctic tundra to boreal forest', *Journal of Vegetation Science*, 15(3), 397-406.

Verweij, R. J. T., Verrelst, J., Loth, P. E., Heitkonig, I. M. A. and Brunsting, A. M. H. (2006) 'Grazing lawns contribute to the subsistence of mesoherbivores on dystrophic savannas.' *Oikos*, 114(1), 108-116.

Waldram, M. S., Bond, W. J. and Stock, W. D. (2008) 'Ecological Engineering by a Mega-Grazer: White Rhino Impacts on a South African Savanna', *Ecosystems*, 11(1), 101-112.

Williamson, S. N., Barrio, I. C., Hik, D. S. and Gamon, J. A. (2016) 'Phenology and species determine growing-season albedo increase at the altitudinal limit of shrub growth in the sub-Arctic.' *Global Change Biology*. 22 3621–31.

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