Dung Beetle Diversity to Specific Land-Use and Vegetation Structure Heterogeneity at Varying Scales

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Introduction:

Background:

Globally, humans are causing a rapid loss of biodiversity (Folke et al. 2004). A significant reduction of biodiversity in an ecosystem can lead to ecosystem deterioration, and, ultimately, affect the services that it provides (Naeem et al. 1994). A collapse in ecosystem function, due to declines in biodiversity, can eventually lead to economic damage and declines in human health (Ostfield & LoGuidice 2003). Additionally, losses in biodiversity can make a system vulnerable to exotic species, which can further degrade ecological function (Levine and D'Antonio 1999). One of the major causes of the global decline in biodiversity has been land use alteration (Vitousek et al. 1997). Specifically, the conversion of undeveloped lands into intensive agriculture production, leading to accelerated loss of biodiversity (Wilby et al. 2006). The food demands of the world will likely increase over the next 35 years, and with expanding agricultural land use biodiversity will likely decline if the effects of land-use change are not fully understood (Godfray et al. 2010).

Land use change and habitat fragmentation has led to many areas of the world having a mosaic-style landscape: a system with many different land uses dotting a small area. Areas like these are considered to have high habitat heterogeneity. Heterogeneity is measured in two principle components: composition and configuration (Fahrig et al. 2011). Composition is the number of land use types that are present within the observed area, while configuration quantifies shapes, edges, and layout of the area. High habitat heterogeneity has been shown to increase biodiversity (Tews et al. 2003). While understanding how these land uses each affect biodiversity is essential, it is also important to understand how land uses affect their surrounding areas. For this reason, land context becomes relevant in biodiversity conservation. Land context is defined by the heterogeneity of area that surrounds a study site. With unmanaged lands and non-anthropogenically generated land uses becoming more fragmented, the way in which land context affects biodiversity must be better understood. In particular, the components of land context most responsible for the maintenance and generation of biodiversity need to be explained.

An excellent model taxa for studying the influences of land use change on biodiversity are dung beetles (*Scarabaeidae*). Dung beetles are good indicators of environmental health, especially in areas of rapid land use change (Nichols et al. 2007). Dung beetles also act as biodiversity indicators, with the biodiversity of dung beetles strongly correlated with the biodiversity of vertebrates and other invertebrates (Pearson & Cassola 1992). Additionally, the life cycle of beetles is considerably shorter than that of other taxonomic groups, meaning they respond on shorter time scales, and act as more rapid indicators (Murphy et al. 1990). This makes them useful in the study of small or fragmented patches of land that are too small to support any significant number of larger species (Murphy et al. 1990). Dung beetles are also economically important as they indicate land-use disturbances in and around agricultural areas that may affect crop yields (Cole et al. 2002).

Previous research on dung beetles has shown that as land uses intensifies beetle diversity and ecological productivity tended to change as well (Shahabuddin 2011; Almeida et al. 2011).

While numerous studies have looked at the effects of land use change on dung beetles (Grimbacher et al. 2006, Davis and Sutton 1998, Murphy et al. 1990, Van Nuland and Whitlow 2014), there is limited information to help us understand how the scale, quantities, and configuration of land use change shape dung beetle Limited research exists on the impacts of land context on dung beetle communities, and the scale of heterogeneity that effects dung beetle biodiversity is also not fully understood. It is unclear what will affect dung beetle diversity to a greater extent: high heterogeneity of vegetation structure at a fine scale or land use heterogeneity at a broad scale.

To understand how the scale, quantities, and configuration of heterogeneity shape biodiversity, we will examine dung beetle biodiversity in the Lowveld savanna of north-eastern Swaziland. This study will present information on the importance of land context as it relates to biodiversity at scales that have yet to be investigated. By observing change in dung beetle diversity in respect to land context, a relationship between land heterogeneity and biodiversity can be established at multiple different scales.

Objectives:

The aim of this study is to gain a comprehensive knowledge of the impacts of varying levels of landscape heterogeneity diversity of dung beetles. The diversity of land uses across the mosaic landscape of north eastern Swaziland make it the ideal area to study the effects of land use composition and configuration on biodiversity. With the data that will be collected in Swaziland, we will address the objective of determining the influence of land uses composition and configuration on savanna dung beetle diversity at scales of 50 meters, 500 meters and 1 kilometer from the trap. Additionally, predictions can be constructed for these objectives. Landscapes with more agriculture and human influences will display lower biodiversity than those surrounded with less human-influenced land uses (Crooks and Soule 1999)

Methods:

Study Location:

This study was conducted in north-eastern Swaziland in the Lowveld Savanna. The study area (Figure 1) is roughly 100 km x 30 km, and encompasses many protected areas, as well as intensive agriculture and communal rangelands. This area of the Lowveld is part of the Maputaland-Pondoland-Albany biodiversity hotspot: a hotspot with over 1900 endemic species (Steenkamp et al. 2004). In the Lowveld, the average temperature in July is 18°C, while in January it is 26°C (Goudie and Price Williams 1983). The average rainfall is 550-725 mm per year (Goudie and Price Williams 1983). Two types of soils are present in the study area. Basaltic soils in the east of the area create *Acacia* bushveld in protected area such as Mbuluzi game reserve and other areas at the base of the Lubombo Mountains, while granitic soils in protected areas such as IYSIS Cattle Ranch give rise to dense stands of *Spirostchys africana* and *Combretum sp.* (Sweet & Khumalo, 1994). Understory shrubs such as *Dichrostachys* occur and dominate on all soil types (Roques et al. 2001).

Any land uses exist within the mosaic system of the study area. Agriculture present in the system is exclusively intensive sugar cane monocultures: all other kinds of agriculture were described as community lands. Protected areas vary from government-owned park) to managed rangelands to sugar cane farm-owned conservancies Much of the land use in the study area,

including within many protected areas, cattle graze year round, and exist as the main producers of dung. Other producers include wildebeest, impala, zebra, nyala, bushbuck, and giraffe.
To map land use, we obtained 30 m x 30 m land-cover data through supervised classification of Landsat 8 data in Google Earth Engine (Figure 1). The land cover was classified into five predominant land-use types: agriculture, riparian/forest, communal lands, closed savanna, and open savanna.

Study Site Selection:

To pick the sites used in this study, we used a moving window analysis to gather the compositional and configuration heterogeneity of the study area landscape. For compositional heterogeneity, the number of landscapes within 2 km of each cell on the map were quantified for their total variation in land use. Shannon diversity was used to index the land uses. For configurational heterogeneity, the edges between plots and the total number of plots were used instead of the land use types. Additionally, the largest patch size in an area was quantified, in addition to a “patch cohesion” metric that describes the connectivity of the configured patches.

Once the metrics of the landscape were obtained, two principle components were constructed: one for composition and one for configuration. From here, the study area was divided longitudinally into three sections, north, middle, and south, in order to account for change in rainfall across that gradient. Study sites were then determined using combinations of high, medium, and low composition and configuration. Within each section, one 550 m x 550 m square of entirely savanna was randomly selected for each treatment. All sites were accessible by land, and father than 1 km apart from each other.

Grid/Plot Layout:

Once a study site was selected, it was established as a grid. Grids are square and measure 550m on each side. Within the grids, five 50x50m plots are located at the four corners and the center of the grid (Figure 2). Data was collected at the plot level, with and each plot was defined as having the same compositional and configurational context as the grid in which it was located. Dung beetle traps were set up at each plot in a 3x3 square, with each trap being 20m away from all adjacent cups (Figure 3).

Sampling Method:

Standardized pitfall traps were used for the capture of the dung. Per plot, 9 traps were laid in a 3x3 grid, with 20 meters between each trap. Pitfalls were constructed from 500 ml clear plastic cups sunk into the ground so the lip of the cup was flush with the ground, creating no barrier for the entry of walking species. Five of the traps were baited with fresh cow dung, while the other four were baited with a 50/50 mixture of cow dung and chicken liver. Bait was rolled in shower curtain and suspended over the pitfall using wire. No trap covers were used. The bottom of the cup was filled with a small amount of water and dish soap as a killing fluid. Traps were left out for 96 hours, and were emptied and rebaited at the 48^{th} hour. Beetles were sorted and classified through the use of morphospecies. Beetles were analyzed under a dissecting scope, and divided into groups by species by plot. Each group was put individually into containers and suspended in 95% ethanol. The morphospecies of each group and number of individuals in each group were recorded. Morphospecies were recorded consistently during the entire study.

Data Analysis:

Data was analyzed in R using generalized linear mix-effect models. Species richness, Shannon diversity, and Simpson diversity were each compared to potential impacts from vegetation structure and land-use at scales of 750 m, I km, and 2 km.

Results:

Summary Statistics:

In total, 1687 beetles across 42 different species were captured and sorted. Of the 75 plots in the study, 69 resulted in the capture of at least 1 beetle, and the most beetles captured on a single plot was 105. Morphospecies 2 was captured the most of any beetle, totaling 42% of beetle captured (n=709). Of the 42 species, 6 yielded only a single individual, and 23 species yielded fewer than 10 individuals. The mean number of beetles found per plot was 22.5 individuals, and the median was 16.

The most species found on a single plot was 13, which corresponded with the highest Shannon diversity of 2.43 and the highest Simpson diversity of .901. The average species richness was 6.12, and the median was 6. The average Shannon diversity was 1.56, and the median was 1.73. The mean Simpson diversity was .712 and the median was .769.

Model Results:

After testing models in R, it was determined that neither average vegetation structure nor vegetation structure heterogeneity had any impact on beetle biodiversity. Additionally, land-use composition had no impact at any scale. Land use composition did not have any influence on the Shannon or Simpson diversity of the dung beetles, but had a significant effect on species richness. Specifically, it was found that total agriculture within 1 km, savanna within 1 km, agriculture within 2 km, and savanna within 1 km all influences beetle species richness in significant ways. Ultimately, it was total agriculture with 2 km and total savanna within 2 km that were the most informative in predicting beetle species richness (Figure 2 and Figure 3).

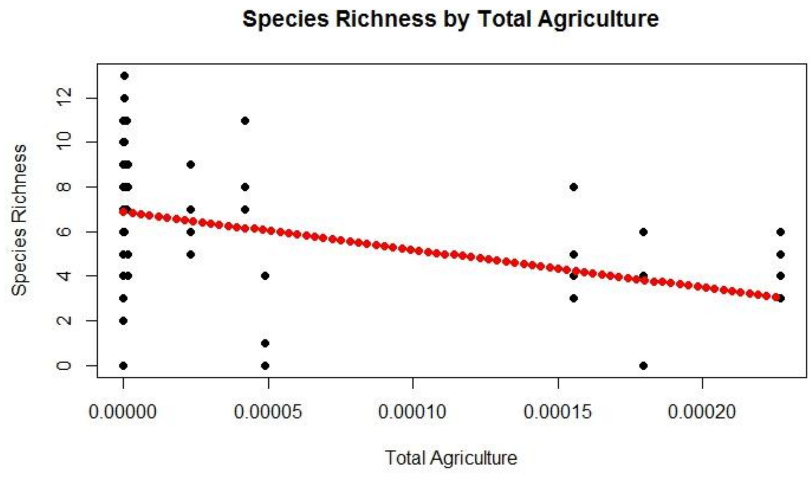

Figure 2. Species richness of indivdual trapping locations is shown by black dots, and increases uop the Y axis, while total agriculture increases up the X axis. The line of best fit is represented in red

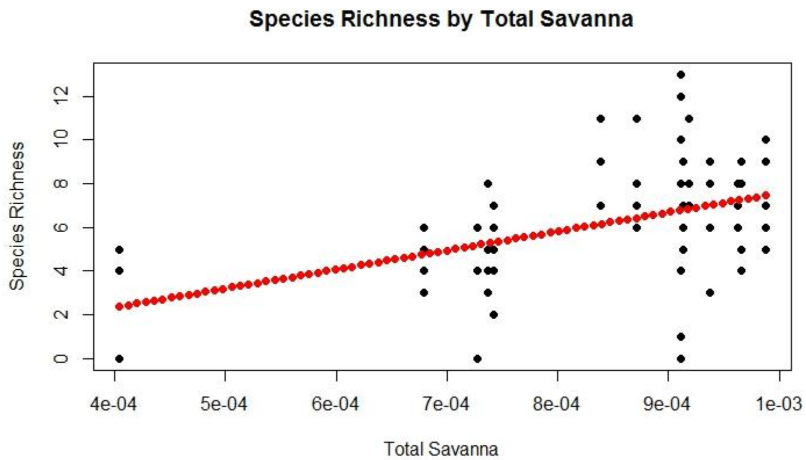

Figure 3. Species richness of individual trapping locations is shown by black dots, and increases up the Y axis, while total savanna increases up the X axis. The line of best fit is represented in red

Discussion:

Impacts of Agriculture:

From this data, it is clear that the amount of agriculture within 2 km has a significant impact on dung beetle diversity. There are many ways that agriculture can have impacts on arthropod communities, and in fact they are often targeted by pesticides specifically. This is a potential reason for the decline in beetle diversity around agriculture: many species are not able to survive the industrial grade pesticide application that may stray further than the limits of the farm. Additionally, while dung is present in much of Swaziland due to the extreme number of cows, there is virtually no dung present in sugar cane farms. The lack of additional habitat and large, impenetrable areas of travel may limit the influx of dung beetles to a location, and reduce species diversity.

A second aspect that must be analyzed about these results was the greater impact of agriculture at larger scales than at smaller scales. This was surprising, as the amount of agriculture within 2 km explained the data better than the amount of agriculture at 1 km, despite the latter being closer to the plots. We surmise this is the case for within 1 km, it is only possible to have a certain amount of agriculture. Because it was required that the entire grid be savanna, we know that 550m x 550m of the 1 km radius circle was already savanna, and it was unlikely that much agriculture was close to the plots. It was only when looking out to 2km that a significant enough amount of agriculture could be present to begin impacting the beetle diversity for the reasons described above.

Impacts of Savanna

In addition to agriculture significantly impacting beetle species richness, the total amount of savanna within 2 km did as well. There are two possible explanations for this. First, it is likely that amount of savanna is directly impacted by amount of agriculture, and for that reason as total savanna goes up, agriculture declines, and in turn increases beetle diversity. Secondly, it is likely that for the same reason agriculture decreases diversity, savanna leads to increases. There is limited dung within agriculture, but plenty to be found within savannas. Savannas naturally have high variation in vegetation structure, floristics, and have many different species of dung depositors, all of which will likely increase dung beetle species richness.

Like with agriculture, savanna within 2 km was found to influence beetle species richness to a greater extent than total savanna at 1 km. Again, the change in species richness likely occurs for the same reason here as with agriculture. Within 1 km, it is difficult to define what landscape ultimately dominates the area, and is likely having the largest impacts. Therefore, it is more descriptive to observe what occurs within in 2 km of the plot than within 1 km

Habitat Heterogeneity Hypothesis

Ultimately, this study confirmed no part of the habitat heterogeneity hypothesis. While the hypothesis states that diversity within a landscape, be it diversity in land use or in vegetation structure, increases biodiversity, that was not found to hold true here. Heterogeneity in plant structure at plot level and at grid level were both found to be insignificant. Additionally, configurational heterogeneity at all scales was found to be insignificant. Even land use heterogeneity was found to not influence beetle diversity, only the specific types of land use present impacted it.

Further Study

There is much left to still be studied on the impacts of land use context, and this study is only a single data point in many studies to come in regards to the habitat heterogeneity hypothesis. More taxonomic groups could be observed, such as other arthropods or higher animals such as reptiles or amphibians. Simultaneously, more precise land cover data could be obtained, and more kinds of land cover could be analyzed within the study (urban vs. homestead vs. small garden vs. ranch). These studies would give us an even better idea of how land context is affecting global biodiversity.

It is also worth observing why the results of this study occurred. While we presented multiple ideas of what impacts agriculture may have on beetle diversity, it is unclear what was truly the cause of agriculture's influence on dung beetle diversity. It is imperative that if pesticides are affecting areas outside of their intended range that data be collected on the extent to which this occurs. Additionally, quantifying species movement and landscape use is important in understanding gene flow, evolution, and biodiversity health in ecosystems around the world.

Conclusion:

This study warrants more studies to be done on the impacts of land use context on taxonomic groups as many area as possible. While the habitat heterogeneity holds true in most systems, the opposite trend occurs in the dung beetles, and may very well so occur in other similarly important groups as well. This study also shows that the habitat heterogeneity hypothesis is not completely defining of all systems.

Citations:

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