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Full Length Research Paper

Prediction of *Osyris lanceolata* (Hochst. & Steud.) site suitability using indicator plant species and edaphic factors in humid highland and dry lowland forests in Kenya

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Osyris lanceolata (African Sandalwood) belongs to the family _Santalaceae_ that hosts some of the most valuable species for perfumery oil extraction. In India and Australia, _Santalum album_ and _Santalum spicatum_ are well developed for perfumery oil extraction through establishment of commercial plantations. In Africa, _O. lanceolata_ has attracted significant attention as potential perfumery oils extraction species. However, African Sandalwood exploitation is through unsustainable smuggling from natural forests and woodlands. Since sustainable production of _O. lanceolata_ oils is only feasible through establishment of commercial plantations, there is need to understand ecological requirements of the species before the remaining natural stands disappear. The aim of this study was to determine plant species and edaphic factors that can predict African Sandalwood site suitability for domestication programs. Sample plots with and without _O. lanceolata_ were selected from natural stands in a humid highland forest and a dry lowland forest, vegetation sampled using nested-intensity plots and soils sampled in the plots simultaneously. Vegetation data was recorded according to species abundance. Soil samples were analyzed for nutrients, texture and moisture retention. Canonical Correspondence Analysis using CANOCO software was used to determine species association and relationship between species to soil variables. In the highland forest, _O. lanceolata_ clustered with _Rhus natalensis_ and six other species, and was correlated to soil nitrogen, moisture and clay. In lowland forest, _O. lanceolata_ clustered with _R. natalensis_ and _Hypoestes forskahlii_ but did not correlate with any of the soil variables. The clustering of African Sandalwood with _R. natalensis_ in both forest types suggests strong predictive capacity of _R. natalensis_ for _O. lanceolata_ site suitability in humid and dry areas. Inconsistence of _O. lanceolata_ relationship with soil variables in the two study sites provides opportunity for further studies in different soil types.

Key words: CANOCO, domestication, edaphic, hemi-parasites, species association, African Sandalwood.

INTRODUCTION

Osyris lanceolata (African Sandalwood) is an evergreen hemi-parasite that belongs to the family *Santalaceae* (Maundu and Tengnas, 2005, Irving and Cameron, 2009). The family hosts culturally and commercially

important species that have long been used for herbal medicine, religion and perfumery oil industry (Tshisikhawe et al., 2012, Subasinghe, 2013). Species such as *Santalum album* and *Santalum spicatum* have long been exploited for perfumery oil and are now more developed commercially with plantations of *S. album* showing an increasing trend in Australia, China, India, Fiji and Sri Lanka (Subasinghe, 2013). In recent past, trade in African Sandalwood oil has also increased because of ready markets in Asia and Europe (CITES Cop 16). However, trade in African Sandalwood is unsustainable because materials are smuggled from natural stands and without clear domestication programs (Mukonyi et al., 2011). Moreover, exploitation of the species for herbal medicine has also increased (Tshisikhawe, 2012) leading to its decline in natural stands (Githae et al., 2011). Arising from this concern, African Sandalwood is now listed as threatened species under USF and WS (2013). Since sustainable production of *O. lanceolata* oils is only feasible through establishment of commercial plantations, there is need to identify predictive abiotic and biotic variables for its occurrence before the remaining natural stands disappear.

African Sandalwood has wide ecological distribution in Africa (Beentje, 1994, Mwang'ingo et al., 2003, Tshisikhawe et al., 2012, International Plant Names Index website (www.ipni.org/). The species can parasitize over 300 species of plants from herbaceous weeds, grass, multi-stem shrubs and trees. Usually, it is found in association with various hosts such as *Dodonea viscosa, Tecomaria capensis, Catha edulis, Apodytes dimidiata, Brachytegia spiciforms, Rhus natalensis* and *Casuarina equisetifolia* (Mwang'ingo et al., 2010). In Kenya, the species grows naturally in both humid highland and dry lowland forests (Maundu and Tengnas, 2005) that differ in altitude, vegetation types, soils and climatic variables (Sombroek et al., 1980). However, the effect of abiotic and biotic variables diversity on African Sandalwood distribution is not well studied, thus limiting site suitability prediction capacity for *O. lanceolata* domestication. The objectives of this study were therefore to determine plant species that associate strongly with *O. lanceolata* in humid highland and dry lowland forests and to determine soil variables that may influence the occurrence of the species in natural stands.

MATERIALS AND METHODS

Study sites

The study sites were Gachuthi humid highland forest and Kibwezi dry lowland forest (Figure 1). Gachuthi forest occurs in agro-climatic zone III (Sombroek et al., 1980), at an altitude range of 2040 to 2200 m above sea level with temperatures ranging from 12 to 25°C and mean annual rainfall range of 990 to 1500 mm. The soils in this forest are nitosols that are derived from volcanic rocks (Okalebo et al., 2002). The characteristics of these soils include high clay content (more than 35%), good moisture-storage capacity, good aeration, and high organic matter content. Cation exchange capacity and the percentage base saturation range from low to high. The soils are acidic (pH < 5.5) due to the leaching of soluble bases (Okalebo et al., 2002). The natural vegetation of Gachuthi forest is dominated by *Calodendrum capense, Ehretia cymosa, Maytenus undata, Teclea simplicifolia,Vangueria madagascariences, Warburgia ugandensis* and *Zanthoxylum usambarense*.

Kibwezi forest lies in a semi-arid region (agro climatic zone V) in south eastern Kenya (Figure 1) within an attitude range of 900 to 1015 m above sea level with a temperature range of 19 to 30°C and mean annual rainfall ranges between 250 and 350 mm (Sombroek et al., 1980). The soils in this forest are classified as sandy loams, gravely volcanic and clayey (Okalebo et al., 2002). Acacia commiphora woodland is the dominant vegetation type. Dominant trees include *Acacia xanthophloea*, *Acacia tortilis, Adansonia digitata*, *Balanites aegyptiaca* and *Commiphora* species.

Vegetation data collection and soil sampling

A reconnaissance visit in both forests was undertaken where *O. lanceolata* was found to be more abundant at the edges than deep in the forest and a sampling framework was designed. The forest edges were found to be fairly heterogeneous over short distances. Subsequently, transects measuring 600 m were laid using a linear tape measure. Modified nested-intensity plots (Barnett and Stohlgren, 2003) were then laid along each transects. To avoid spatial autocorrelation (Tiegs et al., 2005; de Knegt et al., 2010), a distance of ≥ 50 m was adopted between any two plots. In total, 24 plots were sampled in each site. In Gachuthi forest, 7 plots randomly fell in plots with *O. lanceolata* and 17 in plots without *O. lanceolata*. In Kibwezi forest, 18 plots were with *O. lanceolata* and 6 plots without *O. lanceolata.*

A modified nested intensity plot consisted of a main plot "A" measuring 5 by 20 m, a middle sub-plot "B" measuring 2 by 5 m and four sub-plots "C" of 1 by 1 m (Figure 2). Normally, the 1 by 1 m sub-plots are located near the corners of the main plot but their location was modified in this study to be close to *O. lanceolata* trees located at the middle of the main plot (Figure 2). Vegetation data was captured in terms of trees from the main Plot A, shrubs from Sub-plot B and herbaceous species and grass in Sub-plot C. The species were identified in the field, using published keys (Beentje, 1994). If the species could not be identified, its vernacular name was used and a specimen collected for identification at the national herbarium. Species found in each of the three sub-plots were tabulated in appropriate tables and their frequencies recorded for further analysis.

Soil samples were collected under *O. lanceolata* trees and the main plot measuring at depths of 0 to 25 cm and 25 to 50 cm using a soil auger, bulked, homogenized according to their different depths and stored in polythene bags. Soil samples were taken to Kenya Forest Research Institute (KEFRI) soil laboratory for analysis. The analysis included soil moisture, texture, pH and electro conductivity, nitrogen, phosphorous and potassium. Soil moisture and texture was determined using improved hydrometer method for soil particle size analyses, pH and Electro Conductivity(E.C.) values were determined with glass electrode, pH meter Model 691 and E.C. meter Model TOA Cm-20s (Lawal

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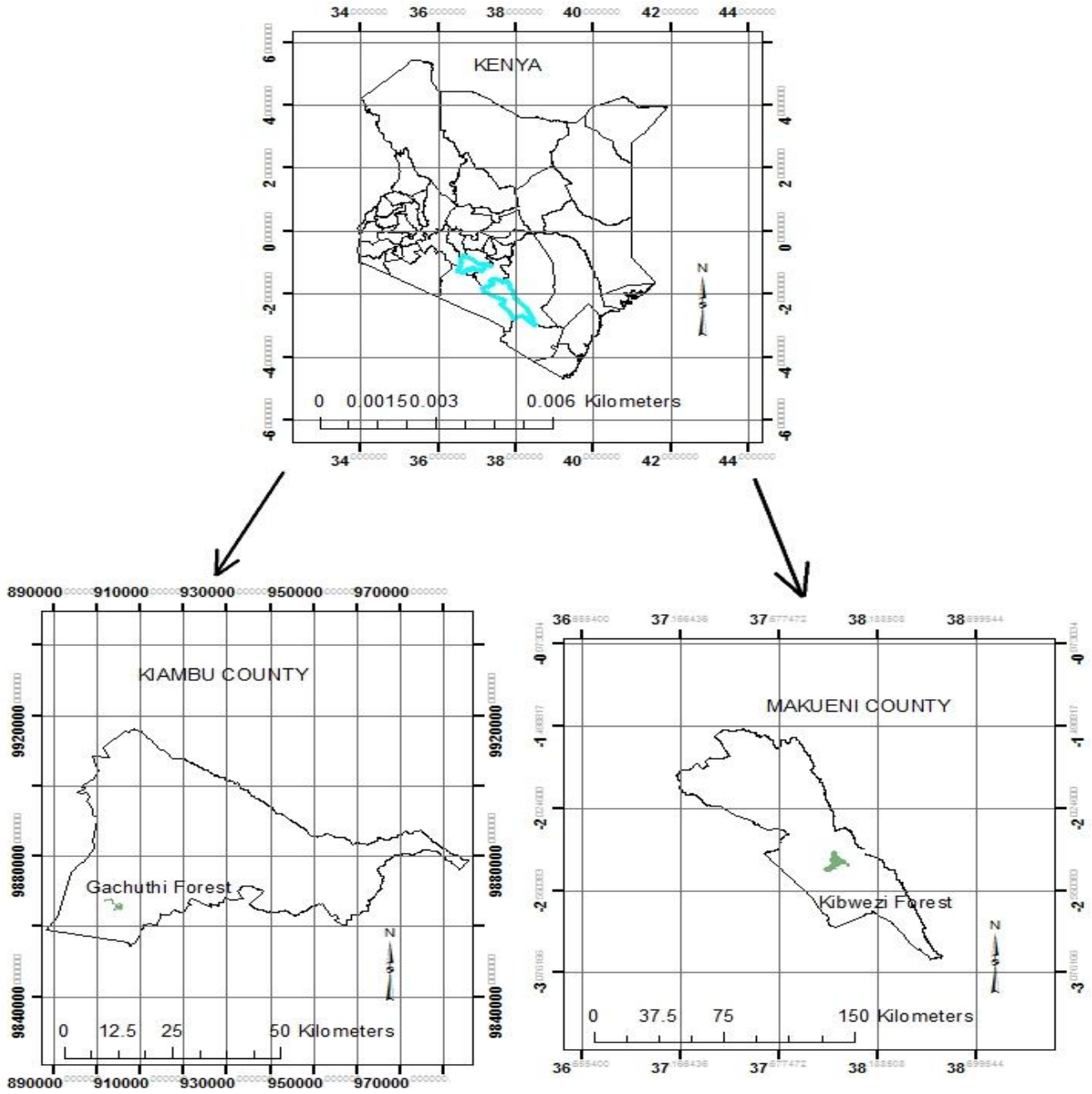

Figure 1. Geographical location of Gachuthi humid highland and Kibwezi dry lowland forests in Kenya.

and Girei, 2013). Total nitrogen was determined using Kjeldahl method with Skalar Block Digester System, Model SA 5640 as described by Okalebo et al. (2002). Available phosphorus was analyzed using UV spectrophotometer method (Olsen et al., 1982) with UV Spectronic Model 21-Milton Roy Co. Potassium was determined specto-photometically (Okalebo et al., 2002) using flame photometer, Model Corning M 410.

Data analysis

Species frequency data was combined into a single MS Excel© spreadsheet and used as species data. Soil nutrients, texture and moisture content data was then saved as a single MS Excel© spreadsheet and used as environmental data. The two data sets were used in Canonical Correspondence Analysis using CANOCO version 4.15 (Ter Braak, 1997) that relates species to measured environmental variables (Palmer, 1993). This relationship is shown graphically in biplots where lengths of the arrows reveal the relative influence of a measured variable to a species. In our case, plant species associations (clustering) was established from the species data and relationship between species and measured soil variables determined by using soil data as the environmental variable data in the analysis.

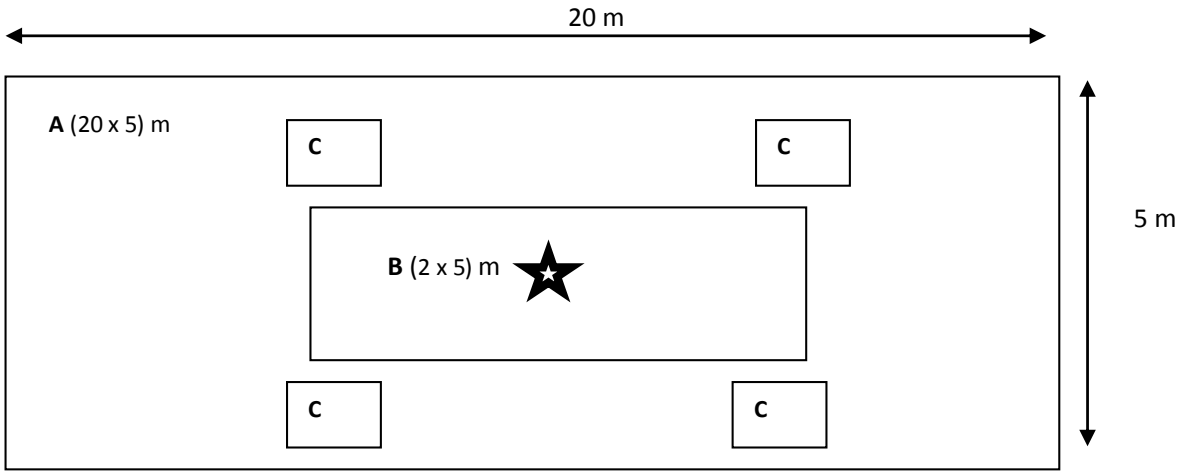

Figure 2. A modified nested-intensity sample plot used for field vegetation data collection. The star indicates approximate location of Osyris trees in the sample plots.

RESULTS AND DISCUSSION

Comparison of species occurrence in plots with and without *O. lanceolata* in Gachuthi and Kibwezi forests

In Gachuthi forest, 16 herbaceous species were found in plots with *O. lanceolata* and 24 herbaceous species found in plots with no *O. lanceolata* (Table 1). In Kibwezi forest, 11 herbaceous species were found in plots with *O. lanceolata* and 6 herbaceous species found in plots without *O. lanceolata* (Table 1). In Gachuthi, there were 3 grass species in plots with *O. lanceolata* and 5 grass species in plots without *O. lanceolata* (Table 1 In Kibwezi, there were 2 species of grass found co-occurring with *O. lanceolata* and only 1 grass species was found in plots without *O. lanceolata* only (Table 1). Twenty-two shrubs were found in plots with *O. lanceolata* and Twenty-one shrubs found in plots without *O. lanceolata* in Gachuthi (Table 2). This was in contrast with 14 and 11 shrubs found in plots with and without *O. lanceolata* in Kibwezi respectively (Table 2). Fourteen and seventeen tree species were found in plots with and without *O. lanceolata* in Gachuthi forest, respectively as compared to 21 tree species in plots with *O. lanceolata* and 7 tree species in plots without *O. lanceolata* in Kibwezi forest. In total, there were 55 species in plots with *O. lanceolata* as compared with 67 species without *O. lanceolata* in Gachuthi forest. This was in contrast to 48 species in plots with *O. lanceolata* and 25 species in plots without *O. lanceolata* in Kibwezi. Results of the study reveal inconsistence of trends in species co-occurrence with *O. lanceolata* between the two sites. The higher number of species found in highland humid forest is consistent with high species diversity of such forests when compared to lowland dry forests as influenced by variation in altitude, rainfall, temperature and soils (Sombroek et al., 1980). Also, the species found in *O. lanceolata* plots are among those reported in related studies (Mwang'ingo et al., 2010; Githae et al., 2011).

Abiotic and biotic factors associated with occurrence of *O. lanceolata* in Gachuthi and Kibwezi forests

Although, *O. lanceolata* was found co-existing with many species in both sites (Tables 1 and 2), CCA biplots (Figure 3a and b) revealed that the species could only cluster with a few species in each of the two sites. This suggests some of the species that coexisted may have little or no functional associational roles. Our findings are not surprising since studies on host preference of *O. lanceolata* have demonstrated that the species has a wide range of hosts but a few are more effective in its establishment and early growth (Mwang'ingo et al., 2005; Kamondo et al., 2007). The clustering of *O. lanceolata* with *R. natalensis* in both sites is consistent with the coexistence of both species in natural environments (Githae et al., 2011; Teklehaimanot et al., 2012) and effectiveness of *R. natalensis* as host species for *O. lanceolata* (Mwang'ingo et al., 2005; Kamondo et al., 2007). Therefore, we opine that *R. natalensis* is a good tree indicator for *O. lanceolata* site suitability. Since *O. lanceolata* also coexists with numerous herbaceous and grass species (Githae et al., 2011; Teklehaimanot et al., 2012), the functional association of the species with *Glycine wightii, Gutenbergia condifolia* and *Microglossa pyrifolia* at Gachuthi forest and *Hypoestes forskahlii* at Kibwezi is subject of further studies to provide a more effective stratification of *O. lanceolata* hosts among trees, shrubs and herbaceous species.

Relationship between species with soil nutrients (N, P, K), clay sand, silt, moisture, pH and EC revealed a contrasting trend between sites. In Gachuthi forest, *O. lanceolata* occurrence was correlated to nitrogen, clay

Table 1. Herbaceous (H) and grass (G) species found in plots with *O. lanceolata* (With Osyris) and those without Osyris (No Osyris) in Gachuthi and Kibwezi Forests. Species occurrence is denoted by √ whereas species absence is denoted by ×.

Plant species	Plant form	Gachuthi Forest		Kibwezi Forest	
		Osyris	No Osyris	Osyris	No Osyris
Abutilon mauritianum	H	√	√	√	×
Achyranthes aspera	H	√	√	√	×
Ageratum conyzoides	H	√	√	×	×
Asparagus racemosus	H	√	√	√	√
Barlelia acanthoides	H	×	×	√	√
Bidens pilosa	H	√	√	×	×
Chenopodium pumilio	H	×	√	×	×
Chloris sp	G	√	×	×	×
Cissus quadrangularis	H	×	×	√	√
Clematis brachiata	H	×	√	×	×
Commelina benghalensis	H	√	√	×	×
Conyza sumatrensis	H	√	√	×	×
Cyathula sp	H	×	√	×	×
Cynodon dactylon	G	×	√	√	√
Cyperus sp	G	×	×	√	×
Cyphostemma maranguense	H	×	√	×	×
Digitaria abyssinica	G	×	√	×	×
Duosperma kilimandscharicum	H	×	×	√	×
Fuarstia Africana	H	√	√	×	×
Galinsoga parviflora	H	√	√	×	×
Glycine wightii	H	√	√	×	×
Gutenbergia condifolia	H	√	√	×	×
Hyparrhenia rufa	G	√	√	×	×
Hypoestes forskahlii	H	√	√	√	√
Ipomea wightii	H	×	√	√	×
Justicia diclipteroides	H	×	×	√	×
Ocimum gratissimum	H	√	√	×	×
Oplismenus hirtellus	G	√	√	×	×
Oxalis obliquifolia	H	×	√	×	×
Pennisetum clandestinum	G	×	√	×	×
Periploca linearifolia	H	×	√	×	×
Seddera hirsute	H	×	×	√	×
Setaria verticillata	H	√	√	×	×
Sida tenuicarpa	H	×	×	×	√
Solanum incanum	H	√	√	√	√
Zehneria scabra	H	√	√	×	×
Total		19	29	13	7

and moisture in contrast to lack of such relationship in Kibwezi forest. The natural distribution of *O. lanceolata* in Kenya (Maundu and Tengnas, 2005; Githae et al., 2011; Mukonyi et al., 2011) and the soil maps of the range (Sombroek et al., 1980) revealed a great soil diversity in the range. Since our study was only restricted to two sites with two soil types, further studies with more representative soil types may be required to elucidate on edaphic factors that may influence *O. lanceolata* distribution.

Conclusion

In Gachuthi, Osyris clustered with *R. natalensis* and six other species whereas in Kibwezi, it clustered with *R. natalensis* and *H. forskahlii*. Therefore, *O. lanceolata* site suitability for domestication can be predicted using *R. natalensis*. CCA biplots showed clearly that *O. lanceolata* in Gachuthi forest positively correlated to soil nitrogen, moisture and clay whereas in Kibwezi forest; the species did not have a relationship with any of the soil variables.

Table 2. Shrub (S) and tree (T) species found in plots with *O. lanceolata* (With Osyris) and those without Osyris (No Osyris) in Gachuthi and Kibwezi Forests. Species occurrence is denoted by √ whereas species absence is denoted by ×.

Plant species	Plant form	Gachuthi Forest		Kibwezi Forest	
		Osyris	No Osyris	Osyris	No Osyris
Acacia brevispica	S	×	×	√	×
Acacia mearnsii	T	×	√	×	×
Acacia robusta	T	×	×	√	×
Adenium spp	S	×	×	×	√
Antidesma venosum	T	×	×	√	×
Aspilia mossambicensis	S	√	√	√	√
Balanites maughamii	T	×	×	√	×
Calodendrum capense	T	√	√	×	×
Cassipourea malosana	T	√	√	×	×
Celtis Africana	T	×	√	×	×
Clausena anisata	T	√	√	×	×
Clutia abyssinica	S	√	×	×	×
Combretum sp	T	×	×	×	√
Combretum sp	T	×	×	×	√
Commiphora baluensis	T	×	×	√	×
Commiphora eminii	S	×	×	√	×
Commiphora spp	T	×	×	√	×
Crotalaria mauensis	S	√	√	×	×
Croton dichogamus	S	×	×	√	×
Croton megalocarpus	T	×	×	√	×
Cussonia hostii	T	×	×	√	×
Diospyros consolatae	T	×	×	√	√
Dodonaea viscose	S	×	×	×	√
Dombeya burgessiae	S	√	×	×	×
Dombeya kirkii	S	×	×	√	√
Ehretia cymosa	T	×	√	×	×
Elaeodendron buchananii	T	√	√	×	×
Erythrococca bongensis	S	√	√	×	×
Euclea divinorum	T	√	√	√	×
Euphorbia candelabrum	T	×	×	√	×
Euphorbia scheffleri	S	×	×	√	×
Fagaropsis angolensis	T	√	×	×	×
Ficus vasta	T	×	×	√	√
Grewia similis	S	√	×	×	×
Grewia spp	S	×	×	√	×
Haplocoelum foliolosum	T	×	×	√	×
Helichrysum sp.	S	√	√	×	×
Heteromorpha trifoliate	T	×	×	√	×
Hibiscus diversifolius	S	√	√	×	×
Hibiscus fuscus	S	×	×	√	√
Hymenodictyon parvifolium	T	×	×	√	×
Indigofera swaziensis	S	×	√	√	√
Juniperus procera	T	×	√	×	×
Lantana trifolia	S	√	√	×	×
Leucas grandis	S	√	√	×	×
Leucas spp	S	×	×	√	√
Lippia javanica	S	√	√	×	×
Maerua oblongifolia	S	×	×	√	√
Maytenus senegalensis	S	×	×	√	×

Table 2. Contd.

Maytenus undata	S	×	√	×	×
Microglossa pyrifolia	S	√	√	×	×
Mystroxylon aethiopicum	S	√	√	×	×
Mystrxylon aethiopicum	T	×	×	√	×
Nuxia congesta	T	√	√	×	×
Ochna ovate	T	×	×	√	×
Olea europaea ssp. Africana	T	√	√	√	√
Pappea capense	T	×	×	√	√
Pittosporum viridiflorum	T	√	√	×	√
Plectrunthus barbatus	S	×	×	×	√
Pterolobium stellatum	S	√	√	×	×
Pterolobium stellatum	S	√	√	×	×
Rhus natalensis	S	√	√	√	√
Ritchiea albersii	T	×	√	×	×
Schrebera alata	T	√	√	×	×
Scutia myrtina	S	√	√	×	×
Steganoteenia oraliacea	T	×	×	√	×
Syphorstermma viminale	S	×	×	√	√
Teclea simplicifolia	T	√	√	√	×
Trimeria grandifolia	S	√	√	×	×
Triumfetta tomentosa	S	√	√	×	×
Turraea abyssinica	T	√	√	√	×
Vangueria madagascariensis	S	√	√	×	×
Vernonia brachycalyx	S	√	√	×	×
Vernonia lasiopus	S	√	√	×	×
Warburgia ugandensis	T	√	×	×	×
Zanthoxylum usambarense	T	√	√	×	×
Total		36	38	35	18

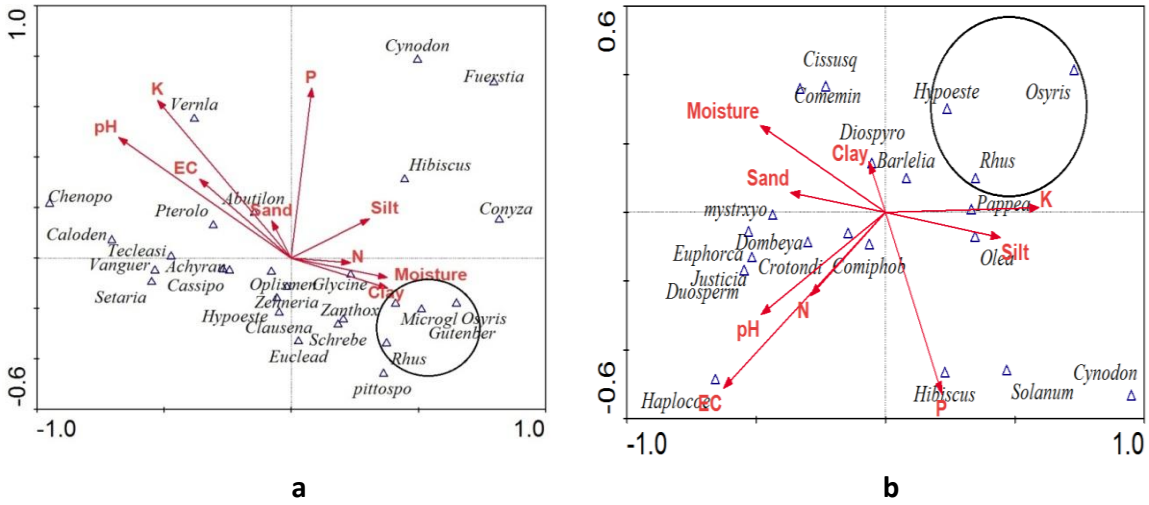

Figure 3a. CCA biplot of first and second axes showing species association and relationship between species with soil variable at Gachuthi humid highland forest. The first two axes explain 53.3% of species-soil variables relations. The circle highlights species that clustered with *Osyris lanceolata.*Species are abbreviated by the first 8 letters of their genus name shown in Tables 1 and 2**.** CCA biplot of first and second axes showing species association and relationship between soil variable at Kibwezi dry lowland forest. The first two axes explain 51.6% of species-soil variables relations. The circle highlights species that clustered with *Osyris lanceolata.* Species are abbreviated by the first 8 letters of their genus name shown in Tables 1 and 2.

Due to the limited number of sites used in the current study, we recommend further studies on relationship between soil variables and *O. lanceolata* occurrence in natural ecosystems.

Conflict of Interest

The authors have not declared any conflict of interest.

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