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GUIDELINES FOR HABITAT MANAGEMENT: THE INFLUENCE OF SLOPE ON POPULATION EXPANSION OF *EUPHORBIA CLIVICOLA* R.A. DYER: A CASE STUDY

SELOBA IGNITIUS CHUENE[1,2*], MARTIN JOHANNES POTGIETER[1] AND JOHANNES WILHELMUS KRUGER[2]

[1]*Department of Biodiversity, University of Limpopo, Private Bag 1106, Sovenga, 0727, South Africa*
[2]*Biodiversity Management, Limpopo Department of Economic Development, Environment and Tourism, P.O. Box 55464, Polokwane, 0699, South Africa*
[*]*Corresponding author's email: selobac@gmail.com*

Abstract

Topographical factors such as slope aspect and position play a significant role in plant survival and community arrangement. *Euphorbia clivicola* is a rare and critically endangered plant species in the Limpopo Province, South Africa. This species tend to grow on northern slopes that are usually earmarked for urban development within its distribution area. The aim of this research was to assess the significance of slope on population structure. The occupied habitat was stratified into three positions: top slope, middle slope and bottom slope. Population structure and density of the plants were documented. *Euphorbia clivicola* plants gradually decreased in canopy size as the slope gradient decrease (from top to bottom). Thus the significance of slope on population structure is that; slope influences propagule dispersal and ultimately population structure through surface water runoff. Density was inversely proportional to canopy size, which suggests that colonisation of sites by *E. clivicola* is influenced by slope gradient. Conservators should discourage development on the northern aspects of habitats occupied by *E. clivicola,* as it will negatively affect the relief site of the population.

Key words: *Euphorbia clivicola*, Slope, Canopy size, Density.

Introduction

Africa has the dubious distinction of having 72 (42%) of the 171 threatened *Euphorbias* worldwide, of which 25 (15%) species are listed as Endangered or Critically Endangered (Anon., 2015). *Euphorbia clivicola* R.A. Dyer falls within the 15% category. One of the major reasons for the endangered status of so many *Euphorbias* is habitat destruction due to anthropogenic influences (Pfab & Witkowski, 2000). Habitat destruction and consequently habitat fragmentation, lead to small and isolated populations with compromised demographics (Heinken & Weber, 2013).

Population demography is an important tool to estimate the performance of a population as it delimits the fundamental importance of relationship between plant population size, fitness, life stage and genetic diversity (Leimu *et al.,* 2006). Through its effects on demography and population genetics, reproductive biology has important consequences for the viability of rare plant populations (Evans *et al*., 2003). Population persistence and expansion in the long term, normally is still dependent on seedling production, as some mortality is inevitable (Burne *et al.,* 2003).

Population expansion depends on propagule dispersal. This may be influenced by many factors, such as: land use as well as habitat and soil properties, topography, interspecific competition, herbivory, dispersal ability and inbreeding (Amat *et al*., 2013). Competition is usually intensified by high plant density that leads to limited biotic and abiotic resources (Xiaohang *et al.,* 2018). Under mountainous landscape conditions, plant survival is not only determined by large scale topographical factors such as altitude, but also by small scale topographical factors such as slope aspect and position (Tingting *et al*., 2011). For example, Badano *et al.*, (2005) found a significant correlation between slope aspect and plant cover, and shrub-clump size in the matorral of Central Chile.

The aim of this project was to assess the significance of slope aspect on the population expansion direction. This was done by investigating the life stages, canopy size structure, and population structure along a slope. Results will aid the Limpopo environmental management authorities in South Africa to adaptively manage *E. clivicola* habitats, and thus ensure plant population sustainability.

Materials and Methods

Study sites: *Euphorbia clivicola* has been documented to occur in four localities within the Limpopo Province, namely: the Percy Fyfe Nature Reserve (near Mokopane) with an Area of Occupancy (AOO) of 11 428.64 m^2, Radar Hill (in Polokwane) with an AOO of 14 984.71 m^2, Dikgale (Kgwareng Village) with an AOO of 245 868.68 m^2 and Makgeng (near Boyne) with an AOO of 82 634.83 m^2 (Chuene, 2016). All of the above mentioned populations occur on rocky gentle slopes at a north, north-west and north-east aspects, with an angle range of 0 to 20°.

All of the *E. clivicola* populations occur in an area that consists of undulating plains covered with a short open tree layer and a well-developed grass layer. Scattered trees occasionally occur at higher altitudes. The vegetation type of this area falls within the Polokwane Plateau Bushveld (Mucina & Rutherford, 2006).

Site stratification: The north, north-west and north-east sides of the slope (5—20°) was divided into three sections; top slope (include crest), middle slope and bottom slope (foothill). Sampling techniques were chosen based on the sizes of the AOO. The Nearest Individual Sampling Technique (NIST) (Hill *et al*., 2006) was used for smaller (Percy Fyfe Nature Reserve and Radar Hill) populations, while~~,~~ the Point Centred Quarter (PCQ) method (Mark & Esler, 1970) was used on populations with a larger AOO (Dikgale and Makgeng). Transects traversed from the bottom to the top slope, with a distence of 10 m between them.

Density: The NIST entails that the plant nearest to the sample point (transect) is located. The distance between the plant and the sample point is then measured. Transects were placed 5 m apart, and two people traversed 2.5 m on either side of a transect line searching for *E. clivicola* plants. The density was calculated as follows:

$$Density = {}^{1}/_{(2Dm)^2}$$

where *Dm* = mean distance for all samples (Hill *et al*., 2006). The density was thus calculated using the formula from NIST. The distance between sampling point and nearest plant was averaged (Dm).

Life stages: Sampled plants where classified into one of the following four classes (Pfab, 1997):

a) Senescent: are plants that showed no signs of life (Fig. 1a).
b) Adults: are plants showing flower formation or definite positive signs of flower formation. Adult plants are characterized by a large underground tuberous body and many above-ground branches (2—3 cm in length), clustered together in a dense mass (Fig. 1b).
c) Juveniles: are plants showing either primary or secondary growth characteristics, but flower formation or signs of flower formation are absent. Juvenile plants have a poorly-developed underground tuberous body, and form two to five small loosely arranged above-ground branches (Fig. 1c).
d) Seedlings: are plants that have only one above-ground branch (Fig. 1d).

Canopy size: The canopy size of each plant sampled was recorded. Where (W1) was the widest diameter of the canopy, and (W2) was the diameter perpendicular to W1. The readings were subsequently used to calculate the canopy area using the following equation (Pfab, 1997):

$$Canopy\ size = \pi \times {w_1}/_2 \times {w_2}/_2$$
$$= 0.7854 \times w_1 \times w_2$$

Data analysis: IBM Statistical Package for Social Sciences (SPSS) version 22 software package was used to analyse the population structure and size for individual populations. This was done by cross-tabulating the desired variables in columns and rows using descriptive statistics. SPSS was further used to perform the Pearson's correlations test on various data sets (populations' canopy sizes and slope position: canopy sizes).

A one-way ANOVA test, in combination with Homogeneity of Variances Test was performed on the canopy sizes of sampled populations in order to ascertain significant differences. These results did not indicate which of the groups in a variable and/or variables differed from which, so a follow-up analysis with a Tukey HSD Post Hoc test was performed to counter this deficiency.

Results

Density along slope: Density was positively correlated to slope position; Pearson's Correlation p<0.01 and r = 0.37. The interquartile range for all of the data set presented in Fig. 2 had moderate negative skew results (the lower limit values were more than the upper limit values). The interquartile distance range of 3.0 to 4.5 m was observed at the top slope, while the median value was 4 m (Fig. 2). The middle slope's interquartile range and median value were similar to the ones observed at the top slope. The top slope position had the highest density which was highlighted by a lower whiskers value of 0.75 m (Fig. 2). The bottom slope was composed of *E. clivicola* individuals with an interquartile distance range of 3—8 m with a median value of 6.2 m. The bottom slope position had the highest distance between *E. clivicola* individuals with an upper whiskers value of 13 m (Fig. 2).

Life stages: Senescent plants were observed in all populations with Percy Fyfe Nature Reserve contained the highest percentage of senescent plants at 42.90% (Fig. 3). All populations were dominated by adult plants ranging between 50% (Percy Fyfe Nature Reserve) and 87% (Radar Hill). Juvenile plants were absent in Percy Fyfe Nature Reserve and Makgeng populations. Seedlings were present in all documented populations. The Percy Fyfe Nature Reserve population was the smallest population with only 8 living and 6 senescent individuals; 50% of adults (n=7) and 7.10% of seedlings (n=1).

Life stages along slope: Age class structure of *E. clivicola* along the slope showed that younger (seedlings and juveniles) plants were more concentrated at the bottom slope (Fig. 4). Adult plants were observed in all slope positions, but a greater proportion was observed at the top and middle slope positions. Senescent plants were present at both the top and middle slope positions, but absent at the bottom slope (Fig. 4).

Canopy size: The canopy sizes of *E. clivicola* plants ranged from an area of 0.79 cm^2 to an area of > 2000 cm^2 (Fig. 5). Variations from very weak to moderately positive correlations were observed to range between r = 0.001 and 0.043. The Percy Fyfe Nature Reserve population was the only one that had no plants with a canopy size > 2000 cm^2 (Fig. 5), and the mean canopy size was the smallest at 2.64 cm^2.

Canopy size along slope: Slope position at the Radar Hill, Dikgale, and Makgeng above R71 road populations were observed to be negatively correlated to the canopy sizes of *E. clivicola*; Pearson's Correlation was p<0.01 and r = - 0.42. The canopy sizes of *E. clivicola* plants gradually decreased in size from the top of the slope to the bottom. The top slope was composed of plants with an interquartile canopy size ranging between 250 and 875 cm^2 (slight positive skew) with a median value of 400 cm^2 (Fig. 6). The middle slope had an extreme positive skew upper limit of 575 cm^2 and a lower limit of 0 cm^2, while the median value was 200 cm^2. The bottom slope had an interquartile range of 50—420 cm^2 and the median was observed at 200 cm^2 (Fig. 6). Although the medians on both the middle and bottom slopes are equal, the variation in canopy size distribution was observed when considering the whiskers ranges. The middle slope consisted of plants with a canopy size that were > 50 cm^2 but ≤ 1500 cm^2, while the bottom slope had plants that were < 50 but > 0 cm^2 and < 1 125 cm^2 (Fig. 6).

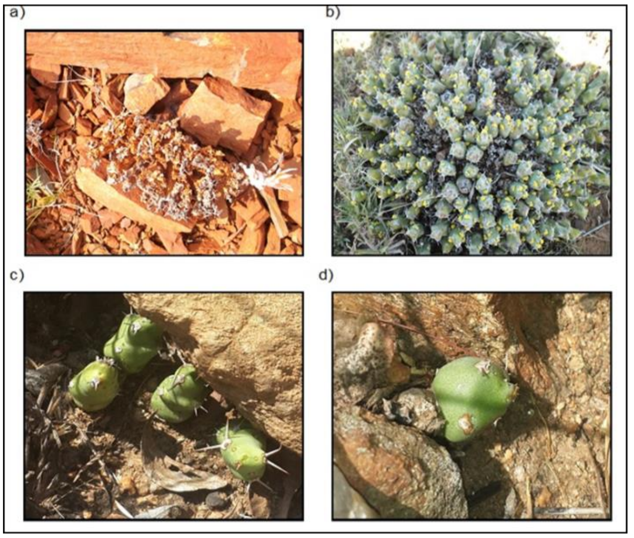

Fig. 1. Four age classes of *Euphorbia clivicola*; a) senescent, b) adult, c) juvenile, and d) seedling.

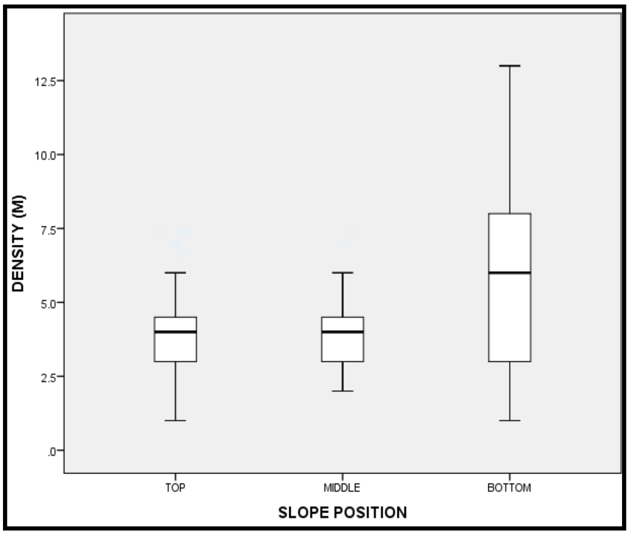

Fig. 2. Distances between *Euphorbia clivicola* individuals at various slope positions.

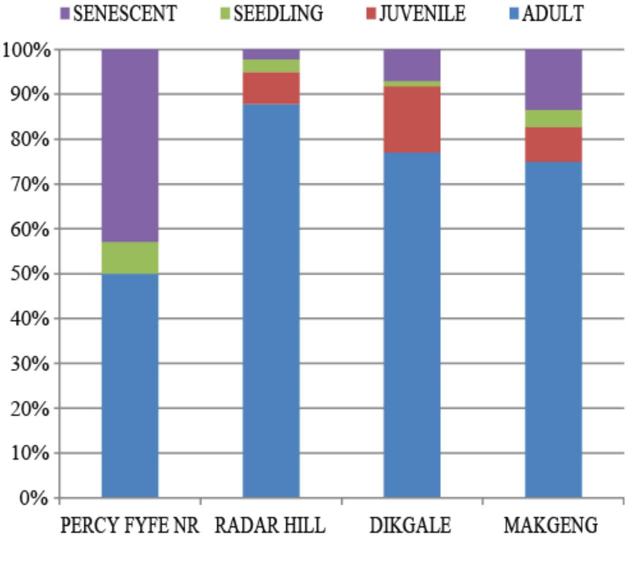

Fig. 3. A demographic distribution of all known populations of *Euphorbia clivicola*.

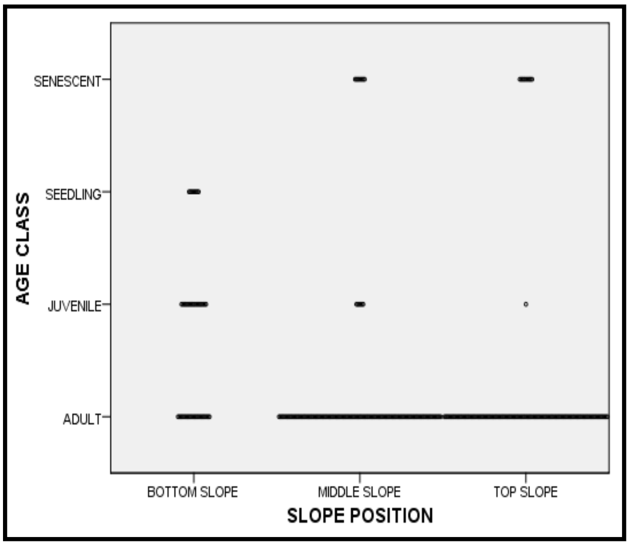

Fig. 4. Age classes of *Euphorbia clivicola* along various slope positions.

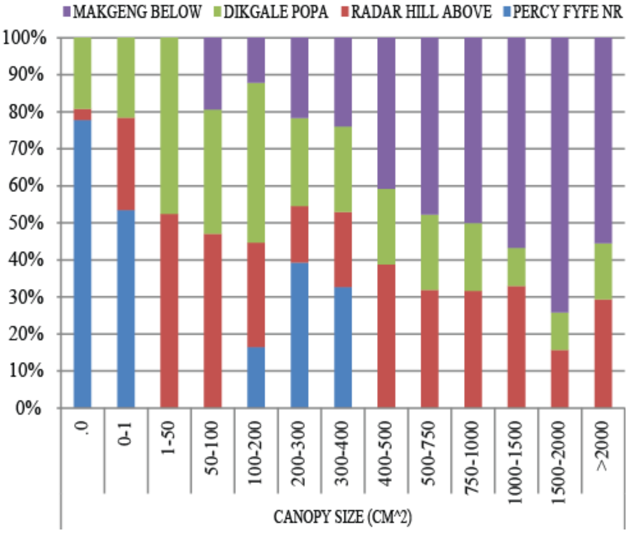

Fig. 5. The size structure (canopy area) of all known populations of *Euphorbia clivicola*.

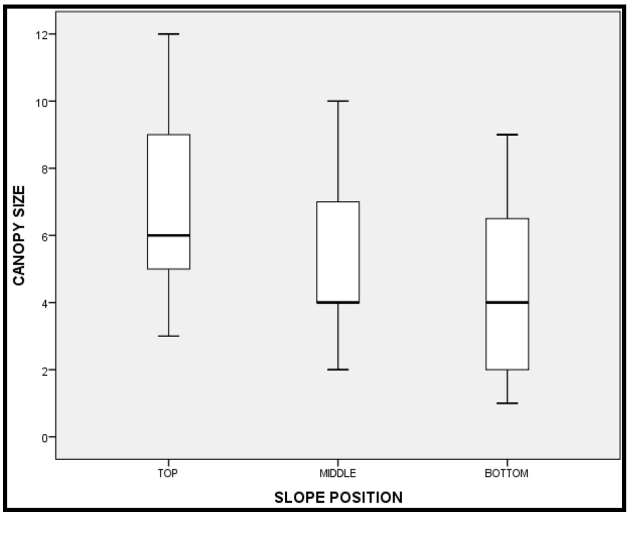

Fig. 6. Canopy sizes of *Euphorbia clivicola* along various slope positions. Canopy sizes (2 = 50, 4 = 200, 6 = 400, 8 = 750, 10 = 1500, and 12 = > 2000 cm^2) of the plant.

Discussion

Density along slope: High density between *E. clivicola* individuals was observed at the top and middle slope positions, while it was less dense at the bottom slope. Increased density of plant species is significantly related to competition within and between species (Armin & Asghripour, 2011). Taking into account the canopy sizes of *E. clivicola* plants on various slope positions and the density per slope position; the populations' structure of *E. clivicola* is arranged in a hierarchy along the slope. The maximum density was observed to be 0.75 m^2. This implies that intra-specific competition is at its maximum when the distance between individual plants is between 0.75 to 3 m. The emergence of seedlings and juveniles at the top and middle slope is observed when some of the older plants reach the senescent stage and habitat for recruitment is available again, hence it is rare to observe plants with a smaller canopy size at these two slopes.

The present study supports the theory of intra-specific competition; the increase of density often leads to a decrease in the available resources for the individual, and thus a decrease in fitness (Shaltout *et al*., 2015). The occurrence of senescent plants and high density on both the top and middle slope position, suggests that the core of the population is at the top and to a lesser extent on the middle slope position, with a higher level of intraspecific competition occur at these slope positions. The significance of density on population structure was also highlighted by Puckridge and Donald (1967), who experimented on the growth of wheat plants at a range of sowing densities and found a direct-proportionality between density and mortality.

Life stages: According to Van Tonder (2011), there are four developmental stages of a plant that are of utmost importance to plant ecologists and biologists. These are: seedling, juvenile, adult and senescent. Determining the cause of the decline of a species is not simply a question of which factor is threatening the species' existence, but also which life stage is being affected (Österling *et al*., 2008). Plant life stages (age classes) are in most cases determined by canopy size and evidence of reproductive organs (buds, flowers, seeds and sori) (Witkowski *et al*., 1997).

Fifty percent of the *E. clivicola* populations were composed of plants with all four age classes, while adult plants dominated in all populations. Adult plants signify a great reproduction potential, as chances for cross-pollination is higher. Plant density and canopy size are significantly affected by slope aspect (Badano *et al*., 2005). The Makgeng population contains individuals from three life stages (senescent, adults and juveniles), and there are more senescent plants than juveniles. Thus 15% of senescent plants are not replaced during each reproduction season. The Percy Fyfe Nature Reserve population is also facing the same fate as the Makgeng population. Reproduction has a direct effect on wild populations because reproductive success and certain features of the life cycle (longevity, dimension, and frequency) determine population growth (Cursach & Rita, 2012). When reproduction success supersedes mortality (senescence) then the population is growing, but, when mortality surpasses reproduction as in the Makgeng and Percy Fyfe Nature Reserve populations, then the population is declining. The remaining populations have a healthy ratio of young (seedling and juvenile) and senescent plants, with younger plants in the majority.

Canopy size along slope: It is evident from the results that slope plays a pivotal role in supporting the various age classes of *E. clivicola* along the habitat. Adult *E. clivicola* plants with larger canopy sizes were found to be concentrated at the top slope position. This was supported by the median value (400 cm^2) of plants sampled at the top slope. In contrast, seedling and juvenile plants (smaller canopy sizes) were mostly observed at the bottom slope. Pfab (1997) described the propagule dispersal mechanism of *E. clivicola* as two fold; firstly, seeds are released ballistically and secondly, there is a secondary downhill dispersal. This systematic arrangement of age classes along the habitat is strongly influenced by slope and propagule dispersal.

Euphorbia clivicola seeds are ballistically dispersed to an approximate distance of less than 1 m. However, the spatial distribution of the plants and relatively steep slopes (0—20°), suggest secondary dispersal downhill from the parent occurs (Pfab, 1997). This suggestion by Pfab (1997) is supported by the concentration of smaller canopy sized plants (seedlings and juveniles) at the bottom slope. The secondary dispersal mechanism is believed to be surface water runoff. Cerda and Garcia-Fayos (1997) also demonstrated the influence of surface water runoff on slope on seed dispersal.

Conclusion

In conclusion, the results of this study suggest: that 1) The density of *E. clivicola* plants at the top and middle slopes is high, thus, interspecific competition increased, and the competition is relieved by recruitment or emergence of seedlings at the bottom and unoccupied slope position. 2) The canopy sizes (life stages) of *E. clivicola* are significantly influenced by slope. 3) *E. clivicola* propagules are distributed/dispersed by a secondary mechanism (surface water runoff) and gravity directs this secondary disperser down the slope. 4) Fragmentation across the north, north-west and north-east aspect of the *E. clivicola* habitat will hinder propagule dispersal and consequently restrict population expansion. These revelations will advise conservation managers and environmental practitioners in Limpopo Province to adequately manage the *E. clivicola* habitat, and ultimately preserve the ecological processes influencing the dynamics of this rare and critically endangered plant species. These results also signify the importance of habitat preservation for the persistence of rare and endangered plant species that are similar (habitat requirements and growth form) to *E. clivicola* (e.g. *Euphorbia groenewaldii*). Preservation of *E. clivicola* habitat is important for not only being a substrate that harbours this rare and critically endangered plant species, but also playing a pivotal role in modelling the population structure and directing expansion. Damage to the *E. clivicola* habitat will significantly affect the *E. clivicola* population demography negatively and lead to the extinction of this special plant species. In this regard an extensive buffer on the northern slope (foothill) of the *E. clivicola* is suggested to allow sufficient space for population expansion.

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