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Modelling the spatial-temporal distribution of tsetse (*Glossina pallidipes*) as a function of topography and vegetation greenness in the Zambezi Valley of Zimbabwe

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A B S T R A C T

In this study, we developed a stable and temporally dynamic model for predicting tsetse (*Glossina pallidipes*) habitat distribution based on a remotely sensed Normalised Difference Vegetation Index (NDVI), an indicator of vegetation greenness, and topographic variables, specifically, elevation and topographic position index (TPI). We also investigated the effect of drainage networks on habitat suitability of tsetse as well as factors that may influence changes in area of suitable tsetse habitat. We used data on tsetse presence collected in North western Zimbabwe during 1998 to develop a habitat prediction model using Maxent (Training AUC = 0.751, test AU = 0.752). Results of the Maxent model showed that the probability of occurrence of tsetse decreased as TPI increased while an increase in elevation beyond 800 m resulted in a decrease in the probability of occurrence. High probabilities (>50%) of occurrence of tsetse were associated with NDVI between high 0.3 and 0.6. Based on the good predictive ability of the model, we fitted this model to environmental data of six different years, 1986, 1991, 1993, 2002, 2007 and 2008 to predict the spatial distribution of tsetse presence in those years and to quantify any trends or changes in the tsetse distribution, which may be a function of changes in suitable tsetse habitat. The results showed that the amount of suitable tsetse habitat significantly decreased (r^2 0.799, $p = 0.007$) for the period 1986 and 2008 due to the changes in the amount of vegetation cover as measured by NDVI over time in years. Using binary logistic regression, the probability of occurrence of suitable tsetse habitat decreased with increased distance from drainage lines. Overall, results of this study suggest that temporal changes in vegetation cover captured by using NDVI can aptly capture variations in habitat suitability of tsetse over time. Thus integration of remotely sensed data and other landscape variables enhances assessment of temporal changes in habitat suitability of tsetse which is crucial in the management and control of tsetse.

1. Introduction

The tsetse fly (Glossina spp.) is a vector that transmits the trypanosomes that are responsible for Human African Trypanosomiasis (HAT) in Humans, also known as sleeping sickness and African Animal Trypanosomiasis (AAT) in animals, which is often termed Nagana in cattle. The tsetse fly causes rural poverty across large areas of sub-Saharan Africa where the keeping of livestock is curtailed or prevented (Holmes, 2013; Matawa, Murwira, & Shereni, 2013). Thus, the understanding of the spatial-temporal dynamics of the tsetse flies may guide the application of vector control and eradication measures that would in turn improve rural livelihoods.

The distribution of tsetse is often linked to specific habitat types, particularly those places with vegetation cover including thickets

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and riverine woodlands that provide ample shade and reduce the chances of dehydration (Adam et al., 2012; Batchelor et al., 2009; Odulaja & Mohamed-Ahmed, 2001; Van Den Bossche, De La Rocque, Hendrickx, & Bouyer, 2010). Such habitats are also home to wildlife species that provide the requisite blood meals for the tsetse fly (Ducheyne et al., 2009; Van Den Bossche et al., 2010). Thus, any landscape change that results in thicket reduction could affect not only the wildlife species but also affect the tsetse population both directly and indirectly (Kitron, Otieno, Hungerford, Odulaja, & Brigham, 1996; Munang'andu, Siamudaala, Munyeme, & Shimumbo Nalubamba, 2012). We therefore assert that characterisation of landscape changes is critical to understanding changes in the tsetse population and its distribution. Such characterisation also has potential to provide insights into the temporal and spatial dynamics of AAT in domestic animals and HAT in humans within ecosystems that are home to the tsetse fly.

Although an understanding of the spatial dynamics of key ecosystems is critical in characterising the dynamics of Trypanosomiasis, studies on ecosystem change and its effect on tsetse habitat dynamics have remained limited. Of the few studies on ecosystem change, the focus has mainly been on agricultural and human settlement expansion following the suppression of tsetse (Baudron, Corbeels, Andersson, Giller, & Sibanda, 2010; Sibanda & Murwira, 2012a). Understanding ecosystem change in relation to tsetse habitat could provide improved insights into how these changes alter the interactions between the host, vector and parasite (Devisser, Messina, Moore, Lusch, & Maitima, 2010; Van Den Bossche et al., 2010). However, in order to track fine scale environmental changes, as well as, link these changes to tsetse fly presence or abundance there is need for the development of spatially explicit models at a fine spatial resolution (Rogers, Hay, & Packer, 1996) that incorporate dynamic variables that are able to capture changes in landscape condition.

The distribution of tsetse has been widely linked to vegetation cover as it influences micro-climate and availability of hosts (Cecchi, Mattioli, Slingenbergh, & De La Rocque, 2008; Devisser et al., 2010; Hay, Packer, & Rogers, 1997; Welburn et al., 2006). Vegetation cover inherently changes over time and hence could be a useful dynamic variable that can be included in habitat suitability models. However, traditional approaches of quantifying vegetation cover have often been tedious, time consuming and limited to small areas. To this end, objective measures of quantifying vegetation cover over large spatial extents are important.

The advent of remotely sensed data has allowed objective measures of vegetation cover to be developed. For example, remotely sensed indices such as Ratio vegetation index (RVI), the Transformed vegetation index (TVI) and the Normalised Difference Vegetation Index (NDVI) have been developed to estimate vegetation cover across landscapes. Among these indices, NDVI has been widely used for characterizing vegetation cover, vegetation biomass and vegetation greenness (Devisser et al., 2010, Dicko et al., 2014; Robinson, Rogers, & Williams, 1997; Rogers, Hay, & Randolph, 2000). For example, NDVI in combination with temperature and rainfall were used to explain the distribution of tsetse flies in West Africa based on the discriminant analysis approach (Rogers et al., 1996). Although these studies have provided insights into factors influencing the distribution of tsetse, the studies failed to take into account temporal variation in tsetse habitat.

Furthermore, remotely sensed data used in previous studies particularly NDVI was derived from low resolution satellite data which tend to over-generalise tsetse habitat. It is well known that tsetse populations can be maintained in small patches of suitable habitat particularly micro-habitats with woody vegetation (Devisser et al., 2010). Thus, habitat suitability models developed using low resolution NDVI data derived from, e.g., 250 m MODIS and 1 km NOAA-AVHRR sensors may fail to capture patches of suitable habitat smaller than 250 m spatial resolution (Devisser et al., 2010). In addition, use of low spatial resolution imagery may compromise the results of epidemiological analyses (Atkinson & Graham, 2006). In this regard, inclusion of remotely sensed estimates of vegetation cover at a fine resolution is imperative for enhancing the accuracy and usefulness of tsetse distribution models in tsetse eradication campaigns.

In this study, our main objective was to assess temporal changes in tsetse habitat based on a habitat model developed using dynamic and stable environmental variables. We hypothesised that ecosystem changes resulting from changes in landcover reduce the amount of suitable tsetse habitat. Specifically, we tested whether tsetse habitat can be predicted based on three variables namely 30 m resolution Landsat TM based Normalised Difference Vegetation Index (NDVI) (temporally dynamic variable) as well as elevation and Topographic Position Index (TPI) (temporally stable variables). We then tested the ability of the model to predict tsetse suitable habitat over a period of twelve years. We also tested whether suitable tsetse habitat varied over the same period due to reduction in vegetation cover. We also investigated the relationship between variation in suitable habitat and rainfall as well as burnt area.

We considered topographic variables such as elevation and TPI due to the fact that Tsetse is mostly found in low-lying areas as they are associated with high temperatures (Devisser et al., 2010; Matawa et al., 2013; Terblanche, Clusella-Trullas, Deere, & Chown, 2008). TPI measures slope position and landform category i.e. identifies hilltops, ridges, valleys and flat areas (Pittiglio, Skidmore, Van Gils, & Prins, 2012). However, elevation and TPI may fail to capture the spatial-temporal dynamics in tsetse fly occurrence as they are largely temporally stable. Thus, their integration with remotely sensed vegetation cover could provide a spatially and temporally dynamic model that can allow modelling of changes in tsetse suitable habitat over time.

2. Materials and methods

2.1. Study area

The study area is located in north western Zimbabwe at 16° south and 29° east (Fig. 1). The study was conducted in an area straddling protected areas (including safari areas) and settled areas comprising large and small scale farming areas and the communal lands of the Zambezi Valley. Communal lands are areas characterised by community land ownership and are subdivided into administrative units called wards (Sibanda & Murwira, 2012a).

The area has a dry tropical climate, characterised by low and variable annual rainfall averaging between 450 and 650 mm per year and a mean annual temperature of 25 °C (Baudron et al., 2010; Sibanda & Murwira, 2012a). The rainfall patterns based on mean monthly precipitation calculated using data recorded at the three closest whether stations namely Karoi, Makuti and Rekomitje (Rukomichi) show that the 1985/1986 rainfall season had higher rainfall as compared to all the other rainfall seasons under consideration (Fig. 2). The area has two clearly defined seasons: a wet season from December to March and a long dry season from April to November (Baudron et al., 2010). The climatic conditions, thus, make the study area a suitable habitat for tsetse. The natural vegetation is mainly deciduous dry savannah, that includes *Colophospermum mopane* (Baudron et al., 2010; Sibanda & Murwira, 2012a), *Combretum* woodlands and riparian vegetation. The elevation of the study area ranges from 340 m to 1400 m (SRTM-DEM). Areas below 1100 m are climatically suitable for tsetse (Pender, Mills, & Rosenburg, 1997).