THE EFFECTS OF LEAF HARVESTING ON THE MORPHOLOGY, REPORODUCTION AND SAP PRODUCTION OF THE CAPE ALOE (*ALOE FEROX*)

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INTRODUCTION

The Cape Aloe, *Aloe ferox,* is one of the 150 South African *Aloe* species in the family Aloaceae (Reynolds 1950, Newton and Vaughan 1996, van Jaarsveld 1996). *Aloe ferox* has an extensive range (> 1000 km) occurring from Swellendam in the Western Cape to the Mtamvuna river in KwaZulu Natal, and in parts of the Free State and Lesotho (Hoffman 1988, van der Bank et al 1995). Cape Aloes inhabit a wide range of vegetation types (including renosterveld, fynbos, succulent karoo, Nama-karoo, and Eastern Cape grasslands) and a wide variety of soils (such as, shale, granite, limestone, quartzitic sandstone and mineral-poor soils) and thrive in both winter and summer rainfall regimes (Hoffman 1988, van der Bank 1995, Newton and Vaughan 1996, van Jaarsveld 1996).

The Cape Aloe, which can grow to 5 m tall, is a single stemmed tree-like *Aloe*, which produces large succulent leaves at the stem apex, forming a single large leaf rosette (branching into multiple stems occurs, but is rare). Leaves are bordered with short sharp teeth and in unharvested plants the lowest (oldest) leaves in the rosette die but are retained on the stem, protecting it against stem damage and fire (Newton and Vaughan 1996, van Jaarsveld 1996). Sexual maturity is reached after 4 – 6 years of age, at about 1 m in height (Newton and Vaughan 1996). Cape Aloes are bisexual and, every winter (May to October), each plant produces a single inflorescence at the stem apex that branches into erect racemes (flower stalks) giving the inflorescence a candelabrum-like form (Hoffman 1988, van Jaarsveld 1996). Many bright-orange (occasionally white or yellow) scentless tubular flowers are produced on each raceme. *Aloe ferox* is essentially a self-incompatible by definition (less than 33 % of self-fertilized flower produce fruits) relying predominantly on sunbirds and bees for pollination (Hoffman 1988). Temporal separation in the development of flowers on the same plant seems reduces self-fertilization – as a result, bees only visit one or two flowers at time before they move to the next plant – thus reducing wastage of reproductive material and increasing the percentage of successful fruit production (Hoffman 1988).

Genetic variation between populations of *Aloe ferox* is low partly due to the succulent habit of *Aloes* that enables them to survive in a wide-range of habitats, and the chemical composition of their leaves that renders them bitter and inedible, which reduce the normal selection pressures that act on other plants (van der Bank et al 1995, Newton and Vaughan 1996). Moreover, the species is thought to have reached genetic stability at it biogeographical age of approximately 0.28 million years and (van der Bank et al 1995), hybridization with other closely related species is common (Reynolds 1950, Hoffman 1988) – factors that also serve to explain the low genetic variation between *Aloe ferox* populations. Variations in morphological characteristics have however been noted between *Aloe* populations. Chemical characteristics vary significantly between populations, enabling chemical fingerprinting of plants where genetic fingerprinting is not possible (van der Bank et al 1995). Chemical fingerprinting may have important implications for the industry, as it will allow selection for harvested products from areas where favoured compounds are in higher concentration.

Aloe ferox is generally highly resistant to disease and pests, however occasional local acute infestations have been known to cause major damage to individual populations (van Jaarsveld 1996). Pests include the larvae of the *Aloe* snout weevil, which burrows into the stem core eventually resulting in crown rot, and white-scale insects, which burrow into the waxy cuticle causing damage and scaring on the leaf surface (Newton and Vaughan 1996, van Jaarsveld 1996). When infestation does occur *Aloe ferox* can usually recover well, thus pests and diseases are not a major threat to populations (van Jaarsveld 1998). The biggest potential threat to *Aloe ferox* at present is thought to be harvesting (Newton and Vaughan 1996). The evidence of a long history of importance and/or use of *Aloe ferox* by humans includes Khoi-San rock paintings, and the drawings and annotations of ancient Egyptian, Greek, and Roman physicians. Documented accounts of early use in South Africa include: medicinal use by early Settlers and indigenous people (1700s); export to Europe (1760s); and cultivation of plants on the Cape Peninsula (early 1800s) (Newton and Vaughan 1996, van Jaarsveld 1996). The *Aloe ferox* industry has grown since then and is listed as one of the world's most widely used medicinal plants yet local secondary processing of the raw-products has remained low – only a few *Aloe* factories have been established over the years (the first in Albertinia in the Western Cape 1986) (Newton and Vaughan 1996, van Jaarsveld 1996).

Today, *A. ferox* is South Africa's main commercial *Aloe* species the derivatives of which are used in medical preparations for treating a range of conditions including: gastric aliments (indigestion, constipation, heartburn, colic, spastic colon); cancer (as a cancer cell-growth inhibitor); skin related conditions (eczema, acne, sunburn, grazes, cuts, bites, stings and rashes); diabetes and more minor conditions such as hay fever and headache (van der Bank 1995, Newton and Vaughan 1996, Mac Farlane 2004). *Aloe ferox* derivatives are also use in cosmetics, and skin and hair care products because of their moisturising, soothing, anit-aging, scar reducing and skin and lymph cell-growth stimulating properties. *Aloe ferox* derivatives also have fungicidal, anti-inflammatory, and antiseptic properties (van der Bank 1995, Newton and Vaughan 1996, van Jaarsveld 1996). Uses of *Aloe ferox* have also been extended to the care of livestock – leaves soaked in drinking water helps rid animals of ticks, fleas and intestinal parasites (Newton and Vaughan, van Jaarsveld 1996). Dried plant parts are used in dry flower arranging and are also marketed as ornaments or curios. Live *Aloes* are considered ornamental and are highly frost resistant making them popular garden plants and *Aloe* leaves are even used to make jam (van der Bank 1995, Newton and Vaughan 1996, van Jaarsveld 1996).

Aloe ferox leaves are harvested for two plant products – a bitter pale-yellow leaf sap exuded by the epidermis of the leaf for the production of crystal bitters, and the fleshy inner tissues (fillet) for the production of *Aloe* gels (Newton and Vaughan 1996). Leaf sap, which functions as a deterrent against herbivory as well as a sealant for leaf wounds, is extracted (tapped) by cutting leaves from the base of the rosette, arranging them in a circular tower around a plastic-lined depression in the ground, and allowing the sap several hours to drain out of the leaves (Newton and Vaughan 1996). Sap collected in the depression is boiled and allowed to cool into a greenish-brown bitters crystal, which is exported in large quantities, or sold in smaller amounts to the local market (Newton and Vaughan 1996). Aloe gel is not a traditional extract and in the past leaves were left to rot. More recently however leaves are sold to processing factories where the fillet is crushed and strained and used to produce gel, which is marketed as such or dried and sold as a powder (Newton and Vaughan 1996, van Jaarsveld 1996).

Harvesting of *Aloe ferox* was estimated (in 1996) to bring in an annual income of R4 million per year to rural communities alone – a vital source of income for full-time tappers who rely solely on *Aloe ferox* as their only form of financial survival. They are joined on occasion by casual-tappers who rely on tapping to supplement their incomes in times of hardship (Newton and Vaughan 1996). Landowner's also benefit by allowing harvesting on their land in exchange for a percentage of the harvest (Newton and Vaughan 1996). Trade in bitters sap or gel far outweighs that of other plant parts so care is taken by harvesters to keep the plants alive for future tapping. Leaves from only the lower third of the leaf rosette (10 – 15 leaves) are harvested, and 2 – 4 cm at the base of the leaves are left to prevent damage to vascular tissues (Newton and Vaughan 1996, Mac Farlane 2004). Populations are only harvested every 18 – 36 months allowing plants to recover from the loss of leaf material. Plants suffering from insect-infestation or disease are not harvested to avoid weakening the plant further and possibly causing death (Newton and Vaughan 1996). Effort is also made by landowners to relocate plants growing in areas they plan to transform and to monitor harvesting activities on their properties (Newton and Vaughan 1996).

The vested interest in keeping the plants alive has inadvertently assured the preservation of populations at past harvesting levels although no formal conservation or resource management policy presently exists for *A. ferox* (Newton and Vaughan 1996). Effects of harvesting, which are not limited to the direct effect of leaf removal on the plant but include indirect effects – such as reduced reproductive output, reduced sap production and even trampling of recruits – have nonetheless raised concern for the long-term survival of populations (Newton and Vaughan 1996). This study addressed some of the indirect effects of harvesting on *Aloe ferox* on both population and individual plants levels. On the population level plant density, mortality, susceptibility to disease and size-class structure was compared between unharvested and harvested populations. On the individual plant level vegetative traits, flower production and sap production were compared between unharvested and harvested plants. One of few other studies on ecology of *A. ferox* by Hoffman (1988) assessed some of these characteristics for a population in Port Elizabeth, South Africa. Some of the findings by Hoffman (1988) are presented, and used for comparison, with the results found in this study below.

METHODS

Study area

Populations of *Aloe ferox* in the Uniondale/Willowmore region of the Western Cape Province were sampled during the July 2004flowering season. The vegetation in the broader area is classified as sub-tropical thicket, with Renosterveld vegetation dominating the higher lying regions and Succulent Karoo vegetation dominating the lower lying regions. In order to answer the key questions above, sampling sites falling into two harvesting treatments (harvested and unharvested) were selected. Six study sites, three harvested and three unharvested, where chosen in lower-lying areas with height above sea level ranging between 627 – 834 m. Within these sites the dominant species included *Asparagus* sp., *Carissa bispinosa, Crassula* sp., Mesembryanthemaceae genrea such as *Delosperma, Ruschia,* and *Glottiphyllum, Eriocephalus* sp., *Euclea undulata, Euphorbia mauritanica, Galenia* sp., *Grewia* sp., *Lycium* sp., *Pentzia incana, Portulacaria afra, Pteronia incana, Rhigozum obovatum, Rhus* sp., and *Zygophyllum* sp. Vegetation cover ranged from 40 – 50 %. Appendix 1 provides further details of each site.

Assessing the impact of harvesting on populations

Data collection

Three transects at each of the six study sites were sampled and the following variables measured for plants in each transect area: 1) plant height (from the ground to the top of the youngest leaf in the central spiral of the leaf rosette); 2) height to the base of the leaf rosette; 3) length of harvested stem; 4) leaf rosette diameter; 5) number of leaves; 6) number of racemes; 7) the length of each raceme and 8) phenophase index (where 1 = flower buds only, 2 = Open flowers and buds, 3 = Immature fruits < 2 mm long, and some flowers remain, 4 = Immature fruits >2 mm long, and flower remains rare, 5 = all flowers aborted) (see Appendix 1 for transect areas). One leaf per plant was also selected from the middle of the leaf rosette (since these leaves are of average age and size with respect to other leaves in the rosette) and the following variables measured: 1) leaf length; 2) leaf width and 3) leaf thickness. Some plants were branched into multiple rosettes (up to ten rosettes) so the number of rosettes for each plant was noted. Dead plants and plants with diseases (such as scale insect infestation, leaf cancer and crown rot) falling within the transect were also noted.

Data analysis

For the purpose of this study plants showing signs of white/red scale insect, fungus, crown rot, and leaf cancer where categorized and analyzed together as "diseased plants". Plant densities (total number of plants sampled/ha), dead plant densities (number of dead plants/ha) and diseased plant densities (number of diseased plants/ha) were calculated for each transect and a mean value of each density calculated per site. A Student's t-test for independent sample means was used to test for a significant difference in mean plant densities, dead plant densities and diseased plant densities between harvested and unharvested sites. The null hypothesis is that there is no difference between the means for harvested and unharvested sites (H_0: $\mu_{\text{unharvested}} = \mu_{\text{harvested}}$). A significant difference in the means for either plant density, dead plant density or diseased plant density will indicate that harvesting effects population density, mortality or susceptibility to disease respectfully.

Plant height measurements for all sites were collated for each treatment. The frequencies of plants in each 0.5 m height size-class (between 0.01 and 3.50 m) were determined and size-class frequency distributions created for unharvested and harvested treatments separately. A few unharvested plants occurred within harvested sites and these plants, as well as the number of dead plants (for both treatments), occurring in each size class were also represented in the size-class frequency distributions. Pearson χ^2 tests were constructed to test for significant differences in 1) the frequency data for all plants and 2) the frequency data for dead plants, between unharvested and harvested populations. To determine which size-classes are responsible for overall differences (if any) a test for differences in two proportions (from Basic Statistics and Tables in STATISTICA) was used to test the significance of differences between unharvested and harvested populations in each individual size-class. The height of the smallest harvested plant was taken as the minimum harvesting size.

Assessing the impact of harvesting on vegetative traits

Data collection

Using the transect data above, the vertical height of the leaf rosette (= plant height - height to the base of the leaves) was calculated for each plant.

Data analysis

A Pearson product-moment correlation matrix was constructed using STATISTICA for harvested and unharvested plants together to examine relationships between the following variables: 1) plant height; 2) leaf rosette height; 3) leaf rosette diameter; 4) number of leaves; 5) leaf length; 6) leaf width; 7) leaf thickness; 8) number of racemes and 9) mean raceme length. Due to the difficulty of measuring these variables for dead plants they were excluded from these analyses. Plants with multiple rosettes had proportionately larger rosette diameters and proportionately higher numbers of leaves and were therefore also excluded from the analyses to avoid confounding the result with the additional variable of multiple rosettes. As racemes reach phenophase 5 they wilt to a much shorter length relative to other racemes and were therefore also excluded in these analyses.

Linear regression analyses of the relationships between plant height and 1) leaf rosette height and 2) number of leaves were conducted for all unharvested plants and all harvested plants separately. Students t-tests were constructed to test for significant differences in 1) mean rosette height per unit plant height and 2) mean number of leaves per unit plant height between unharvested and harvested plants. Again, dead plants and plants with multiple heads where excluded from these analyses however plants bearing racemes in phenophase 5 were not excluded.

Assessing the impact of harvesting on reproductive traits

Data collection

Twenty flowering plants bearing racemes of a wide range of lengths were identified within the study area. The length of one raceme from each plant was measured and the number of flowers on it counted.

Data analysis

A linear regression analysis of raceme length (x) vs. the number of flowers per raceme (y) was performed for the 20 sampled racemes. The regression equation for the number of flowers with respect to raceme length for the 20 sampled racemes was used to estimate the total number of flowers per flowering plant in the transect data, where x is the total raceme length per plant (sum of raceme lengths for each flowering plant). Similarly, the equation for the number of flowers with respect to raceme length presented by Hoffman (1988) was used to estimate the number of flowers per flowering plant in the transect data, where the number of flower = 21.35x + 19.8, and x is the total raceme length per plant. A Students t-test for differences in the mean number of flowers per unit raceme length was constructed to compare the expressions explaining the relationship for the number of flowers vs raceme length from this study to that of Hoffman (1988).

The mean number of flowers per flowering plant was calculated for each transect and a mean value calculated per site. Using the transect data the density of flowering plants for each transect was calculated (# flowering plants/ha) and a mean value calculated per site. Similarly, the mean number of racemes per flowering plant, and the mean raceme length per flowering plant was calculated for each transect and a mean value of each calculated for each site.

Student's t-tests for independent sample means were used to test for significant differences in flowering plant density, mean number of racemes per flowering plant, mean raceme length per flowering plant and mean number of flowers per flowering plant between harvested and unharvested sites. Dead plants, and plants with multiple rosettes where excluded in all these analyses. Plants bearing inflorescences in phenophase 5 where excluded in analyses of mean raceme length per plant and mean number of flowers per plant. The null hypothesis is that there is no difference between the means for harvested and unharvested sites (H_0: $\mu_{unharvested} = \mu_{harvested}$). A significant difference in the means for either flowering plant density, mean number of racemes per plant, mean raceme length per plant or mean number of flowers per plant will indicate that harvesting effects reproduction of *Aloe ferox*.

Regression analyses were to determine the relationship between the number of flowers per plant and 1) leaf rosette height and 2) number of leaves, for harvested and unharvested plants from the transect data. Students t-tests were constructed to determine if there is a difference between the means for unharvested and harvested plants with respect to 1) the number of flowers per leaf (# flower/# leaves) and 2) number of flowers per unit rosette height (#flowers/rosette height (cm)). Again, dead plants, plants with multiple rosettes and plants bearing racemes in phenophase 5 were excluded from these analyses.

Assessing the impact of harvesting on sap production

Data collection

Twenty plants (9 harvested, 11 unharvested) within the transect area were randomly sampled for the following variables: 1) plant height; 2) leaf rosette height; 3) horizontal leaf rosette diameter and 4) number of leaves. For each plant, one leaf from each was selected (again from the middle of the leaf rosette) and the following variables measured: 1) leaf length; 2) leaf width, and 3) leaf thickness. This leaf was then cut from the plant and the thickness of both the epidermal layer and inner fillet tissue was measured. A bag to collect leaf sap was secured to the cut end of each leaf and left for 24 hours for the sap to drain into the bags. Wet leaf weight and wet sap weight was measured for each plant.

Data analysis

A correlation coefficient matrix for the 20 plants sampled for sap production was constructed using STATISTICA for harvested and unharvested plants together to examine relationships between the following variables: 1) leaf length; 2) leaf width; 3) leaf thickness; 4) leaf volume (leaf length x leaf width x leaf thickness); 5) leaf surface area (leaf length x leaf width); 6) fillet thickness; 7) epidermis thickness; 8) sap wet weight and 9) leaf wet weight.

A linear regression was conducted for sap weight vs. the external leaf variable (1 to 5 above) to which sap weight is most strongly related. Using the regression equation sap weight on leaf level was scaled up to whole plant level for each plant in the transect data. A Students t-test was constructed to test for differences in whole plant sap-production relative to plant height (calculated as whole plant sap mass / plant height) between unharvested and harvested plants.

RESULTS

Effect of harvesting on populations

A total of 586 plants, with a mean plant height of 0.73 m (± 0.54SD) were sampled in the transects (265 unharvested and 321 harvested). Plant heights ranged from 0.04 – 3.17 m for unharvested sites and 0.05 – 3.69 m for harvested plants. No significant difference in mean plant height ($p = 0.092$) was found between unharvested (0.78 m ±0.62SD) and harvested sites (0.68 m ±0.45SD). Harvested sites, on average, had higher mean values for plant density, dead plant density and diseased plant density, however the differences between unharvested and harvested sites were found to be non-significant at $p > 0.05$ for all densities (Table 1).

Table 1: Student's t-test for differences in the means between harvested and unharvested sites for total plant density, dead plant density and diseased plant density (where density = number of plants/ha). The t-values for all three densities are non-significant (at $p < 0.05$).

	Mean Unharvested	Mean Harvested	t - value	d.f.	p - value
Plant density (± s.d.)	1765 (±1098)	2309 (±654)	-0.737	4	0.502
Dead plant density (± s.d.)	81 (±57)	101 (±111)	-0.28	4	0.790
Diseased plant density (± s.d.)	69 (±56)	150 (±162)	-0.82	4	0.460

Size-class frequency distributions differed significantly between the unharvested and harvested populations ($\chi^2 = 54.4$, df = 6, $p < 0.001$). The proportion of plants in the 0.51 – 1m size-class was lower for the unharvested population (23 %) than for the harvested population (48.9 %), but higher for both the 1.01 – 1.50 m size-class and the 1.51 – 2 m size-class for the unharvested population (21.5 % and 7.2 % respectively) than for the harvested population (14.3 % and 1.9 % respectively), $p < 0.05$ in all three cases. Differences between the remaining size-class frequencies were not significant. No significant difference in the frequency distribution of dead plants was found between unharvested and harvested sites ($\chi^2 = 3.38$, df = 4, $p < 0.50$).

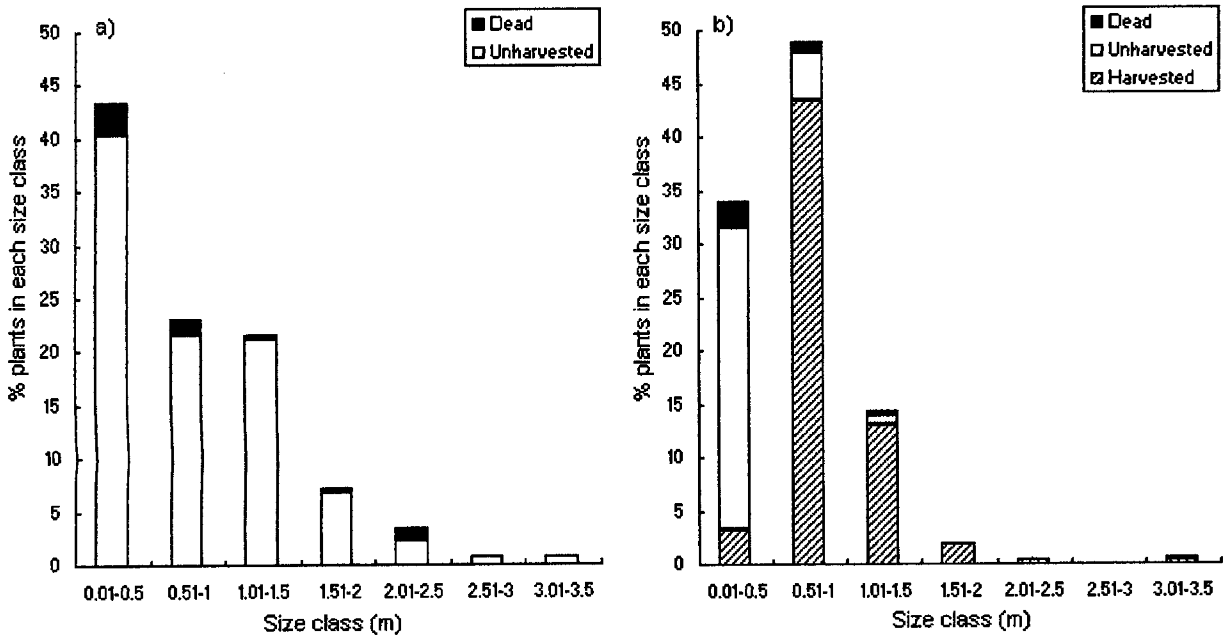

Figure 1: Size class frequency distributions of dead, harvested and unharvested plants for a) harvested (n = 265) and b) unharvested (n = 321) sites separately.

Juvenile's (plants < 0.5 m tall) account for the largest proportion of the plants in unharvested sites (43.4 %). Each successive size-class in the unharvested population accounts for a decreasing proportion of the population, with the largest size-class (3.01 – 3.50 m) accounting for only 0.8 % of the population, giving the distribution an inverse J-shape (Figure 1). For the harvested population the size-class frequency distribution has a normal shape, which is skewed to the right, with the 0.51 – 1.00 m size-class accounting for the highest proportion (48.9 %) of the population (Figure 1).

Plants < 1 m tall dominate in both the unharvested and harvested populations (66.4 % and 71.9 % respectively). All sexually immature plants (< 0.35 m) fall into the juvenile size-class resulting in high proportions of immature plants in both the unharvested and harvested populations (79 % and 71 % immature respectively). Very few plants of harvesting size (> 0.30 m) escape harvesting. In harvested sites, only 20 % of plants larger than 0.30 m escaped harvesting (Figure 1). The proportion of these plants with multiple rosettes is 28%. This is comparatively high compared to the proportion of harvested plants (3 %) and unharvested plants (7 %) that have multiple rosettes.

Effect of harvesting on vegetative traits

The strongest correlation between individual plant variables was for the relationship between leaf rosette height and the number of leaves per plant (Table 2). Both variables also demonstrated the strongest relationship with plant height than any of the other variables. The mean leaf rosette height per unit plant height for unharvested plants is significantly higher than the mean for harvested plants (0.66 ±0.27SD and 0.33 ±0.12SD respectively, where $t = 15.88$, d.f. = 504, $p < 0.001$. Similarly, the difference in mean number of leaves per unit plant height is significant ($t = 9.03$, d.f. = 457, $p < 0.001$), with a higher mean value for unharvested plants (0.64 leaves/m ±0.36SD) than for harvested plants (0.39 leaves/m ±0.17SD).

Table 2: Correlation coefficient matrix for all plants sampled at three unharvested and three harvested sites. Correlations exclude dead plants, plants with multiple heads or plants bearing racemes with aborted flowers (i.e. in phenophase 5). For each correlation the top value is the r-value and the bottom value is the n-value. Pearson Product-moment r-values are all significant at $p < 0.001$ except for those marked with a *, which are only significant at $p < 0.05$.

	Leaf rosette height	Leaf rosette diameter	No. of leaves	Leaf length	Leaf width	Leaf thickness	No. of racemes	Mean raceme length
Plant height	0.63 502	0.56 502	0.43 459	0.42 370	0.33 370	0.24 * 370	0.47 153	0.52 153
Leaf rosette height		0.68 504	0.73 459	0.66 370	0.51 370	0.40 370	0.69 153	0.62 153
Leaf rosette diameter			0.62 459	0.71 370	0.47 370	0.50 370	0.58 153	0.55 153
No. of leaves				0.63 370	0.35 370	0.37 370	0.58 153	0.50 153
Leaf length					0.49 370	0.40 370	0.64 153	0.55 153
Leaf width						0.24 * 370	0.57 153	0.47 153
Leaf thickness							0.30 153	0.39 153
No. of racemes								0.57 153

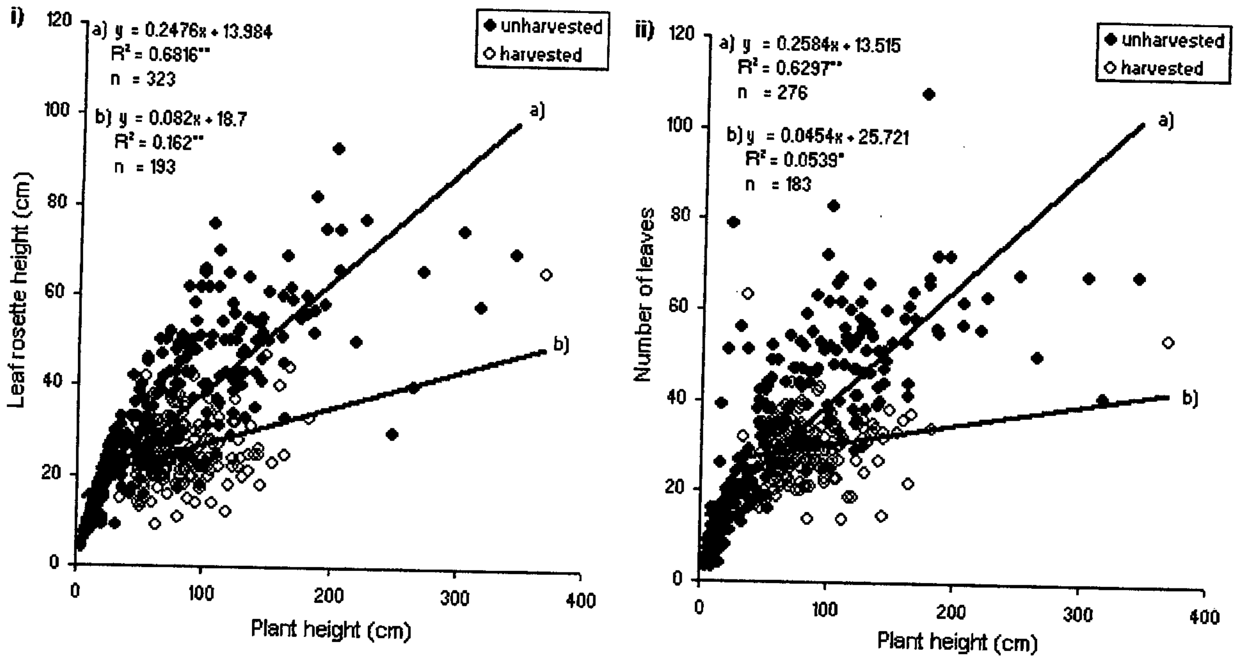

Figure 2: Regression analyses for plant height versus i) leaf rosette height and ii) number of leaves for a) unharvested and b) harvested plants separately. Values for r^2 are significant at $p < 0.01$* and 0.001.**

Effect of harvesting on reproductive traits

The number of flowers per raceme was strongly related to raceme length ($r^2 = 0.95$) at a significance level of $p < 0.001$. The linear relationship between the number of flowers and raceme length was explained by the equation $y = 13.299 * x - 64.712$ (where y = number of flowers and x = raceme length). The equation describing the relationship for the number of flowers vs. raceme length from Hoffman (1996) produced a significantly higher estimate of the mean number of flowers per unit raceme length (21.58 flowers/cm ±0.57SD) than was estimated using the regression equation for the relationship calculated in this study (12.665 flowers/cm ±0.78SD, t = -114.15, d.f. = 305, $p < 0.001$).

Table 3: Student's t-test for differences in the means between harvested and unharvested sites for flowering plant density, mean number of racemes, mean raceme length, and number of flowers per plant, per unit rosette height and per leaf.

	Mean Unharvested	Mean Harvested	t - value	d.f.	p - value
Flowering plant density (±s.d.)	703 (±472)	408 (±239)	-0.972	4	0.386
Mean number of racemes per flowering plant (±s.d.)	6 (±0.0)	3 (±1.0)	-4.298	4	0.013
Mean raceme length per flowering plant (cm) (±s.d.)	35.75 (±2.8)	26.7 (±6.5)	-2.232	4	0.089
Mean number of flowers per flowering plant	2660 (±225)	1102 (±574)	-4.38	4	0.0119
Mean number of flowers per unit rosette height	53 (±22.71)	38 (±20.40)	3.88	151	< 0.001
Mean number of flowers per leaf	53 (±23.98)	35 (±21.23)	4.25	136	< 0.001

Unharvested plants have a higher mean number of flowers per plant and a higher mean number of racemes per plant than harvested plants, although mean raceme length between unharvested and harvested sites does not differ significantly (Table 3). Flowering plant density does not differ significantly between harvested and unharvested sites (Table 3). A strong relationship was found for the relationship between leaf rosette height and both the number of racemes per plant and the mean raceme length per plant (Table 2). Pearson correlation coefficients calculated for the number of flowers per plant vs. 1) leaf rosette height and 2) number of leaves are significant at $p < 0.001$ with r-values of 0.74 and 0.59 respectively. Mean number of flowers per unit rosette height and per leaf is higher for unharvested plants than for harvested plants (Table 3).

The effect of harvesting on sap production

The strongest relationships between internal and external leaf variables were for the following relationships: 1) fillet thickness vs. leaf volume, 2) epidermis thickness vs. leaf volume, 3) wet leaf mass vs. leaf volume and 4) sap weight vs. leaf surface area (Table 4). Although sap weight is related to leaf volume, it is not related to leaf thickness thus, a linear regression analysis was performed for sap weight vs. leaf surface area and the relationship was explained by the following equation: sap weight= 0.0098*leaf surface area – 2.7888. This regression equation was used to calculate total sap weight from values for total leaf surface area (leaf surface area x number of leaves) for plants sampled in the transects. The mean amount of sap produced per unit plant height is significantly higher for unharvested plants than for harvested plants (means are 193.5 g/m and 147.4 g/m respectively where $t = -4.36$, d.f. = 365 and $p < 0.001$)

The strongest relationships between the internal variables are for epidermis thickness vs. 1) wet weight and 2) fillet thickness (Table 4). The next strongest relationship is for wet weight vs. fillet thickness. Of the internal variables sap weight is only significantly related to epidermis thickness.

Table 4: Correlation coefficient matrix for the 20 collected leaves. Pearson Product-moment r-values are significant at $p < 0.05$*, $p < 0.01$, $p < 0.001$***, or not significant^{ns}, n = 20 for all correlations.**

	Leaf width	Leaf thickness	Leaf volume	Lea surface area	Fillet thickness	Epidermis thickness	Sap weight	Leaf wet weight
Leaf length	0.83 ***	059 **	0.93 ***	0.98 ***	0.71 ***	0.72 ***	0.69 ***	0.68 ***
Leaf width		0.55 *	0.82 ***	0.88 ***	0.58 **	0.74 ***	0.69 ***	0.63 **
Leaf thickness			0.77 ***	0.56 ***	0.93 ***	0.67 **	0.35 ^{ns}	0.60 **
Leaf volume				0.95 ***	0.86 ***	0.78 ***	0.56 **	0.72 ***
Leaf surface area					0.68 ***	0.72 ***	0.67 **	0.67 ***
Fillet thickness						0.65 **	0.40 ^{ns}	0.59 **
Epidermis thickness							0.55 *	0.68 ***
Sap weight								0.32 ^{ns}

DISCUSSION

The effect of past levels of harvesting on *Aloe ferox* in the Uniondale/Willowmore region was examined on both population level and individual plant level in order to address important factors such as survival and reproduction as well as sap production, all of output in each population. The lower frequencies in the harvested population may result in a decrease in the number of recruits in the future, and may already have been responsible for the presently low proportion of juveniles in the population. It is important that size-structure of these populations are monitored in the future to determine the effects of current and future harvesting levels on the populations.

In harvested sites, harvesting effort on population level is intense – very few plants (only 20%) over the minimum harvesting size of 0.30 m escape harvesting. Plants > 30 cm that escaped harvesting have a higher proportion of individuals with multiple heads than for both harvested plants, and plants in unharvested sites. This result may be site specific since most of the multiple-headed plants that escaped harvesting are from the harvested site called Pietslaagte, however it still indicates an overall discrimination against multiple-headed plants by harvesters.

Morphological variation occurs between different populations but for the most part *Aloe ferox* generally have a highly uniform morphology within populations. In other words the plants generally look the same and small plants look like miniature versions of large plants. The highly significant correlations between vegetative traits measured in this study demonstrate this point. Leaf rosette height and the number of leaves per plant were both strongly related to plant height and are the traits that are directly affected by harvesting. Since the basal leaves of unharvested plants die as new leaves are produced it can be argued that the loss of leaves (or decrease in rosette height) by harvesting is similar to the loss of these leaves by natural leaf death. This is not the case however since harvested plants where found to have significantly lower means for leaf number and leaf rosette height (with respect to plant height). Thus, in some cases it was inferred that any plant traits strongly related to leaf number or leaf rosette height would also be affected in some way by harvesting.

Flowering plant density did not differ between harvested and unharvested populations indicating that harvesting does not affect the ability of plants to produce an inflorescence. The number of racemes per inflorescence was however lower for harvested plants, which explains the reduction in the number of flowers per plant found for harvested plants. Flower production calculated as the number of flowers produced per leaf is also reduced in harvested plants. The effect is magnified by the significant reduction of leaves in harvested plants. In other words between a harvested and an unharvested plant with the same number of leaves, harvested plants already produce fewer flowers per leaf. In addition to this harvesting significantly reduces the number of leaves per plant further lowering the reproductive potential of harvested plants. The effect of reduced reproductive output has not resulted in a decrease in population density, but size-class frequencies already show a reduction in the proportion of juveniles recruited in the last couple of years. The long-term effects of reduced reproductive output and recruitment can eventually lead to local extinctions of harvested populations. It is important that size-structures of harvested populations are monitored in the future to determine the effects of current and future harvesting levels on the populations, and so early action can be taken to population decline.

The relationships between the internal and external leaf traits, and their relationships between themselves produced some interesting insights into sap production. Since sap weight is not related to wet leaf mass and fillet thickness, sap production should not be directly affected by decreases in the water content of the inner fillet (due to drought for example), allowing the plant to chemically protect itself even in times of water stress. Sap weight was related more strongly to leaf surface area than it was to leaf volume, due to its non-significant relationship to leaf thickness, and the only internal variable it was related to is epidermis thickness. Sap is produced occurs in the epidermis and is likely to be related to epidermis volume. Epidermis volume should also correlate very strongly with leaf surface area. Sap production, scaled up to whole the whole plant level, is significantly lower per leaf in harvested plants, and therefore even lower at whole plant level due to the significant reduction of leaves by harvesting.

The nature of the aloe trapping industry has traditionally promoted the preservation of live plants and formal resource management plans for *Aloe ferox* were probably not considered a necessity at past harvesting levels. With the growing market for *Aloe ferox* products harvesting levels will undoubtedly increase, putting pressure on the resource. This study shows that harvesting has large effects on an individual plant level causing significant reductions in reproductive output and sap production. Effects on population level can be seen in the changing size-structure of the harvested population and although changes still appear to be minimal, effects will increase rapidly with increased harvesting pressures. *Aloe ferox* plays a vital socio-economic role in the lives of a large number of people living in rural areas around South Africa, who not only depend on harvesting

Cape Aloes for their sole source of income but whose life-styles revolve entirely around activities related to harvesting and preparing crystal bitters. *Aloe ferox* also supports a considerable export market that has, until recently, been a largely unrecognized industry and whose full social and economic potential has not yet been, but most definitely soon will be properly recognised (Newton and Vaughan 1996).

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APPENDICES:

Appendix 1: Table of site information for the sample area in the Uniondale/Willowmore region of the Western Cape. Table includes coordinates, elevation, area sampled, plant density and vegetation cover for each transect.

Site name	Treatment	Transect no.	Transect starting point		Elevation (m above sea level)	Transect area (m^2)	No of plants	Density (plants/ha)	Vegetation cover (%)
De Tuine	harvested	1	33 30 48.7 S;	23 06 12.7 E	827	250	37	1480	40
De Tuine	harvested	2	33 30 48.9 S;	23 06 12.5 E	834	250	37	1480	40
De Tuine	harvested	3	33 30 47.9 S;	23 06 14.3 E	831	250	44	1760	55
Rooikrans	harvested	1	33 31 13.2 S;	22 56 58.7 E	669	70	35	5000	40
Rooikrans	harvested	2	33 31 13.2 S;	22 56 58.3 E	663	210	34	1619	35
Rooikrans	harvested	3	33 31 12.6 S;	22 56 56.3 E	658	175	33	1886	50
Pietslaagte 1	harvested	1	33 32 38.3 S;	22 55 44.2 E	697	140	37	2643	40
Pietslaagte 1	harvested	2	33 32 36.9 S;	22 55 44.0 E	697	175	35	2000	40
Pietslaagte 1	harvested	3	33 32 35.0 S;	22 55 44.6 E	695	100	29	2900	45
Buffelsklip 1	unharvested	1	33 32 31.0 S;	22 54 10.3 E	634	170	34	2000	50
Buffelsklip 1	unharvested	2	33 32 29.4 S;	22 54 09.6 E	635	140	33	2357	55
Buffelsklip 1	unharvested	3	33 32 28.9 S;	22 54 09.4 E	641	210	34	1619	50
Buffelsklip 2	unharvested	1	33 32 21.0 S;	22 53 46.0 E	630	130	34	2615	60
Buffelsklip 2	unharvested	2	33 32 21.5 S;	22 53 46.3 E	627	145	41	2828	60
Buffelsklip 2	unharvested	3	33 32 21.8 S;	22 53 46.7 E	630	120	33	2750	60
Pietslaagte 2	unharvested	1	33 32 33.0 S;	22 55 33.3 E	706	980	56	571	50