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The effect of ploughing and augmenting natural vegetation with commercial fynbos species on the biodiversity of Overberg Sandstone fynbos on the Agulhas Plain, South Africa

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Abstract

In an attempt to reconcile wildflower cultivation with plant diversity conservation, we investigate the effect that different augmentation techniques (including ploughing and burning) have on the plant diversity of the Fynbos Biome. We evaluated the effects of two ploughing intensities followed by augmentation at one site, and augmentation without ploughing at another on the plant diversity in Overberg Sandstone fynbos on the Agulhas Plain, South Africa. Results showed that plant diversity was the highest in areas which were either shallow-ploughed and augmented or augmented only; thus these treatments appear not to have a significant negative effect on plant diversity at least in the short-term. Deep ploughing, however, was detrimental to plant diversity. Results could be explained by the intermediate disturbance hypothesis i.e. intermediate levels of disturbance prevent the competitive exclusion of subdominant species. The conclusion drawn from this study is that low-intensity cultivation of commercial fynbos species can be diversity-friendly, but high-intensity disturbance practices should be avoided.

Keywords: Augmentation; Fynbos Biome; Intermediate disturbance hypothesis; Ploughing; Wildflower harvesting

1. Introduction

The Agulhas Plain (AP) forms an important part of the Cape Floristic Region (CFR), situated in the smallest (~9000 km^2) and richest of the six floral kingdoms (Bond and Goldblatt, 1984). The CFR has over 9000 species (Goldblatt and Manning, 2000) of which 68% are endemic to the area (Bond and Goldblatt, 1984).

Habitat transformation for agricultural intensification was identified as one of three main threats to the Fynbos Biome (Turpie et al., 2002). This includes the monoculture of indigenous species, as would be the case in the wildflower industry (Heydenrych, 1999). Wildflower harvesting is an important component of the agricultural sector in the Western Cape (Wessels et al., 1997; Privett et al., 2002) as well as on the Agulhas Plain where ~28% of all farms are fynbos farms (Agulhas National Park Management Plan, 2006).

Wildflowers were originally harvested from the natural fynbos vegetation (veld), and approximately 60% of wildflowers on the Agulhas Plain are still harvested in this way (Brits et al., 1983; Carinus et al., 2004). However, the industry is market driven and the market demands focal flowers that are not always available in the natural veld or in the quantities required. Therefore, many wildflower producers augment the natural vegetation with commercial fynbos species (Carinus et al., 2004). Augmentation is the process of adding commercial fynbos species (such as *Protea compacta* and *Leucadendron platyspermum*) to the natural vegetation causing higher densities of the commercial species than would be considered natural. In preparation for augmentation, natural fynbos is often ploughed or burned.

Although previous research investigated the effect of wildflower harvesting on natural fynbos and agrees that overexploitation is a risk (Rebelo and Holmes, 1988; Mustart

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and Cowling, 1992; Maze and Bond, 1996), there is a lack of scientific evidence concerning the effect of augmentation on the plant diversity of the Fynbos Biome. The general perception regarding augmented areas is that they represent localized diversity-poor patches within a matrix of intact, natural vegetation (Heydenrych, 1999).

Acknowledging the risk of overexploitation of natural resources, the detrimental effect of habitat transformation, and the market's demand for focal flowers, we ask the question, "Are all augmentation techniques of the wildflower industry bad for plant diversity in the Fynbos Biome?" We first address this question by investigating the impact that augmentation has on the plant diversity of conventionally-ploughed and non-inversion ploughed areas. Then plant diversity is compared between an augmented area and a non-augmented (natural) area — both recently burned, but not ploughed.

2. Methods

2.1. Description of location

The three study sites, Vlakberg Farm (34°31′28″S/19°50′48″E), Springs Farm (34°38′00″S/19°41′50″E) and Sandberg Private Nature Reserve (34°33′55″S/19°41′00″E), are all located on the Agulhas Plain (AP, 2160 km^2). They lie within the Elim land system (Bezuidenhout, 2003; in ANP Management Plan 2006) where slight soil and topographic differences create a complex mosaic on a larger spatial scale. Overberg Sandstone fynbos is the dominant vegetation type in all of these areas (Mucina et al., 2006).

2.2. Treatments

Vlakberg Farm (hereinafter referred to as "Vlakberg") is a commercial fynbos farm where a natural fynbos (control) area was compared with two treatments, namely conventional and non-inversion ploughing (referred to here as deep and shallow ploughing), followed in both cases by augmentation. Virgin fynbos was ploughed only once, thereafter it was seeded (augmented) with commercial fynbos species, in this case *Protea compacta* or *P. cordata*. During the process of deep ploughing, the soil is loosened with a disc plough to a large depth (>10 cm), and turned over. The purpose of this technique is to minimize or eliminate other fynbos species' competition with the augmented species, thus increasing fecundity (i.e. the number of flowers per plant during its lifetime, as defined in Vlok and Yeaton, 2000) of the commercial, augmented species. In contrast, shallow ploughing loosens the soil up to a depth of ~7 cm with minimal disturbance to the subterranean parts of plants. The plant material is not burned, but is left on the soil surface to decompose instead. The traditional purpose of shallow ploughing is to create a seedbed in which seeds can germinate and grow.

On Springs Farm, a commercial fynbos farm approximately 50 km from Vlakberg, suitable land has systematically been augmented since 1994 with *L. platyspermum*, but not ploughed. Control sites were in virgin fynbos on the neighbouring Sandberg Private Nature Reserve (hereafter referred to as "Sandberg"). In February 2005, a wild fire burnt through the whole of Sandberg and parts of Springs Farm. The freshly-burned land has not been augmented since the fire.

2.3. Experiment design

On Vlakberg, a T-junction divided the fynbos into three areas that received different treatments. The first area was deeply ploughed and augmented with *P. compacta* — a large shrub species that grows approximately 1.5 m high. The second was shallow-ploughed and augmented with *P. cordata*, which is a low-growing protea (<0.5 m). An advancing wave of pine trees encroached downhill into the control site, and control plots were located to avoid their effect. Furthermore, the control sites were located directly upslope of two treatments — introducing a possible soil catena effect. No other control sites were available. Ten 5×5 m (25 m^2) plots were allocated within each treatment after excluding areas heavily invaded by pines and areas with obvious soil differences. Edge effects were avoided by positioning replicates at least 7 m from the road.

At Springs Farm, a fence-line contrast study was conducted between the augmented and burned areas (hereafter referred to as "augmented areas") on Springs Farm and the burned areas (hereafter referred to as "natural areas") on Sandberg. Eight 5×5 m (25 m^2) plots were located on either side of the fence-line and situated at least 15 m from this fence to avoid edge effects.

2.4. Vegetation sampling

All vegetation sampling was done during June/July 2007. The cover of the vegetation within each plot was scored following the Braun-Blanquet cover-abundance scale (Braun-Blanquet, 1928). Individual plants with more than 50% of their canopy outside the (5 m×5 m) plot were considered to be off the quadrat.

All plant species were categorized into life history and growth form categories. The life history categories merely classified species as resprouters or reseeders. This classification was applied even though there is a continuum from weakly- to very strongly-sprouting (Bond and Midgley, 2001). Indeed, plants with the ability to resprout were recorded as resprouters even if they may have had reseeding abilities too. Reseeder species are unable to resprout and instead rely on their seed (soil or canopy stored) for regeneration after a fire.

Plant species were categorized into one of six growth form categories: (1) graminoids — consisting of all restios, grasses and sedges, (2) small (<50 cm) shrubs, (3) medium-sized (between 50 cm and 100 cm) shrubs, (4) large (>100 cm) shrubs, (5) geophytes — consisting of all plant species that have bulbs or underground stems (rhizomes) and (6) herbaceous plants. The height of a shrub was the sole criterion for assigning it into a size class.

2.5. Data analysis

General trends in the data were obtained from the cover of each growth form in each treatment, calculated by summing the cover of all species classified in that growth form. This new dataset was examined using Principal Component Analysis (PCA), where the similarity between replicates of the same treatment was assessed. The relationship between different growth forms was determined with regression analysis (Spearman rank coefficient). A Correspondence Analysis (CA) showed the relationship between certain growth forms and treatments.

The original dataset, where different species were not summed into categories, was then examined to identify more specific patterns in the data. After verifying the assumptions of ANOVA, different treatments were compared to each other with respect to the number and cover of species in each life history and growth form category. A one-way ANOVA (*Post hoc*: Tukey test) in Statistica 8.0 with a confidence interval of 95% was used.

3. Results

3.1. Species richness

Species richness in shallow-ploughed areas was significantly higher than in deep-ploughed and control areas (Table 1). There was no significant difference between the control and the deep-ploughed areas with respect to species accumulation (data not shown) or species richness. Species richness in the augmented areas was significantly higher than in the natural areas (Table 1). There was no difference between the species accumulation curves of augmented and natural areas (data not shown).

3.2. Reseeders vs. resprouters

The number of resprouting species was significantly higher in the shallow-ploughed areas than in the deep-ploughed and control areas (Table 1). The percentage cover of resprouters was significantly lower in the deep-ploughed areas than in the shallow-ploughed and the control areas (Table 1). There was a significantly higher number of reseeding species in the shallow-ploughed areas than in the control and the deep-ploughed areas (Table 1). The high number of reseeding species in the shallow-ploughed areas is not reflected in their cover. The percentage cover of reseeding species was highest in the deep-ploughed areas, second highest in the control area and lowest in the shallow-ploughed areas (Table 1).

The augmented veld on Springs Farm had significantly more resprouting and reseeding species and a significantly higher cover of reseeders than the natural veld at Sandberg (Table 1).

3.3. Growth forms

At Vlakberg, small shrub cover correlated positively with geophyte cover (Spearman $r=0.76$, $P<0.01$), and negatively with large shrub cover (Spearman $r=-0.82$, $P<0.01$). Large shrub cover correlated negatively with geophyte cover (Spearman $r=-0.61$, $P<0.01$).

The PCA analysis of the replicates at Vlakberg separated shallow-ploughed areas from deep-ploughed and control areas, but deep-ploughed areas overlapped with the control areas (Fig. 1). The first two axes explained 71% of the data (Axis 1, Eigenvalue 3.3318, total variance 55.53%; Axis 2, Eigenvalue 0.9957, total variance 16.60%). A CA of different treatments and the cover of different growth forms showed that herbs, small shrubs and geophytes tended to associate with the shallow-ploughed areas, large shrubs with the deep-ploughed areas and medium-sized shrubs with the control areas. Graminoids did not show preference for any of the treatments (Fig. 2).

The shallow-ploughed areas had a significantly higher number of graminoid species, small shrub species, geophytic species and herbaceous species than the deep-ploughed and control areas (Table 1). Shallow-ploughed areas also had a greater cover of graminoids, geophytes and herbs than the deep-

Table 1
Statistical comparison of mean number and cover (±standard deviation) of species, life history and growth form categories for the control (C), deep ploughing (DP) and shallow ploughing (SP) treatments at Vlakberg and natural vegetation (NV) versus augmented vegetation (AV) at Sandberg and Springs farm.

		C	DP	SP	$F_{2,27}$	Sig	NV	AV	$F_{1,14}$	Sig
Total # spp		27.1 ± 4.28^{a}	24.0 ± 3.59^{a}	45.5 ± 3.44^{b}	94.1	**	39.13 ± 4.32^{a}	47.5 ± 4.69^{b}	13.8	**
Resprouters	Cover	59.5 ± 16.87^{a}	34.8 ± 8.88^{b}	72.1 ± 7.20^{a}	26.0	**	80.13 ± 18.41^{a}	91.91 ± 16.84^{a}	1.2	NS
	# spp	18.4 ± 3.84^{a}	13.1 ± 2.92^{b}	29 ± 1.83^{c}	73.9	**	26.13 ± 3.83^{a}	31.64 ± 3.53^{b}	8.4	**
Reseeders	Cover	68.5 ± 19.63^{a}	99.7 ± 24.89^{b}	44.7 ± 7.17^{c}	21.6	**	30.00 ± 6.85^{a}	47.88 ± 7.94^{b}	23.3	**
	# spp	8.7 ± 1.16^{a}	11 ± 2.31^{a}	16.6 ± 2.59^{b}	39.9	**	13.38 ± 1.69^{a}	15.75 ± 1.67^{b}	8.0	**
Graminoids	Cover	21.6 ± 7.63^{a}	19.1 ± 5.11^{a}	26.6 ± 4.65^{ab}	4.1	*	35.00 ± 4.14^{a}	34.63 ± 6.39^{a}	1.2	NS
	# spp	7.9 ± 2.33^{a}	6.6 ± 1.78^{a}	11 ± 2.11^{b}	11.7	**	11.13 ± 1.13^{a}	10.88 ± 1.81^{a}	0.1	NS
S shrubs	Cover	14.2 ± 6.71^{a}	8.8 ± 4.80^{a}	38.8 ± 9.46^{b}	48.6	**	39.25 ± 11.95	46.50 ± 11.93	1.5	NS
	# spp	7.4 ± 2.27^{a}	6.2 ± 2.15^{a}	16.3 ± 3.02^{b}	48.3	**	15.13 ± 2.36^{a}	17.63 ± 2.62^{a}	4.0	NS
M shrubs	Cover	21.3 ± 13.90^{a}	8.5 ± 5.36^{b}	3.90 ± 2.47^{cb}	10.7	**	18.25 ± 13.32^{a}	23.38 ± 6.57^{a}	1.0	NS
	# spp	2.8 ± 0.79^{a}	1.7 ± 0.95^{b}	2.2 ± 0.79^{ab}	4.2	*	4.25 ± 1.39^{a}	5 ± 0.53^{a}	2.0	NS
L shrubs	Cover	56.9 ± 18.18^{a}	87.2 ± 27.14^{b}	14.5 ± 2.37^{c}	37.3	**	8 ± 1.6^{a}	16.75 ± 5.26^{b}	20.3	**
	# spp	2.7 ± 0.48^{a}	4 ± 0.94^{b}	2.9 ± 0.32^{a}	12.0	**	1.5 ± 0.53^{a}	2.75 ± 0.46^{b}	25.0	**
Geophytes	Cover	13.1 ± 7.68^{a}	10.4 ± 4.45^{a}	26.1 ± 4.56^{b}	21.2	**	8.88 ± 2.95^{a}	16.00 ± 4.41^{b}	14.4	**
	# spp	6 ± 2.83^{a}	5.1 ± 1.45^{a}	11.7 ± 1.34^{b}	32.3	**	6.63 ± 1.51^{a}	9.88 ± 2.36^{b}	10.8	**
Herbs	Cover	0.9 ± 1.45^{a}	0.4 ± 0.52^{a}	5.5 ± 3.34^{b}	17.5	**	1.38 ± 0.74^{a}	0.25 ± 0.46^{b}	13.2	**
	# spp	0.3 ± 0.48^{a}	0.4 ± 0.52^{a}	1.4 ± 0.52^{b}	14.4	**	0.5 ± 0.53^{a}	1.38 ± 0.74^{b}	7.3	**

Letters in superscript show where significant differences exist between treatments (ANOVA with *post hoc* Tukey test;** $P<0.01$; * $P<0.05$).

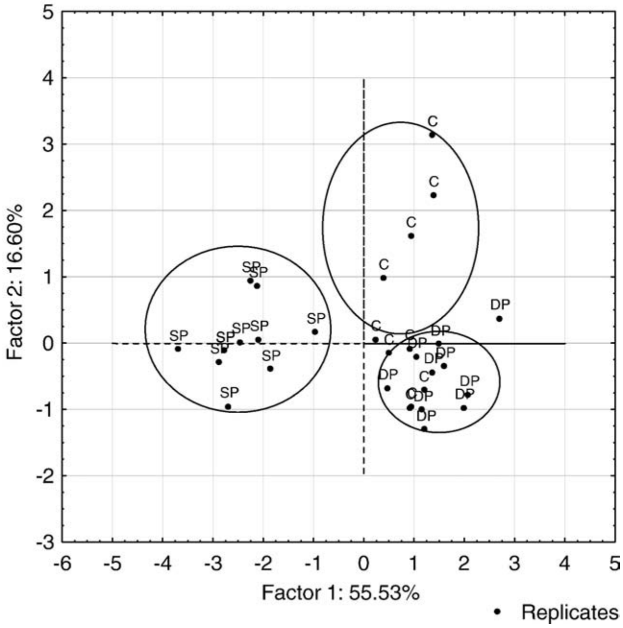

Fig. 1. Principal Component Analysis (PCA) of the different treatments at Vlakberg. The circles indicate distinct groups (SP = shallow ploughing; Control = control; DP = deep ploughing) formed by the PCA analysis. Eigenvalues are presented in the text.

ploughed and control treatments (Table 1). The percentage cover of small shrubs in the shallow-ploughed areas was significantly higher than the deep-ploughed areas (Table 1).

The average number of medium-sized shrub species was highest in the control plot, second highest in the shallow-ploughed areas and lowest in the deep-ploughed areas (Table 1).

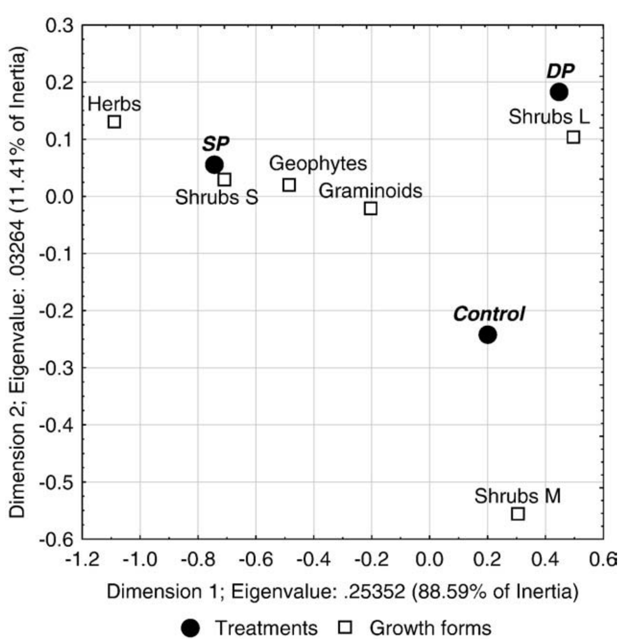

Fig. 2. Correspondence Analysis (CA) showing the relationship between treatments and the cover of the different growth forms at Vlakberg. Abbreviations are: SP (Shallow ploughing); DP (Deep ploughing); Shrub S (small shrubs); Shrub M (medium shrubs); and Shrub L (large shrubs).

The differences between the control areas and the deep-ploughed areas were significant, but shallow-ploughed areas did not differ significantly from either the deep-ploughed areas or the control areas. The medium-sized shrubs in the control areas had significantly higher cover than in the deep- and shallow-ploughed areas (Table 1).

The number of large shrub species in the deep-ploughed area was significantly higher than the control areas and the shallow-ploughed areas (Table 1). The area covered by large shrubs was highest in the deep-ploughed areas, less in the control areas and lowest in the shallow-ploughed areas. All differences were significant (Table 1).

During the initial post-fire period (<4 years) at Springs Farm, the impact of augmentation on the regeneration of fynbos was less dramatic than the impact of the ploughing treatments. However, the PCA analysis for the growth forms at Springs Farm still showed two distinct groups — one for the natural and one for the augmented areas with the first two axes of the PCA accounting 62% of the total variance (Axis 1, Eigenvalue 2.2330, total variance 37.22%; Axis 2, Eigenvalue 1.5084, total variance 25.14%). The CA showed that graminoids are more likely to occur in natural veld, and herbs, large shrubs and geophytes in augmented veld, but that small and medium-sized shrubs do not show any preference for either of the two (Fig. 3).

A more detailed discussion of the differences between growth forms, relative to the treatments, follows (Table 1). The augmented veld had a significantly higher number of large shrub species, geophytic species and herbaceous species than the natural veld but did not differ from the natural vegetation with respect to the number of small shrub species, medium-sized shrub species and/or graminoid species (Table 1). The augmented veld had a significantly higher area covered by large shrubs, geophytes and herbs than the natural areas (Table 1). No significant results were found when comparing cover of graminoids, small shrubs and medium-sized shrubs among the different treatments.

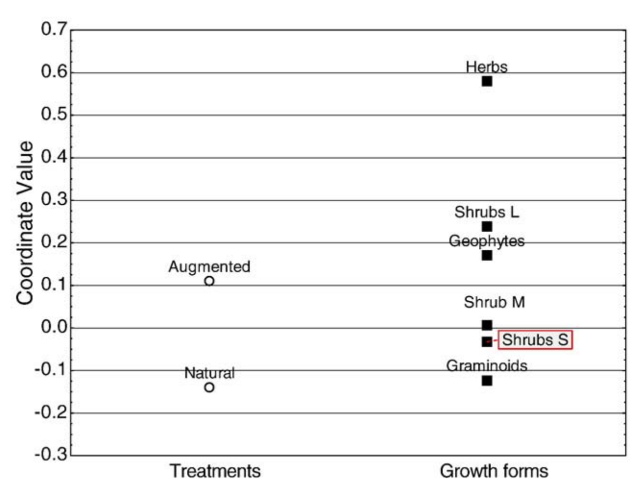

Fig. 3. Correspondence Analysis (CA) showing the relationship between treatments and the cover of the different growth forms. Abbreviations: Shrub S (small shrubs); Shrub M (medium-sized shrubs); and Shrub L (large shrubs).

4. Discussion

In an attempt to balance wildflower production and biodiversity conservation, recent conservation initiatives on the Agulhas Plain have focussed on the sustainable harvesting of natural fynbos as a viable conservation land-use (Privett et al., 2002). Augmentation of natural fynbos is still necessary, however, to fulfil market requirements (Carinus et al., 2004). Here, results have shown that it is indeed possible to augment natural fynbos vegetation with commercial fynbos species (such as *P. compacta* and *L. platyspermum*) without jeopardizing fynbos conservation on the Agulhas Plain. High-impact management practices (e.g. conventional ploughing, repeated ploughing and repeated fires), however, should be avoided, because these practices can promote competitive exclusion of subdominant species, which may lead to a reduction in plant diversity.

The intermediate disturbance hypothesis states that diversity will be low at sites of very high and very low disturbance levels, but that an intermediate level of disturbance will maintain diversity by preventing competitive exclusion (Connell, 1978; Huston, 1979), and this hypothesis may explain our findings. Previous research found that the (beta) diversity in fynbos cannot be explained by the intermediate disturbance hypothesis, but Schwilk et al. (1997) investigated the frequency of a disturbance event (fire) and not the intensity of such an event. It is acknowledged, however, that the intensity and frequency of a disturbance event might be interlinked in determining plant diversity.

4.1. The effect of ploughing on plant diversity

The PCA analysis showed shallow ploughing to be very different from the other two treatments. The shallow-ploughed treatment coincided with the highest total species richness as well as the highest species richness of resprouters, reseeders, graminoids, small shrubs, geophytes and herbs, but not that of medium-sized or large shrubs. The increased richness of growth forms observed in the shallow-ploughed treatment appears to be representative of early successional stages in fynbos when fire-ephemerals and long-lived species co-exist (Cowling and Pierce, 1988), but before shorter-lived species are eliminated (Bond and Van Wilgen, 1996). It is possible that shallow ploughing delays the successional process by introducing and creating a niche for weedy, pioneer species. Van Wilgen and Kruger (1981) documented a similar situation where tall proteoid communities with an understorey were replaced by low shrublands dominated by resprouters and short-lived reseeders when two disturbance events (fire) followed each other in quick succession.

There are alternative explanations for increased diversity in the shallow-ploughed area. Firstly, shallow ploughing involves an intermediate intensity of soil disturbance that could prevent the competitive exclusion of any subdominant plant species (Connell, 1978; Huston, 1979). Secondly, the increased plant diversity might be an artefact of plant size (Oksanen, 1996), which is supported by the strong, positive relationship between small shrubs and geophytes. The CA analysis also shows a close association between small growth forms and shallow ploughing. A third explanation draws on findings by Vlok and Yeaton (2000), who found that an overstorey protea canopy such as in the deep-ploughed areas, could suppress the vegetative growth and fecundity of understorey resprouters. The augmented species in the shallow-ploughed areas (*P. cordata*) is a low-growing protea species that does not form an overstorey canopy; thus, it does not suppress the resprouter understorey community (Cowling and Gxaba, 1990).

The low resprouter diversity in the deeply ploughed areas is difficult to explain satisfactorily. It might be a result of the augmented *P. compacta*, which forms a dense overstorey canopy; thus, suppressing the understorey resprouter community (Vlok and Yeaton, 2000). The negative relationships between (1) large and small shrubs, and (2) large shrubs and geophytes support such a conclusion. However, there is possible synergy between the effects of the augmented species, *P. compacta*, and the effect of deep ploughing on plant diversity. The traditional purpose of deep ploughing is, after all, to reduce competition from other fynbos species, such as resprouters, with the augmented species.

The augmented species in the deep-ploughed area, *P. compacta*, is a large, reseeding shrub whose flowers are harvested for the wildflower market. This partially explains the high percentage cover of large shrubs (as shown in the CA analysis) and reseeding species in the deep-ploughed areas.

4.2. The effect of augmentation on plant diversity in natural vegetation

In the initial stages (~4 years) after a fire, the total species richness, the species richness of resprouters and reseeders, as well as the area covered by reseeders was higher in the augmented veld than in the natural veld. Additionally, the number and cover of large shrub, geophytic and herbaceous species were higher in the augmented veld than in the natural veld. These results are in direct contrast with initial expectations that competition from augmented species (e.g. *L. platyspermum*) will exert stress on the naturally occurring fynbos species, leading to competitive exclusion and thus, a reduction in plant diversity. It might be argued that the vegetation in the natural and augmented areas was not old enough to allow valid conclusions regarding augmentation effects. However, Vlok and Yeaton (1999) found that it is the "previous fire history of a site, and not the last fire, which affects plant species richness of fynbos communities through its effect on the abundance of overstorey proteas". Therefore, it might be valid to make a prediction regarding the outcome of augmentation irrespective of the age of the vegetation. Nonetheless, it would be interesting to monitor changes in plant community composition as the augmented species, *L. platyspermum*, matures. Finally, we cannot exclude the possibility that results might be explained by previous fire history or by soil differences between sites. Richards et al. (1997) found that soil factors were the primary determinant of survival and biomass production, and thus distribution, of Proteaceae species across a landscape.

In summary, our results suggest that plant species diversity of Overberg Sandstone fynbos is not negatively affected by intermediate-intensity disturbance events, at least in the short-term. These results have important implications for the augmentation of wildflower production in semi-natural plantations, which is needed to fulfil the demands of the wildflower market. As a rule of thumb, it is the high-intensity disturbance techniques such as deep ploughing that should not be advocated as a viable augmentation practice. Low-intensity disturbances (e.g. non-inversion ploughing and augmentation), however, do not have a detectable negative effect on plant diversity in the short-term; thus, these are worth exploring as viable options within the wildflower industry.

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