Is buchu (*Agathosma betulina*) harvesting sustainable? Effects of current harvesting practices on biomass, reproduction and mortality

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Is buchu (*Agathosma betulina*) harvesting sustainable? Effects of current harvesting practices on biomass, reproduction and mortality

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Abstract: *Demand for the oil of buchu (Agathosma betulina) has increased significantly in the last few years and buchu is not yet extensively cultivated. Most of the buchu currently consumed is harvested from wild populations, and some concern has been raised about the conservation status of this endemic species. Consultations with stakeholder groups, regarding the effect of harvesting frequency on plant regrowth, oil quantity and quality, plant reproductive behaviour and plant mortality were carried out. This paper addresses the following questions: 1) How does plant leaf and shoot biomass and oil yield vary with age? 2) At what age and size do buchu plants produce flowers? 3) What proportion of seedlings survives the summer drought characteristic of the region? 4) What is the impact of different harvesting frequencies on plant biomass and mortality?*

Correlations between variables associated with the structure, reproduction and oil yield of 26 buchu plants were determined. The relationship between plant volume and dry mass was established and used in subsequent analyses to circumvent the need to destructively sample buchu plants in the field. Results confirm that the leave-shoot ratio diminishes with age, and although there is considerable variation, oil yield increases with age. If this relationship is confirmed with further sampling, a shift in the population toward younger individuals, as a result of frequent harvesting, will result in a lower oil yield per mass unit. Buchu plants with less than 2 years of growth since harvesting or fire do not produce flowers, and the number of flowers and fruits increases if allowed to reach 3 or 4 years of vegetative growth. Seedling survival rates in the wild vary depending on environmental factors such as post-fire age, rainfall, temperature and microhabitat, and a large percentage do not survive the summer drought characteristic of the region. Regrowth of coppiced plants is affected by the past history of harvesting. Plants that have never been harvested have significantly more regrowth than plants harvested once a year and plants harvested once every two years. However, mortality rates are significantly higher for plants that are harvested once a year, indicating that high intensity harvesting negatively affects buchu survival. To successfully conserve buchu populations in the wild and simultaneously guarantee a profitable industry, sustainable harvesting practices have to be implemented. This study supports traditional harvesting practices, which recommend harvesting cycles of 3 years. This will allow buchu plants to generate higher oil yields, to produce viable seeds, and to re-establish carbohydrate reserves between harvesting events, which will lead to higher regrowth rates and reduced mortality.

Keywords: sustainable harvesting, buchu, resprouter, seedling survival, harvesting practices, poaching.

INTRODUCTION

"Buchu" (*boegoe* in Afrikaans), is the common name given in South Africa to members of the Rutaceae family, which includes useful aromatic plants. Many of them produce oils and extracts that are used for a wide variety of purposes (van Wyk & Gericke, 2000).

Khoi and San people used buchu for its medicinal properties and fragrance long before the arrival of the European settlers to the Cape region (Simpson, 1998; van Wyk & Gericke, 2000). Buchu tea, buchu vinegar and buchu brandy are used in traditional and conventional medicine especially to treat kidney and urinary tract problems. These products are produced and consumed locally to treat stomach complaints, fever and rheumatism (Roberts, 1999; Coetzee *et al.*, 1999; van Wyk & Gericke, 2000). However, most of the buchu harvested today is distilled and the essential oils are exported to Europe (WESGRO, 2000; Buchu Forum, 2002b). Some components are used in the perfume industry or in pharmaceutical formulas. The highest demand, however, comes from the food industry, where it is used as a food flavour enhancer, or as a substitute for black currant aromas (Simpson, 1998; Grassroots Natural Products, 2001; Lis-Balchin *et al.*, 2001; South African Museum, 2001) (Appendix 1).

While many species within the family produce useful extracts, currently only two species (*Agathosma betulina* and *A. crenulata*) have commercial value (van Wyk & Gericke, 2000). At present buchu demand exceeds supply. Consequently prices have strongly increased (Buchu Forum, 2002b). Because it is not yet extensively cultivated, the demand is met from the harvesting of wild populations (Raath & Coetzee, 2000). Prices are mostly driven by exports to overseas market, with an estimated value of R20 million (WESGRO, 1999). At present, 1 kg of fresh material costs between R40 and R60 (R8.50 = US$ 1). The price of 1 kg of dry leaves is ca. R320. Oil is obtained from fresh material with a yield of 1 or 2%, and its market price reaches R5,500-6,000/kg.

The quantity of buchu harvested from the wild is unknown and probably underestimated in the few economic studies available (WESGRO, 1999, 2000). Unpublished estimates suggest that the buchu industry generates about R25 million a year (Raath & Coetzee, 2000). However, international demand for natural flavours and fragrances is expected to rise by over 7%per year in the next decade (WESGRO, 2000).

As a consequence of the high prices, overharvesting is the main threat for many commercially exploited medicinal plants (Cunningham, 1991) including buchu. Concern has been raised about the conservation status of the species, danger of extinction in the wild being the worst scenario (Lovell, 2000). Stakeholder opinions are divided about the impact of current harvesting practices on the long-term survival of buchu. Some qualified conservationists affirm that buchu will be driven to extinction in the wild within the next 5 to 10 years. They argue that frequent cutting reduces plant size and resprouting vigour, causing eventually death of the individual. Additionally, frequent cutting reduces flower and seed production and therefore impacts on the long-term survival of local populations.

However, some local farmers hold less extreme positions. They suggest that because buchu is a widespread species, not all the populations are equally threatened. Even if extinction happened locally, it would not affect the species as a whole. Moreover, the patchy distribution of buchu makes it very difficult for the harvesters to find all the individuals at once. Often some plants are missed during the harvesting process and they succeed in producing seeds.

Local concerns for the sustainability of the industry have also been raised due to the high prices of the harvested material (Raath & Coetzee, 2000). Illegal harvesting has become a major social and environmental problem. Even though some farmers would like to harvest only every two or three years, illegal harvesters are cutting buchu on private farms and in nature reserves more frequently. As a result, farmers are also harvesting every year, at least in the more accessible zones of their farms, to avoid economic losses due to poaching (Buchu Forum, 2002b).

Cultivation of buchu seems the only viable alternative to service the ever-increasing demand for the product and to safeguard the species in the wild (Blomerus, 2002). Although many farmers are already cultivating buchu, more than half of the production still relies on wild populations (Raath & Coetzee, 2000; WESGRO, 2000). A shortage of seeds, seedlings and the low rate of success from propagation by cuttings prevent widespread cultivation Buchu Forum, 2002a) and indicate that overharvesting and poaching will continue for some time.

Different *Agathosma* species have different chemical characteristics and proportions of desirable oil components (Collins *et al.*, 1996; Posthumus *et al.*, 1996). Although both species (*A. betulina* and *A. crenulata*) are affected by overharvesting and poaching, the focus of this study is on *A. betulina*. Limonene, menthone, isomenthone, pulegone, diosphenol, mercapton-menthone and acetylthio-menthone are the main chemical components of *A. betulina* (Collins et al., 1996; Posthumus et al., 1996). Demand for *A. betulina* is much higher than that for *A. crenulata*, due to its larger content in desirable oil components, especially diosphenol and 8-mercapto-p-menthan-3-one (Kaiser *et al.*, 1975; Collins *et al.*, 1996) and lower pulegone concentration, which is potentially toxic (van Wyk & Gericke, 2000). Prices for *A. betulina* are also higher (up to R60 per kilo of fresh material) and so is the environmental and economic pressure.

A. betulina is a multi-stemmed shrub that can reach up to 2 metres high. It is also called 'round-leaf buchu' due to the shape of its leaves. Flowers are pink or white and star-shaped (Bond & Goldblatt, 1984). *Agathosma* species have visible oil glands in the leaves, which are responsible for the aromatic properties (van Rooyen & Steyn, 1999). "Round-leave buchu" is endemic to the mountains of the Western Cape Province, mostly between Nieuwoudtville and Tulbagh. It occurs in rocky sandstone slopes among other fynbos species (Bond & Goldblatt, 1984) often in small clusters of individuals with variable density. It resprouts strongly after fire or after being harvested (van Wyk & Gericke, 2000). It is a typical character of resprouters to have large underground storage organs (Cunningham, 2001), and this is the case for *A. betulina.*

Despite being a crucial conservation issue, little research has been carried out on buchu. Many basic questions regarding its biology, physiology and ecology have not been answered.

Consultations with stakeholders (farmers, harvesters, conservationists and distillers) have highlighted the effect of harvesting frequency on plant regrowth, oil quantity and quality, plant reproductive behaviour and plant mortality as the most important issues to be considered. I addressed several of these concerns by investigating the following questions:

- How do leaf and shoot biomass and oil yield vary with age? Local stakeholders affirm that buchu biomass increases as the plant ages, but that the leave-shoot ratio diminishes. Leaves become smaller, they disappear from the lower portions of the bush and stems grow thicker. This is a generalised concern for local farmers and oil industry managers because oil is found predominantly in the leaves (Endenburg, 1972) and therefore the amount of oil extracted per kilogram of fresh material diminishes with age. However older plants have a better oil yield than younger ones, because of the lower water content of the leaves in older plants. A general increase in harvesting frequency (and consequently the widespread harvesting of younger plants) could therefore diminish the amount of oil obtained per unit mass harvested.

- At what age and size do buchu plants produce flowers and what proportion of seedlings survive the summer drought characteristic of the region? Anecdotal evidence suggests that *A. betulina* only produces flowers after two years of vegetative growth since being cut or burnt. However, the first year they flower, they do not produce flowers in large numbers, and many of the flowers abort, or the fruits fail to produce seeds. By harvesting plants before they have been able to produce seeds, several stakeholder groups are concerned that this will eventually lead to the local extinction of these populations. They are also of the view that very few of the seedlings that germinate under natural conditions survive to adulthood. Therefore, the recently adopted practice of removing seedlings from the natural environment to transplant them in cultivated land is thought to have little impact on the long-term survival of local populations.

- What is the impact of different harvesting frequencies on plant biomass? Does high frequency harvesting increase mortality? This is perhaps the greatest concern of local stakeholders, who suggest that high frequency harvesting leads to a lower regrowth rate (i.e. smaller shrubs) and could eventually result in the death of individuals. There is thus concern that illegal and frequent harvesting could potentially result in the local extinction of the species over large areas.

The ultimate aim of this study was to provide stakeholders with scientific evidence of the impact of different buchu harvesting practices and to suggest guidelines for the conservation of wild buchu populations so as to guarantee a sustainable and profitable industry. It was beyond the scope of this investigation to undertake long-term controlled experiments to fully answer the response and effect of harvesting practices on the survival and conservation status of the species. Nonetheless, answers to some of the more urgent questions regarding sustainable buchu harvesting practices have been provided in this preliminary analysis.

METHODS

Study site

Data were collected at 7 sites in the southern Cederberg (Table 1) between October 2002 and January 2003. Six farms were situated near Citrusdal (Baadjieskraal, Liermanskloof, Boskloof, Allandale, Elandskloof and Bergsoom) and one in the Cederberg Nature Reserve (Uitkyk Pass).

Table 1: Study sites in which buchu data was collected, showing physical attributes and type of data collected. (Se: tagging of seedlings for survival analysis; Me: biological and physical measurements; Ha: harvesting of buchu individuals to obtain biomass relationships).

Farm	*Coordinates*		*Altitude (m.a.s.l.)*	*Aspect*	*Se*	*Me*	*Ha*
Baadjieskraal	32 40.714 S	19 05.492 E	700	W/SW	✓	✓	✓
Liermanskloof	32 43.118 S	19 06.301 E	700	SW/S			✓
Boskloof	32 45.134 S	19 05.029 E	500	SW		✓	
Allandale	32 39.907 S	19 06.459 E	750	SW	✓		
Elandskloof	32 39.202 S	19 07.793 E	700-950	SW		✓	
Bergsoom	32 38.394 S	18 58.304 E	700	SW	✓		
Uitkyk Pass	32 24.405 S	19 06.552 E	900-1100	SW/SE		✓	✓

Allometric and age-related relationships

To avoid having to sample all study individuals destructively, a total of 26 individuals of different age classes were harvested and volume-biomass relationships determined (Appendix 2). Among the harvested individuals, 10 grew in the Cederberg Nature Reserve (Uitkyk Pass), 9 in Baadjieskraal and 7 in Liermanskloof.

Prior to harvesting, a complete set of variables was measured *in situ* in an attempt to control for differences in abiotic influences on the sampled individuals. These include GPS coordinates, altitude, aspect, slope, year of the last fire and some habitat parameters (soil depth, rock cover, rock size, distance to nearest *Protea nitida* and habitat type). Fire age was obtained through interviews with farmers and Western Cape Nature Conservation Board (WCNCB) authorities.

Plant height and both perpendicular axes were measured to calculate shrub volume. For this purpose the shrubs were considered as oblate spheroids (i.e. an ellipse rotated about its minor axis) and the volume was calculated according to the formula $\mathbf{V = a^2 * b * \pi / 6}$, where **a** is the minor axis (either height or the average axis, whichever is smaller) and **b** is the major axis (Phillips & MacMahon, 1981).

Other biometric measurements included the canopy cover of each plant (using a 50x50 cm grid and expressing it as a percentage of cover within a square meter), the number of stems (measured at 10 cm from the ground) and mean stem diameter (also at 10 cm above the ground and with 10 replicates).

Two reproductive parameters were considered. The number of flowers and fruits per plant, were ranked as follows: **0** for no flowers or fruits, **1** for 1 to 100, **2** for 100 to 1 000, and **3** for more than 1 000. I also recorded the number of seedlings from the last year in a radius of 2 m around each individual. Any signs of herbivory or disease of adults were also recorded in the field.

The plants were then cut as close to the ground as possible, labelled and the wet weight measured. Once in the lab the stems and leaves were separated manually. Ten replicates of 10 cm stems were randomly selected to measure the internode length and the number of leaves. Two groups of 50 leaves were randomly selected to measure the leaf-area using a leaf-area meter. A 15.0 g sample of the leaves was removed for the oil analysis. Another replicate was also separated as a control sample and both stems and leaves (including the replicate) were dried in the oven for 5 days at 70°C. Then, the samples were weighed to obtain the dry weight and the leaf-shoot ratio was calculated from these data. The relationship between volume and biomass was derived using a least squares regression between dry weight and volume.

Also, a correlation matrix was developed to explore the relationships between all the variables measured.

The 15.0 g subsample of leaves of the 26 harvested individuals was sent to Grassroots Natural Products for analysis. The essential oils were extracted through distillation using a Clevenger apparatus and a Liebig condenser device. The resulting oil and distilled water were separated by density. Extracted oil was weighed and the percentage yield of oil calculated on a mass/mass ratio.

Seedling survival

Although classified as a resprouter, seedling survival experiments were set up to assess the percentage of seedlings that survive the critical summer drought period in the wild. Three groups of 50 seedlings were tagged in the second week of October using numbered aluminium tags. The vegetation at three sites was 8 months old having been burnt in February 2002. An additional 25 seedlings were tagged in 10-year-old vegetation. The sites were visited regularly during the summer to check on seedling survival. Survival rates are expressed as a percentage of the total tagged at the start of the experiment.

Rainfall and temperature data were obtained from Schulze (1997) for each site with two objectives: 1) to explain possible differences among sites; 2) to understand the possible causes of seedling mortality.

The impact of harvesting frequency on plant biomass

The same physical and biological parameters described above for the volume-biomass relationships were measured for 110 individuals within the 7 different study sites. Information about the age of the last fire, the year and month of last harvest and the frequency of past harvesting practices for each individual were recorded.

Three sites were selected, each representing a different harvesting frequency, ranked from high to low harvesting intensity. The treatments were: (1) annual (or more frequent) harvesting at Elandskloof farm for the last 5 or 6 years; (2) harvesting every two or three years at Baadjieskraal farm for the last three decades; (3) no harvesting at all at Uitkyk Pass within the Cederberg Nature Reserve. However, in March 2002 some plants were illegally harvested within the Nature Reserve.

In order to reduce variability in fire age, 4 year-old post-fire sites were selected. Rainfall and temperature data were also determined from Schulze (1997) for the three sites. In all three cases, plants had been cut one year before this study was carried out. Above-ground plant volume after one year 'sregrowth was determined. I used the volume-biomass regression equation described above to infer the dry weight for each one of the plants of the 3 sampling groups. The differences among the biomass values were statistically compared using a test of analysis of the variance (ANOVA) after log-transforming the data. Tukey and Scheffe *post hoc* tests were used to establish between site differences (Zar, 1998).

The impact of harvesting frequency on plant mortality

Any sign of mortality or disease was consistently recorded throughout the sampling. Plants showing complete or partial death of above-ground parts were classified into one of the following categories: **1** for plants with none of the above-ground material dead or presenting any sign of yellowing; **2** for individuals with less than 50% of the above-ground material dead or yellowing; **3** for individuals with 50% or more of the above-ground material dead or yellowing; **4** for dead individuals, with no remaining green leaves. Data was arranged in a contingency table, and analysed for significance using a G-test (Zar, 1998).

RESULTS

The relationships between the most important variables are shown in a correlation matrix for the 26 harvested buchu plants (Table 2; Appendix 2). Several significant allometric relationships, particularly those that relate to plant age, are described further below.

Correlation between dry weight and plant volume

To avoid sampling all the specimens destructively, a regression equation ($y=1287.9x + 97.615$; $R=0.902$; $p< 0.0005$) was calculated for the relationship between the dry weight (g), measured for 26 harvested individuals of *Agathosma betulina*, and plant volume (m^3) (Figure 1). Sampling was done among individuals of different ages to represent the maximum variation found in wild populations.

Table 2: Correlation matrix (n=26) showing the linear correlation coefficient (R) between several variables describing buchu (*Agathosma* betulina) shrub architecture, structure and growth (* = p< 0.05; ** = p < 0.01; *** = p< 0.001).

	Age (years)	*Volume (m^3)*	*% cover*	*Stem number*	*Stem diameter (mm)*	*Internode Length (cm)*	*Leaf area (cm^2)*	*# leaves /10 cm*	*Flower rank*	*Seedling number*	*Wet weight (g)*	*Dry weight (g)*	*Leaf-shoot ratio*	*Oil Yield (%)*
Age (years)	X	0.810 * * *	0.780 * * *	0.148	0.864 * * *	- 0.384	- 0.335 *	0.150	0.491 *	0.327	0.760 * * *	0.775 * * *	- 0.737 * * *	0.388 *
Volume (m^3)		X	0.938 * * *	0.177	0.791 * * *	- 0.152	- 0.206	- 0.064	0.426 *	0.576 * *	0.854 * * *	0.902 * * *	- 0.673 * * *	0.226
% cover			X	0.364	0.856 * * *	- 0.151	- 0.176	- 0.008	0.516 * *	0.590 * *	0.886 * * *	0.945 * * *	- 0.674 * * *	0.332
Stem number				X	0.168	- 0.198	0.339	0.430 *	0.483 *	0.159	0.433 *	0.450 *	- 0.324	0.323
Stem diam. (mm)					X	- 0.365	- 0.381	0.122	0.655 * * *	0.343	0.807 * * *	0.825 * * *	- 0.776 * * *	0.439 *
Internode length (cm)						X	0.672 * * *	- 0.860 * * *	- 0.568 * *	0.047	- 0.344	- 0.258	0.488 *	- 0.267
Leaf area (cm^2)							X	- 0.548 * *	- 0.673 * * *	0.023	- 0.335	- 0.319	0.639 * * *	- 0.243
# leaves /10 cm								X	0.386	- 0.108	0.227	0.132	- 0.306	0.190
Flower rank									X	0.129	0.577 * *	0.610 * * *	- 0.746 * * *	0.422 *
Seedling number										X	R=0.519 * *	0.552 * *	- 0.184	- 0.185
Wet weight (g)											X	0.939 * * *	- 0.757 * * *	0.310
Dry weight (g)												X	- 0.770 * * *	0.336
Leaf-shoot ratio													X	- 0.312
Oil yield (%)														X

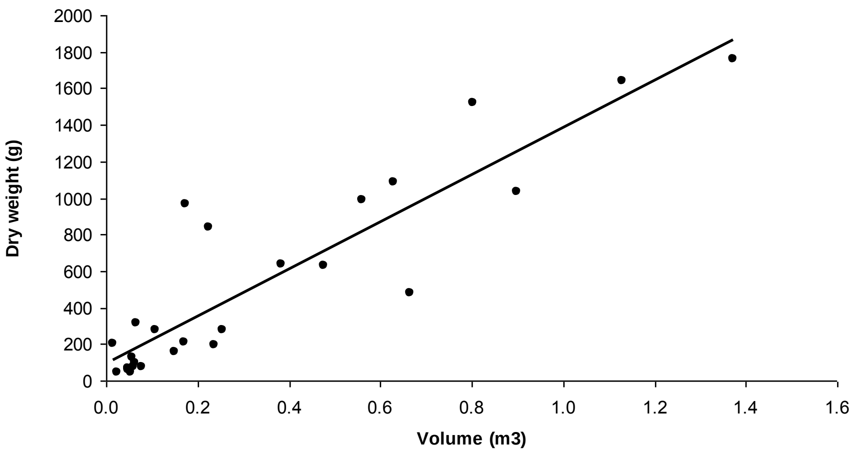

Figure 1: Correlation between dry weight (g) and plant volume (m^3) for 26 Agathosma betulina *plants from Baadjieskraal, Liermanskloof and Uitkyk Pass.*

How do leaf and shoot biomass and oil yield vary with age?

Age and leave-shoot ratio: The analysis carried out with a total of 26 plants confirms that the leave-shoot ratio diminishes significantly with age ($y=-0.4371 \ln(x) + 0.3434$; $R=0.793$; $p< 0.0005$) (Figure 2). For younger plants, the dry mass of leaves is greater than that of stems (leaf-shoot ratio >1), while for plants three years and older the relationship is reversed and the stems generally make up more than half the weight of the plant. However, there is considerable variation within age-classes ($X=1.37\pm 0.34$ for 1 year old; $X=0.38\pm 0.22$ for 10 year old plants). As an average for all the classes, plants have 75% more of their dry mass occurring as stems than as leaves. The extreme values are for a 1-year-old plant with up to 85% more leaves than stems and a 10-year-old plant with only 4.5% of the total of dry mass comprised of leaves.

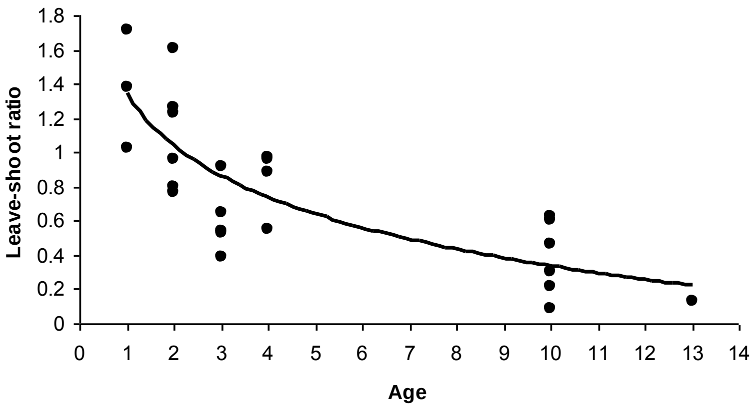

Figure 2: The relationship between leave-shoot ratio and plant age for 26 buchu individuals.

The leaf-shoot ratio decreases with age not only because stems grow thicker (y = 0.1959x + 2.1116; R=0.864; p< 0.0005), but also because leaf area decreases when plants grow older (y = -1.3807x + 47.997; R=0.3347; p=0.05).

Age and oil yield: Figure 3 shows a relatively weak but positive relationship between the age of the plant and the amount of oil contained in their leaves (y = 0.0034 Ln (x) + 0.0149; R= 0.419; p= 0.025). Due to a sampling error two plants (no. 6 and 19) (Appendix 2) were excluded from the analysis.

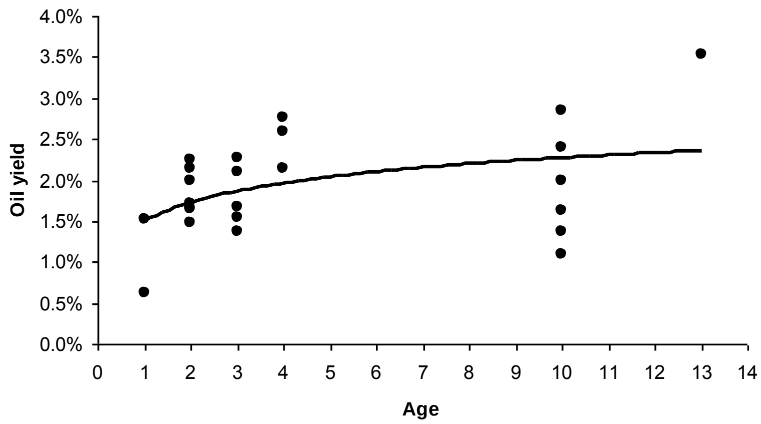

Figure 3: Oil yield (% of mass sampled) in the leaves of 24 sampled buchu plants. Analysis was realised by distillation in the laboratories of Grassroots Natural Products. The mean oil yield was 1.93± 0.6% and the range was 0.61% to 3.52%.

Considerable variation in oil yield exists between individuals, particularly within 10-year-old plants. The high oil yield measured for the single 13 year-old plant also exerts a significant influence on the relationship between plant age and oil yield. Removal of this point results in a non-significant relationship (y= 0.0021 Ln (x) + 0.016; R=0.290; p=0.1).

At what age and size do buchu plants produce flowers?

Individuals with less than 2 years of growth since harvesting or fire do not produce flowers (Figure 4). The number of flowers increases with age and levels off after three or four years. A positive relationship (y=0.7507 Ln (x) + 0.369; R= 0.838; p=0.05) has been found between the average rank number of flowers and fruits and the six age-classes sampled. All 10 year-old individuals and the single 13 year-old plant possessed between 101 and 1000 flowers and fruits. Reproductive output appears not to decline significantly in older plants.

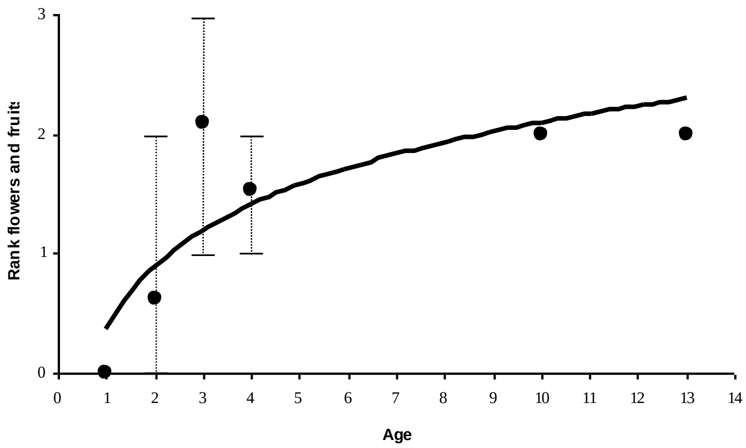

Figure 4: Trend showing the average rank of flowers and fruits produced by each buchu age class. A total of 136 plants were sampled. Variability within the age-classes is shown with the error bars. Ranks were established as follows: 0 = no flowers or fruits; 1 = 1 to 100 flowers and fruits; 2 = 101 to 1 000 flowers and fruits; 3 = more than 1 000 flowers and fruits.

The number of seedlings in a radius of 2 m around buchu plants (n=26) depends on the size of the adult. Although there is considerable variation, larger plants with more biomass, generally had significantly more seedlings that smaller plants (y=0.0026x + 0.5246; R=0.552; p=0.005) (Figure 5).

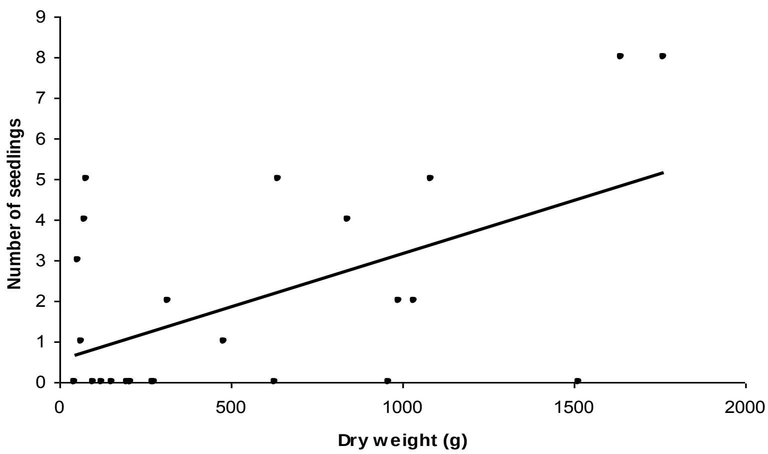

Figure 5: Relationship between the numbers of seedlings counted in a radius of 2 m around buchu individuals and the dry weight (g) of the corresponding plants for the 26 specimens harvested.

What proportion of seedlings survives the summer drought characteristic of the region?

The survival of the seedlings for the study period (November 1st to January 20th) is variable (Table 3). Sites A and B, both located in the farm Baadjieskraal, have a survival rate of 80.9% and 82.4% respectively. However, only 44% of the seedlings in Site C (Bergsoom farm) survived. The survival rate of the seedlings at Site D (Allandale farm) is 41.7%. This last site is located in 10 year-old vegetation, suggesting that seedling recruitment might also occur between fires. An increase in seedling mortality occurred in January following a particularly hot period typical of the region when temperatures rose to over 40°C, and lasted for several days.

Table 3: Seedling survival (%) at four sites between November 1st and January 20th. Sites A, B and C are one-year post fire and Site D is located in 10 year-old vegetation.

	N	*1 Nov*	*28 Nov*	*7 Dec*	*20 Jan*
Site A	*47*	100%	100%	93.6%	80.9%
Site B	*51*	100%	100%	92.2%	82.4%
Site C	*50*	-	100%	74.0%	44.0%
Site D	*24*	100%	100%	87.5%	41.7%

What is the impact of different harvesting frequencies on plant biomass?

The regrowth biomass after one year was compared for three harvesting treatments. The results indicate significant differences among harvesting treatments [$F(2,71)= 12.798$; $p= 0.00002$] (Figure 6). A *post hoc* test confirms that there are significant differences between buchu regrowth in Elandskloof and Uitkyk Pass, as well as between Baadjieskraal and Uitkyk Pass. Plants that have been harvested (independently of the intensity) have significantly less biomass after one year than plants that have never been harvested. However, no differences were found in the regrowth of the two different harvesting treatments (i.e. once a year in Elandskloof and every two years in Baadjieskraal).

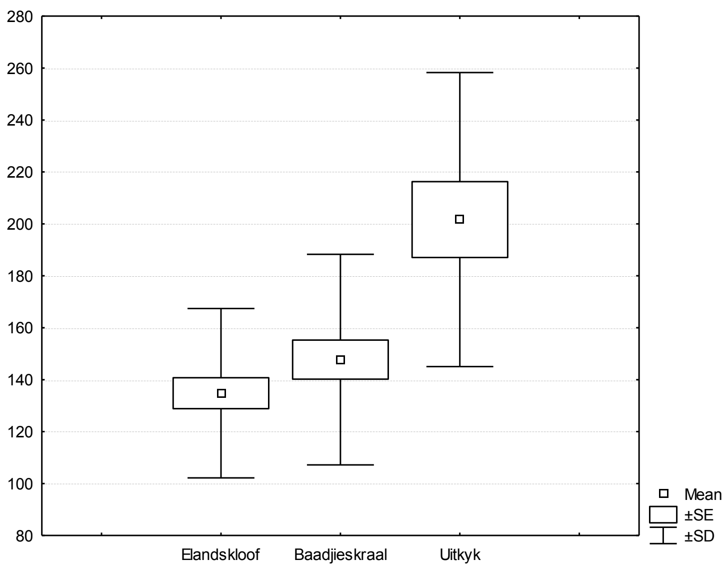

Figure 6: Mean, standard deviation and standard error for the biomass values (g) for the three harvesting treatments. Elandskloof buchu [n=30; X=113.70 ± 6.87] has been harvested at least once a year. Baadjieskraal buchu [n=29; X=116.43 ± 8.54] has been harvested every 2 years. Uitkyk Pass buchu [n=15; X=127.79 ± 11.93] has never been harvested in the past.

Does high frequency harvesting increase mortality?

The number of plants with evidence of dead material was significantly different for the three sites (n=138; G=24.8448; $p < 0.001$) (Table 4). Plants were counted as non-healthy when some branches (or all) were dead and dry. On occasion the plant failed to resprout evenly throughout the entire crown after being harvested. This was observed in 6 individuals in Elandskloof farm (harvested once a year or more frequently). The proportion of non-healthy buchu plants was thus 27.3%. This value was 5.5% for the farms harvested every two years: Baadjieskraal, Liermanskloof and Boskloof (lumped as "Baadjieskraal" in the figure) and 2.0% for Uitkyk (never harvested).

*Table 4: Total number of buchu plants at three sites, ranked according to their health status as follows: **1** = plants with none of the above-ground material dead or presenting any sign of yellowing; **2** = individuals with less than 50% of the above-ground material dead or yellowing; **3** = individuals with 50% or more of the above-ground material dead or yellowing; **4** = dead individuals, with no remaining green leaves.*

Site	*N*	*Harvesting frequency*	*Health status rank*			
			1	***2***	***3***	***4***
Uitkyk Pass	50	Never harvested	49	1	0	0
"Baadjieskraal"	55	Once every two years	52	3	0	0
Elandskloof	33	Once a year (or more frequently)	24	2	6	1
TOTAL	138	-	125	6	6	1

DISCUSSION

Agathosma betulina is a robust resprouter, common and widespread in the mountainous regions of the Western Cape Province. Currently it provides very high returns to farmers, distillers and traders, and due to the increasing global demand for natural products (Akerele *et al.,* 1991) it presents a promising economic outlook. As a part of South Africa's heritage, it could also be used as a powerful tool to provide emerging farmers with a significant source of income; especially those coming from previously disadvantaged groups.

However, this enormous potential is threatened by the unsustainable harvesting practices in evidence at present. Also, if prices continue to increase, other alternative products could substitute buchu oil in the international market. Urgent measures have to be taken to accommodate the harvesting pressure and to assure both the survival of the species in the wild and the profitability of the industry.

As early as 1913, some concern was already raised about the conservation status of buchu and the dangers related to the rising prices (von Wielligh, 1913). The first measures of protection of buchu plants were taken by the government of the Cape Province of the time (Phillips, 1917; in Endenburg, 1972). Currently, all buchu species are legally protected in the Western Cape Province under the Nature and Environmental Ordinance of 1974 (Ord. 19, 1974). This regulation has been updated by Proclamation No. 31 of 1999, which includes all the species in the Rutaceae family as Schedule 4 plants. To prevent poaching, a system of permits has been established. Harvesting, selling, buying or transporting buchu is not legal without the possession of a permit issued by WCNCB. However, with such a high price currently realised for buchu, it is inevitable that poaching still occurs.

A Buchu Forum has been created and several workshops have been organised by the researchers of the Agricultural Research Council (ARC) and the authorities of WCNCB to deal with the most urgent issues regarding buchu in the Cederberg area, and to disseminate research and management findings about the species.

They suggest a management strategy, consisting of a 3 year rotational cycle for buchu harvesting, allowing plants to produce seeds and thereby perpetuate themselves (Buchu Forum, 2002b). Organic cultivation of buchu is considered the best long-term safeguard for wild populations (Buchu Forum, 2002b), as cultivated buchu should relieve the pressure on natural plants. Improvement in seed germination and increased rooting success of cuttings will soon increase the availability of propagation material (Buchu Forum, 2000a).

However, attention should be drawn to the problems related to the cultivation of buchu, especially the hybridisation of natural populations due to genetic contamination from other cultivated species and varieties, and threats to the already diminished lowland and mountain fynbos vegetation, due to the clearing of many hectares of new land for buchu farming.

How does biomass and oil yield vary with age?

This study has developed a number of key allometric relationships for buchu that have not been published to date. These data provide a valuable resource for researchers, conservationists, harvesters and distillers. This is exemplified in the relationship between volume and biomass, which enables the accurate assessment of buchu biomass per hectare without destructive sampling.

Uncertainty regarding oil yield can be reduced through additional sampling, especially of medium-age and older plants. However, if the results of this study are confirmed, and oil yield increases as the plant ages, a shift of the population toward younger individuals, as a result of frequent harvesting, would result in a lower oil yield per mass unit (kg of buchu harvested). The implications of this scenario are that more buchu will have to be harvested to produce the same amount of oil, which will result in increased pressure on the resource. On the other hand, if no relationship is to be found between oil yield and age, there should be no effect on the industry or impact on the plant.

At what age and size do buchu plants produce flowers?

Seeds are currently in high demand to extend the area under cultivation. Therefore, it is against the farmer's interests to harvest buchu more frequently than once every two years, because a more frequent harvesting programme would not give plants enough time to flower. Harvesting is known to keep populations of other wild harvested species in a vegetative phase, preventing sexual reproduction and out-breeding (Cunningham, 1991). More conservative stakeholders even recommend buchu-harvesting cycles of three years, because flower and seed production appear to be lower for two-year-old plants than for plants that are three years and older. In addition, from a conservation perspective, the recruitment of new individuals into natural populations is necessary to guarantee the long-term survival of the species in the wild.

Although the number of seedlings in a 2 m radius around buchu plants is not correlated with the age of the adult, a positive relationship between the number of seedlings and the biomass of these adults has been found. This suggests that plants that grow larger produce more viable seeds. The same result was found (maybe as an effect of growing in better locations) for an *Erica* species (*Erica australis*), which can regenerate by sexual (seedling) or asexual mechanisms after disturbance (Cruz & Moreno, 2001). In the case of buchu harvesting, larger plants are easier to identify in the field and are likely to be the first plants to be targeted under an increased harvesting frequency. This could lower the overall contribution of seed from larger plants to the soil-stored seedbank over time.

What proportion of seedlings survives the summer drought characteristic of the region?

Although there is some doubt as to the contribution of seedlings to the populations of resprouting species in the long-term (Bond & Midgley, 2001; Cunningham, 2001), some recruitment will have to occur to ensure the viability and persistence of local populations. Differences in the survival rate of seedlings in the 4 sites could be partially explained by differences in the rainfall and temperature patterns among the sites. According to Schulze (1997), Bergsoom is the hottest (with a mean annual temperature of 16°C) and driest (458 mm/year) of the sites. Consequently, it shows the highest mortality of seedlings to date (only 44% are still alive). Alternatively, both Baadjieskraal sites (with survival rates of 80.9% and 82.4%) benefit from a cooler mean annual temperature (14°C) and wetter conditions (557 mm/year). The site located in Allandale, in vegetation that is 10 years old, also has a low survival rate (41.7%). Mean annual precipitation and mean annual temperature are in this case intermediate (502 mm and 15°C). However, lower availability of nutrients in older vegetation and water stress due to competition could explain the high mortality rate in this case.

Monitoring of the seedlings throughout the remaining summer months will be done to complete the experiment and to assess the importance of seedling recruitment for the population. Replication of the experiment in older vegetation sites would also indicate if there are differences between post-fire and inter-fire recruitment levels. Local knowledge suggests that even when seeds germinate between fires, recruitment is extremely low and few, if any, seedlings survive the first year.

Microsites are a key determinant of the survival of seedlings. Most adult buchu plants are consistently located under or among big rocks. They also often occur under or near wagon-trees (*Protea nitida*). A plausible explanation is that these places meet the conditions that favour seedling survival.

Depending on the final outcome of the seedling survival experiments, a decision could be made regarding the removal of seedlings from the mountains to plant them in cultivated land. If most of them do not survive through the summer, collecting a portion of seedlings from natural areas would probably not have any significant consequences for the wild populations of buchu. However, survival will probably vary from one year to the next, with higher recruitment happening during wetter years. In general, resprouters allocate most resources to storage, which compromises sexual reproduction. This trade-off has been documented in several resprouting species, which produce comparatively fewer seeds, smaller seed banks, fewer seedlings and poorer seedling survival rates (Bond & Midgley, 2001).

Further research on the resprouting-reseeding capacity of buchu, as well as on pollination, dispersal and longevity of the seeds in the soil is necessary to understand the biology of *A. betulina*.

What is the impact of different harvesting frequencies on plant biomass?

Resprouters generally grow slowly because they relocate energy to developing underground organs (Bond & Midgley, 2001; Cunningham, 2001). Post-harvest growth rates are thus important in determining the appropriate intervals for a sustainable harvesting management strategy. Previous cutting history also affects the productivity and survival of coppicing species (Wildy & Pate, 2002). Generally this can be explained by the depletion of the stored carbohydrates, but other interacting factors could also be important (Wildy & Pate, 2002).

In this study, measures of regrowth after harvesting have been used to assess the impact of buchu harvesting. Variation among sites was minimised to enable the comparison of plants subjected to different harvesting treatments. Altitude, aspect, slope and fire age were not significantly different between sites. However, annual rainfall totals were slightly lower for Elandskloof (460 mm) than at Uitkyk Pass or Baadjieskraal, where annual rainfall is about 560 mm in both cases (Schulze, 1997). Mean annual temperature data (Schulze, 1997) suggest that Elandskloof is cooler (12°C) than the other two sites (14°C). The influence of these factors on post-harvest regrowth is not known.

Despite the uncertainty, the result of this study suggest that harvesting frequencies of a year or less significantly reduce regrowth in relation to unharvested plants, but not in relation to plants harvested once every two years. Significant differences are also found between unharvested plants and plants harvested once every two years.

Other studies carried out on resprouting species, regarding the effects of harvesting treatments, use measurements of the underground storage organs of the plant, and its potential to recover after successive cuttings (van der Herden, 1992; Wildy & Pate, 2002). Information on the reserve organs of buchu, the kind of storage compound, the range of variability and the seasonal fluctuations in stored compounds is needed to understand the full impact of harvesting.

Currently buchu is mostly harvested after the most of the plants have produced seed (January to April), which corresponds also with the higher oil yields due to the high temperatures of the region's summer. However, the effect of the seasonality of harvesting should be experimentally tested because, as suggested for other coppicing species, cutting should be done at the time of the year when natural growth mainly happens, which is generally spring for Mediterranean type climates (Wildy & Pate, 2002).

Does high frequency harvesting increase mortality?

Although post-harvest regrowth did not differ between plants subject to two different harvesting frequency treatments (harvesting at least once a year *vs*. every two years), mortality is significantly higher in Elandskloof (27.3% non-healthy individuals) than in Baadjieskraal (5.4%) and Uitkyk Pass (2.0%).

Causes of death were not ascertained, but the assumption is that mortality is influenced by the high harvesting frequency. High intensity harvesting could affect plants in two ways, by either depleting the carbohydrate energy reserves of the plant (Cunningham, 2001b; Wildy & Pate, 2002) or by increasing the vulnerability of the plant to natural diseases and insect damage. A final consideration is that post-harvest survival is directly affected by the method of harvesting itself. If plants are harvested too close to the underground storage organ, or partially pulled out, the chances that they will resprout properly are diminished. Experiments on the cutting height (distance of the cut from the ground) need to be carried out to establish the impact of this factor on wild buchu.

CONCLUSIONS

The key results of this study are as follows:

1. Oil yield increases with plant age but considerable variation between individuals exists. Additional sampling of particularly older plants is needed to understand more fully the relationship between plant age and oil yield.

2. Flowers and fruits are not produced on plants younger than two years of age. The long-term maintenance of local populations will be compromised if harvesting frequencies less than three years continue for decades. The viability of seeds produced on two-year-old plants

needs to be determined since local evidence suggests that this cohort is generally of low quality.

3. Although the experiment is still incomplete, early evidence points to high mortality of seedlings during the first year. If this is the case, then the collection of a portion of seedlings for transplantation into cultivated lands will have a minimal impact on the long-term viability of local populations.

4. When compared to unharvested plants, regrowth after one year is significantly reduced when plants are harvested. However, there is no significant difference between plants harvested once a year (or more frequently) and those harvested once every two years.

5. Frequent harvesting of buchu (once a year or more frequently) significantly increases the incidence of mortality of adult shrubs. There is however, no significant difference in mortality rates between individuals that have never been harvested and those that have been harvested every two years.

Taken together, these findings support the recommendations of the WCNCB and the Agricultural Research Council (ARC), which suggest a three-year harvest rotation. With buchu currently reaching such high prices pressure will be exerted on local populations and harvesting cycles of less than three years are likely to increase in the region. An increase in the contribution of cultivated buchu to the overall supply might relieve some of the pressure on wild populations.

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APPENDIX 1

Main uses of the extracts derived from *Agathosma betulina* and *A. crenulata*. Industrial and traditional applications are included. (Roberts, 1990; Simpson, 1998; Coetzee et al., 1999; van Wyk & Gericke, 2000; Grassroots Natural Products, 2001; Lis-Balchin et al., 2001; South African Museum, 2001).

Uses:	***Description:***
Food industry	To enhance fruit flavours (especially for black currant flavours). Often in cool drinks and juices Also as a substitutive for salt
Cosmetics industry	Oil used in perfumes and colognes
Pharmaceutical industry	Urinary tract antiseptic and diuretic Treatment of chronic urinary tract disorders Also mild laxative and stimulant Included in the British Pharmacopoeia since 1821
Aromatherapy	Oil used in massages to alleviate muscular and joint pain. Indicated for rheumatism, water retention, cystitis, menstrual problems and cellulite treatment
Traditional uses	As an infusion for stomach complaints (also chewed) Powdered and mixed with sheep fat for anoints (Khoi and San people) Used by householders as brandy (stomach complaints, menstrual cramps, digestive) and vinegar (used externally to heal fresh and septic wounds and to alleviate muscular pains) Infusions to alleviate fever, tiredness, menstrual cramps and congestion of the chest

APPENDIX 2

Data collected for 26-harvested buchu specimens including physical and ecological characteristics of the site, structural measurements, reproductive parameters and oil yield. Site names are: A (Uitkyk Pass) and B (Baadjieskraal). In habitat classification: UR stands for “under rock”, when buchu stems grow from under a rock larger than 50 cm; O for “Open”, when there are no rocks in the immediate vicinity; and NR for “near rock”, when the distance is less than 10 cm to a large rock. Buchu distance to *Protea nitida* value is 1, when buchu is closer than 5 m to a wagon tree; and 0, when it is further away. The size of the rocks is defined as XL (> 50 cm); L (50-20 cm); M (20-2 cm); S (< 2 cm) and XS (soil). Oil yield values were measured at the laboratory of Grassroots Natural Products.

SPECIMEN NUMBER	*SITE*	*AGE (years)*	*ALTITUDE (m.a.s.l.)*	*ASPECT*	*SLOPE (%)*	*HABITAT*	*P, Nitida DISTANCE*	*ROCK SIZE*	*SOIL DEPTH (cm)*	*HEIGHT (cm)*	*AXIS 1 (cm)*	*AXIS 2 (cm)*	*VOLUME (m^3)*	*% COVER*	*NUMBER OF STEMS*	*MEAN STEM DIAMETER (mm)*	*MEAN INTERNODE LENGTH (cm)*	*LEAF AREA AVERAGE (cm^2)*	*MEAN NUMBER OF LEAVES/10 cm STEM*	*WET WEIGHT (g)*	*DRY WEIGHT ((g)*	*LEAF/SHOOT RATIO*	*RANK FLOWER-FRUIT*	*NUMBER OF SEEDLINGS in 2 m radius*	*OIL YIELD (%)*
1	A	3	1015	ESE	18	UR	1	XL	27.0	62	100	72	0.173	60	672	2.72	1.11	29.3	22	1680	962.7	0.53	3	0	2.27%
2	A	3	1030	ESE	22	UR	0	XL	23.5	95	145	57	0.477	51	114	2.99	1.29	20.9	13	1050	630.7	0.39	3	0	2.10%
3	A	3	1024	ESE	20	UR	0	XL-L	30.0	71	93	77	0.224	61	169	3.60	1.69	24.2	12	1440	842.1	0.54	3	4	1.67%
4	A	3	1032	ESE	-	O	0	L	7.0	58	45	45	0.061	15	37	2.65	1.65	17.0	12	230	98.0	0.91	2	0	1.37%
5	A	3	945	ESE	7	O	0	L	23.5	60	44	39	0.054	12	37	2.28	1.05	27.8	19	900	42.6	0.65	1	0	1.54%
6	A	4	1047	SW	12	NR	1	XL	13.0	45	41	24	0.025	10	36	2.66	1.05	30.8	18	950	46.0	0.55	1	0	0.44%
7	A	13	1042	SW	13	NR	0	M	18.0	104	100	98	0.561	72	260	3.96	1.32	23.0	15	1690	990.3	0.13	2	2	3.52%
8	A	4	1046	SW	-	O	0	XL-L	13.0	45	68	59	0.067	25	140	2.89	1.16	31.0	17	660	315.6	0.88	2	2	2.14%
9	A	4	1050	SW	18	UR	1	XL	13.0	80	20	17	0.014	27	59	2.82	1.07	44.4	16	480	205.7	0.96	2	0	2.77%
10	A	4	1055	SW	15	O	1	M	18.0	64	64	50	0.109	30	89	3.29	1.14	35.8	18	515	274.1	0.97	2	0	2.58%
11	B	2	594	W	12	O	0	M-S	5.0	80	88	68	0.255	43	108	2.69	1.87	48.2	12	615	275.2	0.76	1	0	1.47%
12	B	2	599	W	11	O	0	M-S	22.0	88	103	86	0.383	73	256	3.21	1.87	57.1	11	1355	639.7	0.80	2	5	2.25%
13	B	2	601	W	27	O	1	M	5.0	56	41	39	0.047	15	35	2.30	1.76	60.7	12	1080	64.9	1.61	0	1	1.64%
14	B	2	601	W	27	UR	0	XL	9.0	79	70	59	0.172	30	81	2.44	2.26	57.5	10	545	209.8	0.96	0	0	1.70%
15	B	2	596	W	36	UR	0	XL-L	11.0	74	71	53	0.149	33	57	2.67	2.15	61.9	10	395	155.4	1.23	0	0	1.66%
16	B	2	592	W	29	UR	1	XL-L	24.0	45	68	39	0.057	28	74	2.16	2.33	67.0	9	315	125.6	1.26	0	0	2.00%
17	B	2	595	W	24	UR	0	XL	18.0	83	74	74	0.238	39	97	2.11	1.59	36.8	13	550	195.7	1.26	0	0	2.14%
18	B	1	673	SW	20	NR	0	XS	26.0	48	73	54	0.077	29	125	2.11	1.52	41.3	16	295	77.9	1.38	0	5	1.52%
19	B	1	709	SW	7	UR	0	XL-XS	8.0	56	44	36	0.047	21	35	2.16	1.68	58.1	12	200	56.5	1.03	0	3	0.60%
20	B	1	725	SW	21	O	0	XS	15.0	44	67	51	0.060	30	124	1.74	1.81	70.0	13	280	76.5	1.71	0	4	0.61%
21	A	10	681	W	18	O	0	XL	8.0	130	120	110	0.900	100	148	4.26	1.36	53.7	13	1908	1037.1	0.63	2	2	2.84%
22	A	10	681	SW	18	O	0	XL	20.0	150	120	120	1.131	100	220	3.34	1.69	45.2	12	2215	1638.1	0.30	2	8	1.09%
23	A	10	674	SW	20	NR	0	XL	22.0	128	160	160	1.373	130	130	4.60	1.31	23.3	15	2774	1762.6	0.22	2	8	1.99%
24	A	10	681	SW	20	UR	0	XL	22.0	113	125	115	0.802	99	118	4.51	1.20	37.1	16	2062	1517.2	0.09	2	0	2.40%
25	A	10	681	W	20	UR	0	XL	35.0	105	130	100	0.664	69	68	3.78	1.49	40.1	13	903	482.1	0.60	2	1	1.36%
26	A	10	660	NW	20	UR	0	XL	3.0	120	100	100	0.628	100	140	4.67	1.34	38.8	14	1867	1083.5	0.47	2	5	1.63%