Population structure and reproductive success of *Aloe calidophilla* and *Aloe yavellana* in Yavello District of Southern Ethiopia

Fikre Dessalegn

Department of Biology, Hawassa University, P.O. Box 5, Hawassa, Ethiopia
fikredessalegn@yahoo.com

Abstract

A study was conducted on two Aloe species (A. yavellana, narrow endemic) and (A. calidophilla, near endemic) in Yavello district of southern Ethiopia. It was aimed to compare the population structure and reproductive success of the above species with varying range of geographical distribution. Six quadrates measuring (5 m × 20 m^2) were established on naturally occurring populations following their time of flowering and fruiting (November to February) 2011-2012. In each quadrate, all the genets and ramets were sorted and marked. Each genet was recorded for the number of ramet (s) and each ramet was measured for rosette diameter and noted for state of flowering. Data on recruitments and mortality were also carefully recorded. The clone size structure revealed that A. yavellana had greater density of genets (89), ramets (255), and multi-ramet (> 2) genets (64%) as compared to A. calidophilla. The populations of the species also displayed varying size structure of ramets defined in the 10 cm size class of rosette diameter (RD). The stage structure revealed low proportions of seedlings, juveniles and young adult stages compared to mature adults indicating dominance of long lived individuals in both species. Absence of seedlings in A. calidophilla indicated that the species relay more on vegetative propagation despite good seed set. Ramets in reproductive size class that were in state of flowering comprised 56.3% in A. yavellana and 46.2% in A. calidophilla in the study period. The mean number of capsules per raceme were (6.3±0.41) and (24±0.81) in A. yavellana and A. calidophilla respectively. Despite these variations in the extent of flowering and fruiting, the mean number of seeds per capsule was only slightly different. Mortality in the study period was low for both species and confined to only ramets. Based on the observed recruitment, survival strategies and mortality, it is reasonable to state that the A. calidophilla populations are nearly stable (stagnant) whereas A. yavellana populations are expanding for comparative purpose. Hence, appropriate conservation strategies have to be adopted for the studied species.

Keywords: *Aloe yavellana, Aloe calidophilla, Genets, Population structure, Ramets, Reproductive success*

Introduction

The aloes are perennial plants that comprise herbs, shrubs and small trees. Most aloes are characterized by their thick and fleshy leaves with spiny margin. They have tubular flowers that are brightly yellow, orange or rarely white in colour. About 450 *Aloe* taxa are known today (Smith and Steyn, 2004). They are distributed mainly in the Sub-Saharan Africa and island of Madagascar. The majority of *Aloe* species occur in southern and eastern side of the African continent (Newton, 2004). Members of the genus *Aloe* have wide range of uses in medicine (e.g. in treatments of wounds and in reducing blood sugar and lipid levels); and also in commerce and horticulture (Mascola *et al.*, 2004).

In the flora of Ethiopia and Eretria, 46 species of *Aloe* have been described out of which (41, 89%) are endemic or near endemic indicating that they have high degree of endemism in the flora area. Only five species: *A. laterita, A. macrocarpa, A. rivae, A. secundiflora* and *A. vituensis* have wider distribution extending to east or west Africa. However, most other species have restricted distribution area and known from few localities and populations. The altitudinal distribution of aloes in the flora area is wide ranging from 500 m (e. g. *A. megalacantha* in desert and semi-deserts of Somalia region to above 3000 m (e.g. *A. steudneri* and *A. ankoberensis*), both of which reach the sub-afroalpine vegetation (Sebsebe Demissew *et al* 2001; 2003; 2011).

Though not yet fully investigated and exploited for their use as in other parts of Africa, aloes in the flora of Ethiopia and Eretria may have potential economic and ecological values. For example, there are recent reports that the leaf gels from *A. debrana* and *A. trichosantha* are used in the manufacturing of sucks for coffee export. It has also been reported that *A. gilbertii* individuals are being used by the local community in rehabilitating degraded land (Fikre Dessalegn, 2006). *A. calidophilla*, a shrubby species with relatively wider range of distribution in the southern lowlands of Ethiopia and in the northern part of Kenya, is identified to be one of the commercial important species and listed among species that need conservation attention in Kenya (Wabuyele and Keyalo, 2008).

According to Carter (2001), many species of *Aloe* are threatened due to habitat destruction caused by urban and regional developments. A few species are collected for their use in medicine and cosmetic industry. While, still others may also be a target for succulent enthusiasts in their quest for rarities. Consequently, all species of *Aloe* (except *A. vera*) are in the CITES (Convention on International Trade on Endangered Species) list, clearly indicating their vulnerability (Newton, 2004). The red list assessment conducted on endemic vascular plant species in the flora of Ethiopia placed eighteen *Aloe* species in different IUCN threat categories. It was also identified that the threats to these endemic species have been caused mainly due to habitat destructions for agricultural expansion, urbanization, settlements, development construction such as roads and overgrazing (Friis *et al* 2003). Some of the narrow endemic *Aloe* species evaluated (e.g. *A. pulcherrima, A. monticola, A. harlana* and *A. yavellana*) which occur as small population and with very restricted distribution area were categorized as rare.

There is no doubt that plant species that are endemic and rare; and also at the same time have potential economic value but under threat are of conservation priority (IBC, 2004). However, in order to design appropriate conservation strategies for a species and hence conservation decision making, information on the causes of rarity are crucial. The reasons for rarity of a given plant species might be twofold: linked to the biology of the species such as population structure and reproductive strategies and also the ecology of the species distribution area (Reveal, 1997). Consequently, this study was focused to compare the population structure and reproductive success of two selected *Aloe* species: *A. calidophilla* (identified as commercially important and with relatively wider distribution range) and *A. yavellana* (narrow endemic and rare) so as to suggest appropriate conservation strategy.

Materials and Methods

The study area

This study was conducted on the natural populations occurring in Yavello district in Sidamo (SD) floristic region (see figure 1). Yavello is located in southern part of Ethiopia, about 590 km from Addis Ababa on the road to Moyale, at 4° 53’ N; 38° 04’E and elevation of

1910 m. The district mainly falls within the so called *Acaccia-Commiphora* woodland and scrubland vegetation type with scattered remnant forests. Data on the labels of herbarium specimens at the National Herbarium (ETH), Ethiopia and published literatures (Reynolds, 1966 and Sebsebe Demissew and Gilbert, 1997) were consulted to trace the distribution area of the studied species. The populations of *A. yavellana* and *A. calidophilla* co-occur in the study area, thus selected for comparative purpose.

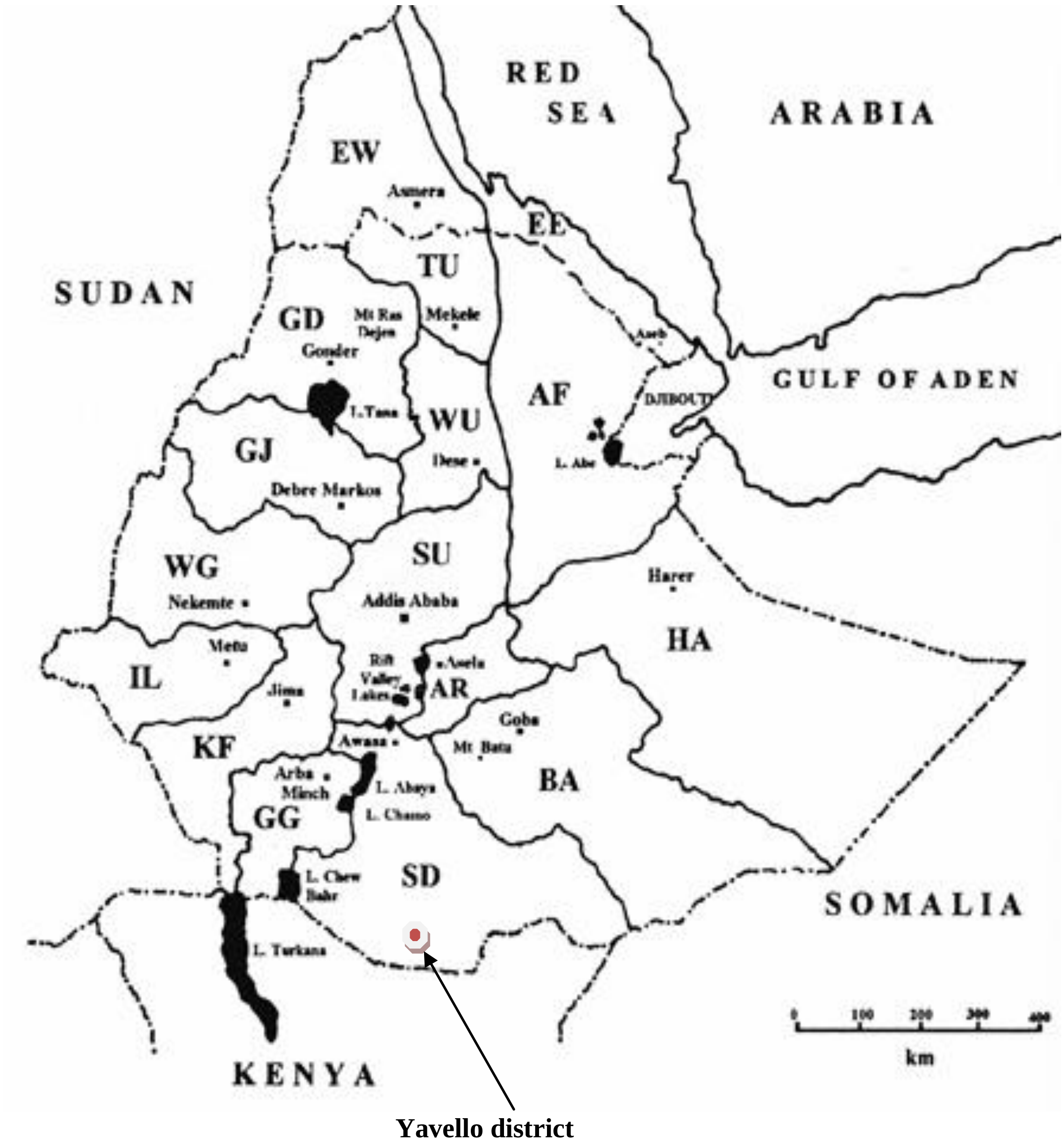

Figure 1 Map showing the study area, arrow indicates Yavello district within Sidamo floristic region

The species studied

Aloe yavellana Reynolds

It is a shrubby species with straight to slightly curved leaves; narrow endemic, restricted to only two localities (near Yavello town and in the north-eastern slopes of Mega Mountain) in Sidamo floristic region. In these localities occurs inside remnants of *Juniperus* forest, on rocky slopes and in more disturbed areas near roads between 1600 and 1900 m. The flowering time starts

Aloe calidophilla Reynolds

It is a shrubby species with strongly re-curved leaves; near endemic with wider distribution ranges occurring in different localities in Sidamo and Gamo Gofa floristic regions in Southern Ethiopia and also in Northern Kenya. In these localities the species found grow in woodlands, bush lands or open wooded grasslands often on dark soils at alt, between 1300 to 1600 m. The flowering time starts

A **B**

Figure 2 Individuals with infruitscences of a) *A. yavellana*; photo taken at 5 km from Yavello on the road to Konso, Alt.1600m, Lat.-38 30 E, Long.-7 00 N; b) *A. calidophilla*; photo taken at 35 km from Yavello on the road to Hagremariam, Alt.1300m, Lat.-38 30 E, Long.-7 00 N

Data collection and analyses

Population structure

Data to investigate the population structure of *A. calidophila* and *A. yavellana* were obtained from the naturally occurring populations in the Yavello district. Six quadrates of 5 x 20 m² were established, three for *A. calidophila* and three for *A. yavellana* populations. The quadrates were circumscribed using plastic rope and four wooden pegs fixed at each corner. Each individual clone consisting of one genet and one to several ramets was sorted and marked. Marking was done on the leaves with double numbers (G-R) by a water proof marker starting bottom left corner of the quadrate as origo. 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 seed comprising one to several ramets. A ramet was defined as an individual (or, the vegetative offshoot) connected to a single underground rhizome of the genet. In each quadrate, the following population attributes were recorded at genet and ramet levels. Each genet was recorded for the number of ramet (s) and each ramet was measured for its rosette diameter (RD) and noted for state of flowering. Data on recruitments (i.e. small seedlings and vegetative offshoots) and mortality (i.e. dead genets and ramets) were also carefully recorded.

These data were analyzed for the population structure, i.e. the size structure and developmental stage structure. The size structure of the populations was investigated by the clone size and size of ramets. The size of a clone was determined by the abundance of ramets per genet and presented as frequency distribution of the genets and ramets per genet (see figure 3). The size of a ramet was determined by the size expressed by its rosette diameter. Accordingly, ramets were classified by 10 cm size class of their rosette diameter (RD) and the relative frequency (%) distribution of ramets in each size class was established (see figures 4 & 5). In order to investigate stage structure of the populations of species, all the genets in the quadrates were assessed for their developmental stages. The number of ramet (s) per genet and/or the size of ramet as expressed by their rosette diameter were employed as criteria to define stage classes. Accordingly, genets were characterized by four developmental stage classes: seedlings: genets with one ramet and RD < 10 cm; Juveniles: 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. The stage structure of the populations of a species was presented as proportions of genets in each life stage class (see figure 6 & 7). In the analyses and presentation of the data on the population structure, Microsoft Excel office 2007was used.

Reproductive success

Reproductive successes of the two species were investigated and compared using data on recruitments, flowering, fruiting and seed sets. Recruitments by the two alternative recruitment strategies (sexual vs. asexual) means were compared as proportion of the small seedlings and vegetative offshoots recorded in the sampled populations (see table 1). Extent flowering was assessed and compared as proportion ramets in state of flowering and non flowering in reproductive size class. Fruiting was evaluated from six randomly sampled racemes per species. Accordingly, each raceme sampled was counted for number of capsules. The degree of fruiting was compared as average number of capsules per raceme. Seed set data were obtained from twenty randomly selected capsules per species. Each capsule selected was counted for number of seeds and extent of seed production was investigated and compared as mean number of seeds per capsule in the species studied (see table 2).

Results

Population structure

The data recorded in the field from sampled populations of *A. calidophila* and *A. yavellana* were analyzed for the size and life stage structures. The size structure by clone size, i.e. number of genets and ramet (s) per genet investigated is presented in figure 4. It was found that *A. yavellana* populations contained the greater number of genetic individuals (genets) (89) as compared to *A. calidophilla* populations (68). Similarly, the total numbers of vegetative offshoots (ramets) of *A. yavellana* populations were (255) and *A. calidophilla* (207). On the other hand, genets that comprised only one ramet (or, single ramet genets) account 36%, in the populations of *A. yavellana* as compared to *A. calidophilla* populations that had 46.3% single rameted genets. Out of the total genets recorded in the populations of two species, multi-ramet genets (2-12) comprised 64%, and 53.7% for *A. yavellana* and *A. calidophilla* populations respectively. Simple correlation showed that the two species populations are different in the extent of clone formation.

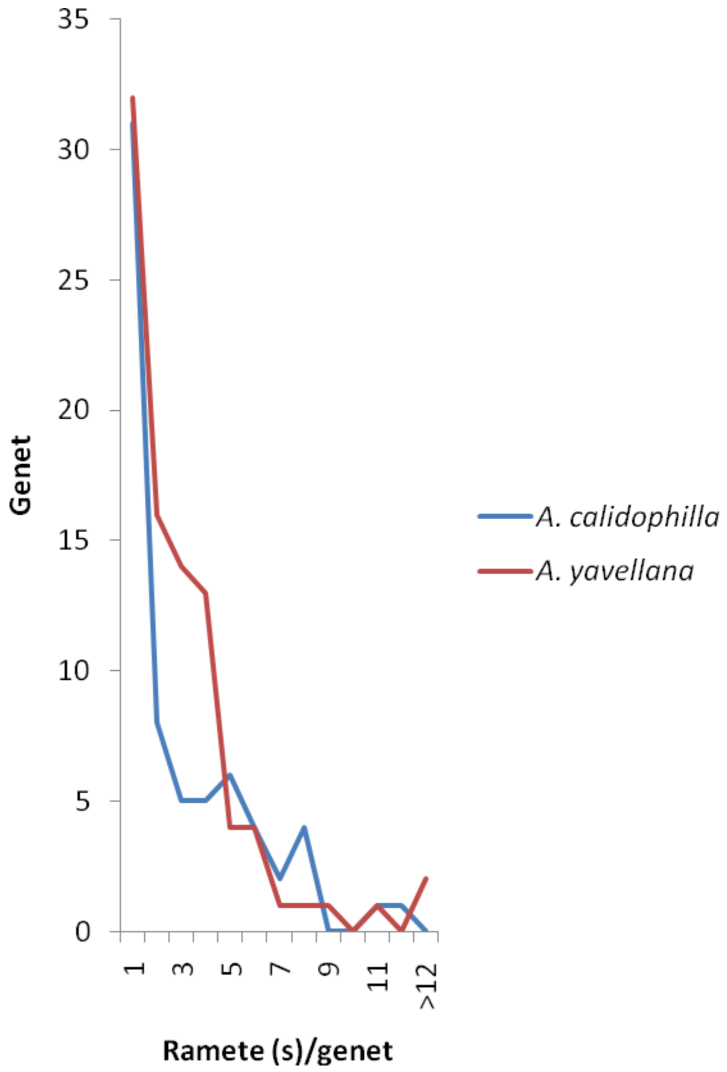

Figure 3 Population structure by clone size (the number of genets and ramets/genet) for *A. calidophilla* and *A. yavellana*

A. yavellana and A. calidophilla populations also displayed varying distributions of ramets in the size classes defined by 10 cm of their rosette diameter (RD). The relative frequency distributions of ramets in each size class per populations of two species are presented in figure 4 & 5. In *A. yavellana* populations, ramets with rosette diameter less than 30 cm (small sized) comprised 30.97%; between 30-90 cm (medium sized) comprised 63.15%; and above 90 cm (large sized) comprised 5.88%. On the contrary the size class distribution of *A. calidophilla* populations revealed 25.10% and 41.57% for ramets with rosette diameter less than 30 cm (small sized) and between 30-90 cm (medium sized) respectively. Large sized category of (> 90cm) rosette diameter comprised 33.33% of the ramets recorded. Therefore, the proportion of ramets in small and medium sizes outnumbered (94.2%) in *A. yavellana* populations as compared to *A. calidophilla* whose populations had greater proportion (74.9%) of ramets in medium and large size classes

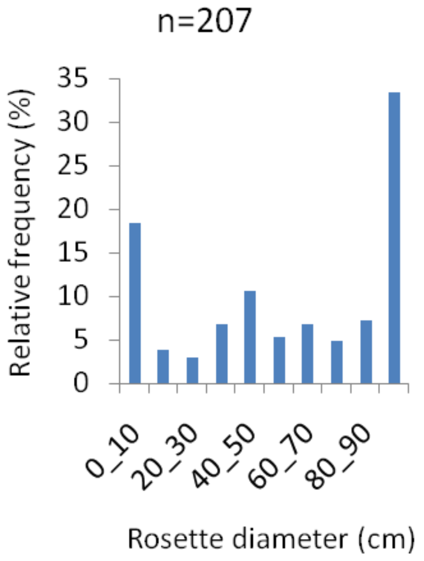

Figure 4 Relative frequency distribution of ramets of *A. calidophilla* in 10cm size classes of rosette diameter of ramets

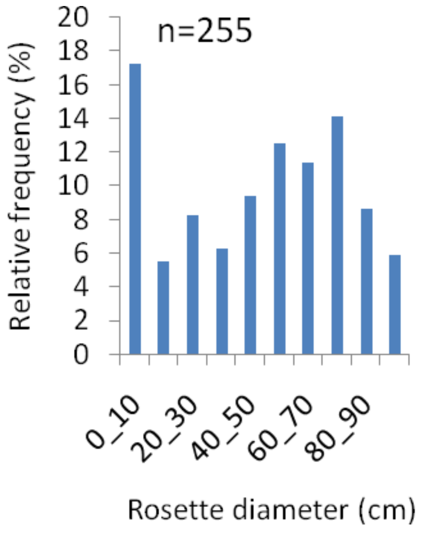

Figure 5 Relative frequency distribution of ramets of *A. yavellana* in 10cm size classes of rosette diameter of ramets

The genets in the populations of *A. yavellana* and *A. calidophilla* were classified into four developmental stage classes namely seedling, juvenile, young adult and mature adult genets. The stage structure of species populations are presented in figures 7 and 8. The stage structure of *A. yavellana* displayed that 11% of genets were at seedling stage and the remaining 8%, 16%, and 65% were at juvenile, young adult and mature adult stages respectively. The stage structure of *A. calidophilla* populations, on the contrary, revealed that none of genets were at seedling stage and few in juvenile (4%). The remaining 42% and 54% were at young adult and mature adult stages respectively.

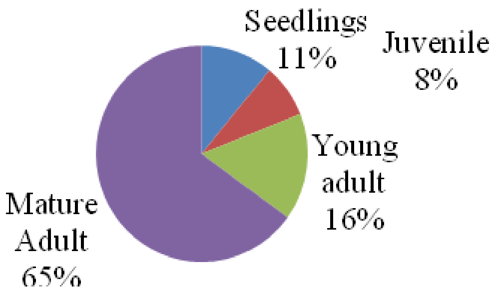

Figure 6 Proportion of genets in the four life stage classes defined (seedling, juvenile, young adult and mature adult) in the populations of *A. yavellana*

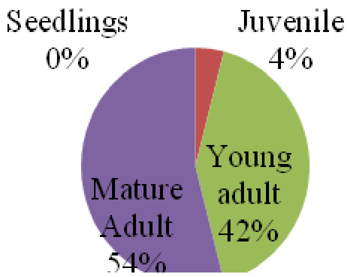

Figure 7 Proportion of genets in the four life stage classes defined (seedling, juvenile, young adult and mature adult) in the populations of *A. calidophilla*

Reproductive success

Reproductive performance of the two species studied was investigated and compared by their ability to recruit from seed and vegetative means, and also in the extent of flowering, fruiting and seed set. Of the total small recruits recorded in the quadrates, 72.7% were due to vegetative propagation and the remainder (27.3%) was due to seedling establishment in *A. yavellana* populations. However, the recruits recorded in the quadrates were all due to vegetative means and seedling establishment were not observed in *A. calidophilla* populations (table 1). Therefore, *A. yavellana* and *A. calidophilla* differ both in their strategies of recruitments. *A. yavellana* can produce genet ramets (12) by seedling establishment and ramets (32) by vegetative propagation indicating that the species had shown combined strategies of recruitment. *A. calidophilla*, on the other hand, entirely produced new ramets (31) vegetatively revealing absence of recruitments from seeds.

Table 1
Summary of data on recruitments of the populations of *A. yavellana* and *A. calidophilla* recorded in their respective quadrate

Species	Quadrate	Recruitment from seed	Recruitment from veg. prop	% Recruitment from veg. prop
A. yavellana	1	9	16	
	2	3	5	
	3	0	11	
	Total	**12**	**32**	**72.7**
A. calidophilla	1	0	14	
	2	0	7	
	3	0	10	
	Total	**0**	**31**	**100**

The extent of flowering of ramets in *A. yavellana* and *A. calidophilla* populations was investigated by the proportions of ramets in state of flowering and non-flowering in the study period. The total proportion of ramets flowered were 34.9% and 26.5% in *A. yavellana* and *A. calidophilla* populations respectively. When compared ramets in reproductive size class that were in state of flowering and non-flowering, 56.3% in *A. yavellana* and 46.2% in *A. calidophilla* had produced inflorescence (s) in the season of study (table 2). Ramet size relationship to flowering of ramets in the populations of *A. yavellana* and *A. calidophilla* had shown remarkable variations. It was found out that ramets that flowered in the populations of *A. yavellana* (90.7%) were mostly the medium sized ramets between 40 to 90 cm RD and the remaining flowered ramets (9.3%) had RD > 90 cm RD. None of the ramets whose rosette diameter < 40cm RD produced flower in the season and hence the minimum size to be attained by the ramet in the populations produce flower is 40 cm. On the contrary, out of the total flowered ramets in the *A. calidophilla* populations, 12.7% had RD between 60 to 90 cm and 87.3% had RD above 90 cm. As opposed to *A. yavellana*, minimum flowering size of ramets was found to be 60 cm RD. Extent of capsule production was assessed and compared based on mean number of capsules per raceme. Surprisingly different performance was observed as to production of capsules per raceme. Accordingly, the mean number of capsules produced per raceme were (6.3±0.41, n=6) and (24±0.81, n=6) in *A. yavellana* and *A. calidophilla* populations respectively. Despite the variations in the extent of flowering and fruiting, the mean number of seeds per capsule of *A. yavellana* (35.1±0.29, n=20) and *A. calidophilla* (37.3±0.30, n=20) populations studied (table 2). However, seed production varied from capsule to capsule.

Discussion

The population structure provides a snapshot of the current demographic situation, from which some insights can be drawn (Widyatmoko & Norton 1997). The population structure of *A. yavelllana* and *A. calidophilla* showed variations in their clone size. Analysis from sampled populations revealed that *A. yavellana* had greater number of both the genets and ramets. It also had greater number of multi-ramet genets as compared to *A. calidophila* which had greater number of single ramet genet.

Table 2
Extent of flowering, fruiting and seed set in *A. yavellana* and *A. calidophilla*

Species	Ramets flowered (%)	Capsule/raceme (Mean ±SD, n=6)	Seed/capsule (Mean ±SD, n=20)
A. yavellana	56.3	6.3± 0.41	35.1± 0.29
A. calidophilla	46.2	24± 0.81	37.3± 0.30

Variations in the number of genets and ramets/genet might be attributed to the relative magnitude of the two modes of reproduction and hence indicative of whether the species rely more either on vegetative propagation or seedling recruitment or both as a strategy to maintain their population. *A. yavellana* populations which had highest number of genets, ramets and multi-ramet genets might recruit both from seeds and vegetative propagation. This was also supported by the recruitment data in the quadrates established for the study (table 1). In clonal plants like aloes, a genet can be viewed as a population of ramets and the size of the clone is therefore determined by the number of ramets. The clone size of the genets that make up the population has some indicative of the probability of the survivorship of individuals, because increased rate of clonal growth increases the probability of genet survival. In another words, clonality compensates for the loss of parts of plants due to disturbance and can thereby considerably enhance genet longevity and prolong population persistence over long periods of time ((Pandey and Shukla 2001 and Witte *et al*., 2011). Thus, it is possible to state that genets in the *A. yavellana* populations that displayed large proportion of multi-ramet (2-12) might have the greater tendency to live longer. Similar finding was reported in the populations of *Aloe pulchrrima* in the latter situations (Fikre Dessalegn, 2011).

Size structure is the most conspicuous aspect of population structures and driven by genetic or internal factors such as their ability to rejuvenate new ramets that contribute to the small size class of the population or strategic resource allocation for vegetative growth and sexual reproduction such as flowering, fruiting and seed set. The observed variations in the size structure of ramets might also be resulted from the action of external factors to which their members have been exposed during or even before the study period. For example, size specific deaths, and such factors as competition together can account for much of the variation in number of individual ramets in different size class distribution (Crawley, 1997).

The life stage structure distribution showed that the number of genets varied in the four life stage classes (seedlings, juveniles, young adults and mature adults) recognized. Mature adults account greatest proportions (65.2% in *A. yavellana* and 54% in *A. calidophilla*) as compared to young adults, juveniles, and seedlings. Besides, the populations of *A. calidophilla* had only few juveniles and none of the genets was at seedling stage. Nordal *et al*. (1997) on *Papaver radicatum* reported that, “A high number of seedlings and juvenile plants may be indicative of dynamic vegetation under establishment; whereas a low number of seedlings and a high number of old rosettes would characterize a senescent population." Accordingly, it is reasonable to state that *A. calidophila* populations with none of genets at seedling stage, few juvenile genets but again with greater proportions of mature individuals fit to the second phenomena. Wabuyele (2000) reported a greater proportion of ‘juvenile’ and ‘young adult’ classes as opposed to the ‘seedling’ and ‘mature adults' on the population structure of maculate aloes in Kenya and Ethiopia.

Reproductive performance was assessed and compared taking into account the different successive events in their reproduction processes: recruitment, flowering, fruiting and seed set. When the two species studied were compared by their recruitment strategies, *A. yavellana* combined recruitments both from seedling establishments and vegetative suckers as opposed to *A. calidophilla* that solely depend on vegetative means despite good seed set. The aloes, being clonal plants, strongly benefit from their capability to reproduce asexually as well as sexually. Although most aloes produce high numbers of seeds, establishment of recruits is only occasional and dependent on several ecological factors. If they become successful to recruit from seed, the seedling can persist almost indefinitely as the mortality risk of genets is spread among their ramets. Hence, the long-lived perennial habit of the aloe plants leads to the predominance of older plants in aloe populations (Midgley *et al*., 1997). Therefore, survival of clonal perennials like aloes depends on population pressure on adult persistence and seedling recruitment. Thus, slightly increased rates of adult mortality or decreased rates of seedling recruitment might potentially cause local extinction. Accordingly, *A. calidophilla* populations with low rates of rejuvenation from seed might be subjected to difficulty in maintaining its populations provided that the prevailing mortality (e.g. eight of the ramets found died) and destruction of their habitats are un abated. However, recruitment ability by vegetative means or clonal growth is again important because of better survival relative to seedlings of offspring in new and sometimes difficult environments for reduced population turnover and dependence on seeds (Douhovnikoff *et al*. 2004).

The flowering of ramets in relation to their size showed that number of flowered ramets varies in different size classes in studied species. 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) and should attain a minimum of 40 to 60 cm to flower in *A. yavellana* and *A. calidophilla* respectively. The analysis made on the status of flowering and non-flowering of ramets showed that the proportion of non-flowering ramets is large (65%) as compared to flowering ramets in *A. yavellana* where as *A.calidophila* had (73%) of non-flowering ramets indicating that both species have moderately low rate of flower production for comparative purpose. Clonal plants are often characterized by reduced sexual reproduction (flowering, fruiting and seed production) compared with non-clonal species. Factors causing plants to make the switch from sexual to clonal growth are generally correlated with suboptimal environmental conditions (Beatty *et al*., 2008). Consequently, local population dynamics of many species may depend heavily on clonal reproduction (Weppler *et al*., 2006). Thus, both *A. yavellana* and *A. calidophilla* perform better by vegetative reproduction (ramet sprouting) to maintain their populations. However, ecological forces including human activities can modify the entire extent of their narrow geographic range, leading to their extinction. Rare species confined to only one or a few populations, such as *A. yavellana* have a greater chance of becoming extinct because the probability of all populations becoming extinct is higher as a result of environmental disturbance.

Conclusions

A. yavellana and *A. calidophilla are* two of the endemic and near endemic species of aloes confined in their distribution to low lands of southern Ethiopia. The population structure of *A. yavellana and A. calidophilla* described revealed that *A. yavellana* had greater number of both the genets and ramets. They also had greater number of multi-ramet genets. This is might be due to effective clonal growth (vegetative sprouting) and seedling recruitment in *A. yavellana*. The stage class distribution in studied species showed low number of seedling and juvenile and a high number of young and old rosette (mature adults) indicating dominance of long lived and old individuals. Absence of seedling recruitment in *A. calidophilla* in the season indicated that the species rely more on clonal growth that ensure the longevity of genet survival despite good seed set. Hence, *A. yavellana* and *A. calidophilla* differ in their extent and strategies of recruitments. This might be due to the difference in the viability of seed, i.e. the presence of active and viable seeds in *A. yavellana* and viable of seeds of *A. calidophilla* needs further investigation. Mortality in the season was found to be low in both species and confined only to ramet level.

Based on findings from recruitment and associated survival strategies, it is reasonable to state that the populations of *A. calidophilla* are nearly stable (stagnant) whereas *A. yavellana* populations are expanding in the season of study for comparative purpose. However, the statement must be taken cautiously for it is difficult to fully predict the future fate of the populations of the two species by taking into only one season data. Therefore, further research has to be conducted stretching for over long periods on the recruitment, survival and mortality.

Therefore, from the tremendous potential benefits of aloes and existing threats thereof it is suggested that the species should be conserved by both *in-situ* and *ex-situ* conservation strategies n their natural habitats. For example establishing nursery station that disseminate seedling of *Aloe* species for different purposes might minimize the threats to *Aloe* species in wild.

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AUTHOR'S PROFILE

Fikre Dessalegn Associate professor of Botany. BSc, MSc in Biology from Addis Ababa University, PhD in Botany from Addis Ababa University/University of Oslo. Currently a Vice President for academic and research at Hawassa University. Vice President at Dilla University 2007-2011. Main coordinator in the South of the project: *Children, young people and local knowledge.* His research interests are in the broader areas of Plant systematics, Biodiversity, Ethnobotany and Plant Ecology. Published more than ten articles in an International journals and author of a book: The Biology of Land Plants.