Factors driving the expansion of *Helichrysum splendidum* in Menz-Guassa community conservation area of the Afroalpine ecosystem of Ethiopia

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Abstract

Background: The rapid expansion of *Helichrysum splendidum* shrub into Menz-Guassa community conservation area has resulted in the scarcity of Guassa grasses and this has threatened the livelihoods of the local community.

Objective: A field survey was undertaken to examine the effect of human disturbance and soil burrows on the expansion of *H. splendidum.*

Materials and Methods: Two transects were laid out along altitudinal gradient with a 200 m interval and 15 quadrats (5 m × 5 m each) were arranged on each quadrat at every 100 m for data collection on the level of human disturbance, number of soil burrows, and the abundance of *H. splendidum.* In total, 90 composite soil samples were collected from three soil layers (litter, 0–3 cm and 3–6 cm) from the five subplots (size: 1 m x 1 m each) which were established in the four corners and one in the center of each quadrat. The soil seed bank study was undertaken in the greenhouse and the seedlings grown were identified to the species level the density of which was recorded. The General Linear Model (GLM) was employed to test the effects of human disturbance and soil burrows on the abundance and density of seedlings of *H. splendidum*.

Results: The results showed that abundance of *H. splendidum* significantly increased with increasing level of human disturbance, but decreased with the increasing number of soil burrows ($P < 0.001$). Higher germination density was recorded from soil seed bank with moderate and high levels of human disturbance compared to soil banks with very high levels human disturbance. However, the density of seedlings showed an increasing trend with increasing the number of soil burrows.

Conclusion: Our overall results suggest that human disturbances (i.e., grass cutting and wood collections) and soil burrowing by mole rats are the major drivers of the expansion of *H. splendidum* and hence mechanisms that halt such process need be sought to restore the cover of *Guassa* grass on which the livelihoods of the local community largely depend.

Keywords: Afroalpine Ecosystem; Conservation; Disturbance; Seed Bank; Soil burrows

1. Introduction

The Afroalpine ecosystems are characterized by harsh climatic conditions such as low temperature, high solar radiation and strong wind (White, 1983). In this nexus, earlier studies have revealed that the vicinity to the equator and high elevations fundamentally govern the nature of Afroalpine climate and the associated ecological processes (Yuan *et al.,* 2016). The Afroalpine plant life forms are comprised of the giant rosette plants; tussock forming grasses and sedges; acaulescent rosette plants; cushion plants; and sclerophyllous and dwarf-shrubs.

The Guassa Community Conserved Area is found in Afroalpine ecosystem of Ethiopia where several indigenous and endemic characteristic species such as *H.splendidum* (Thunb.) Less *Festuca macrophylla* Hochst. *exA*. Rich, *Kniphofia foliosa* Hochst, *Urtica simensis* Steudel, *Lobelia rhynchopetalum* Hemsl, *Euryops pinifolius* A. Rich and *Cynoglossum densefoliatum* Chiov are dominantly growing (Zelalem Tefera *et al.*, 2012; Habtamu Wodaj *et al.*, 2016).

In recent years, a rapid expansion of sclerophyllous and dwarf-shrubs such as *H. splendidum* into the Afroalpine grassland or the changing dominance from grasses such as *guassa* grass (*F. macrophylla* Hochst. *exA*) to scrub land has been observed in central highlands of Ethiopia (Girma Nigussie *et al.*, 2019), where this study was conducted.

Guassa grass is biennially harvested for various purposes, such as, rope making, floor mat, fodder, rain hut, whip (Giraf) and income generation from the sale of the grass (Gomeje Amessie, 2014). At the present time, the expansion of *H. splendidum* has caused the scarcity of *guassa* grass and this is a worrisome to the local community for their livelihoods rely on the services that this grass provides them (Zelalem Tefera, 2004; Steger *et al.,* 2020*). H. splendidum* is a shining sclerophyllous dwarf bushy shrub which commonly grows in *Erica arborea* bush land, and in Afroalpine grassland within the altitudinal range of 2500–4300m above sea level (Hedberg *et al.,* 2004). It belongs to the family of Asteraceae that is famous for high seed production and dispersibility. The plant is widely distributed in

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Africa with distributional range extending all the way to South Africa (Hedberg *et al.,* 2004). It is a fast-growing shrub capable of reaching 1.5 m in height, has aromatic smell and its flowers have a long-lasting sweet scent (Hae, 2016). Several reports have denoted that essential oil is extracted from this plant has antifungal and antibacterial properties (Bruno *et al.*, 2006; Lourens *et al.*, 2008; Mashigo *et al.,* 2015).

Recently, research findings have showed that grassland cover is shrinking in Menz-Guassa community conservation area while the cover of shrub land is dominated mainly by *H. splendidum* is increasing (Girma Nigussie *et al.,* 2019). However, the processes driving the expansions of *H. splendidum* at the expense of *F. macrophylla* is not fully understood (Girma Negussie *et al.,* 2019). In Menz-Guassa community conservation area, shrews, such as *Crocidura thalia* and *C. baileyi,* and rodent species including porcupine (*Hystrix cristata*), common mole rat (*Tachyoryctes splendens*), unstriped grass rat (*Arvicanthis abyssinicus*), harsh-furred rat (*Lophuromys flavopunctatus*), Abyssinian meadow rat (*Stenocephalemus grisecauda*), and groove-toothed rat (*Otomys typus*) are commonly observed (Zelalem Tefera *et al.,* 2005). Burrowing animals increase the porosity of soil and thereby speed up the decomposition of organic debris (Zhang and Liu, 2003) and this may lead to changes in shrub-grass coexistence (Louw *et al.,* 2019). For example, recently, *H. splendidum* has colonized *F. macrophylla* in Afroalpine ecosystem (Sillero-Zubiri and Macdonald, 1997; Girma Nigussie, 2019), but the mechanisms that drives such dynamics is not well understood (Aramde Fetene *et al.,* 2014). The present study explored the factors driving the expansion of *H. splendidum* in Menz-Guassa community conservation area of Afroalpine ecosystem of Ethiopia. Based on these background evidences, we hypothesized that anthropogenic disturbance and soil borrows are the factors that drive the expansion of *H. splendidum* in Guassa community conservation area.

To our knowledge, this study is the first of its kind in Ethiopia and there is no known literature on this topic. From the several workshops we have been organizing with the local community, we learned that the expansion of *H. splendidum* is one of the major threats to the socio-ecological sustainability of the area. Currently, *H. splendidum* shrub is expanding extensively at the expense of the *Guassa* grass (Claudio-Sillero *et al.*, 1997; Ephrem *et al.,* 2011). The local communities are worried about this expansion of this shrub as they think that it may replace the *guassa* grass which is highly valuable to their livelihoods (Personal communication). In line with this, we examined the factors driving the expansion of H. *splendidum* shrub.

2. Methods

2.1. Study Area

The study was conducted in Menz-Guassa community conservation area which spans 111 km^2 in area (Fig. 1). It is located between the geographical coordinates of 10^o 15′–10^{o}27' N latitude and 39°45–39°49' E longitude in the central highland of Ethiopia, North-East of Addis Ababa between the elevation range of 3200–3700 meters above sea level. Guassa is named after the *guassa* grass (*Festuca macrophylla*) that has multiple benefits for the local communities including thatch, rope, construction material and forage (Steger *et al.*, 2018). The rainfall distribution of the area is characterized by a bimodal pattern where the main rainy season is during June to September and the short rainfall season occurs from February to April (Gomeje Amessie, 2014). The mean annual rainfall is 1650 mm while the mean monthly temperature is 12.3ºC.

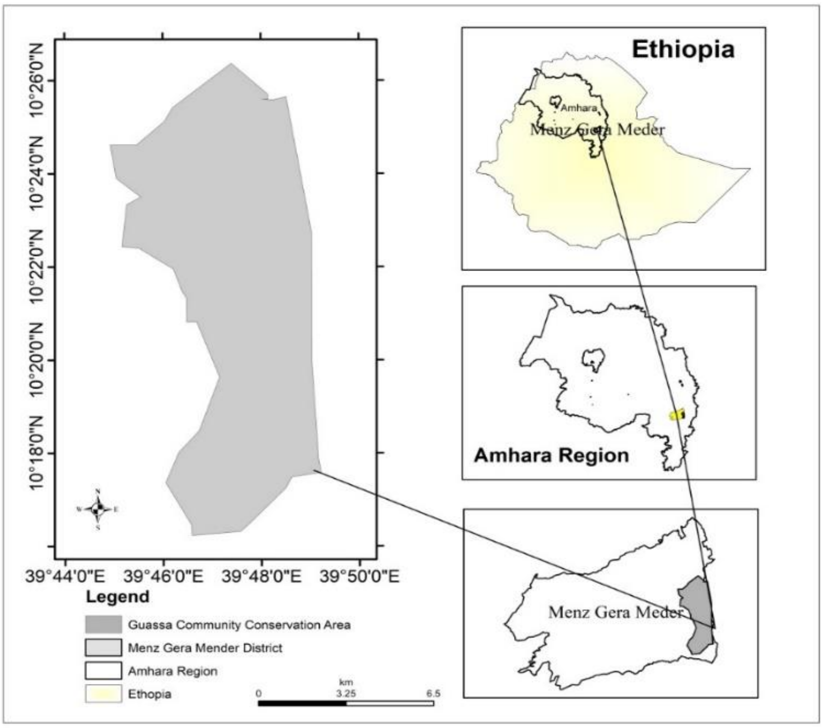

Figure 1. The map of the study area (Menz-Guassa community conservation area) in relation to the map of Amhara region and Ethiopia.

2.2. Study Design and Data Collection

Data were collected from two transects laid out along an altitudinal gradient with 200 m interval apart from each other. Along each transect, 15 quadrats (size = 5 m × 5 m each) were laid at 100 m interval. From both of these two transects, in total, 30 quadrats were used for the survey and assessment. First, the level of human disturbance was visually estimated for each quadrat using categorical scale of low (< 10%), moderate (10–20%), high (20–40%) and very high (40). These categories of human disturbance were estimated based on the status of destruction from cutting of *H. splendidum* within quadrates. Secondly, the stems or abundance of *H. splendidum* and the number of soil burrows were counted for each quadrat. Along with this, five subplots (size = 1m x 1m) were established in each quadrat, four at the corner and one at the center to collect composite soil samples and in total 90 composite soil samples from three soil layers (litter, 0-–3cm and 3–6cm) were collected for the soil seed bank study. A one kg composite soil sample was separately stored in plastic bags for each soil layer and transported to Addis Ababa University greenhouse for soil seed bank study.

These soil samples were dried at room temperature and sieved using a 4 mm sieve to remove debris and transferred to 90 perforated circular plastic buckets with 30 cm diameter at the top and depth of 10 cm. This soil seed bank study was undertaken for four months during December, 2017 to April, 2018. The soils were watered every third day to maintain moisture to initiate seed germination. After two months, identification of the seedlings to the species level was made at National Herbarium of Addis Ababa University. The number of germinated seedlings for each species was recorded for two consecutive months by discarding the counted seedlings at the time of recording.

2.3. Data Analysis

The effects of human and soil burrowing disturbances as explanatory factors on the dependent variables, i.e., abundance and the density of germinated seedlings of *H. splendidum* from soil seed banks were tested using general linear model (glm) with Poisson distribution. Since we did not find a significant effect of human disturbance on the density of seedlings germinated from each soil layers (surface litter, 0–3 cm, 3–6cm), the data of density of seedlings were pooled together and accordingly the effect of human disturbance was tested. The Analysis was conducted using R statistical program (Version 3.5.0).

3. Results

The results of the general linear model analysis showed that the level of human disturbance is positively related to the abundance of *H. splendidum* ($P < 0.001$, Figure 2). However, the number of soil burrows was negatively correlated with the abundance of *H. splendidum* ($P<0.001$, Figure 3). Moreover, the pooled density of seedlings of *H. splendidum* significantly varied with the levels of human disturbance ($P < 0.001$) and the density was higher at moderate and high disturbance levels and lower at low and very high disturbances categories (Figure 4). Moreover, the pooled density of seedlings was significantly and positively affected by the soil burrows where density increased with increasing number of burrows ($P < 0.001$, Figure 5).

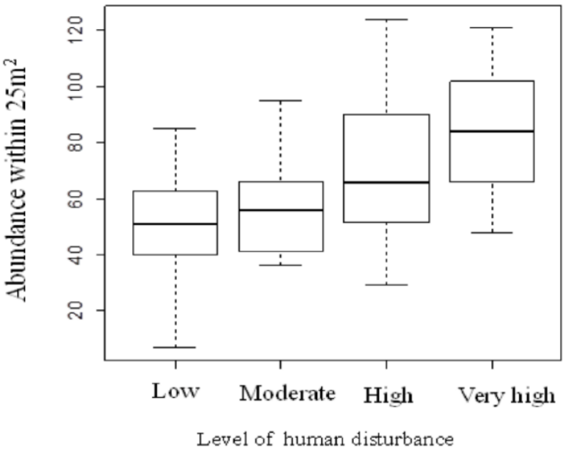

Figure 2. Boxplot showing the abundance (number of stems) of *H. splendidum* within 25 m^2 in relation to the disturbance level. The abundance of *H. splendidum* is higher at higher human disturbance level in Menz-Guassa community conservation area.

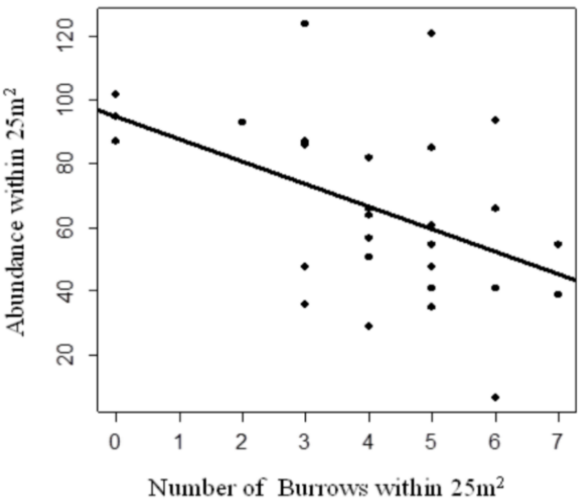

Figure 3. Line graph showing the abundance of *H. splendidum* in relation to the number of soil burrows in Menz-Guassa community conservation area. Abundance decreases with increasing number of soil burrows.

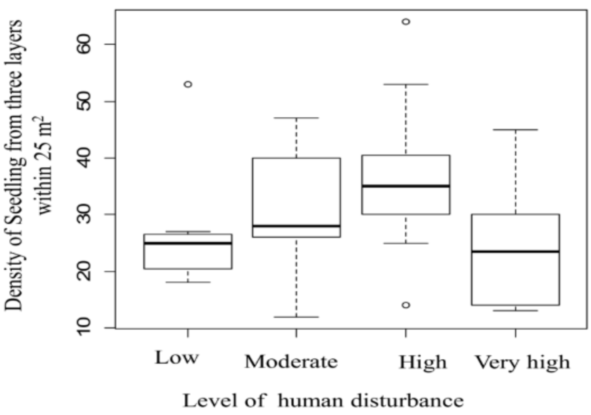

Figure 4. Boxplot showing the pooled density of seedlings emerged from soil seed bank for *H. splendidum* in Menz-Guassa community conservation area. The density was higher at moderate and high human disturbance while it was lower at two extremes of lower and very high disturbance levels.

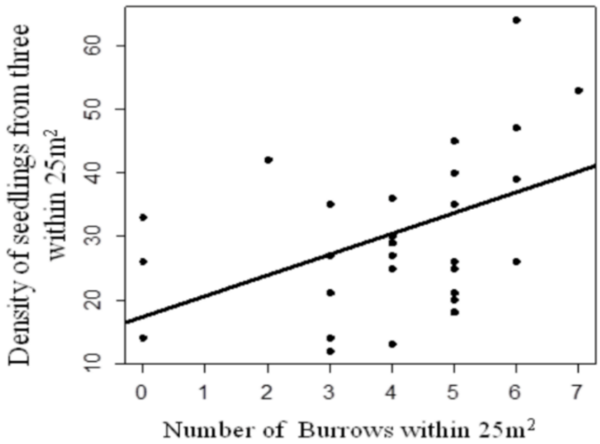

Figure 5. Line graph showing the pooled density of seedlings emerged from three soils layers for *H.splendidum* in relation to the number of soil burrows in Menz-Guassa community conservation area. The density of seedlings increased with increasing the number of soil burrows.

4. Discussion

Not only human and ecological disturbances but also the type and extent of disturbances in natural ecosystems may differently favor a certain plant species across growth structure at the expense of the coexisting species (James, 1999).

Here, we showed how human disturbances such as cutting fire wood and grass collection and soil burrowing by shrews and rodents differently affected abundance and regeneration of *H. splendidum* in Afroalpine ecosystem in the central highlands of Ethiopia. Although the density of soil burrows was negatively correlated with the abundance of *H. splendidum* (Figure 3), the density of seedlings emerged from soil seed bank showed an increasing pattern with increasing density of soil burrows (Figure 5). Similarly, the expansion of *H. splendidum* was higher at moderate level of human disturbance, but lower at lower and extreme levels of disturbances (Figure 4). This trend corroborates the intermediate disturbance hypothesis that states that moderate level of disturbance favors the expansion unlike the low and extreme level of disturbances (Wilkinson, 1999; Catford *et al.,* 2012).

The increasing trend of the expansion of *H. splendidum* triggered by the different level of disturbances may be related to the exposure of soil mainly litter layer to sunlight and fast decomposition and nutrient availability to plants, improved air circulation in the soil and seed production and dispersal potential of the plant. Firstly, the grass harvesting or cutting of shrubs exposes the ground to sun light and heat, and air circulation (Wanga *et al*., 2005). The significance of this factor in ecological processes in extreme environmental conditions such as in the present study area could be more pronounced in speeding up the decomposition of thick litters and open more space for the germination of seeds and growth of seedlings of *H. splendidum* (Wearne and Morgan, 2001). Secondly, *H. splendidum,* an Asteraceae family, produces abundant small seeds which can easily be dispersed by animals (Gomes *et al*., 2019) and humans may also serve as a dispersal agent while collecting the plant for its appealing smell during smoking in houses and collecting grasses and shrubs. Thirdly, the soil burrowing by animals in cold environments are one of the important ecological functions in emulsifying soils (Zhang and Liu, 2003; Lara *et al*., 2007) through making nutrients available for plants and thus promoting regeneration of plant species (Hagenah and Bennett, 2012).

Even if very high level of human disturbance opens up impervious top layer of the bushes and promotes growth, the recruitment process is disrupted and as a consequence seedlings are exposed to extreme environmental conditions such as extreme cold and heat. Moreover, due to cumulative effects of very high human disturbance and intensive burrows, plants are liable to strong run off and as a result roots could be exposed to harsh conditions which affect the abundance of *H. splendidum.* It is an established fact that disturbances affect plant growth pattern and structure (Hansen and Clevenger, 2005; Hill *et al*., 2005). Consistent with our findings, several previous findings have asserted that disturbances including soil burrows expose the roots of the cushion plants and thereby are damaged by the harsh environmental factors and the cumulative impacts of which may negatively attribute to the decreasing of their abundances (Zhang *et al.,* 2003; Tort *et al.,* 2004; Alvarez-Aquino *et al.,* 2005; Galiano *et al*., 2014). However, some studies, such as, Zelalem Tefera, (2012) indicated that soil burrows by rodents has no effect on abundance of plants. The justification given in this regard is that these soil burrows are not habitat selective and effects on species diversity is not significant.

Results from soil seed bank analysis showed that very high level of human disturbance had negative impact on the density of seedlings of *H. splendidum,* in contrary to the abundance of *H. splendidum* where the density of seedlings from soil seed bank increased with increasing number of burrows. Likely, this result may indicate that soil burrows facilitate the availability of nutrients, moisture and aeration in the soil that promotes germination and growth of seedlings. Related to this, Wanga *et al.,* (2005) and Zhang *et al.*, (2003) have also found that such disturbances create favorable conditions for the germination of seeds in soils. However, Leder *et al.* (2017) showed similar results but noted that higher levels of disturbance disfavored the initiation of germination from soil seed banks. Here, more soil burrows imply more soil mixing, soil aeration and higher chance of seed distribution. However, this was not reflected well in the above ground abundance since germinating seedlings in the field may be eaten by rodents or could die due to uprooting during the time of burrowing. This means that human disturbances and soil burrows differently affect the abundance and regeneration of *H. splendidum*. The overall results suggest that human disturbances and soil burrows have both positive and negative impacts on the abundance and regeneration of *H. splendidum* shrub species in Menz-Guassa community conservation area of Afroalpine ecosystem.

5. Conclusion

Our findings showed that moderate human disturbance and the soil burrows have favored the expansion of *H. splendidum* into *F. macrophylla* grassland. On the contrary, the abundance of *H. splendidum* shrub was disfavoured at lower and extreme levels of disturbances. This implies that human disturbances (i.e., grass cutting and wood collections) and soil burrowing by mole rats are the major drivers of the expansion of *H. splendidum* and overall mechanisms that halt such process need be sought to restore the cover of *Guassa* grass on which the livelihoods of the local community largely depend. However, the present study is limited to exploring the effects of two factors; human disturbance and the number of soil burrows on the expansion of *H. splendidum* and hence further research is suggested to fully understand the whole process of outcompeting, colonization and co-existence of these species in Menz-Guassa community conservation area of Afroalpine ecosystem of Ethiopia.

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