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Some ecological side-effects of chemical and physical bush clearing in a southern African rangeland ecosystem

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ABSTRACT

Bush thickening is a major concern to farmers of arid and semi-arid rangelands; reactive intervention remains the norm. Here we compared some of the short-term ecological implications of chemical and physical removal of the bush encroacher *Acacia mellifera* in the central Highland savanna of Namibia. We selected 21 invaded sites, 7 had been chemically cleared, 7 had been physically cleared and 7 had never been cleared. From each site, we recorded grass species composition, as well as the densities of *A. mellifera*, the undesired perennial shrub *Pechuel-loeschea leubnitziae* and a non-targeted tree *Acacia erioloba*, 24–30 months post-treatment. We fitted one-way ANOVA models to test for the effect of treatment on grass species richness and density of targeted and non-targeted tree species. A canonical correspondence analysis was used to determine how treatment affected grass species composition. While both treatments reduced the density of the bush encroacher, *P. leubnitziae* effectively replaced *A. mellifera* in chemically treated sites, where die-back presumably happened faster and nutrient and water competition decreased more rapidly. In such sites, perennial grass species were effectively outcompeted by *P. leubnitiziae*.

1. Introduction

Bush thickening forms a major agricultural concern in arid savanna ecosystems (de Klerk, 2004; Ward, 2005; Wiegand et al., 2006), where the associated suppression of palatable grasses, formation of impenetrable thickets and consequent reductions in carrying capacity have dire economic consequences (Bovey, 2001; de Klerk, 2004). Although a number of models have been proposed to explain the transformation from a grassy to a bushy state (e.g., Joubert et al., 2008; Wiegand et al., 2006) the ecological mechanisms causing bush thickening remain poorly understood (Smit, 2004; Ward, 2005). As a result, reactive intervention remains the norm (Joubert et al., 2008).

One of the main African bush encroachers is the woody shrub, *Acacia mellifera* (M.Vahl) Benth (synonym: *Senegalia mellifera* (Benth.) Seigler & Ebinger). This deciduous species has an extensive root system, concentrated in the top of the soil profile, and is considered a pioneer on shallow soil (Adams, 1967). Two of the most common methods to clear *A. mellifera* are chemical clearing through the application of arborocide and physical clearing, mostly by manual axe hacking. The method of application is generally based on the size of the area that needs to be cleared, funding and availability of labour force (de Klerk, 2004). Furthermore, whereas manual hacking is labour intensive and slow, there are ecological concerns associated with the use of arborocides. These concerns are mostly related to their environmental persistence and effects on non-target species (Bovey, 2001; du Toit and Sekwadi, 2012; Emmerich, 1985).

The active ingredient present in many of the arborocides commonly used by Namibian rangeland owners is tebuthiuron (chemical formula: $C_9H_{16}N_4OS$). Tebuthiuron is a non-selective photosynthesis inhibitor (Hatzios et al., 1980). It has a long half-life, especially in areas of low rainfall (Chang and Strizke, 1977), and residues have been detected in the soil more than a decade after application (Johnsen and Morton, 1991). Areas treated with tebuthiuron form bare patches, which may or may not be recolonised, depending on edaphic factors and local seed banks, and can be lethal to seedlings up to 8 years post-treatment (du Toit and Sekwadi, 2012). Research has been conducted on the efficacy of tebuthiuron on selected target species (Borrel et al., 2011), its environmental fate (Chang and Strizke, 1977; Johnsen and Morton, 1991), and its potential toxicity to cattle and other fauna (Morton and Hoffman, 1976; van Duyn et al., 1976). However, comparatively little is known about its effects on plant species composition, and more specifically

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grass species composition. In general, plant life forms and/or functional groups differ in their susceptibility to tebuthiuron, with grasses and deeply-rooted species generally being less susceptible than woody and shallowly-rooted species (Emmerich, 1985). However, the susceptibility of individual species is mostly unknown, making it difficult to predict which species will recolonise a bare patch (du Toit and Sekwadi, 2012).

Physical methods used for the control of woody plants generally range from manual hacking and chopping to using heavy machinery, such as tractors equipped with dozer blades (de Klerk, 2004). Because the use of heavy machinery is expensive, manual axe clearing or hacking is more common in Namibia (Namibia Agricultural Union, 2000). Trees can be manually removed either above-ground or also a few centimetres below-ground, with the intention of reducing the plant's resprouting capability. Whereas regrowth of *Acacia* stumps is almost certain with above-ground removal (Barnes, 2001), regrowth rarely occurs when tree stumps are also removed below-ground (de Klerk, 2004). Although physical clearing is preferable to chemical clearing from an ecotoxicological perspective, there are also ecological consequences associated with physical clearing, especially when the topsoil is disturbed (Adams, 1967; de Klerk, 2004). Physical disturbance of the topsoil may alter habitat structure (Zou et al., 1989) and ultimately favour the re-establishment of the problem species (Zapke, 1986). In addition, exotic plant species are often favoured in areas of increased physical disturbance (Haussmann et al., 2013; Kalwij et al., 2008), such as those associated with physical clearing. Although manual clearing is undoubtedly less disruptive than mechanised clearing, it is labour-intensive and slow, especially when trees are also removed below-ground (de Klerk, 2004).

In this study we evaluate the short-term ecological effects (24–30 months post-treatment) of chemical and physical bush clearing in an arid savanna ecosystem. We do this by comparing grass species richness and composition of plots where *A. mellifera* had been cleared using tebuthiuron-containing arborocides with manually cleared plots, as well as uncleared, invaded control plots. We also compared the abundance of *A. mellifera* individuals between treatments, as well as the abundance of *Pechuel-loeschea leubnitziae* (Kuntze) O. Hoffm, an undesired perennial shrub species native to Namibia. Lastly, as a measure of undesired impacts on non-target tree species, we compared the abundance of the ecologically important, protected tree *A. erioloba* E. Mey. (synonym: *A. giraffae* Willd., *Vachellia erioloba* (E. Mey.) P.J.H. Hurter) between treatments.

2. Materials and methods

2.1. Study area

The central Highland savanna of Namibia is situated in a semi-arid climatic region. The area receives on average approximately 360 mm rainfall annually, predominantly during summer. Days are usually warm (27 °C average annual maximum), while nights are cool to cold, with temperatures normally staying above freezing in winter (Namibia Meteorological Service, 2015a). The vegetation is characterised by woody species, of which *A. mellifera* is dominant. Soils in the area are typically shallow lithic leptosols (Joubert et al., 2008). Where grazing is heavy and fires are rare, *A. mellifera* forms dense impenetrable thickets, which slowly decreases the carrying capacity for livestock such as cattle and sheep (Joubert et al., 2008). In such areas, the cover of palatable, perennial grasses is low. As a result, both chemical and physical bush clearing methods are commonly applied in the region and the area thus forms an ideal setting to select independent treatment replicates across a large spatial extent.

2.2. Study sites

A total of 21 invaded sites were identified on commercial cattle ranches within the central Highland savanna area of Namibia (Fig. 1). Seven sites had been chemically cleared of *A. mellifera* using tebuthiuron, another 7 had been cleared physically (through manual hacking) and the remaining 7 sites had never been cleared to the knowledge of the ranch owners. Chemical treatment consisted of applying granular arborocide

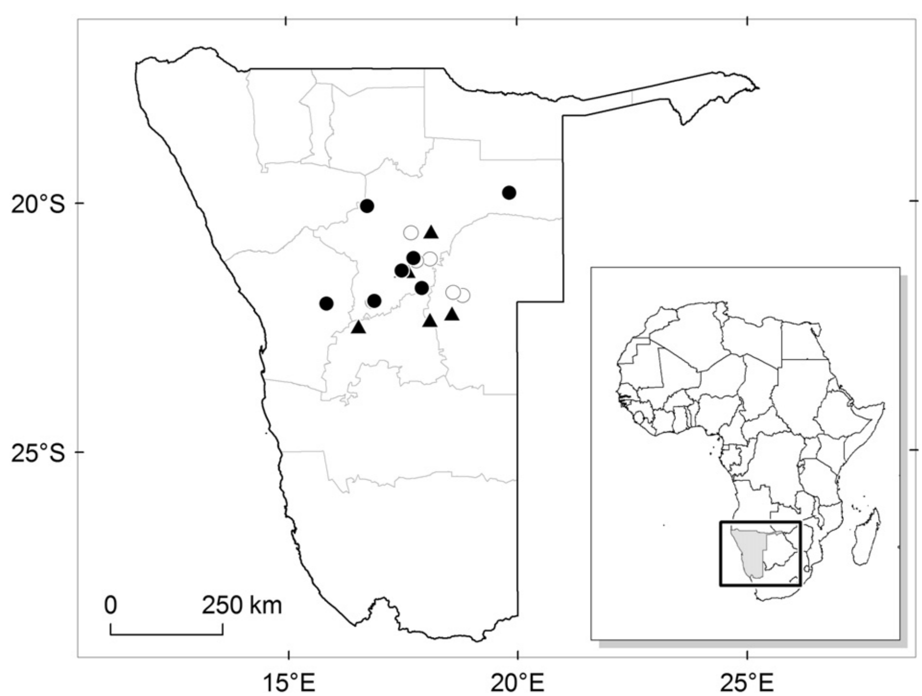

Fig. 1. Overview of the distribution of sites in Namibia and the respective treatments used to remove *Acacia mellifera* shrubs; triangles (▲) indicate arborocide treatment ($N = 7$), filled circles (●) physically cleared sites ($N = 7$), and open circles (○) untreated control sites ($N = 7$). Due to the scale of this map some site symbols overlap. For reference purposes we included the delineation of the administrative divisions of Namibia and its location in southern Africa (inset).