

Social and ecological characteristics of an expanding natural resource industry: *Aloe* harvesting in South Africa

Melin, A.*^{1,2,3}, Grace, O.M.⁴, Duckworth, G.D.^{5,1}, Donaldson, J.S.^{1,2} and Milner-Gulland E.J.^{3,6}

¹ Kirstenbosch Research Centre, South African National Biodiversity Institute, Cape Town, South Africa

² Department of Biological Sciences, University of Cape Town, Cape Town, South Africa
(corresponding author currently based here)

³ Department of Life Sciences, Silwood Park Campus, Imperial College London, United Kingdom

⁴ Comparative Plant & Fungal Biology, Royal Botanic Gardens, Kew, Surrey TW9 3AB, United Kingdom

⁵ Statistics in Ecology, Environment and Conservation, Department of Statistical Sciences, University of Cape Town, Cape Town, South Africa

⁶ Department of Zoology, University of Oxford, South Parks Road, Oxford OX1 3PS, UK

*corresponding author: annalie.melin@gmail.com

Melin et al.: Social and ecological characteristics of *Aloe* harvesting

<H1>Abstract

Sustainable harvesting practices are important for conserving plant species and their habitats; but also the livelihoods of those that depend on them. *Aloe ferox*, a valuable natural resource harvested for its leaves, is the focus of a recent rural development initiative in the Eastern Cape of South Africa. This has the potential to benefit poor residents through a high value, sustainable, export market. We characterize the social and ecological components of the system, in order to evaluate the potential for effective natural resource management. We interviewed aloe tappers to obtain information on their dependence on the *A. ferox* industry and harvesting practices. We assessed the harvesting pressure on *A. ferox* populations, sampling plants at three plots positioned along each of four transects at distances of 1.5 km, 3.45 km, and 7 km from the factory, grouping plants into two size classes: small (height <0.5m) and large (>0.5m). We investigated the influence of proximity to the factory and plant size class on the likelihood and intensity of harvest. The majority of aloe tappers were women, unemployed and in receipt of government welfare grants, and the main reason for harvesting *A. ferox* was to generate a cash income for their daily needs. Training guidelines did not appear to be followed, with aloe tappers leaving on average 6 leaves, rather than the recommended 18-20 leaves, allowing insufficient time to pass between harvesting episodes and harvesting outside of the prescribed wetter periods. In line with training guidelines aloe tappers were targeting larger plants; however, against recommendations, smaller plants were also regularly harvested. Harvesting pressure decreased with increasing distance from the factory. We discuss requirements to ensure *A. ferox* is harvested at sustainable levels in the region, particularly in light of a possible regional roll out of the program, and provide recommendations for regulating use and better training.

Keywords: *Aloe ferox*; sustainable use; non-timber forest products; natural resource use; plant products; Eastern Cape; tappers; ethnobotany

48 <H1> Background

49 Sustainable harvesting practices are important for conserving plant species and their habitats; but also
 50 the livelihoods of those that depend on them (Ticktin 2004). Non-timber forest products (NTFPs), in
 51 particular medicinal plants, are likely to be harvested from wild populations (Schippmann et al. 2002;
 52 Schippmann et al. 2006) but science-based assessments of sustainable levels of harvest are lacking for
 53 many species (Ticktin 2004; Schippmann et al. 2006; Ghimire et al. 2007). Consideration of ecological
 54 processes alongside anthropogenic factors is required to understand the sustainability of NTFPs
 55 harvests (Mandle et al. 2013). To maintain a target medicinal plant resource or NTFP at sustainable
 56 levels, implementation of an effective resource management plan is required to regulate use (e.g.
 57 through harvest quotas, plant parts or size class restrictions) (Ticktin 2004; Schippmann et al. 2006;
 58 Wolfgang et al. 2010; Schmidt et al. 2011) Besides the ecological effects of harvesting, effective
 59 resource management also requires an understanding of socio-economic factors such as harvesters'
 60 cash income and land tenure systems, which influence the success of a management plan (Cunningham
 61 2001; Belcher et al. 2005; Ghimire et al. 2007; Shackleton and Gumbo 2010).

62 In some cases leaf harvesting appears to be ecologically sustainable, if kept at low intensities (Ticktin
 63 2004; Schmidt et al. 2011; Stanley et al. 2012). Partial removal of leaves from standing plants can bring
 64 about increased or equal rates of growth as opposed to leading to the death of the harvested individual
 65 (e.g. harvesting of the whole plant such as *Aloe peglerae* Schönland (Pfab and Scholes 2004)).
 66 However, the findings related to leaf harvesting are predominantly based on species of palm. Leaf
 67 harvesting of succulent plants was not considered in Stanley et al.'s (2012) review of ten years of
 68 research on NTFP harvesting; this is attributed to a lack of available studies. Stanley et al.'s (2012)
 69 review highlights that concern over the possible impact of harvest on NTFPs was not supported by the
 70 evidence, suggesting that the majority of NTFP harvest impacts appear to be ecologically sustainable.
 71 The perception of negative impacts has led to bans on NTFP harvests which may in fact be sustainable,

such as in South Africa where traditional harvest of forest restio (*Ischyrolepis eleocharis* (Nees ex Mast.) H.P.Linder) was prohibited despite research showing it to be a sustainable activity (Ruwanza and Shackleton 2015). Similarly in Brazil, local people were prohibited from harvesting arumã (*Ischnosiphon polyphyllus* (Poepp. & Endl.) Körn.) in protected areas with tree cover, where harvest appears sustainable, and forced to harvest along river margins, where it is not (Nakazono and Magnusson 2016).

The benefits of harvest and trade in NTFPs for communities, sometimes promoted as a silver bullet for linking conservation and rural development, has not always delivered positive benefits in terms of poverty alleviation and livelihood security (Marshall et al. 2003; Adam et al. 2013). While research has been undertaken to quantify the poverty alleviation potential of wild plant harvesting, the results remain ambivalent (Marshall et al. 2003; Belcher et al. 2005; Shackleton et al. 2008; Adam et al. 2013; Adam and Shackleton 2016). Despite this, it has been shown that wild plant harvesting plays an indirect role in enhancing the livelihood security of poorer households (e.g. food, health) and provides a safety net to cope with environmental and economic shocks, especially for women (Shackleton and Shackleton 2006; Shackleton and Gumbo 2010; Adam et al. 2013; Djoudi et al. 2015).

The *Aloe ferox* Mill. industry in South Africa exemplifies the complex interaction between ecological and socio-economic factors in securing sustainable wild-harvested resources. *Aloe ferox* is a CITES-listed plant indigenous to South Africa, where it occurs widely from the Western Cape to the southern Free State province and southern Lesotho (Fig. 1) (Reynolds 1950; van Wyk and Smith 2003). Natural populations in the Cape have historically sustained local and export markets for natural products (e.g. laxatives) derived from the leaves since the 18th century, for use in European *materia medica* (van Wyk 2008; Grace 2011). Today, two raw products are derived from the leaves: the leaf exudate known as ‘bitters’, and colorless leaf mesophyll known as ‘gel’. Contemporary commercial uses include cosmetic

95 (e.g. skin care), horticulture (e.g. ornamental plant trade) and food (e.g. fruit juice blends, condiments,
 96 preserves and confectionary). (Grace et al 2009; Grace 2011). *Aloe ferox* recently became the focus of a
 97 development initiative within the species' natural range (Fig. 1). A processing factory was established
 98 in the Seymour region of the Eastern Cape province, and traditional harvesting methods that have been
 99 practiced in the historic center of the *A. ferox* industry – in the Western Cape – were introduced to
 100 residents of the Seymour region hundreds of kilometers away.

101 The socio-economic benefits of the *A. ferox* industry for communities in the Western Cape are
 102 potentially high, as harvesting provides employment and may be the only source of income for some
 103 (Newton and Vaughan 1996). In the Western Cape, the potential annual income for a full-time tapper
 104 (harvesting throughout the year) was estimated to be R10000 (US\$3509 at the time) in 1992 but, due to
 105 a complex debt cycle and lack of empowerment, this was seldom, if ever, realized (Newton and
 106 Vaughan 1996; Grace 2011). The recently established *A. ferox* industry in the Eastern Cape also has the
 107 potential to benefit the poor local residents, as there is a high value export market, and the harvest is
 108 likely to be sustainable, potentially acting as a model for sustainable natural resource harvesting as a
 109 conservation and development tool. It has been estimated to generate an income of approximately R400
 110 - R1000 (US\$34 - 86) a month for harvesters (Eastern Cape Development Corporation 2004)
 111 harvesting on an *ad hoc* basis (depending on season, demand from industry, needs of the harvesters and
 112 availability of other employment in the area). However, the social and ecological impacts of the *A.*
 113 *ferox* industry in the Eastern Cape are unclear; concerns have been raised regarding the sustainability of
 114 the initiative and benefits it may bring to local residents. In this study, we aimed to characterize the
 115 social and ecological components of the system, in order to evaluate the potential for effective natural
 116 resource management of the industry. We investigated the dependence of local communities on the *A.*
 117 *ferox* industry, their harvesting practices, and assess harvesting pressure on *A. ferox* populations in the
 118 Eastern Cape, in the context of the sustainable harvesting guidelines established during the set-up of the

119 new industry. Finally, we make recommendations for future intervention to improve the sustainability
 120 of the nascent industry in the Eastern Cape.

121 <H1> Methods

122 <H2> Study species

123 *Aloe ferox* is a tall (2-3 m, but can reach 5 m), single-stemmed leaf succulent plant (Fig. 2, Reynolds
 124 1950; van Wyk and Smith 2014). The dull green leaves are boat-shaped (15 x 100 cm) and form a
 125 rosette on top of the stem (Klopper and Smith 2011). The stem is covered in a fire-resistant skirt of old
 126 dry leaves (Reynolds 1950; van Wyk and Smith 2014). It is distributed in South Africa from the
 127 Western Cape province with a few localities in the extreme southwestern part of Free State and
 128 southwestern Lesotho (Fig. 1, Smith et al. 2016). Here, *A. ferox* occurs in a wide variety of vegetation
 129 types, e.g. succulent Karoo and Thicket (van Wyk and van Wyk 1997). From May to August *A. ferox*
 130 produces a bright orange-red, candelabra-like inflorescence with 5-12 erect racemes (Reynolds 1950;
 131 van Wyk and Smith 2014). *A. ferox* reproduces by wind-dispersed seed (Holland 1978) and appears not
 132 to, or very seldomly, resprout (Smith et al. 2008). *A. ferox* appears to be mostly resistant to diseases
 133 (van Jaarsveld 1996). There are a number of insect pests associated with it (see Greengrass 2004), but
 134 these do not appear to threaten the species (Newton and Vaughan 1996).

135 Few ecological studies have been undertaken on this species (Shackleton and Gambiza 2007). Here, we
 136 provide a brief overview of available information. *A. ferox* is often found in dense stands with
 137 approximately 2000 plants/ha (Holland and Fuggle 1982). In the succulent Karoo Biome of the
 138 Western Cape province, Greengrass (2004) found unharvested sites had plant densities on average of
 139 1765 ± 1098 plants/ha. In the Thicket Biome of the Eastern Cape province (the same vegetation type as
 140 this study), Parker and Bernard (2008) report lower plant densities (> 1000 plants/ha). Shackleton and
 141 Gambiza (2007) provided the first empirical results on the growth rates of *A. ferox* from unharvested

142 sites in the Eastern Cape province. They found that plants grew on average 2.8 ± 0.2 cm/year. Smaller
 143 plants (<6 cm) doubled their height in one year's growth, whereas taller plants (2 m) only grew 1% of
 144 their height over the year. On average, plants grew two new leaves per year. Greengrass's (2004) study
 145 found that in unharvested sites, the largest proportion (43%) of plants was made up of juveniles (<0.5m
 146 tall), whereas large size plants (3-3.5 m) made up <1% of the population.

147 <H2> Study system

148 The *A. ferox* industry has been historically centered in the Western Cape province of South Africa (Fig.
 149 1) and harvesting practices, known as aloe tapping, have changed little over the past two centuries
 150 (McCarthy and van Rheede van Oudtshoorn 1966; van Wyk 2008), as the knowledge and skills are
 151 passed down through generations as a family custom (Newton and Vaughan 1996). *A. ferox* leaves are
 152 harvested and rapidly stacked around a shallow basin, with the cut ends facing inwards, to collect the
 153 liquid leaf exudate. Finally, the exudate is boiled and allowed to solidify into crystalline form known as
 154 'aloe lump' (Newton and Vaughan 1996; Chen et al. 2012).

155 Aloe tapping was a relatively recent activity in the study area (Eastern Cape province) at the time of
 156 this study, with harvesting undertaken on a non-commercial informal basis from approximately 1999.
 157 Aloe tapping for commercial purposes was initiated by the International Trade Centre (ITC),
 158 Switzerland (as part of their Export Led Poverty Reduction Programme) in the study area in 2004 as
 159 part of a rural development initiative to create sustainable jobs and alleviate poverty. The ITC's aim
 160 was to secure market linkages and facilitate the export of aloe products, organize tappers as a
 161 cooperative and train them in sustainable harvesting techniques (ITC report 2006). Ikhala Products
 162 (Pty) Ltd was established through a joint venture between the Eastern Cape Development Corporation
 163 (ECDC), which had a majority share (75%), Aloe Africa with a 15% share, and Ikhala Agricultural
 164 Cooperative with a 10% share (Shackleton and Gambiza 2007). It included the development of a pilot

165 processing factory in Seymour. A core group of eight aloe tappers registered the Ikhala Agricultural
 166 Cooperative and any new members paid a R10 (US\$0.70) joining fee to the cooperative. It is unknown
 167 how profits accrued from Ikhala Products (Pty) Ltd were distributed among the cooperative members
 168 or how the governance structures operated within the cooperative. The initiative came to a close in
 169 2007 due to bad water quality (high microbial count) in Seymour prohibiting any further processing. At
 170 the time of this study, tappers were paid a rate per liter of sap collected.

171 As mentioned above, *Aloe ferox* leaf harvesting and exudate tapping are not traditional practices in the
 172 study area. Members of the Ikhala Agricultural Cooperative were provided with training and given an
 173 illustrated training manual published by the ITC (Domeisen et al. 2006). The emphasis of the training
 174 was to provide guidelines for harvesting and managing local populations of *A. ferox* in a sustainable
 175 way. The guidelines were produced with project partners (Aloe Africa) who had many years'
 176 experience and firsthand involvement in the *A. ferox* industry; additionally the harvesting protocol is
 177 based on techniques employed in the Western Cape industry which has been in existence for over two
 178 centuries. However, the recommendations provided in the training guidance, such as how many leaves
 179 should be left on a plant (Newton and Vaughan 1996) and harvesting after good rains for better sap
 180 yields (McCarthy and van Rheede van Oudtshoorn 1966), have not been empirically tested so should
 181 be treated with some degree of caution. As part of the training, a custodianship attitude towards
 182 harvesting and protecting of harvested plants was encouraged; however no other incentive measures
 183 were implemented (International Trade Centre 2005).

184 *Aloe ferox* is only harvested from wild populations and no augmentative planting of aloe plants is
 185 undertaken (Burgess 2007). Harvesters select an area with a dense patch of aloe plants, typically within
 186 walking distance from their homes. They focus on the lower leaves of the plants, scoring the leaves
 187 with a sickle, three to four centimeters from the base of the leaf, deep enough to enable the harvester to

188 tear off the leaf. The harvested leaves are then stacked in a pile around a shallow, plastic-lined basin so
189 that the sap can drain out into the basin. The pile is left for approximately six to eight hours, and then
190 the sap is poured into a plastic container. Once the sap is ready, the harvesters arrange for collection
191 with the cooperative collectors at a central collection point usually accessible by car (International
192 Trade Centre 2005).

193 The prospect of a new industry aimed at job creation was welcomed because the region is characterized
194 by high unemployment levels (ca. 49%) (Statistics South Africa 2001) and household incomes are well
195 below the national poverty line (Shackleton et al. 2007). Consequently, there are high levels of
196 dependence on social welfare grants, such as child support and old age pensions. Many communities in
197 the region rely on a diverse range of livelihood strategies to make ends meet, including natural resource
198 harvesting for fuelwood, wild fruits, edible herbs, and grass hand-brushes (Shackleton and Shackleton
199 2006). A further consideration was to try to secure a steady demand for *A. ferox* through committed
200 buyers, as opposed to relying on the variability of the current market (Burgess 2007).

201 The provincial government has reportedly committed to expanding the project together with the
202 Industrial Development Zone Programme, and planned to roll out several more pre-processing units
203 within the Eastern Cape province (Leclercq 2008). At the time of writing, we were unable to ascertain
204 if these plans were still in place. Although this study was completed some time ago, it is still highly
205 relevant, because little to no research has been undertaken since the conception of the *Aloe* harvesting
206 development initiative. This means that the ecological and socio-economic impacts of the *A. ferox*
207 industry in this region are still poorly understood. Additionally, this study, together with a recently
208 completed resource assessment for South Africa (Department of Environmental Affairs 2014) provides
209 valuable preliminary insights.

210 <H2> Assessment of *Aloe ferox* wild harvesting profiles and practices

211 Key informant interviews were conducted with five stakeholders who were selected based on their
 212 knowledge and expertise. One informant was instrumental in setting up the Ikhala Products (Pty) Ltd
 213 and managing director of Aloe Africa (based in Western Cape) with over ten years aloe product
 214 experience. One informant had many years' experience of the aloe industry and acted as Ikhala
 215 Agricultural Cooperative secretary. Two informants were collectors for the Ikhala Agricultural
 216 Cooperative, and also provided introductions to the communities. And one informant was from local
 217 government. These interviews were designed to obtain information on the time-line of events in the
 218 harvesting calendar, main participants involved in harvesting, processing, buying and selling *A. ferox*
 219 exudate, and to provide insights into the institutional framework governing the harvest of *A. ferox* in
 220 the region.

221 Two study sites were selected based on their association with the Ikhala Cooperative and their vicinity
 222 to the pilot processing factory on the outskirts of Seymour (Fig. 4). The village of Cathcartvale is a
 223 rural community with limited infrastructure (e.g. no electricity) approximately 5.2 km northeast of
 224 Seymour. Izinyoka is a small urban settlement, within the urban limits of Seymour.

225 Aloe tappers were selected for one-to-one interviews using purposive sampling (de Vaus 2002), in
 226 which respondents were selected because they were recognized as members of the Ikhala Cooperative.
 227 Further respondents were identified using a snowballing technique (de Vaus 2002) whereby aloe
 228 tappers interviewed were asked to recommend the next tapper. In total, we interviewed 22 aloe tappers
 229 (representing 15% of aloe tappers (~150 members) within the study area) in Cathcartvale and Izinyoka
 230 in June 2009. The Ikhala Cooperative, including Whittlesea in the north, Fort Beaufort in the southwest
 231 and King William's Town in the southeast, had a membership of approximately 650 aloe tappers.
 232 Semi-structured interviews focused on the techniques and practices used when collecting *A. ferox* leaf

233 exudate. Open-ended questions, aided by an *isiXhosa* translator, were used in order to obtain a greater
 234 understanding of household composition, employment status, livelihood dependence, collection
 235 practices and techniques, and whether formal training in harvesting methods had been received. Minor
 236 modifications to the questionnaire were made following a pilot study on four households.

237 <H2> Assessment of harvesting pressure on wild *Aloe ferox* populations

238 We carried out a field study to investigate the influence of proximity to the factory and plant size class
 239 on the likelihood and intensity of harvest. This field study was undertaken four years after the factory
 240 was opened. The training in aloe harvest methods received by the tappers suggested that larger plants
 241 (>0.5m) should be harvested, and so we expected larger plants to be targeted if people were following
 242 the guidelines. We also expected that the abundance of each size class would not be influenced by
 243 distance from the factory, but that harvest intensity would be higher in closer proximity to the factory,
 244 which was a central hub for harvesters.

245 Using the factory as a central point, four random compass bearing points were selected as transects to
 246 sample *A. ferox* plants (*sensu* Shackleton et al. 1994); Fig. 4). Sampling was done at three plots
 247 positioned along each transect at distances of 1.5 km, 3.45 km and 7 km from the factory (Fig. 4). We
 248 were not able to obtain access to one of the plots (bearing 60° at 7 km), giving a total of 11 plots. The
 249 furthest plot was positioned on the basis that this is the maximum distance aloe tappers are reported to
 250 walk to reach their harvesting site (Leclercq 2008).

251 Each of the 11 plots consisted of a belt transect of 45 m x 5 m in which the height of each live *A. ferox*
 252 plant (taken from ground level to the apex of the plant) and proportion of plant harvested (measured
 253 height of harvested section and estimated proportion harvested from the total height of plant) were
 254 recorded. The height variable was classified as small (<0.5m) or large (>0.5m) based on Shackleton
 255 and Gambiza's (2007) study on growth rates in *A. ferox*.

256 We performed a Pearson's chi-squared test to determine if the observed frequency of each size-distance
 257 combination was significantly different from what we would expect, under the assumption that a plant
 258 has an equal probability of occurring in each size class-distance combination (equal frequencies of
 259 small and large plants; expected probability of 1/6). We next developed two models, examining the
 260 effect of size class and distance from the factory on: (1) the probability of a plant having been
 261 harvested, and (2) the intensity of harvest for wild populations of *A. ferox*. We ran generalized linear
 262 mixed effects models (GLMMs) with a binomial family to test for significant differences in both cases.
 263 Specifically, distance from the factory and size class were fixed factors while the response variable in
 264 the first model was a binary variable (presence-absence of harvest), and in the second it was the
 265 proportion of leaves harvested from individual plants. For both models we considered plot nested
 266 within transect as a nested random effect, and used Akaike Information Criterion (AIC) to select for the
 267 best supported model (Akaike 1974). All analyses were performed using the software R (R Core Team
 268 2015, version 3.2.3), using package "nlme4" to run the GLMMs and "ggplot2" (Wickham 2009) to
 269 produce the figures.

270 <H2> Ethics statement

271 The fieldwork was done in collaboration with, and approved by, the South African National
 272 Biodiversity Institute (SANBI), and has SANBI co-authors. No permissions were required to carry out
 273 this work because it did not take place in a protected area. Although Imperial College did not at the
 274 time require ethics clearance, we nonetheless endeavored to put in place all necessary measures (see
 275 below) to conduct the interviews in accordance with appropriate ethical standards. Aloe harvesting is
 276 legal, and aloe is not protected by any national legislation (other than its CITES listing, which pertains
 277 to international trade), hence there were no issues of investigating sensitive behavior or sampling
 278 protected species.

279 Before beginning the social and ecological fieldwork, AM requested permission from the community
 280 elders in the study areas. AM was introduced to aloe harvesters by members of the cooperative. The
 281 nature of the research was explained before starting each interview and participants were provided with
 282 the opportunity not to participate in the study. All participants consented to continue. We treated all
 283 interviews as confidential and did not request or record any identifiable information such as
 284 participants' names.

285 For the ecological fieldwork, no specific permissions were required. No permits were required from
 286 conservation authorities because no plant materials were collected. *Aloe ferox* is not an endangered
 287 species or protected by any national legislation. All measurements of plants were done in situ and
 288 plants were handled with care in order not to damage them during measurements. Land accessed was
 289 either communal or privately owned; specifically:

- 290 • Plot P7 (Bearing 163°) was the only site situated on privately owned land and the land owner
 291 verbally gave permission and accompanied AM when conducting measurements.
- 292 • All remaining plots, P1, P2, P4-P6, P8-P12 were on communal land. Permission was granted
 293 verbally from community elders.

294 <H1> Results

295 <H2> Harvesting profiles and practices

296 <H3> Socio-economic profiles of Aloe tappers

297 The livelihoods of the 22 aloe tappers comprised informal employment (with the exception of two, who
 298 were employed as laborers), government welfare grants (17 were dependent on child support grants or
 299 pensions) and *A. ferox* harvesting. Twenty-one aloe tappers reported that they had been harvesting on
 300 average for 5 years (range 1 – 10 years). Based on this length of time, it appears that aloe tapping is a
 301 worthwhile activity, provides a meaningful contribution to their income and that there is some level of

302 reliance on it. All but one household was headed by women and their main reason for harvesting *A.*
 303 *ferox* was to generate a cash income for their daily needs. Nine of the aloe tappers reported that the
 304 benefits of this cash income were specifically to buy food, clothing and pay school fees for their
 305 children. Only four aloe tappers owned livestock (e.g. cows and goats). The aloe tappers we
 306 interviewed were typically middle-aged women (average age 52 years; range 20 – 79 years) and one
 307 man. All respondents were Xhosa.

308 <H3> Collection practices

309 Based on a key informant interview, the number of days that harvesting took place was dependent on
 310 several factors: demand for Aloe sap; needs of the aloe tappers (e.g. need for school fees, extra money
 311 or the time of year); availability of other jobs (e.g. invasive alien plant clearing, road maintenance) and
 312 weather (*A. ferox* is not harvested on windy days and it must be hot). On the days when aloe tappers did
 313 harvest, nine tappers reported they harvested from 7 to 10 hours a day. Based on aloe tappers' recall of
 314 the amount of sap collected on their last harvesting trip, 21 tappers reported that on average 17 liters
 315 (range 3 – 40 liters) was collected. Twelve tappers provided information on how many days it took to
 316 collect a liter of sap, on average 8 liters/day was collected. A key informant reported that aloe tappers
 317 were paid R8 per liter (US\$1.08). From this we estimated that if aloe tappers harvested every day of the
 318 month, they had the potential to earn around R1920 (US\$259). It was not clear if this potential was ever
 319 realized.

320 The training received by the aloe tappers gave guidelines on sustainable harvesting practices
 321 (summarized in Table 1). One group (of 7 respondents) reported having been given formal training by
 322 the ITC while the others (15 respondents) were taught informally by their peers and therefore all these
 323 informally-trained tappers may not have been aware of the guidelines. The guidelines state that
 324 approximately 16-20 leaves should be left on the plant, but both groups of aloe tappers reported that

325 they left on average 6 leaves on the plant. Although no recommendations for harvest intervals were
326 given during training, the time left between harvest episodes is significantly less ($t = 4.89$, $df = 12.22$, p
327 < 0.001) for ‘trained’ aloe tappers (who on average return to the same area to harvest within 8 months)
328 than ‘informally taught’ tappers (who return within 19 months on average). Training guidelines advise
329 harvesting after rains; however, trained and informally taught groups harvested similarly across both
330 dry and wet periods (Table 1). Overall, there appear to be no real differences between the two groups.

331

332 **Table 1. Comparison of harvesting practices (for trained and informally taught tappers) obtained**
 333 **from household interviews to the guidelines from the training manual.** “Trained” tappers were
 334 those that received formal training through the initiative (provided by the ITC) in harvesting methods.
 335 “Informally taught” tappers were taught informally by their peers.

Task	Training guidelines	Trained (n=7)	Informally taught (n=15)
Leaves left on plant	16-20; harvest too many leaves and the plant could die	mean=6; range 4-10	mean=6.15; range 4-9
Time intervals between episodes of harvest (years)	Not suggested	mean=0.8; range 0.5-1	mean=1.7; range 1-2
Time of year harvested	Soon after good rains ¹	Harvesting 83.3% of wetter months and 66.7% of drier months	Harvesting 91.1% of wetter months and 61.1% of drier months

336 ¹ Our study site in the Eastern Cape falls within a late summer rainfall zone with peak rainfall in
 337 February-March (Schulze and Maharaj 2007). Based on Schulze and Lynch (2007), we classed
 338 October-March as the wettest months (mean=63 mm; range 49-81 mm) and the remaining months
 339 (April-September) were lumped as the drier months (mean=23 mm; range 12–37).

340 <H2> Harvesting pressure on wild populations

341 Both small and large plants were significantly less abundant near the factory than further away (Chi
 342 squared goodness-of-fit: $\chi^2 = 44.35$, $df = 5$, $p < 0.001$; Table 2). However, Table 2 shows that across the
 343 three distance classes, density of plants increased from Near to Mid, and decreased from Mid to Far.
 344 For plot P11, the lowest plant density was recorded at the Mid distance (Table 2) and this was
 345 attributed to close access from a major road (Fig. 4). For plot P8, the highest plant density was recorded
 346 at the Mid distance (Table 2) and this was attributed to restricted access for harvesters as the plot was
 347 on private land. In terms of harvesting pressure, a much higher proportion of plants was harvested near

the factory than further away, to the extent that all available large plants had been harvested at plots near to the factory, while none of the small plants and only 22% of large plants were harvested at the most distant plots.

Table 2. Summary statistics of transect data assessing harvesting pressure over size classes and distance from factory on wild *Aloe ferox* populations in the Eastern Cape, South Africa. Plant size classes: Small = <0.5m, large = >0.5m. Sampling was done over three plots (except Far with 2 plots) positioned along each transect at distance classes of: Near = 1.5 km from the factory, Mid = 3.45 km, Far = 7 km.

Summary statistics	Near		Mid		Far	
	<i>Small</i>	<i>Large</i>	<i>Small</i>	<i>Large</i>	<i>Small</i>	<i>Large</i>
Count of all plants within plots across transects	75	37	90	103	49	87
Mean count of all plants and range across transects	28 (11-56)		48 (14-110)		45 (28-80)	
Mean height (m) and range (m) of all plants across transects	0.49 (0.02-2.45)		0.81 (0.02-3.53)		1.04 (0.03-3.2)	
Plants harvested (%) of total count	21	100	8	40	0	22
Mean height (m) and range (m) of all harvested plants (m)	0.90 (0.13-2.45)		1.06 (0.21-2.4)		1.80 (1.1-3.2)	
Mean harvest intensity and range (% of leaves per plant harvested)	46 (7-96)		22 (2-83)		20 (5-44)	

371 By far the best fitting model for the probability a plant of being harvested, based on AIC score, was an
 372 additive model that included both distance from the factory and plant size (Table 3). This suggests that,
 373 large plants have a higher probability of being harvested than small ones, and plants further from the
 374 factory were less likely to be harvested (Fig. 5). It was not possible to test for the interaction between
 375 distance and plant size class due to the limitations of sample size.

376 **Table 3. Summary of model selection for models of the probability of harvest and harvest**
 377 **intensity on wild populations of *Aloe ferox* in the Eastern Cape, South Africa.** Model selection was
 378 based on Akaike's Information Criterion (AIC), and a lower value indicates a better fit. Δ AIC gives the
 379 difference in AIC between the current model and the best model (in bold), a difference of >2 indicates
 380 strong support for the best model. K indicates the number of model parameters (including the random
 381 effects).

Model	Structure	K	Δ AIC
Probability of harvest			
1	Size + Distance	6	0
2	Size	4	4.57
3	Distance	5	88.89
4	Intercept	3	89.84
Harvest intensity			
1	Distance	5	0
2	Intercept	3	0.52
3	Size + distance	6	1.21
4	Size	4	1.82

382

383 For harvest intensity (proportion of leaves cut per plant), although the best model suggested that more
 384 leaves were cut closer to the factory, the intercept-only model had a Δ AIC of only 0.52 (Table 3). For
 385 reasons of parsimony, therefore, we select the intercept model, suggesting that neither distance from
 386 the factory nor size class affect harvest intensity.

387 <H1> Discussion

388 Biodiversity in South Africa is recognized as a valuable resource for income generation and poverty
 389 alleviation (Lawes et al. 2004; van Wyk 2008; Shackleton 2009) and the National Department of
 390 Environmental Affairs has recently completed a National Biodiversity Economy Development Strategy
 391 (Department of Environmental Affairs, South Africa, unpublished). The value of natural resources for
 392 livelihood security in South Africa is, however, poorly understood and difficult to quantify (Shackleton
 393 2009). *Aloe ferox* appears to have all the hallmarks of a suitable natural resource that can be
 394 commercialized to provide benefits to poor communities; it has a widespread natural distribution, it has
 395 a historical commercial use spanning hundreds of years and therefore established harvest techniques
 396 exist; the plants appear to be resilient to leaf harvesting; and there is an established international market
 397 with potential for expansion. If the development plan is rolled out, with provincial government
 398 backing, the initiative has the potential to improve the wellbeing of poor rural communities particularly
 399 in a region with high unemployment levels. Our study indicates that aloe harvesting provides
 400 harvesters, particularly women, with a cash income over and above their limited government welfare
 401 grants. Due to the preliminary nature of this study we are not able to make inferences about the
 402 livelihood benefits accrued from this income or the economic sustainability of aloe tapping. In order to
 403 do so, future household surveys of aloe tappers should include more in-depth questions to obtain
 404 information on: average net monthly income; contribution of harvesting to the annual household cash
 405 income; expenditure of cash income; number of household members involved in harvesting; and time
 406 use patterns and collection rates (Stanley et al. 2012; Adam and Shackleton 2016).

407 However, the ecological impacts of harvesting pressure caused by the recently established industry
 408 need to be considered alongside the potential socio-economic benefits. Despite the development
 409 initiative including training to promote sustainable harvesting techniques, the interviews highlighted
 410 that too few leaves are left on the plants and insufficient time passes between harvesting episodes.

411 These findings are based on the best available information. However, harvesting thresholds on which
412 we based these conclusions still require empirical testing. The lack of adherence to harvesting
413 guidelines may be a result of inadequate or the absence training, and potentially a lack of formal
414 governance. In the development of sustainable wild plant harvesting initiatives it is essential to allow
415 sufficient time and funds to train harvesters in resource assessment, harvest monitoring, collection and
416 processing techniques (Wolfgang et al. 2010). In addition, the lack of adherence to the guidelines raises
417 a fundamental issue underlying the harvest of NTFPs, and may be attributed to the short-term profits
418 gained by harvesting as many leaves as possible in an area. This is in conflict with establishing long-
419 term sustainability practices such as management practices, which includes lower harvest intensities
420 that would ultimately preserve resource stocks over time (Hernandez-Barrios et al. 2015). Within the
421 Eastern Cape, *A. ferox* plants are harvested on communal lands, where natural resources are often open-
422 access and management practices are difficult to implement. Within our study area, only one plot
423 occurred on private land, where harvesting pressure was limited owing to restricted access and
424 harvesting on only a single plant was recorded. Potentially, lessons can be drawn from the established
425 industry in the Western Cape whereby aloe tappers are permitted to harvest 10-12 leaves per plant over
426 a six-week period returning only after 18-36 months (Newton and Vaughan 1996). The key difference
427 between these regions is that the land is privately owned in the Western Cape, and therefore
428 management is based on the discretion of individual landowners (with more conservative landowners
429 only permitting 4-8 leaves to be harvested in a 3-4 year cycle (Newton and Vaughan 1996)). These
430 differences highlight the need to tailor harvesting practices and management plans to local
431 circumstances and to reconcile opposing social and ecological imperatives (Ticktin 2004; Ticktin and
432 Shackleton 2011; Milner-Gulland 2012; Allsopp et al. 2014). This is particularly so in the case of
433 harvesting from communal lands, where consideration of changing socio-economic circumstances of
434 harvesters coupled with changing demands of the industry is crucial (Ticktin 2004).

435 Newton and Vaughan (1996) considered *A. ferox* to be highly resilient to heavy leaf harvesting with
436 few plant mortalities. However, the impact of harvest on the life span of plants is unknown (Newton
437 and Vaughan 1996). Despite the species being used commercially for hundreds of years and its wide
438 distribution, little is known about the ecology of *A. ferox* (see reviews by Chen et al. 2012; Cousins and
439 Witkowski 2012) nor about its growth rates (Holland and Fuggle 1982; Shackleton and Gambiza
440 2007). In a recent study, Shackleton and Gambiza (2007) concluded that plants below 0.5 m should not
441 be harvested as they were considered pre-reproductive. It appears that tappers are indeed targeting large
442 plants, as all large plants were harvested close to the factory. This is in line with training guidelines
443 which aim to ensure that plants have a chance to grow before being subjected to leaf harvesting.
444 However, aloe tappers were also regularly harvesting plants from below 0.5 m, at a higher rate closer to
445 the factory and less so further away. A possible explanation could be that if aloe tappers travel longer
446 distances it would only be worth their while to harvest larger plants, which produce more leaves
447 (Greengrass 2004). Future ecological assessments of the species should go beyond using single proxy
448 measures, such as plant size, to assess the ecological health status of individuals. In order to make any
449 substantive conclusions, environmental factors or stressors (e.g. temperature, rainfall, soil types,
450 parasite load, habitat type, slope and aspect, fire or browsing) should be considered, as they may
451 interact with harvesting impacts and/or influence the rate of recovery and survival (Bond 1983; Gaoue
452 and Ticktin 2007; Parker and Bernard 2009; Mandle et al. 2015; Ruwanza and Shackleton 2015; Gaoue
453 2016). Incorporating a range of measures will ultimately provide a more complete measure of the
454 ecological health status of a given individual or population and the influence of harvesting on this
455 health in the context of other factors (Mandle and Ticktin 2012; Mandle et al. 2013; Mandle et al. 2015;
456 Gaoue et al. 2016). More research on understanding the life cycle of the species (such as that conducted
457 by Shackleton and Gambiza 2007; Holland and Fuggle 1982) would be useful to support robust
458 guidelines on ecological sustainable harvest levels. In addition, there is a great need for empirical data

459 to assess different harvesting and management scenarios, particularly under different environmental
460 conditions, to ultimately estimate sustainable harvest levels (Shackleton and Gambiza 2007; Mandle et
461 al. 2015). Another important consideration in terms of assessing sustainable harvest and long-term
462 persistence of populations would be to examine any possible effects caused by harvesting implements
463 (e.g. sickles) resulting in cutting leaves too close to the stem, damaging the stem and/or if the sickle is
464 not clean leading to possible spread of disease. As Ticktin (2004) highlights, local experimentation in
465 management techniques in conjunction with harvester participation may be crucial in establishing
466 guidelines that promote persistence of wild plant populations.

467 <H1> Conclusion

468 To ensure *A. ferox* is harvested at sustainable levels in the region, an effective resource management
469 plan needs to be implemented including harvest quotas, restricting harvest to certain size classes and a
470 system of rotation between harvests. Our study has highlighted some areas of concern for the ongoing
471 sustainability of the Eastern Cape aloe harvesting industry. Additional research is required to further
472 understand the biology and ecology of the species, in order to assess the long-term impact of harvesting
473 intensity on aloe populations. Moreover, long term social and ecological assessments would provide
474 more substantive conclusions on the sustainability of aloe harvesting in the region (Ticktin 2004;
475 Hernandez-Barrios et al. 2015). Of key importance is provision of improved and regular training to all
476 aloe harvesters on sustainable harvest techniques (with the harvest protocol regularly updated as new
477 research comes to light). Governance also needs to be reviewed so that harvesters are able to abide by
478 the guidelines and manage their resources effectively. Take-up of such recommendations would be
479 essential if the planned roll-out of aloe harvesting in other areas of the Eastern Cape is to go ahead as
480 planned.

481 **Acknowledgements**

482 Financial support for the fieldwork was provided by the South African National Biodiversity Institute.

483 We thank the aloe tappers whom AM interviewed for participating in our research. We also wish to

484 thank Natalie Uys and Mluleki Nkosi for their assistance in the field. We are very grateful to Mr. Ken

485 Dodds for providing valuable insights into the *Aloe ferox* industry as whole, the new initiative in the

486 Eastern Cape; giving of his time and introducing us to members of the Ikhala Cooperative.

487

488 <H1> References

- 489 Adam, Y. O. and C. M. Shackleton. 2016. Distribution and use of cash income from basket and mat
490 crafting: implications for rural livelihoods in the Eastern Cape, South Africa. *Forests, Trees and*
491 *Livelihoods* 25(3): 199–211.
- 492 Adam, Y. O., J. Pretzsch, and D. Pettenella. 2013. Contribution of Non-Timber Forest Products
493 livelihood strategies to rural development in drylands of Sudan: Potentials and failures.
494 *Agricultural Systems* 117: 90–97. Akaike, H. 1974. A new look at the statistical model
495 identification. *IEEE Transactions on Automatic Control* 19(6): 716–723.
- 496 Allsopp, N., P. M. L. Anderson, P. M. Holmes, A. Melin, and P. J. O’Farrell. 2014. People, the Cape
497 Floristic Region, and sustainability. In: *Fynbos Ecology, Evolution and Conservation of a*
498 *Megadiverse Region*, eds. N. Allsopp, J. F. Colville, and G.A. Verboom, 337–362. UK: Oxford
499 University Press.
- 500 Belcher, B., M. Ruíz-Pérez, and R. Achdiawan. 2005. Global patterns and trends in the use and
501 management of commercial NTFPs: Implications for livelihoods and conservation. *World*
502 *Development* 33(9): 1435–1452.
- 503 Bond, W. 1983. Dead leaves and fire survival in southern African tree aloes. *Oecologia* 58(1): 110–
504 114.
- 505 Burgess, M. 2007. Aloes alleviate poverty in the Eastern Cape. *Farmer’s Weekly*. 4 April.
- 506 Chen, W., B. E. van Wyk, I. Vermaak, and A. M. Viljoen. 2012. Cape aloes—A review of the

- 507 phytochemistry, pharmacology and commercialisation of *Aloe ferox*. *Phytochemistry Letters* 5(1):
 508 1–12.
- 509 Cousins, S. R. and E. T. F. Witkowski. 2012. African aloe ecology: A review. *Journal of Arid*
 510 *Environments* 85: 1–17.
- 511 Cunningham, A. B. 2001. Opportunities and constraints on sustainable harvest: plant populations. In:
 512 *Applied ethnobotany. People, wild plant use and conservation*, ed. A.B. Cunningham, 145–191.
 513 UK: Routledge, Earthscan Publication Ltd.
- 514 Department of Environmental Affairs. 2014. Resource assessment for *Aloe ferox* in South Africa.
 515 Republic of South Africa.
- 516 Djoudi, H., E. Vergles, R. R. Blackie, C. Koffi Koame, and D. Gautier. 2015. Dry Forests, Livelihoods
 517 and Poverty Alleviation: Understanding Current Trends. *International Forestry Review* 17(S2):
 518 54–69.
- 519 Domeisen, N., P. Röss, and C. Simpson. 2006. New jobs for poor communities through trade.
 520 *International Trade Forum Magazine*. Issue1/2006. International Trade Centre.
- 521 Eastern Cape Development Corporation. 2004. Global allure awaits ECDC's *Aloe Ferox* project.
 522 *Eastern Cape Business News*. 25 June. Available:
 523 [http://www.ecdc.co.za/ecdc/news_article/1029/Global_allure_awaits_ECDCs_Aloe_Ferox_projec](http://www.ecdc.co.za/ecdc/news_article/1029/Global_allure_awaits_ECDCs_Aloe_Ferox_project/25_June_2004)
 524 [t/25_June_2004](http://www.ecdc.co.za/ecdc/news_article/1029/Global_allure_awaits_ECDCs_Aloe_Ferox_project/25_June_2004) Accessed: 8 February 2012.

- 525 Gaoue, O. G. 2016. Transient dynamics reveal the importance of early life survival to the response of a
526 tropical tree to harvest. *Journal of Applied Ecology* 53(1): 112–119.
- 527 Gaoue, O. G., C. N. Ngonghala, J. Jiang, and M. Lelu. 2016. Towards a mechanistic understanding of
528 the synergistic effects of harvesting timber and non-timber forest products. *Methods in Ecology*
529 *and Evolution* 7(4): 398–406.
- 530 Gaoue, O. G. and T. Ticktin. 2007. Patterns of harvesting foliage and bark from the multipurpose tree
531 *Khaya senegalensis* in Benin: variation across ecological regions and its impacts on population
532 structure. *Biological Conservation* 137(3): 424–436.
- 533 Ghimire, S. K., O. Gimenez, R. Pradel, D. McKey, and Y. Aumeeruddy-Thomas. 2007. Demographic
534 variation and population viability in a threatened Himalayan medicinal and aromatic herb
535 *Nardostachys grandiflora*: matrix modelling of harvesting effects in two contrasting habitats.
536 *Journal of Applied Ecology* 45(1): 41–51.
- 537 Grace, O. M., M. S. J. Simmonds, G. F. Smith, A. E. van Wyk. 2009 Documented utility and
538 biocultural value of *Aloe* L. (Asphodelaceae): A review. *Economic Botany*. 63(2):167-168.
- 539 Grace, O. M. 2011. Current perspectives on the economic botany of the genus *Aloe* L.
540 (Xanthorrhoeaceae). *South African Journal of Botany* 77(4): 980–987.
- 541 Greengrass, C. 2004. The effects of leaf harvesting on the morphology, reproduction and sap
542 production of the Cape aloe (*Aloe ferox*). Honours Dissertation, University of Cape Town, South
543 Africa.

- 544 Hernandez-Barrios, J. C., N. P. R. Anten, and M. Martnez-Ramos. 2015. Sustainable harvesting of non-
545 timber forest products based on ecological and economic criteria. *Journal of Applied Ecology*
546 52(2): 389–401.
- 547 Holland, P. G. 1978. An evolutionary biogeography of the genus *Aloe*. *Journal of Biogeography* 5(3):
548 213–226.
- 549 Holland, P. G. and R. F. Fuggle. 1982. Impact of veld management of *Aloe ferox* in Western Cape
550 Province. *South African Geographical Journal* 64(2): 83–96.
- 551 International Trade Centre. 2005. Training manual - Aloe harvesting. 1 – 17. Switzerland: Export-led
552 Poverty Reduction Programme (EPRP), International Trade Centre UNCTAD/WTO.
- 553 van Jaarsveld, E. 1996. The Cape Aloe: *Aloe ferox* and its uses. *Veld and Flora* June: 57–59.
- 554 Klopper, R. R., and G. F. Smith. 2011. The genus *Aloe* L. (Asphodelaceae: Aloioideae) in the Eastern
555 Cape province of South Africa. *Haseltonia* 16(1): 16–53.
- 556 Lawes, M. J., H. A. C. Eeley, C. M. Shackleton, and B. G. S Geach. 2004. Indigenous forests and
557 woodlands in South Africa. Policy, people and practice. South Africa: University of KwaZulu-
558 Natal Press.
- 559 Leclercq, F. 2008. *Aloe ferox* cosmetics sales blossom for South Africa. Switzerland: Export-led
560 Poverty Reduction Programme (EPRP), International Trade Centre UNCTAD/WTO.

- 561 Mandle, L. and T. Ticktin. 2012. Interactions among fire, grazing, harvest and abiotic conditions shape
 562 palm demographic responses to disturbance. *Journal of Ecology* 100(4): 997–1008.
- 563 Mandle, L., T. Ticktin, S. Nath, S. Setty, and A. Varghese. 2013. A framework for considering
 564 ecological interactions for common non-timber forest product species: a case study of mountain
 565 date palm (*Phoenix loureiroi* Kunth.) leaf harvest in South India. *Ecological Processes* 2(1): 21.
- 566 Mandle, L., T. Ticktin, and P. A. Zuidema. 2015. Resilience of palm populations to disturbance is
 567 determined by interactive effects of fire, herbivory and harvest. *Journal of Ecology* 103(4): 1032–
 568 1043.
- 569 Marshall, E., A. C. Newton, and K. Schreckenberg. 2003. Commercialisation of non-timber forest
 570 products: first steps in analysing the factors influencing success. *International Forestry Review*
 571 5(2): 128–137.
- 572 McCarthy, T. J. M. and M. C. B van Rheede van Oudtshoorn. 1966. The seasonal variation in aloin of
 573 leaf juice from *Aloe ferox* and *Aloe marlothii*. *Plant medica* 14(1): 61–65.
- 574 Milner-Gulland, E. J. 2012. Interactions between human behaviour and ecological systems.
 575 *Philosophical transactions of the Royal Society of London. Series B, Biological sciences*
 576 367(1586): 270–278.
- 577 Nakazono, M. E. and W. E. Magnusson. 2016. Unsustainable Management of Arumã (*Ischnosiphon*
 578 *polyphyllus* [Poepp. & Endl.] Körn.) by the Novo Airão Artisans Association, Rio Negro,
 579 Amazon, Brazil. *Economic Botany* 70(2): 132–144.

- 580 Newton, D. J. and H. Vaughan. 1996. South Africa's *Aloe ferox* plant, parts and derivatives industry.
581 South Africa:TRAFFIC East/Southern Africa.
- 582 Parker, D. M. and R. T. F. Bernard. 2009. Levels of aloe mortality with and without elephants in the
583 thicket biome of South Africa. *African Journal of Ecology* 47(2): 246–251.
- 584 Parker, D., and R. Bernard. 2008. Lessons from aloes in the Thicket Biome: Reconstructing past
585 elephant browsing to understand the present. *South African Journal of Science* 104(5-6): 163–164.
- 586 Pfab, M. F. and M. A. Scholes. 2004. Is the collection of *Aloe peglerae* from the wild sustainable? An
587 evaluation using stochastic population modelling. *Biological Conservation* 118(5): 695–701.
- 588 R Development Core Team. 2015. R: A language and environment for statistical computing. R
589 Foundation for Statistical Computing, Vienna, Austria. <http://www.r-project.org>.
- 590 Reynolds, G.W. 1950. The Aloes of South Africa. Johannesburg, South Africa :The Aloes of South
591 Africa Book Fund.
- 592 Ruwanza, S. and C. M. Shackleton. 2015. Density and Regrowth of a Forest Restio (*Ischyrolepis*
593 *eleocharis*) under Harvest and Non-harvest Treatments in Dune Forests of Eastern Cape province,
594 South Africa. *Economic Botany* 69(2): 136–149.
- 595 Schippmann, U., D. Leaman, and A. B. Cunningham. 2006. A comparison of cultivation and wild
596 collecting of medicinal and aromatic plants under sustainability aspects. In: *Medicinal and*
597 *Aromatic Plants*, eds. R.J. Boger, L.E. Craker, and D. Lange, 75–95. Netherlands: Springer

- 598 Schippmann, U., D. J. Leaman, and A. B. Cunningham. 2002. Impact of Cultivation and Gathering of
 599 Medicinal Plants on Biodiversity: Global Trends and Issues. In: FAO. 2002. Biodiversity and the
 600 Ecosystem Approach in Agriculture, Forestry and Fisheries. Satellite event on the occasion of the
 601 Ninth Regular Session of the Commission on Genetic Resources for Food and Agriculture. Rome,
 602 12-13 October 2002. Inter-Departmental Working Group on Biological Diversity for Food and
 603 Agriculture. Rome.
- 604 Schmidt, I. B., L. Mandle, T. Ticktin, and O. G. Gaoue. 2011. What do matrix population models
 605 reveal about the sustainability of non-timber forest product harvest? *Journal of Applied Ecology*
 606 48(4): 815–826.
- 607 Schulze, R. E., and S. D. Lynch. 2007. Monthly rainfall and its inter-annual variability. In: South
 608 African Atlas of Climatology and Agrohydrology. Water Research Commission, South Africa,
 609 WRC Report 1489/1/06, Section 7.2., ed. R. E. Schulze.
- 610 Schulze, R. E. and M. Maharaj. 2007. Rainfall seasonality. In: South African Atlas of Climatology and
 611 Agrohydrology. Water Research Commission, South Africa, WRC Report 1489/1/06, Section 6.2.,
 612 ed. R. E. Schultze.
- 613 Shackleton, C. M. 2009. Will the real custodian of natural resource management please stand up. *South*
 614 *African Journal of Science* 105(3-4): 91–93.
- 615 Shackleton, C. M. and J. Gambiza. 2007. Growth of *Aloe ferox* Mill. at selected sites in the Makana
 616 region of the Eastern Cape. *South African Journal of Botany* 73(2): 266–269.

- 617 Shackleton, C. M., N. J. Griffin, and D. I. Banks. 1994. Community structure and species composition
 618 along a disturbance gradient in a communally managed South African savanna. *Vegetatio* 115(2):
 619 157–167.
- 620 Shackleton, C. M. and S. E. Shackleton. 2006. Household wealth status and natural resource use in the
 621 Kat River valley, South Africa. *Ecological Economics* 57(2): 306–317.
- 622 Shackleton, C. M., S. E. Shackleton, E. Buiten, and N. Bird. 2007. The importance of dry woodlands
 623 and forests in rural livelihoods and poverty alleviation in South Africa. *Forest Policy and*
 624 *Economics* 9(5): 558–577.
- 625 Shackleton, S. E. and D. Gumbo. 2010. Contribution of Non-wood Forest Products to Livelihoods and
 626 Poverty Alleviation. In: *The Dry Forests and Woodlands of Africa*, eds. E. N. Chidumayo and D. J.
 627 Gumbo DJ, 63–92. London: Earthscan.
- 628 Shackleton, S. E., B. Campbell, H. Lotz-Sisitka, and C. M. Shackleton. 2008. Links between the Local
 629 Trade in Natural Products, Livelihoods and Poverty Alleviation in a Semi-arid Region of South
 630 Africa. *World Development* 36(3): 505–526.
- 631 Smith, G. F., R. R. Klopper, E. Figueiredo, A. E. van Wyk, and N. R. Crouch. 2008. Aloes in the
 632 Eastern Cape of South Africa: The value of natural history observations in biological sciences.
 633 *South African Journal of Science* 104(11-12): 421–422.
- 634 Smith G. F., Klopper R. R., Crouch N. R., and Figueiredo E. 2016. Reinstatement of *Aloe candelabrum*
 635 A. Berger (Asphodelaceae: Alooideae), a tree-like aloe of KwaZulu-Natal province, South Africa.

- 636 Bradleya. 34: 59–69.
- 637 Stanley, D., R. Voeks, and L. Short. 2012. Is non-timber forest product harvest sustainable in the less
638 developed world? A systematic review of the recent economic and ecological literature.
639 Ethnobiology and conservation 1(9): 1–39.
- 640 Statistics South Africa. 2001. Census 2001: Primary tables, Eastern cape: 1996 and 2001 compared.
641 Available: http://www.statssa.gov.za/?page_id=5107. Accessed: 14 April 2015.
- 642 Ticktin, T. 2004. The ecological implications of harvesting non-timber forest products. Journal of
643 Applied Ecology 41(1): 11–21. Ticktin, T., and C. M. Shackleton. 2011. Harvesting non-timber
644 forest products sustainably: Opportunities and challenges. In: *Non-timber forest products in the*
645 *global context*, eds. S. E. Shackleton, C. M. Shackleton, and P. Shanley, 149–169. Berlin
646 Heidelberg: Springer.
- 647 de Vaus, D. 2002. Surveys in Social Research. Taylor & Francis.
- 648 Wickham, H. 2009. ggplot2: elegant graphics for data analysis. New York: Springer.
- 649 Wolfgang, K., B. Patzols, D. Leaman, A. Timoshyna, D. Newton, E. Kholi, G. Kinhail, et al. 2010.
650 Wild for a cure: Ground-truthing a standard for sustainable management of wild plants in the field.
651 TRAFFIC International, Cambridge, UK.
- 652 van Wyk, B. E. 2008. A broad review of commercially important southern African medicinal plants.
653 Journal of ethnopharmacology 119(3): 342–55.

654 van Wyk, B. E. and G. Smith. 2003. *Guide to Aloes in South Africa*. 2nd ed. Briza Publications, South
655 Africa.

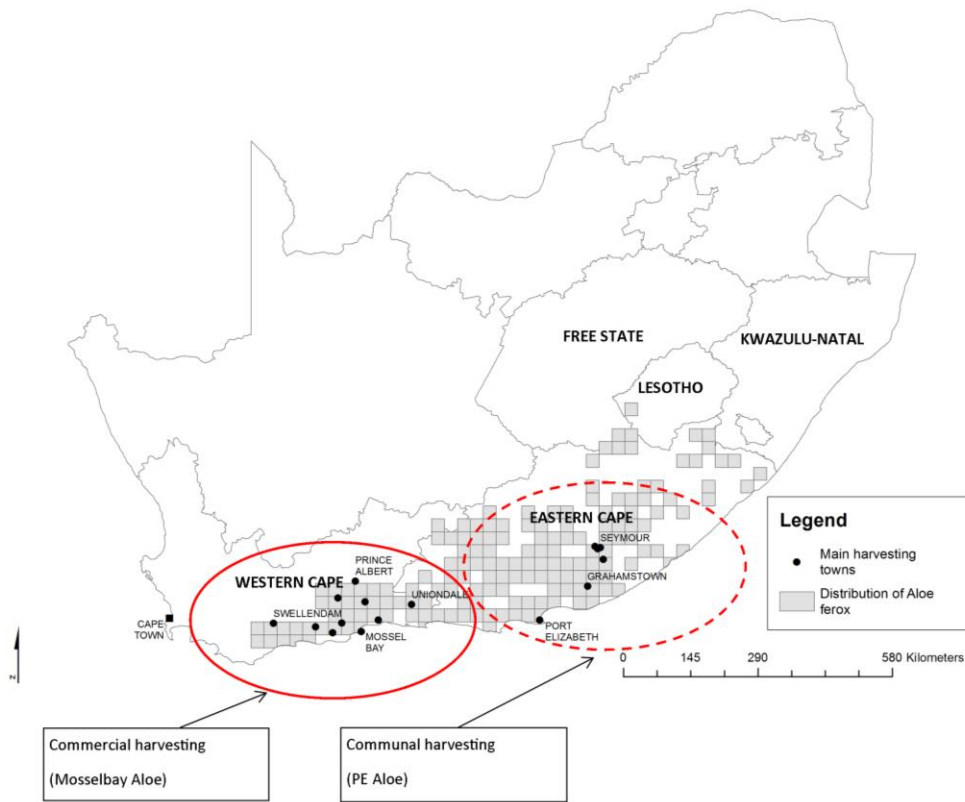
656 van Wyk, B. E. and G. Smith. 2014. *Guide to Aloes in South Africa*. 3rd ed. Briza Publications, South
657 Africa.

658 van Wyk, B. and P. van Wyk. 1997. *Field guide to trees of southern Africa*. Struik., South Africa

659

660

661 Figures



662

663 **Figure 1.** Map of southern Africa showing natural distribution of *Aloe ferox*, provinces, the main
 664 harvesting areas and study sites with annotations.

665

666



667

668 **Figure 2.** Wild population of flowering *Aloe ferox*, Kabouga, Eastern Cape province. Photo credit:
669 Richard Cowling.

670

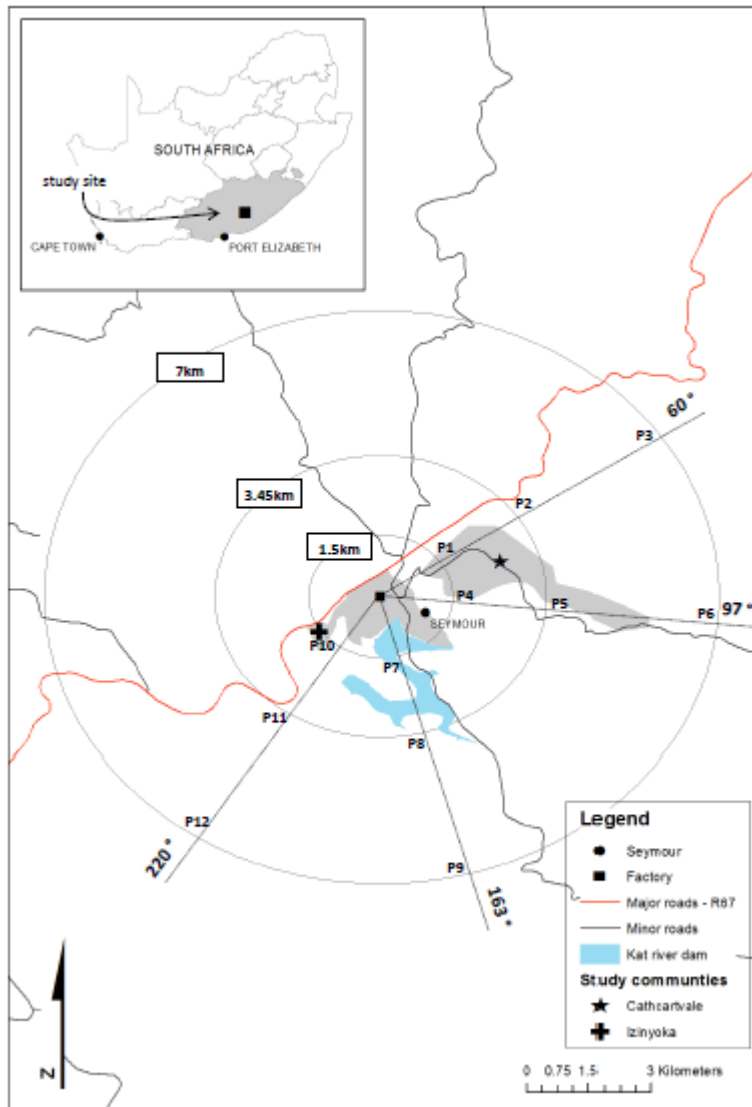


671

672 **Figure 3.** Harvesting and sap extraction of *Aloe ferox*. A) Harvested population of and stack of leaves
 673 in Uniondale, Western Cape province; B) Aloe tappers stacking harvested leaves around a shallow
 674 basin to collect the sap, Uniondale, Western Cape province. C) The cut ends of the harvested leaves
 675 exuding sap, Uniondale, Western Cape province; D) Once the collected sap is boiled, it solidifies into a
 676 crystalline form known as ‘aloe lump’ and sold as a natural product. Photo credits A – C: Timm
 677 Hoffman; D: Annalie Melin.

678

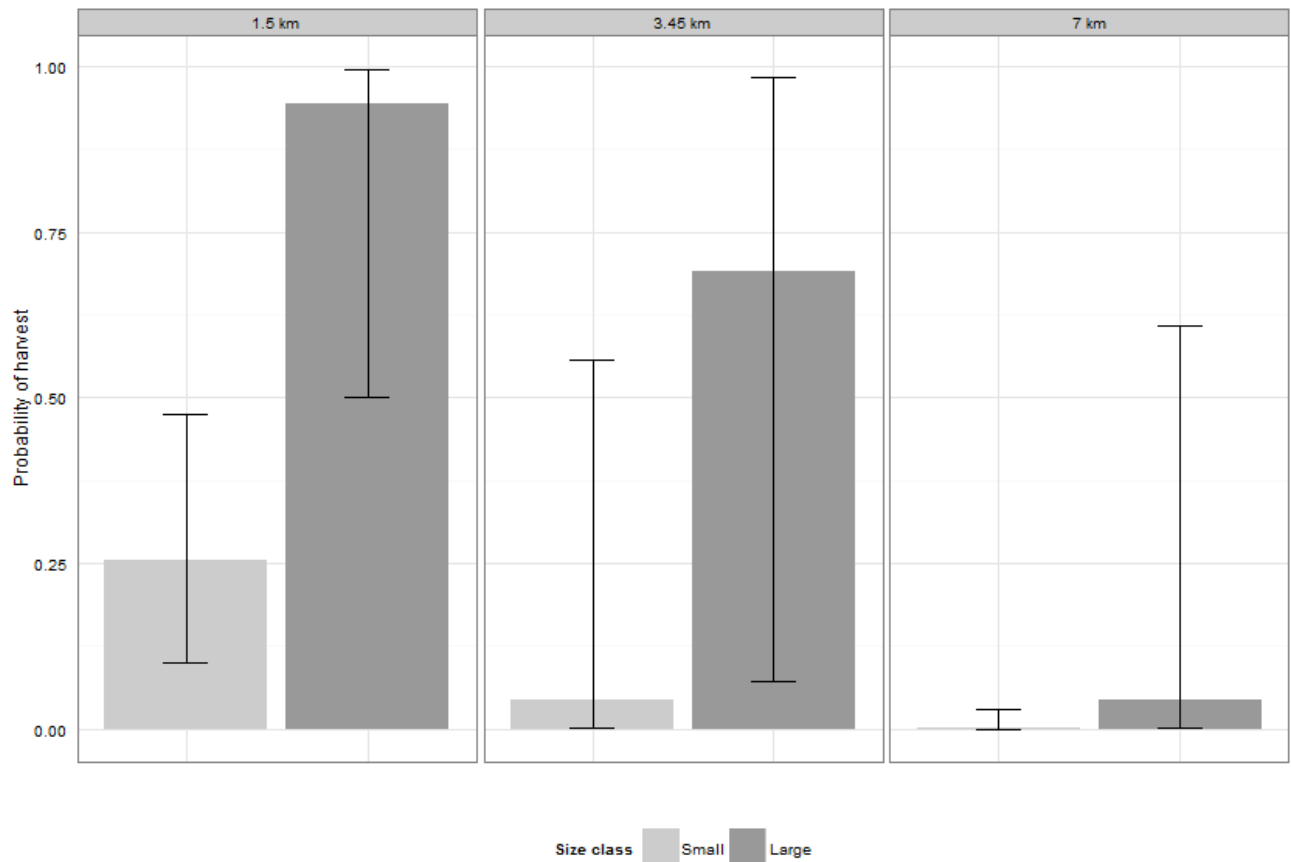
679



680

681 **Figure 4.** Study site and summary harvest data for *Aloe ferox* from 4 transects (60°; 97°; 163° & 220°)
 682 intersected by 12 plots (indicated as P1-P12) at 3 distances categories (1.5; 3.45 and 7km) illustrated by
 683 three circles.

684



685

686 **Figure 5.** Predicted values (and 95% CIs) for the probability of harvest of wild populations of *Aloe*
687 *ferox* populations in the Eastern Cape, South Africa. Predicted values are taken from model 1 in Table
688 3. Light grey bars indicate small plants (<0.5m) and darker grey bars indicate large plants (>0.5m).

689 Proximity to the processing factory: Near = 1.5 km, Mid = 3.45km, Far = 7km.

690

691

692

