Study on the Populations of an Endemic *Aloe* Species (*A. gilbertii* Reynolds) in Ethiopia

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Abstract:
The population structure, uses and threats of an endemic Aloe species (A. gilbertii) were investigated. The naturally occurring populations at three localities namely, Alamura Hill, Arsi Negelle and Alaba were used as data source. Three plots, each measuring 5 m × 20 m (100 m^2) per population, were laid down in the study sites. All the genets (genetic individuals) and ramets (vegetative daughters) were sorted, marked and recorded for selected population attributes. Data on the uses and threats to the species populations were gathered by using focused group discussions, semi-structured interviews and field observations. The size and stage structures were analyzed for each population and combined data set. The density of the populations at genet (154g) and ramet (825r) levels were highly variable. The genet (clone) size structure revealed that the populations had large proportions (66.2%) of multi-ramet (2-12) genets. The relative frequency distribution of ramets (RD, 10 cm size class) indicated that the populations had greater proportion (65.8%) of medium sized (30-90 cm, RD) ramets. The populations were dominated by non-flowering ramets in the season. The developmental stage structure of the populations showed low proportions of (10%) seedlings, (11.4%) juveniles, (13%) young adults; and high proportion (65.6 %) of mature adults. Based on the findings from population structure and extent of floweringin the season, it is possible to state that A. gilbertii populations are either declining or nearly stable. A. gilbertii plants and their parts have been used by local community in the rehabilitation of degraded land, soil conservation, and as sources for traditional medicine and fuel. Targeted field surveys on threats indicated that both the populations and their natural habitats are being destroyed mainly due to agricultural expansion into marginal lands, urbanization and road construction. It is suggested that this useful and yet threatened endemic species needs urgent conservation attention.

Key words: *Aloe gilbertii*, Genet, Ramet, Endemic species, Population structure

Introduction

The aloes are perennial plants that comprise herbs, shrubs and trees. They are recognized by fleshy, strongly cuticularized leaves usually with spiny margins. Most of the members can reproduce both sexually and asexually (Smith and Steyn, 2004). They are native to main land Africa and small islands in Indian Ocean except few species occurring in Arabian Peninsula. For example, Sub-Saharan Africa and the island of Madagascar alone accounts for over 90%

of the 450 taxa of the genus *Aloe* known (Newton, 2001; Oldfield, 2003).

The aloes are adapted to highly disturbed areas and areas with extreme environmental conditions (e.g. arid habitats). They are found flourishing on nutrient deficient, rocky or gravelly soils (Wabuyele and Kyalo, 2008). Some of the most important adaptations to survive in water stress environments include succulence and a waxy coating on the surface of the leaves (Willert *et al*., 1992). These unique adaptations and others enable them to be dominant and important group in such environments by providing shelter, nectar food and moisture, especially to the avifauna (Sebsebe Demissew and Nordal, 2010).

Members of the genus *Aloe* have been known for their current and potential use in medicine, commerce and horticulture. *Aloe* species have been used in folk medicine, e.g. for treatment of constipation, burns and dermatitis (Grace *et al*., 2009). Gel exudate from leaves of *A. lateritia* has been used in some communities in Ethiopia for treatment of eye aliments (Wabuyele, 2000). Some other species is playing great role in ecological restoration in Kenya, e.g. *A. secundiflora* that has been used in fencing, hedging and in soil conservation efforts (Wabuyele and Kyalo, 2008).

The flora of Ethiopia and Eretria possess 46 species of *Aloe*, out of which 89% are reported to be endemic. Only five species: *A. laterita, A. macrocarpa, A. rivae, A. secundiflora* and *A. vituensis*, are wide spread extending to East and West Africa (Sebsebe Demissew *et al*., 2011). As described in Sebsebe Demissew and Nordal (2010), most *A. species* inhabiting in the flora area are highly threatened due to agricultural expansion into marginal lands and habitat destruction due to new development schemes near urban and regional centers. Other species are over collected by succulent enthusiasts and local community for cultivation and their use in traditional medicine. The two species: *A. debrana* and *A. trichosanta* have been collected for their bactericidal property in the suck manufacturing industry (Sebsebe Demissew *et al*., 2003).

It is obvious that base line data on the biological and ecological attributes of species such as the size and life stage structures, reproductive success; and also threats to its populations and habitats are crucial for conservation decision making. Nevertheless, very few studies have been conducted in these lines on the aloes of Ethiopia, (e.g. reproductive biology of two endemic *A.* species (Fikre Dessalegn, 2009); population structure and dynamics of *A. debrana* and *A. pulcherrima* (Fikre Dessalegn, 2011); and population structure and reproductive success of *A. yavellana* and *A. calidophilla* (Fikre Dessalegn, 2012). This paper report, study on the populations of an endemic *Aloe* species (*A. gilbertii*) in Ethiopia.

Materials and Methods

The study area*: *A. gilberttii specimens (or, collections) at National Herbarium (ETH.), Ethiopia and published literatures were consulted for coordinates to evaluate the distribution of the species. A map showing the distribution area of the populations was constructed by using ArcGIS 9.2 software (see figure 2). The study on the population structure, uses and threats to *A. gilbetii* were conducted on the naturally occurring populations in the three selected localities: Alamura Hill, Arssi Negelle and Alaba in the species distribution range. Locality 1:

Alamura Hill, is situated at around 5 km from Hawassa town on the road to Kenya in the southern part of Ethiopian rift valley system. The plot was established at 7° 00' N; 38° 30' E & 1800 m a. s. l. The bed rock in the area seems to be basaltic rock and the soil type over the underlying rock is Leptosols, extremely shallow that seldom exceeding 0.15 m in depth. Locality 2: Arsi Negele**,** is located at 225 km south of Addis Ababa on the road to Shashemene in the central part of Ethiopian highlands. The plot was established about 20 km north of Shashemene at 2300 m a. s. l. The soil type that covers this site seems Andosols,. Locality 3: Alaba, is located at around 310 km south of Addis Ababa on the road to Wolayita Soddo in the southern Ethiopia. The plot was established at 7^{0} 17' N; 38^{0} 06' E & 1800 m a. s. l. The locality is highly degraded with commonly observable gullies where the top soils are washed away by erosions.

Species studied: *A. gilbertii* is a succulent shrub, grouped together with other shrubby (caulescent) aloes such as *A. calidophila* and *A. megalacantha* in the south and eastern Ethiopia respectively. The species is one of the endemic *Aloe* species in Ethiopia; and mainly characterized by erect, ascending or sprawling stems and distinguished from related species by the cylindrical to sub-clavate perianth (flower) (figure 1). The specific epithet '*gilbertii*', was given in honor of one of the collectors of the type specimen, an outstanding botanist who has contributed importantly to the progress of the knowledge of the Ethiopian Flora, M.G. Gilbert (Sebsebe Demissew and Nordal, 2010).

Figure 1 Individuals of *A. gilbetii* species *(*Photography taken from type locality by the Author).

Data collection and Analyses

Population structure: Data on the population structure were recorded from sampled populations in the three localities described above. In each locality, a plot of 5 x 20 m², i.e., altogether 3 plots were established. The plots were circumscribed using plastic rope and four wooden pegs fixed at each corner of the plots during data recording. Each individual clone consisting of one genet and one to several ramets was sorted and marked. Markings were done on the leaves with double numbers (g-r) by a water proof marker, starting bottom left corner of the plots as origin. Here 'g' stands for putative genet and 'r' stands for the individual ramet. A genet was defined as an individual that is derived from a single seedling comprising one to several ramets. A ramet was defined as an individual (or, the vegetative offshoot) connected to underground rhizome of the genet. The following population attributes were counted and measured at genet and ramet levels. For every genet, numbers of ramets were recorded; and for every ramet, rosette diameter (RD) was measured and recorded. Every ramets were also noted for the presence or absence of inflorescence (s) or infruitscence (s). Particular emphases were given not to overlook recruits, i.e. small seedlings and vegetative offshoots. The data recorded from the sampled genets and ramets were assessed for size and developmental stage structures. Further analyses were done for degree of flowering of ramets and ramet size relationship to flowering. These analyses were performed for each population and also for combined data set.

Size structure: The size structure of populations was assessed as density, i.e. total numbers of individual genets (g) and individual ramets (r) in the populations. Secondly, the size structure of the populations was investigated by the size of genets (clones) and by the size of ramets. The genet (clone) size was determined by the number of ramets per genet and presented as frequency distributions of genets and ramets/genet (figure 3). The ramet size was determined by the size of ramet expressed by its rosette diameter measured. Accordingly, ramets were classified by 10 cm size class of their rosette diameter (RD, cm) and the relative frequency (%) of ramets in each size class was established (figure 4).

Life stage structure: In order to investigate life stage structure, all the genets were assessed for their developmental stage. The size of genet and/or ramet size as expressed by their rosette diameter were employed as criteria to define life stage classes. Accordingly, genets were characterized by four life stage classes: seedlings, genets with one ramet and RD < 10 cm; jveniles, genets with one ramet and RD between 10 cm and 30 cm; young adults, genets with one ramet and RD > 30 cm (flowering size); and mature adults, genets with two or more ramets. This characterization of life stages take into account the growth form of the species and presented as proportions of genets in each life stage class defined (figure 6).

Uses: Uses of *A. gilbertii* plants by the Alaba community were investigated. Initial survey was conducted to create an overall insight of the locality and the community. A total of 25 informants were sampled among the community members based on age, sex and socio-economic backgrounds. Data were collected by using diverse tools such as focused group discussions, semi-structured interviews, and field walking. Focused group discussions and semi-structured interviews were conducted with selected key informants to capture broader spectrum of uses of individual *A. gilberttii* plant and its parts in their day to day lives and in relation to their immediate environment (table 1). Respondents were grouped into five (R_1-R_5) to rate the relative preference and efficiency of five plant species including *A. gilbertii*, used by the community in the effort to rehabilitate degraded land and soil conservation. The analytical tools recommended by Martin (1995) such as informant consensus and ranking were employed (table 2). Field walking accompanied by photographic documentations using digitized camera, were conducted to verify ecological use of the species (figure 7 a, & b).

Field survey on the threats: As part of the population attributes, qualitative observations and record were made in the field to trace factors that might threaten the natural populations. Anthropogenic factors that threaten the populations of *A. gilbertii* were observed and recorded with photos (figure 7c).

Results

The distribution of the species populations: Analysis on the data from herbarium specimens and published sources revealed that the populations of the species are distributed in a number of places in Sidamo (SD), Shewa (SU), and Gamo Gofa (GG) floristic regions, mostly confined to rift valley systems of Ethiopia (figure 2). In Sidamo floristic region, for example, the species occur at Alamura Hill and at Tabor Mountain slopes around Hawassa town, and in a large number near Morocho. In Shewa floristic region, it is widely distributed and occurs near Bulbula town, west of Shalla and Abjata Lakes, and at around Gido River. It also occurs near Langano lake beach, Arssi Negelle and Kuyara towns. South of Shashemene it grows at 20 and 60kms near Ajje and Alaba towns respectively. In Gamo Gofa floristic region, the species occurs at 3km from Konso on the road to Yabello. Generally, it was observed during field surveys that the species found growing mostly in *Accacia* woodland; *Accacia-Commiphora* bush land, on rocky places with *Adenia venanata*, near rivers, lakes and on mountain slopes as part of natural vegetation between 1300 and 1800 (1900 m). It is sometimes also occur under cultivation planted as hedges, on terraces to prevent soil erosion and along field margins.

Figure 2 Map showing the distribution of *A. gilbertii* populations in Ethiopia

Population structure: Parameters recorded from gentes and ramets in the sampled populations were analyzed for the structure of the populations. The findings on the size and life stage structures are presented in figures, 3-6 below.

Size structure: The density of the populations at two levels: (genet (g) and ramet (r) levels) were found variable. The population at Alamura Hill had (68g and 253r), Arssi Negelle (42g and 248r) and Alaba (44g and 324r). The density of the populations for the combined data set at genet (154g) and ramet (825r) levels are highly variable indicating the predominant mode of reproduction followed by the species as strategy to maintain its populations.

The structure of populations by genet (clone) size expressed as frequency distribution, i.e., number of genets and ramet (s) per genet were shown in figure 3. Genets (clones) with only one ramet comprised 41.2%, 28.6% and 27.6%; whereas, genets with multi-ramet (≥ 2 ramets) comprised 58.8%, 71.4% and 72.4% in the populations of Alamura Hill, Arssi Negelle and Alaba respectively. The three sites are more or less similar in the extent of potential clone formation. The clone size for the combined data set for the three populations revealed that 33.8% of the genets consisted of only one ramet and the remaining 66.2% were multi-ramet genets.

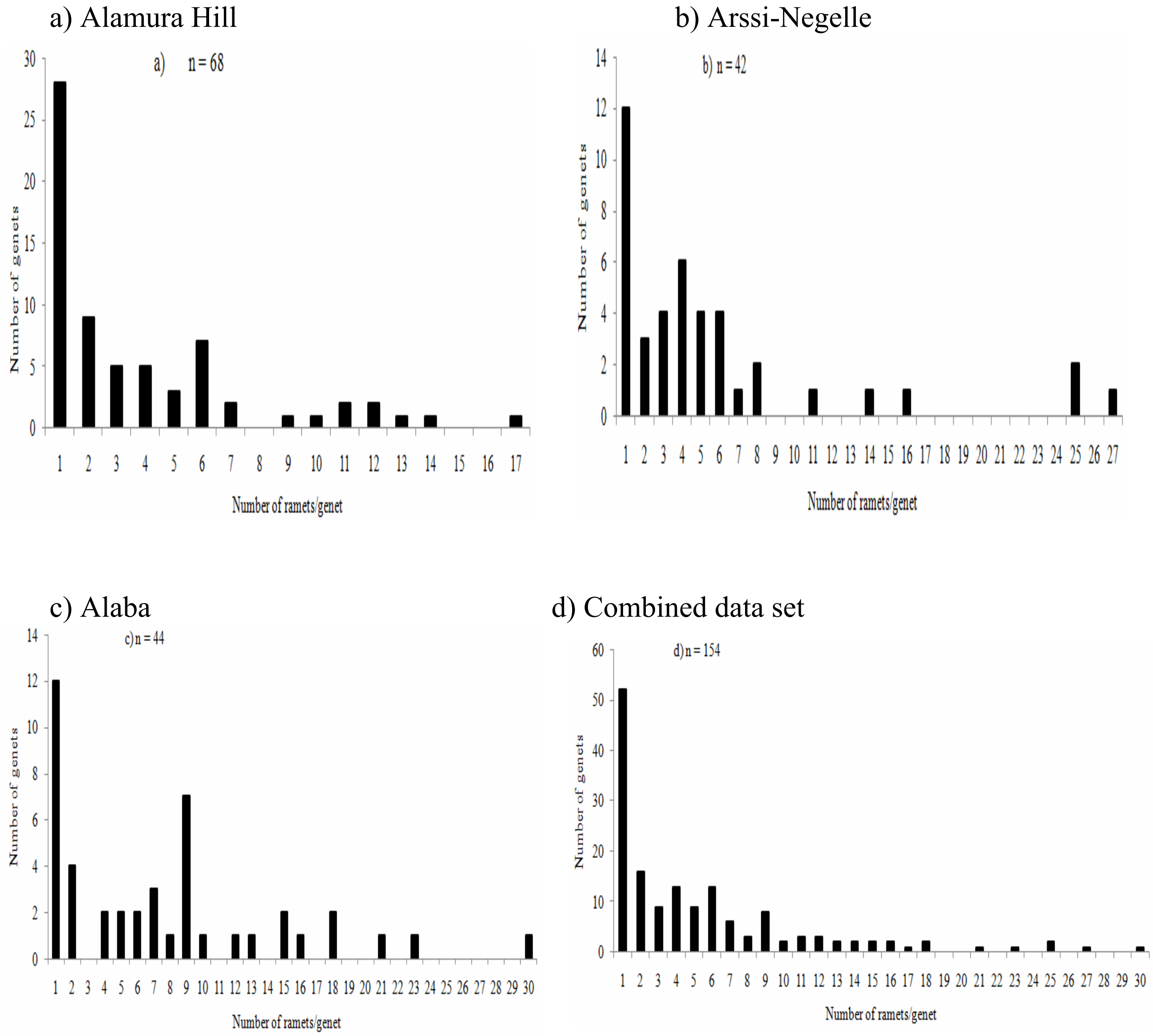


Figure 3 Frequency distributions by clone size (the number of genets and ramets/genet) of *A. gilberti* populations at a) Alamura Hill; b) Arssi-Negelle; c) Alaba and d) Combined data set. (n, represents number of genets)

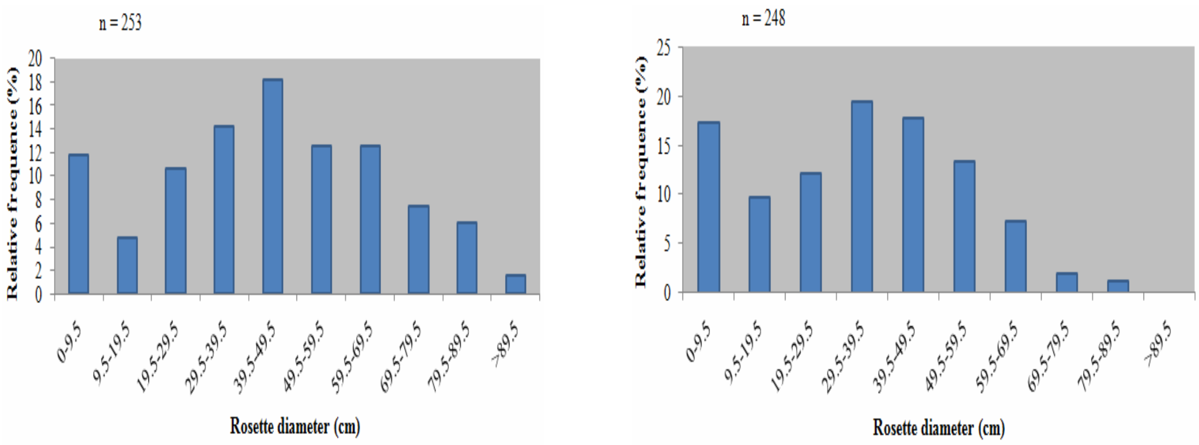
The structure of populations by the ramet size expressed as the relative frequency distributions in the size classes defined by 10 cm of their (RD) were presented in figure 4 a-d. These size classes were further grouped into three categories for comparative purpose. Category 1: ramets with RD < 30 cm (small sized, relatively young ramets); category 2: ramets between 30-90 cm RD (medium sized, mostly ramets in reproductive classes); and category 3: ramets with RD > 90 cm (large sized, post-reproductive ramets). Accordingly, Alamura population comprised 27.2% of ramets in category 1; 71.2% in category 2; and 1.6% in category 3. Arssi Negelle population had 39.1% of ramets in category 1, 60.9% in category 2 but none in the category 3. Alaba population, on the other hand, consisted of 32.7%, 65.5% and 1.8% of ramets in categories 1-3 respectively. The ramet size structure of the combined data from three populations revealed that 33% in category 1, 65.8 % in category 2 and the remaining 1.2% of ramets in category 3, indicating that the populations of *A. gilbertti* had greater proportion of medium sized ramets. The ramet size relationship to flowering was displayed on figure 5a. It was found out that 97.3% of flowered ramets in the populations were mostly from medium sized classes in category 2, 30-90 cm RD. Only two ramets, 2.7% were flowered from categories 1 and 3. The result indicated that the minimum size that has to be attained by ramets to initiate flowering is nearly above 30 cm RD in *A. gilbertii* populations. The extent of flowering of ramets in the populations was evaluated and presented in figure 5b as proportions of ramets in state of flowering and non-flowering in the season. The population at Alamura Hill consisted of 7.1% flowering and 92.9% non-flowering ramets. Similarly, the populations at Arssi Negelle and Alaba consisted 9.3% and 10.2% flowering and 90.7% and 89.8% non-flowering ramets respectively. The combined data set consisted of 9% flowering and 91% non-flowering ramets, indicating the populations were dominated by non-flowering ramets in the season.

Life stage structure: Genets in the populations were classified into four defined developmental stages, including seedling, juvenile, young adult and mature adult. Accordingly, the life stage structure in each of the populations and combined data set were presented figure 6a-d. The stage structure of the combined data set revealed that 10.4% of genets were at seedling stage, and the remaining 11.4%, 13%, and 65.6% of genets were at juvenile, young adult and mature adult stages respectively.

Uses: Alaba, is a district in Ethiopia commonly known for its degraded landscape that has been reported to be resulted from deforestation, traditional farming system and overgrazing. The accompanied successive erosions in the locality mainly by water (flooding) have washed away valuable and nutrient-rich topsoil and what frequently observed today are gullies.

a) Alamura Hill

b) Arsii-Negelle



c) Alaba

d) Combined data set

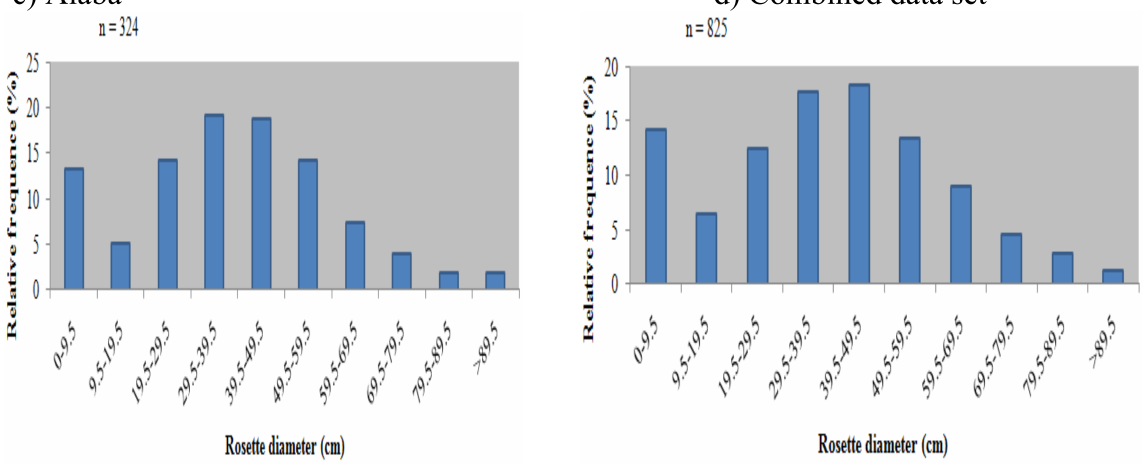


Figure 4 Relative frequency distributions by ramet size at, a) Alamura Hill, b) Arssi Negelle, c) Alaba; and d) Combined data set. (Size class, 10 cm RD; n represents number of ramets)

During field survey, it was observed that *A. gilbertii,* is one of the dominant and important component of plant community in the area. Their succulent leaves; root system that can imbibe minimum precipitation and other adaptive strategies might have enabled them grow in the locality. All the informants indicated that they have been using *A. gilbertii* plant and its parts for various purposes (table 1).

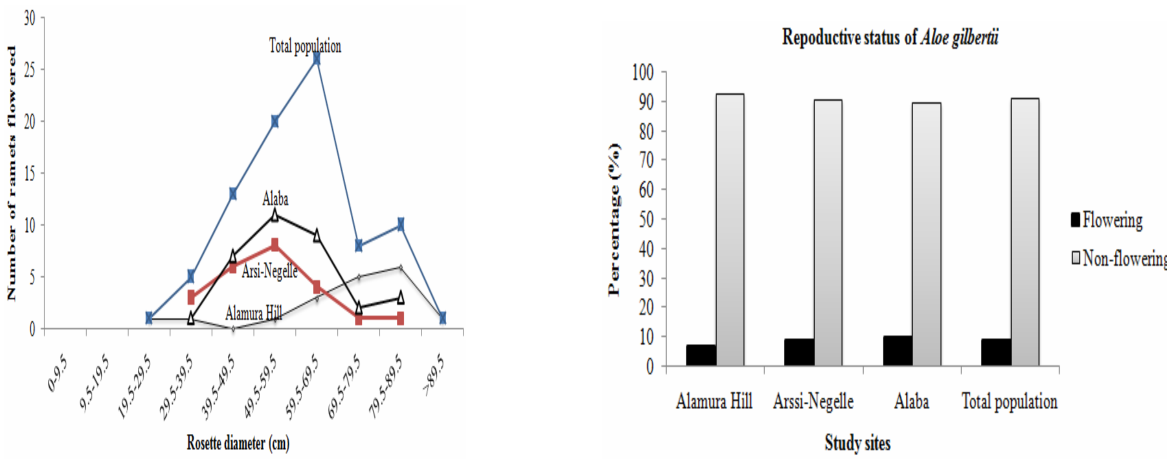


Figure 5 a) flowering in relation to size of ramets; b) states of flowering and non-flowering of ramets in the populations

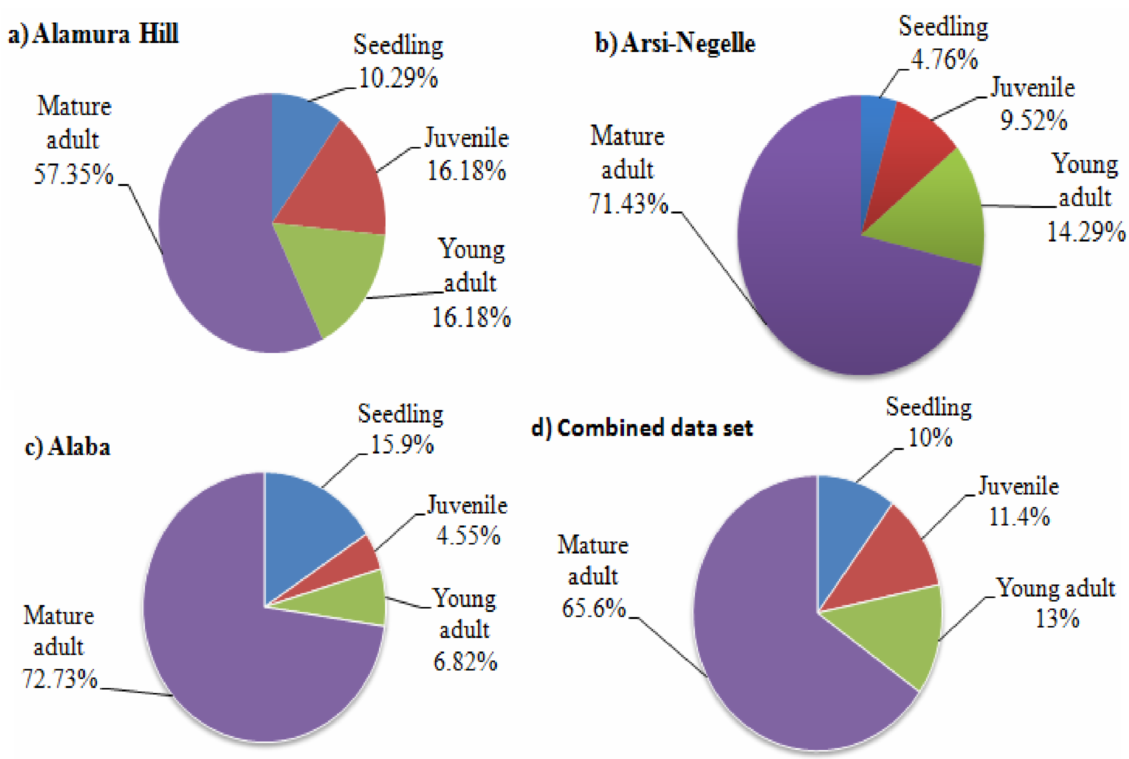


Figure 6 Genets in the four life stage classes defined (seedling, juvenile, young adult and mature adult) in the populations of *A. gilbertii* at a) Alamura Hill, b) Arssi Negelle, c) Alaba and d) Combined data set.

Among others, its uses in the rehabilitation of degraded land and soil conservation efforts were widely mentioned. The whole individuals were transplanted by local community to the areas surrounding their farm lands, range lands and home gardens for the purpose of demarcation and protection in the form of area enclosure, in hedging and fencing. It was also widely observed that individuals of *A. gilbertii* are planted along slopes in bund, terracing or ditch formation against soil erosion and for soil retention during erosion (figure 7 a, and b). The other uses of *A. gilbertii* by Alaba community are as sources of traditional medicine and for fuel. Leaves and root parts have been used by local people mainly for treatment of malaria and wounds. Dried and dead plant body and parts such as stem and leaves are also used as fuel wood. Four other plant species such as *Accacia saligina*, *Agave sesalensis*, *Hypernia species*, and *Accacia senegalensis* were mentioned by local community that has been used alone and in the combination with *A. gilbertti* species for degraded land rehabilitation.

Table 1 Uses of Aloe gilbertii by the Alaba communities

Use category	Application	Specific uses	The plant body used
Ecological uses	Terracing; and in bund or ditch formations	Reduce effects of flooding that erodes soil down slopes	Planting whole individuals on rock outcrops or thin degraded soil
	Area enclosure	Protection from interference and ensure ecological succession and restoration	Planting whole individuals around selected areas
	Fencing (or, Hedging)	Physical protection	Planting whole individuals around home gardens, farm and range lands
	Boundary demarcations	To create boundary between farm or range lands owned by individual farmer/house hold	Planting whole individuals between the boarders of farm or range lands
	Soil retention or compaction	Protect detachment of soil by its resetting leaves and network of rhizomes	Planting whole individuals against erosion agents in sloppy areas
	Ground cover	Facilitate growth of other plants such as grasses and herbs	Individuals in natural habitat such as range land
Traditional medicinal uses	By direct administration of gels or exudates	For treatment of malaria and wounds in humans	Leaves gel and roots exudates
Fuel energy	Burning dried and dead individuals or parts	As source of fuel or fire wood	Leaf and steam

A. gilbertii is the most widely used and preferred plant species for rehabilitation of degraded land in the study area. As presented in table 2, of the total respondents, 80% agreed that *A. gilbertii* is very important and effective in rehabilitation of degraded land and 20% responded that it has little role for same.

Table 2 Preference and efficiency ranking of five plant species used for rehabilitation of degraded land

Plant species	Respondents					Total	Rank
	R1	R2	R3	R4	R5		
Aloe gilbertii	4	4	2	4	4	18	1st
Accacia saligina	2	3	3	4	1	13	3rd
Agave sesalensis	3	2	1	2	2	10	4th
Hypernia species	4	3	3	2	4	16	2nd
Accacia senegalensis	2	2	1	1	3	9	5th

***Threats to the populations*:** There were several factors observed that threaten *A. gilbertii* populations. The major threats identified were urbanization, expansion of farmlands, overgrazing and land sliding in mountain slopes. Urban expansion and associated development construction such as roads was observed destructing the habitats of naturally occurring population at around Hawassa (figure 7c). *A. gilbertii* populations were observed to be highly affected by overgrazing from the increased livestock population. Due to overgrazing, the ability of individuals to recruit from seed and by vegetative means, i.e. branching of ramets from genets has been affected. Increased population has led to loss of habitat while more lands areas are being encroached for cultivation in these localities. It was observed that farmers are uprooting *A. gilbertii* individuals in order to expand their agricultural lands.

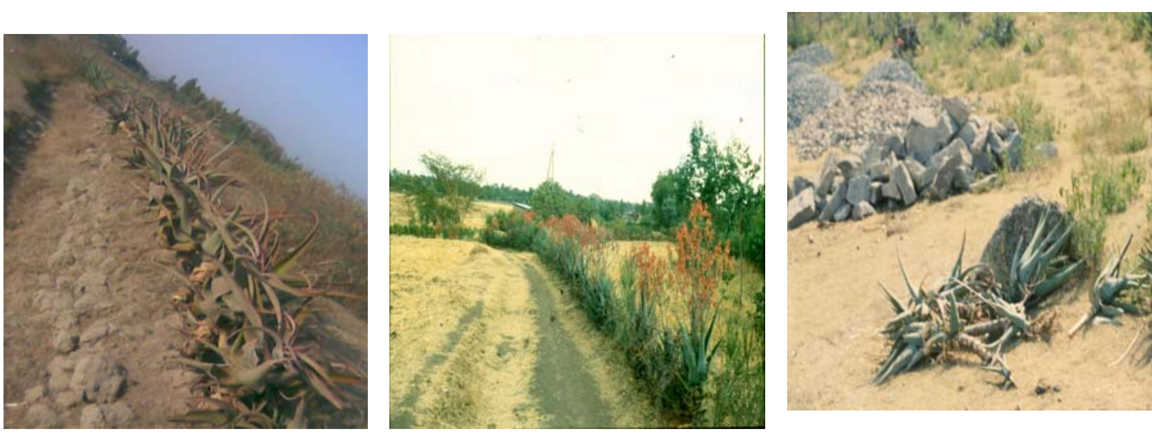


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Figure 7 a) terracing & b) fencing, formed by using individual plants; c) threat to the population due to road construction (photos taken from different localities by the Author).

Discussion

The size structure investigated as density and sizes of genet and ramet showed similar pattern for each population and combined data set. The density for the combined data set at genet (154g) and ramet (825r) levels were highly variable. The genet size structure revealed that the populations had large proportions (66.2%) of multi-ramet (> 2) genets. Aloes are capable of producing potentially independent offspring by means of vegetative growth and have the capacity to multiply by sexual reproduction that determines the number of genets and ramets/genet (Pandey and Shukla, 2001). Clone (genet) size has some indication to the predominant system of reproduction. It is also indicative of the probability of the survivorship, because increased rate of clonal growth increases the probability of genet survival (Witte *et al*., 2011). It seems that *A. gilbertii* populations opts more to asexual vegetative means as compared to sexual reproduction as there were greater density of ramets than genets. Similarly, the greater proportion of multi-ramet genets in the populations signifies that the species depend more on vegetative propagation than recruitment from seed. The relative frequency distribution of ramets (RD, 10 cm size class) indicated that the populations had greater proportion (65.8%) of medium sized ramets in category 2 (30-90 cm, RD) as compared to 33% in category 1 and the remaining 1.2% of ramets in category 3. Size structure is the most conspicuous aspect of population structure and driven by many factors. It might be due to internal genetic factors such as their ability to rejuvenate new ramets that contribute to small size class of the population or strategic resource allocation either for vegetative growth or reproduction such as flowering and fruiting. Size structure might also be resulted from the action of external factors to which their members might have been exposed during or even before the study season. For example, size specific deaths and size specific attack by natural enemies (e.g. herbivores) together can account for much of the variations in size structure (Douhovnikoff, 2004). The observed difference in the structure by size of ramets in populations of *A. gilbertii* species might either be resulted from internal genetic or external environmental factors.

The ramet size relationships to flowering showed that number of flowered ramets vary in different size class categories. Medium size class (30-90 cm, RD) accounts for greatest proportion of flowered ramets. In many species, the probability of flowering is also size dependent, so that plants must exceed a critical threshold size before flowering (Klinkhamer *et al.,* 1987). It was observed that a ramet should nearly attain a minimum of 30 cm RD to initiate flower in *A. gilbetti* populations. The populations were dominated by non-flowering as compared to flowered ramets indicating that they had shown reduced reproductive efficiency in terms of degree of flowering.

The other important attributes analyzed was life stage structure as plant species have certain consistently recognizable life stages in their life cycle. The life stage structure distribution revealed that the density of genets vary in the four life stage classes defined. The developmental stage structure of the populations had low proportions of (10%) seedlings, (11.4%) juveniles, (13%) young adults; and high proportion (65.6 %) of mature adults. According to Nordal *et al*. (1997) on *Papaver radicatum* population "A high number of seedlings and juvenile plants may be indicative of dynamic population under establishment; whereas a low number of seedlings and a high number of old rosettes would characterize a senescent population in a mature community at late successional stage."

Findings on stage structure of *Aloe gilbertii* populations' investigated fit very well to the second situation by accounting a high number of mature adults. Similarly, Wabuyele and Kyalo (2008) reported that most populations of the commercial aloes in Kenya were dominated by mature individuals.

The *Aloe gilbertii* plant has been used by Alaba community in the rehabilitation of degraded lands, soil conservation and also as sources of traditional medicine and fuel. Some *Aloes* species are important components of the dry land ecosystems and have been recognized that they might play a role as primary colonizers in such habitats facilitating later habitation by other less resilient plants (Schamotta, 2010). Accordingly, areas which experience prolonged drought can benefit from planting of aloes in the ecological restoration effort. King and Stanton (2008) reported on *A. secundiflora* stating that it has greatly enhanced vegetation diversity, litter cover, soil retention and soil seed bank in the immediate vicinity where it grows. Analysis on preference and effectiveness of *A. gilbertii* indicated that species is very effective in protecting soil erosion. The preference by farmers in the community might be linked to availability, ease to dug up and transplant. The effectiveness in protecting soil erosion might be due to the nature of the plant body having rosetting leaves that arise together from the base. As the result their big leaves cross over one another to form a natural barrier. This in turn stops water and soil from moving very quickly down the slope resulting in the pilling up of the soil beside the barrier and fills the gullies through time gullies. Similar observation was reported from Kenya that *A. chrysostachys* was planted in rows on eroded slopes and has been protecting the soil in the locality (Schamotta, 2010).

Field surveys conducted during the study period revealed the existence of threats to *A. gilbertii* populations. Destruction of natural habitats for agricultural land, urbanization and road construction were observed to be the major threats. These field observations agree with threats identified to the entire flora of the country (IBC, 2005).

Conclusion

Based on the findings from population structure and the extent of flowering in the season, it is possible to state that *A. gilbertii* populations are either declining or nearly stable. However, it is difficult to predict the future fate of the species populations by analyzing data from sigle season. The species has current and potential benefits to the locality community and their immediate environment. It is suggested that this useful and yet threatened endemic species needs urgent conservation attention through protecting the species and its habitats.

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