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Persistent Effects of Chemicals Used to Control Shrub Densification in Semi-Arid Savanna

Hugo Bezuidenhout[1,2], Tineke Kraaij[3,4] & Johan Baard[3]

[1] South African National Parks, Scientific Services, Kimberley, South Africa

[2] Applied behavioural ecology and ecosystem research unit, UNISA, Florida, South Africa

[3] South African National Parks, Garden Route Scientific Services, Knysna, South Africa

[4] Nelson Mandela Metropolitan University, School of Natural Resource Management – Nature Conservation, George, South Africa

Correspondence: Hugo Bezuidenhout, South African National Parks, Scientific Services, Kimberley office, P.O. Box 110040, Hadison Park, 8306, South Africa. Tel: 27-538-325-488. E-mail: hugo.bezuidenhout@sanparks.org

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Abstract

Mokala National Park (MoNP) was proclaimed in 2007 in an area that used to be managed as a commercial wildlife and hunting farm, and prior to 2003 as a cattle and goat farm. The vegetation comprises sparse to closed woodlands and shrublands of the Savanna Biome. Shrub densification was deemed undesirable in the context of commercial farming where management objectives were to maximise production of grazing animals and to promote visibility of wildlife to tourists and hunters. Accordingly, previous landowners have attempted to eradicate prolific shrubs (particularly *Senegalia mellifera*) by mechanical and chemical means in certain areas during the period 1996–2004. Effects of these treatments are still apparent more than a decade later. Here we document the history of herbicide applications and other management practices in affected areas of MoNP. We furthermore explore potential ecological effects of the herbicide used ('Molopo 200GG' with active ingredient Tebuthiuron) in relation to the ecology of the most-affected shrub species, *S. mellifera*. We conclude with suggestions for future monitoring to establish potential long-term impacts of the chemical control.

Keywords: *Acacia mellifera*, bush encroachment, conservation, herbicide, Mokala National Park, protected area management, restoration, *Senegalia mellifera*, Tebuthiuron, South Africa

1. Introduction

Mokala National Park (MoNP) is one of the most recent (proclaimed 19 June 2007) additions to the suite of parks managed by South African National Parks (SANParks) and currently comprises 27 571 hectares (ha). The deproclamation of Vaalbos National Park (VNP) in 2007 in the Northern Cape Province led to the establishment of MoNP in the general vicinity of VNP in an area that used to be managed as a commercial wildlife and hunting farm (Bezuidenhout, Bradshaw & Bradshaw, in press). SANParks took over management of the farm 'Wintershoek' on 30 May 2006. Not only is the area able to support relatively high numbers of large wildlife, it also includes habitat types that were represented in VNP but not in any of the other national parks. Thus, the proclamation of MoNP helps to fulfil SANParks' mission to 'develop, manage and promote a system of national parks that represents the biodiversity and heritage assets by applying best practice, environmental justice, benefit sharing and sustainable use'. MoNP furthermore provides a tourism product that helps to promote local economic development.

VNP has consisted of two sections, the Than-Droogeveld section (18 120 ha) situated 61 km north-west of Kimberley, and the smaller Gras-Holpan section (4 576 ha) 25 km west of Kimberley (Bezuidenhout, 1994, 1995). In November 1997 and December 1998, reports were received of a land claim that would be lodged against VNP's Than-Droogeveld section, by the Sidney-on-Vaal claimants. After the claim was legitimized, SANParks investigated five potential localities for the new national park. All investigations indicated that Wintershoek, in the Plooysburg area, was the preferred option (Koch et al., 1999). In November 2002, the land claim was gazetted. In November 2004, SANParks officially launched the negotiation process with the landowners. The submission to proclaim the Wintershoek area as a National Park was forwarded to the Minister of Land Affairs and signed on 30 May 2006.

Mokala is a Setswana name for the Camel Thorn tree ('kameeldoring', *Vachellia erioloba* E. Mey. Seigler & Ebinger), a charismatic tree characteristic of the region. MoNP largely comprises savanna vegetation, varying from sparse to dense woodlands and shrublands (Bezuidenhout et al., in press). *Senegalia mellifera* (Vahl) Seigler & Ebinger (previously *Acacia mellifera*) is the dominant shrub in large parts of the region and plays an important role in the ecological functioning of semi-arid savannas. It is furthermore an important food source of the black rhinoceros (Buk & Knight, 2010), one of the endangered wildlife species in MoNP. On the other hand, tree or shrub encroachment or densification is perceived to be a significant problem in savanna areas globally, particularly in the context of commercial farming where management objectives are to maximize production of grazing animals, or to promote visibility of wildlife to tourists and game to hunters (Ward, 2005). Various measures may be employed in an attempt to combat the problem (Ward, 2005).

After proclamation of MoNP, a reconnaissance visit in August 2007 revealed that in certain areas the tree and shrub layers were dead. An investigation into the cause of the large-scale mortality of woody plant species revealed that these areas were chemically treated by the previous landowners. The aim of this note is to document the extent of, and the management history at, these treated sites within MoNP. We explore potential ecological effects of the herbicide applied in relation to the ecology of the dominant shrub species, *S. mellifera*. We conclude with suggestions for future monitoring to establish the potential long-term impacts of the treated areas.

2. Study Area

MoNP is located (29^{o} 10' 20.7" S, 24^{o} 21' 00.5" E) in the Northern Cape Province, 80 km south-west of Kimberley, and west of the national road (N12) to Cape Town (Figure 1). The predominantly summer rainfall is erratic – mean annual rainfall being 415 mm and ranging between 304 mm and 622 mm per annum (September to August; 2008-2013, SANParks unpublished data) (Figure 2). Geographical features of MoNP comprise rolling rocky hills, undulating sandy plains, undulating calcrete plains, degraded old lands, drainage lines and a portion of the Riet River. Within these features, nine landscapes and one degraded land unit (old agricultural land) were identified (Bezuidenhout et al., in press) (Figure 1). Previous management practices included goat farming focussed in the Puntberg area, cattle farming until 2003 with rotational grazing among 33 camps, and gradual re-introduction of wildlife thereafter (W. van der Linde pers. comm., August 2007).

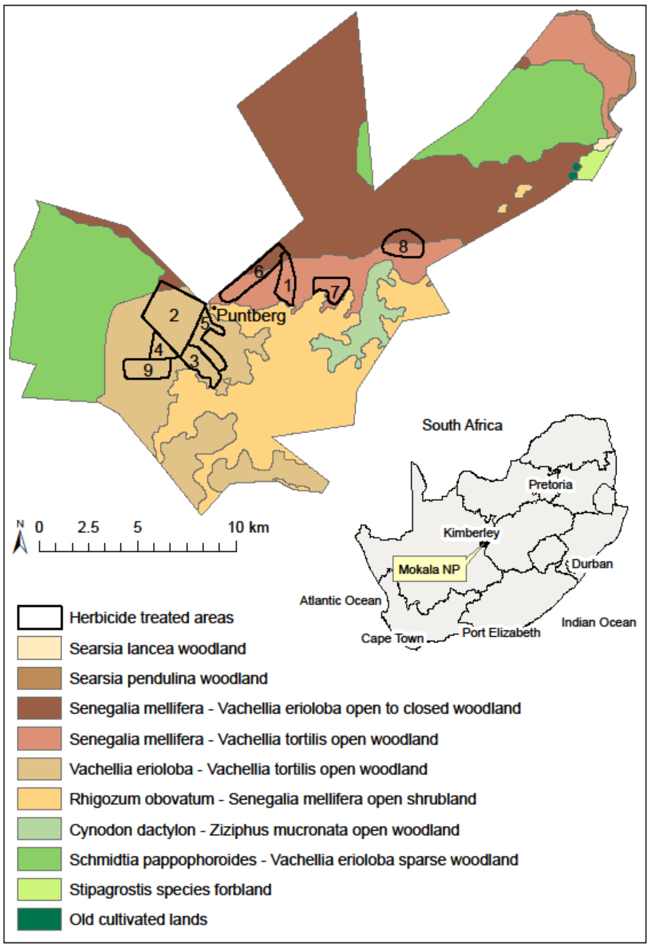

Figure 1. Vegetation landscape units (adapted from Bezuidenhout et al., in press) and the location of treated areas at Mokala National Park, South Africa. Block numbers refer to accounts of herbicide application in Table 1. Spatial accuracy of block boundaries is limited by the level of precision achievable by the relevant application methods

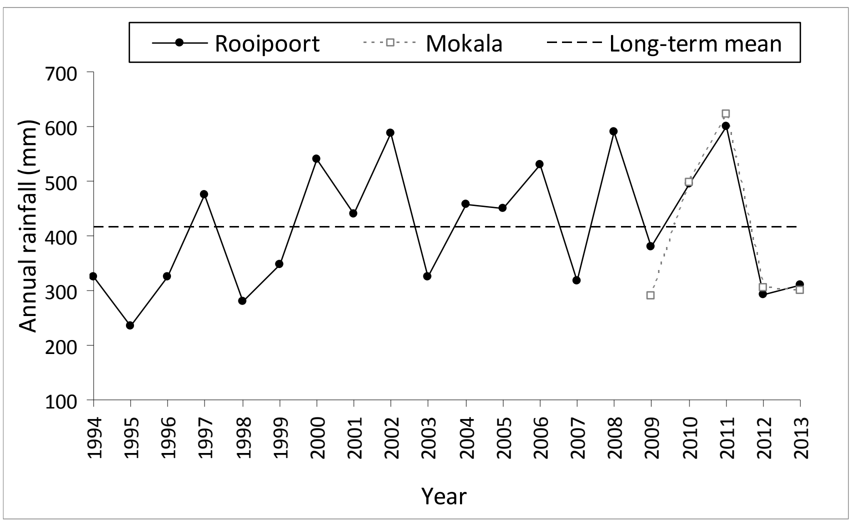

Figure 2. Annual rainfall for Mokala National Park and Rooipoort Nature Reserve (*ca.* 60 km north-west of Mokala National Park) with annual cycles ending in August of each year. The long-term (1994–2013) mean pertains to Rooipoort

3. Management History at Chemically Treated Sites

The two landscapes impacted by chemical treatment are the *Vachellia erioloba – Vachellia tortilis* open woodland west of Puntberg, and the *Senegalia mellifera – Vachellia tortilis* open woodland towards the north of Puntberg (Figure 1). The former is a sandy (clay content of soil less than 6%) plain, and the latter a rocky (clay content of soil more than 10%) footslope. A conspicuous landmark in MoNP is the Puntberg hill, where farming fences used to, and park-fences presently, create a bottle neck which forced domestic animals in the past, and wildlife presently, to move through a 30 m wide corridor. This led to trampling and degradation of the area with erosion also visible.

The rationale for the application of herbicide to woody plant species was to (i) improve accessibility, (ii) increase carrying capacity for grazers, and (iii) increase visibility for hunters in certain places. The granular form of Molopo Graslan herbicide (Molopo 200 GG product; see characteristics below) was used, largely targeting the woody plant species *S. mellifera* and *Vachellia tortilis* (Forssk.) Galasso & Banfi (W. van der Linde pers comm.., August 2007). The method of treatment varied among areas. Plant-specific application by hand in the form of granules was at a dosage of 6 kg/ha while granule application by aeroplane was at a dosage of 3 kg/ha. Treatments were applied on different occasions from 1996 to 2004 mostly during September and as indicated in Figure 1 and Table 1.

Table 1. History of herbicide applications and other management practices in treated areas of Mokala National Park

Block no. Year(s) treated	*Application mode* Area treated	Historical management practices Soil texture
1 1996 & 2003	1996 – *hand application* to *S. mellifera* (some individuals missed) but not applied to *Boscia albitrunca*; 2003 – *aerial* application to all woody species Both sides of road (east and west) treated in strips (30–40 m wide and length not recorded)	• Vegetation impacted by cattle grazing • Clayey in the south and sandy towards the northern section of strips
2 1997	*Aerial* Block (size not measured)	• Vegetation impacted by goats • Sandy
3 1997	*Hand* Strips (30–40 m wide, length not recorded) in areas 300 m wide on northern and southern sides of the road	• Vegetation impacted by goats • Sandy
4 1998	*Aerial* Block (size not measured)	• Vegetation impacted by goats • Sandy
5 1998	*Hand* Strips (30–40 m wide) in areas 300 m wide on east and north side of the road	• Vegetation impacted by goats • Clayey
6 2002	*Hand* 200 m strip, only south side of road	• Former goat camp; fire in 1995 • Clayey
7 2003	*Aerial* Block (size not measured)	• Shrubs manually cleared in 2002; subsequently treated in 2003 • Sandy
8 2003	*Aerial* Block (size not measured)	• Shrubs manually cleared in 2002; subsequently treated in 2003 • Sandy
9 2004	*Hand* 60 m wide and 2 km long strip south of road	• Sandy

4. Characteristics of Molopo Herbicide

Molopo 200GG is a local name for a South African manufactured broad-spectrum herbicide with Tebuthiuron

(200 g/kg) as active ingredient (Dow AgroSciences, 2003). The manufacturer, Dow AgroSciences LLC, sells Tebuthiuron-based products worldwide under the names Brush Bullet, EL-103, Graslan, Spike, Perflan, Herbec, Herbic and Reclaim. Tebuthiuron, a thiadiazole urea herbicide, has demonstrated excellent herbicidal activity on a broad spectrum of woody plant species at rates of 0.56–4.48 kg/ha of active ingredient, which is equivalent to 2.8–22.0 kg/ha of Molopo product (Dow AgroSciences, 2009). After application, Molopo is dissolved by rain and then infiltrates the soil. It is a non-selective herbicide absorbed by the roots of woody plant species and translocated to the leaves by means of transpiration where it inhibits photosynthesis. Woody plant species may successively loose and regain leaves until death occurs.

Tebuthiuron is highly persistent in the soil (potentially active for up to 15 years; G. Verdoorn pers comm., 2007), and has a half-life of 12–15 months in areas with over 1000 mm of annual rainfall while longer half-lives may be expected in drier areas and in soils with high organic matter and clay content (Rainey & Magnussen, 1976; Johnsen & Morton, 1989; Dow AgroSciences, 2003). In Canada, under annual rainfall of 450 mm, Tebuthiuron persisted in the soil for 11 years after application (Canadian Council of Ministers of the Environment, 1999). Given MoNP's annual average rainfall of just over 400 mm per year, persistence of the herbicide in the soil may be similarly protracted. Laboratory studies showed that higher temperature and increased soil moisture enhance break down of Tebuthiuron (Chang & Stritzke, 1977). In areas with low rainfall, Tebuthiuron thus breaks down faster under summer rainfall regimes than under winter rainfall regimes (Dow AgroSciences, 2009). Herbicide application rates also influence persistence in the soil.

Tebuthiuron has all the characteristics of a compound with high potential for groundwater contamination as it is easily translocated by moisture in the soil (Extoxnet, 1993). In Arizona USA, 55–73% of the applied herbicide occurred at depths of 600–900 mm (rainfall 310–450 mm) nine years after application, suggesting that it may leach to, and accumulate at, the depth that rainwater penetrates (Johnsen & Morton, 1989). This alludes to long-term re-poisoning of deep-rooted plants as their roots grow downwards. Accordingly, the manufacturer (Dow AgroSciences, 2009) concedes that Tebuthiuron may occur at soil depths of 600 mm and claims that some leaching of Tebuthiuron is desirable to control deep-rooted woody plant species. Conversely, in coarse soil in Arizona, Tebuthiuron only leached 75–150 mm into the soil after 600 mm of rain in 690 days (Emmerich, Helmer, Renard, & Lane, 1984).

Adsorption of Tebuthiuron depends on soil types, it being greatest in soils with high organic matter content and high clay content (and low in sandy soils), while it is also higher in acidic soils than in neutral or alkaline soils (Dow AgroSciences, 2009). Tebuthiuron does not break down in the soil – it is not lost by volatilisation at normal soil temperatures and not decomposed by sunlight (Beste, 1983). It may only be lost from the soil by microbial decomposition (which is not considered a predominant mode of degradation), leaching, and uptake by plant species (Johnsen & Morton, 1989).

5. Ecology of *Senegalia mellifera* Relevant to the Effects of Molopo Herbicide

Senegalia mellifera has a shallow but extensive lateral root system, extending 8–15 m from the stem parallel to the surface and at a depth of 250 mm (Adams, 1967). It also has a deep tap root which makes it less dependent on surface moisture (Donaldson, 1967). Herbicide present in both the shallow and deeper soil horizons may thus potentially affect the plant species. Chemical control is most effective in March (Van Niekerk & Kotze, 1977) as treatment depends on translocation of photosynthate to the roots, which is correlated with leaf-fall. In the case of MoNP, chemical control was done during September at the start of the growing season of *S. mellifera* (W. van der Linde pers comm.., August 2007; Fabricius & Van den Berg, 1993).

New recruitment of *S. mellifera* into previously treated areas (where the herbicide is no longer active) would depend on the availability of viable seed and the occurrence of conditions favourable to germination. Dispersal by ungulates of viable seeds into treated areas from adjacent sources presumably is limited as seed germination is not enhanced by ingestion. Instead, 97% mortality resulted from ingestion by cattle in another study (Donaldson, 1967). *S. mellifera* seed banks are ephemeral, recruitment thus being dependent on the current season's seed crop (Donaldson, 1967). The species furthermore requires exceptionally good rainfall in order to produce large crops of viable seed, while seeds may be absent, sterile or highly predated in years with low or moderate rainfall (Donaldson, 1967; Joubert, Rothauge, & Smit, 2008). After exceptional rains, seed banks are too large for seed predators to reduce the seed bank significantly. Shrubs or trees occurring alongside roads and receivin increased runoff from road surfaces may create the impression that a large proportion of shrubs or trees reproduce annually, but this may be misleading. Seeds are released during December, before the peak rainy season (January–April). Seeds germinate easily, but above-average rainfall, with regular, evenly spaced events are required for seedling establishment, frequency of rainfall being more important than total amount of rainfall

(Wilson & Witkowski, 1998; Kraaij & Ward, 2006; Joubert et al., 2008). African *Senegalia* and *Vachellia* seeds require a critical level of soil moisture for 10–14 days before emergence, while the minimum water requirements for the first two weeks of establishment are *c.* 3 mm of rainfall every second day (Wilson & Witkowski, 1998) or >5 mm per week during the establishment phase (Joubert et al., 2008). Another good rainfall season or two are required for sapling survival (Meyer, Wiegand, Ward & Moustakas, 2007; Joubert et al., 2008). Multiple consecutive years of good rains may thus be necessary for successful recruitment of *S. mellifera* – something which may only happen a few times per century (Joubert et al., 2008). Assessment of daily rainfall data showed that since the herbicide was applied at the study area, one (January-February 2011) and perhaps a second (February 2010) period with frequent rainfall occurred that may have been suitable for seedling establishment of *Senegalia* or *Vachellia* species.

6. Photographic Evidence

Photographic sequences or comparisons may be useful to detect or assess vegetation change (Rohde & Hoffman, 2010; Masubelele, Hoffman, Bond, & Burdett, 2013). In our study, photographic evidence from chemically treated and adjacent untreated sites showed that chemical treatments resulted in large-scale mortality of shrubs, still apparent more than a decade after application (Figures 3-5). Woody species suffering the greatest mortality were *S. mellifera*, *V. erioloba* and *V. tortilis*. Conversely, *Boscia albitrunca* (Burch.) Gilg & Gilg-Ben largely survived treatments, with live trees present ten years after treatment. The latter is a slow-growing species and should be monitored for potential delayed effects.

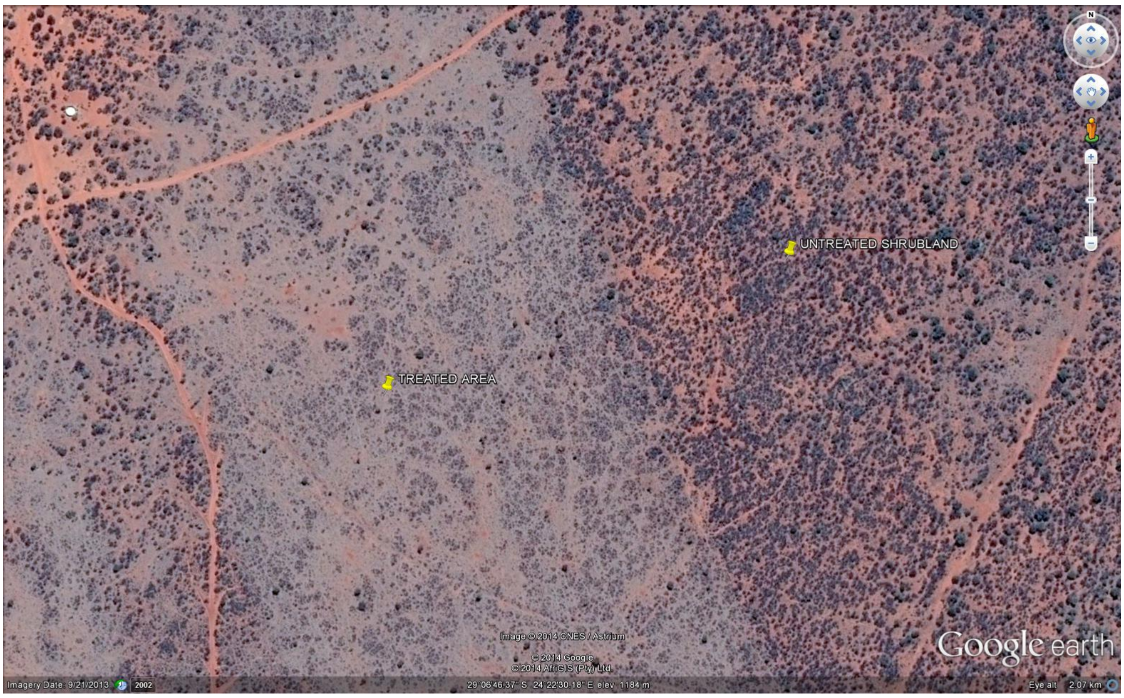

Figure 3. Google earth image (dated 21 September 2013) of block 7 (see Table 1), the treated area appearing dull grey compared to adjacent, untreated shrubland where shrubs and grassland show higher contrast

Figure 4. Aerial view (date of photo March 2007) of block 7 (see Table 1), with shrubs in the treated area appearing dull grey compared to the green shrubland in the adjacent untreated area (Photo by Hein Grobler)

Figure 5. Ground view (date of photos August 2014) of block 7, with treated area on the left and untreated shrubland on the right (Photos by Charlie Rheinhardt)

7. Suggestions for Further Investigations

The following investigations should inform whether active rehabilitation measures would be required in future or whether natural recovery in the treated areas may be adequate to ensure conservation of ecological pattern and process. The level of new recruitment (seedlings) and successful early establishment (saplings) may be compared between treated and adjacent, untreated sites where nearby sources of seeds (mature shrubs) are present in both (e.g. hand application areas where some *S. mellifera* shrubs survived). Recruitment failure in both treated and untreated areas would point to a lack of viable seed or inadequate quantity or frequency of rainfall. If recruitment is successful in untreated areas only, it would suggest that the herbicide is still active and preventing recruitment in treated areas, despite availability of seed and the occurrence of suitable rainfall. If recruitment is evident in treated areas, it would suggest that the Tebuthiuron has either leached out of, or has been metabolised, in the shallower soil horizons where seedlings/saplings are rooted; alternatively, patches within the treated areas may have been missed during application of the herbicide.

Potential recruitment in treated areas may furthermore be quantified in relation to distance from seed source. A negative relationship would indicate that recruitment is hampered by seed availability rather than by persistence of the herbicide in the soil (or rainfall factors). Alternatively, gas chromatography with flame photometric detection (cf. Johnsen & Morton, 1989) could detect residual activity of Tebuthiuron in different soil horizons. Soil samples may furthermore be assessed (using standard procedures) for: (1) textural classes, (2) exchangeable Na, K, Ca and Mg, (3) organic matter content (% carbon), and (4) water pH. These soil properties are known to influence Tebuthiuron fate and behavior in soil (Emmerich et al., 1984). Lastly, soil seed bank sampling coupled with seed viability testing could establish the availability of viable seed of the affected shrub species.

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