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Integrating environmental variables and geospatial technologies in landscape scale habitat modelling of edible stink bugs in Zimbabwe

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ABSTRACT

Encosternum delegorguei spinola (edible stink bugs) is renowned for its high protein and contribution to the local economies of the people in Africa. Although many studies have evaluated the economic and nutritional importance of *E. delegorguei,* little is known about its geographic distribution and habitat yet the insects are an important source of protein and money for many people in Southern Africa. In this study maximum entropy model was used to predict the probability of presence of *E. delegorguei* in southern Zimbabwe. The environmental factors governing its geographic distribution in Zimbabwe were also evaluated. Presence/absence data were selected along thirty-five randomly selected transects. The climatic and topographic variables used to predict the distribution of *E. delegorguei* were: maximum temperature of the warmest month; minimum temperature of the coldest month; the normalised difference vegetation index (NDVI); altitude; slope; and aspect. It was found that *E. delegorguei* is most likely to occur on steep slopes with high NDVI located at an altitude ranging of 856 and 1450 m above sea level. These suitable habitats are characterised by mild temperatures ranging from 17 °C to 28 °C. These results are in agreement with previous studies indicating that *E. delegorguei* is sensitive to temperature, as well as tree cover and may contribute towards conserving its habitat, which is being fragmented by anthropogenic disturbance.

1. Introduction

Encosternum delegorguei spinola commonly known as *harurwa* in Zimbabwe and *thongolifa* in South Africa is renowned for its high protein and contribution to the local economies of the people in Africa. In South Africa its demand exceeds supply such that the bug is imported from Zimbabwe and Mozambique for sale. Besides being a source of income, it is also a source of food with a high nutritional value to the local people (Toms and Nonaka, 2002; Teffo et al., 2007; Yen, 2009). When dried, *E. delegorguei* has a nutritional value of 35% protein, 51% fat, with an energy content of 2600 kJ/100 g. Amino-acid concentrations vary from 0.82 mg/100 g to 1.32 mg/100 g and the mineral content is 1.2 g/100 g (Teffo, 2006). Teffo (2006) and Makhado et al. (2009) found that stink bugs contain essential threonine and valine amino acids at concentration of 0.82 and 1.32 mg/100g respectively. Stink bugs are also rich in vitamins A, B1, B2 and E at concentration of 0.23, 0.63, 0.86 and 2.17 mg/100g, respectively.

The sale of the bug after harvesting on average earns a family an income of about a thousand rands per month in South Africa. For example, in South Africa a cup of dried *E. delegorguei* is sold for 5 rand and when it's scarce it's sold at 10 rand per cup (Teffo et al., 2007). Mapendembe and Mujere (2014) in his research found that the sale of *E. delegorguei* earned a household a sum of approximately 190 United States dollars per year in Zimbabwe. It is of cultural significance to rural communities.

Previous studies have documented that entamophagy, that is insect eating has improves the diet of the rural communities thereby averting cases of malnutrition (Toms and Nonaka, 2002; Teffo et al., 2007; Makhado et al., 2009). *E. delegorguei* cost less than animal proteins, such as beef and chicken. It is sold locally and regionally, especially in South Africa, Botswana, Mozambique and Zambia. Insects may be considered as food for the poor but in actual sense insects are eaten mainly for their good taste and cultural significance (Teffo et al., 2007; Yen, 2009). Makhado et al. (2009) states that insect eating is a livelihood for approximately 70% of the population as it is a cheap source of nutritious food and a source of income.

Encosternum delegorguei spinola is hemiptera in the pentatomidae family. It is said to be similar to *Nezara viridula* which is also in the pentatomidae family. Pentatomidae bugs are also known as shield bugs and feed on plant juice (sap) (Bevis, 1964; Pinhey, 1968; Sweeney,

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1976; Rolston and Kendrick, 2009). In Zimbabwe *E. delegorguei spinola* is found in the Jiri forest of Nerumedzo in Bikita distict, Bani-rembizi in Muzarabani, Bvuma forest in Zaka district and in the Mberengwa district. Nerumedzo is the largest source of *E. delegorguei* in Zimbabwe (Makuku, 1993). In South Africa it is found in three places around Thoyandou.

Although many studies have evaluated the economic and nutritional importance of *E. delegorguei* (Teffo, 2006; Makhado et al., 2009; Mapendembe and Mujere, 2014; Teffo et al., 2007), not much is known about its geographic distribution and habitat. Little isalso known about the variables which explain its distribution. Therefore, in this study we want to predict suitable habitat for and distribution of *E. delegorguei*, as well as to identify the environmental factors explaining its distribution. This information is critical in developing well-informed conservation strategies, as well as protecting and determining habitat suitability for these key species in Zimbabwe.

Mass production of insects has a potential to provide animal proteins for human consumption and for stock feeds which might reduce energy requirements in livestock production there by reducing the environmental footprint in our livestock production. Insect diversity may be the key to food security in traditional societies (Yen, 2009; Durst et al., 2010). Besides *E. delegorguei* is a source of income to the rural communities. Two hypotheses were tested in this study. The first is that since *E. delegorguei* survives and reproduces between temperatures of 5 °C to 28 °C and beyond this range mortality rate is high and fecundity low, the minimum and maximum temperatures of the coldest and warmest month are key determinants of its occurrence. The second hypothesis tested is, as *E. delegorguei* feeds on the sap of woody plants, it is expected to be in woodlands, which have a higher biomass and therefore higher NDVI than grasslands.

2. Materials and methods

2.1. Study site

The study is located between the latitudes 23°00′ and 14°59′ south and the longitudes 24°59′ and 35°00′east of Zimbabwe. The area receives very low and erratic rainfall with an annual mean of 635 mm (Masocha, 2010). The mean temperature of the warmest and coldest month is 28 °C and 5 °C, respectively (www.weather-and-climate 2009).

2.2. Data collection

The study area was divided into upper (1546m), mid and lower slope (783m) using altitude with a range of 254m in between. Thirty-five random transects were generated which were 3 km long and 50 m wide. Each transect had six random sample points. Presence/absence data were selected along thirty-five randomly selected transects and species present in each transect were recorded. Data was collected from the 8th of March to 31st March 2011 because that was the time which was expected to see *E. delegorguei* at its adult stage.

2.3. Species occurrence data

Trees in each plot were shaken to see if there were any *E. delegorguei*. However, nothing was observed, therefore knowledge of the local people was used to provide information on the exact location of the bugs. Also evidence was gathered, such as tree marks (wounds) from the previous harvesting. All the tree species present were recorded in a plot. The plots were along transects and sample points were used as plot centres. Tree specimen identified was brought with the help of a botanist. The plots were 15 m by 15 m.

2.4. Environmental variables

Temperature data was obtained from the worldclim. Maximum temperature of the warmest month and minimum temperature of the coldest month were used. Slope and aspect were derived from the 30 m ASTER digital elevation model (DEM) of Zimbabwe using standard algorithms in ArcGIS (version 3.9). Altitude was obtained from a 30 m digital elevation model (DEM) of Zimbabwe.

2.5. Modelling

The obtained fifty occurrence records of *E. delegorguei* were used together with altitude, slope angle, aspect, maximum and minimum temperature of the warmest and coldest month respectively and NDVI to run the Maximum Entropy model to analyse the data. Environmental variables were saved as ASCII files and occurrence records as Comma separated values (CSV). Temperature data was gathered from the Worldclim (http://www.worldclim.org/). Variables of the study site were resampled using the nearest neighbour interpolation to match the resolution of topographic variables of the study site. moderate resolution imaging spectroradiometer (MODIS) taken on the 27th of May 2007 was calibrated to change it from radiance to reflectance and then calculated NDVI. The data was split into two portions, 70% for calibrating the model and 30% for model evaluation. To evaluate the relative importance of the environmental variables, the jacknife test was applied (Joseph, 1996) (see Fig. 1).

3. Results

Fig. 2 shows that NDVI, altitude, and slope are the most important variables which contributed to the modelling of *E. delegorguei*'s habitat. For instance, NDVI alone contributes almost 60% towards determining the spatial distribution of these insects, followed by slope and maximum temperature approximately 15% individual contribution.

Fig. 3(a) shows that probability of presence is decreasing with the increase in maximum temperature of the warmest month whereas Fig. 3(b) shows that probability of occurrence is decreasing with the increase in minimum temperature of the coldest month. it can be observed that between 26 and 28^{0}Cthere is high probability presence of *E. delegorguei* with a asymptotic decrease with sharp increase in temperature. However, similar trend is observed with minimum temperatures.

Fig. 4(a) shows that probability of presence increases with the increase in NDVI and becomes constant when NDVI is approximately 0.5. Also, it can be observed from Fig. 4(b) that probability of presence of *E. delegorguei* increases with the increase in altitude, whereas Fig. 5(a) shows that probability of presence of *E. delegorguei* is high when aspect is about 86.5° that is when slopes are facing north east. Probability of presence decreases from north to south facing slopes, that is, as aspect increase from 86.5 to 93°, probability decrease from 0.56 to approximately 0.43. Fig. 5(b) shows that probability of presence of *E. delegorguei* is very low (less than 0.1) on flat slopes (0%) but increases as slope percentage increases. On the other hand, Fig. 6 shows the distribution and occurrence of *E. delegorguei* in terms of probability. It can be observed that the probability of occurrence is high on high, steep mountainous areas.

Fig. 7 shows the probability of occurrence of *E. delegorguei* landscape scale, across Zimbabwe. Probability of occurrence is high in Masvingo, Manicaland, Mashonaland East, West and central Provinces. Comparatively, areas experiencing temperatures above 30 °C like Matabeleland north and south are characterised with less occurrences. The probability map shows precisely that the occurrence of *E. delegorguei* is dependent on environmental variables, especially temperatures, NDVI and slope.

In the field, *E. delegorguei* was found on the following woody species: *Annona senegalensis, Antidesma venosum, Brachystegia boehmii, Brachystegia spiciformis, Bridelia carthatica, Burkea africana, Combretum molle, Diospyros lycioides, Dodonaea viscosa, Englerophytum magalismontanum, Euclea natalensis, Faurea saligna, Gardenia ternifolia,*