Blattodea as potential indicators of Peninsula Granite Fynbos restoration following the clear-felling of pine plantations

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Abstract

Alien plant invasions pose a major threat to the biodiversity of the Cape Peninsula; currently facilitating the transformation of native vegetation and alien invertebrate invasions. This threat provided a motive for the removal of alien pine plantations from the lower slopes of Table Mountain, with the aim of restoring the currently endangered Peninsula Granite Fynbos vegetation. Despite some indication that native fynbos vegetation is recovering, the recovery of native invertebrate communities and their associated ecosystem function remains uncertain. Epigaeic invertebrates are easily sampled, highly abundant, responding rapidly to changes in habitat condition. This study investigates the potential of Blattodea species to be employed as ecological indicators of Peninsula Granite Fynbos restoration, along a chronosequence of recently-felled pine stands. Within 10 years of clear-felling, Blattodea communities inhabiting recovering fynbos do not appear to be very distinct in terms of species richness or composition from those inhabiting undisturbed Peninsula Granite Fynbos, indicating restoration progress. Despite the presence of endemic species among both habitat types, the abundance of the invasive Portuguese millipede (*Ommatoiulus moreletii*) at clear-felled sites suggests that the ecological footprint of pine still persists. The influence of pine could be reduced by implementing the follow-up clearance of alien trees and pine debris. Although an ecological indicator species was identified, its robustness needs to be tested under a range of spatial and temporal conditions.

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1. Introduction

Table Mountain National Park (TMNP) is located along the Cape Peninsula within the Cape Floristic Region (CFR), one of the six floral kingdoms of the world (Goldblatt, 1997). As one of the world's 34 biodiversity hotspots (Mittermeier et al. 2004) the CFR is recognised as a centre of exceptional plant diversity and endemism (Cowling et al., 1996; Helme and Trinder-Smith, 2006). Table Mountain is also considered to be an important site of invertebrate diversity and endemism within the region, with 111 of the 112 faunal species endemic to the Cape Peninsula identified by Picker and Samways (1996) being invertebrates. (see also Giliomee, 2003). Due to its close proximity to anthropogenic pressure from urban development and agroforestry, the conservation of Table Mountain's plant and particularly invertebrate communities has been the focus of invertebrate conservation efforts within the region.

Alien plant invasions are a major threat to the biodiversity of the Cape Peninsula (Richardson et al. 1996). Thirty percent of the CFR has already been transformed by urban development, cultivation (especially agroforestry) and invasive alien trees, with an additional 30% of the remaining natural vegetation predicted to be transformed by alien plant invasions within the next 20 years (Rouget et al., 2003). The lower slopes of Table Mountain, characterised by granite soils and Peninsula Granite Fynbos vegetation have been largely transformed since the introduction of commercial pine plantations in the 1880's (Cowling et al. 1996). The two predominant commercial pine species planted on the Cape Peninsula are the American Monterey pine, *Pinus radiata*, and the European Cluster pine, *Pinus pinaster*. Fire-resilience, rapid growth and long dispersal distance have facilitated the spread and invasion of pines into the surrounding native vegetation. This has had significant implications for the loss of habitat and biodiversity, particularly in fynbos, where pines are able to outcompete and displace native plant species. Pine invasion into fynbos increases plant biomass and fuel loads, leading to more severe fires which cause physical damage to the soils and contribute to increased soil erosion and instability (van Wilgen and Scott, 2001). The replacement of fynbos shrubs by pine trees has also been found to increase vegetation water use, thereby reducing surface runoff and the streamflow of river catchments (van Wilgen and Richardson, 2012). Pine plantations are generally associated with lower invertebrate richness than native afromontane forests (Ratsirarson et al., 2002), however appear to support a similar species richness to fynbos (Pryke and Samways, 2009; Uys, 2012). The composition of invertebrate communities occupying pine plantations however differs from fynbos, and in fact is more similar to communities within afromontaine forests. It has therefore been proposed that invertebrate species specific to Peninsula Granite Fynbos are unlikely to persist under pine plantations (Uys, 2012). Further encroachment of alien pines into the remaining patches of Granite fynbos vegetation may therefore lead to the loss of invertebrate species, many possibly endemic to the Cape Peninsula.

The role of pine plantations as a source of the alien plant invasions currently threatening the biodiversity of the Cape Peninsula (Richardson et al. 1996) has provided a motive for their removal within Table Mountain National Park. Peninsula Granite Fynbos, which historically covered an area of 9179 ha within the Cape Peninsula, has been reduced to 30% of its former area by urbanisation and land cultivation (Rebelo et al., 2011). The aim of restoration is to restore the native Peninsula Granite Fynbos plant and invertebrate communities which were originally replaced by pine afforestation, and thereby restore local biodiversity and key ecosystem processes (Holmes and Richardson, 1999). The plant and litter invertebrate communities of Peninsula Granite Fynbos are distinct from those inhabiting Peninsula Sandstone fynbos (Mucina and Rutherford, 2006; Uys, 2012), and are therefore important for the conversation of local endemism and ecosystem function. The focus of ecological restoration efforts have largely been on the recovery of plant community composition towards that of an undisturbed reference state (Ruiz-Jaen and Mitchell Aide, 2005). The monitoring of plant communities alone may however not adequately assess the recovery of native habitats, especially considering the disproportionate contribution of invertebrates to biodiversity. Longcore (2003) recorded inadequate recreation of native arthropod communities within Californian coast sage scrub, a Mediterranean–type ecosystem, despite the successful restoration of the pant community to that of an undisturbed state, highlighting the need for measures of invertebrate biodiversity to be included in assessments of ecological restoration.

A number of challenges to invertebrate biodiversity monitoring are posed by the exceptionally high species richness, diverse life histories and limited taxonomic knowledge of many invertebrate groups (Mound and Gaston, 1993). Because the monitoring and management of so many, often poorly understood, individual invertebrate species is not feasible, the dimensions of multispecies assemblages are often reduced to a subset of surrogate species that will reflect ecological requirements and management objectives for a larger set of species (Cushman et al., 2010; Wiens et al., 2008).

Invertebrates can be useful as indicators of broader ecosystem status by providing proxy measures of biodiversity components such as ecosystem function, habitat restoration and the effects of invasive species (McGeoch 2007). The use of indicator species provides a time and cost-efficient approach to protecting rare and threatened species, while providing a more suitable measure of restoration progress than species richness alone. Epigaeic invertebrate have short generation times and generally lack mobility, making them particularly sensitive to habitat changes. As they rely entirely on the resources produced by leaf litter (Giller, 1996), their populations are expected to respond rapidly to selective pressures brought about by changes in habitat condition. Indicator species must satisfy a number of criteria such as taxonomic identification, sufficient abundance and habitat fidelity (McGeoch, 1998). Using this approach, Uys (2012) identified ants and cockroaches (Blattodea) as the most suitable potential indicators for measuring the ecological changes associated with the restoration of clear-felled pine sites towards a state representative of natural Peninsula Granite Fynbos. Although Blattodea have not been widely employed to assess the effects of disturbance, they have the potential to be employed as ecological indicators due to their sensitivity to disturbances, particularly those affecting the depth and quality of leaf litter (Gerlach et al., 2013).

This study investigates the efficacy of Blattodea as a tool for monitoring the restoration of Peninsula Granite Fynbos, following the clear-felling of alien pine plantations. The composition of Blattodea communities along a chronosequence of recovering fynbos sites are compared against reference communities from undisturbed granite fynbos sites in order to assess restoration of Blattodea communities since clear-felling. Blattodea species which have the potential to act as ecological indicator species (McGeoch, 1998), and thereby contribute to the monitoring of restoration progress in Peninsula Granite Fynbos are selected using two complimentary approaches. The abundance of millipedes, especially of the invasive Portuguese millipede (*Ommatoiulus moreletii*), has been found to be high in alien pine plantations and native forest, intermediate in recently clear-felled pine, and low in undisturbed fynbos (Uys, 2012). The abundance of *O. moreletii* is included in this study as an additional indicator of the transition towards a Peninsula Granite Fynbos state. Habitat variables are explored as potential drivers of invertebrate diversity between habitat types. Together, these results provide insights into the potential for Blattodea to be incorporated into long-term monitoring of Peninsula Granite Fynbos restoration.

2. Material and methods

2.1 Study sites

The study took place on the east-facing slopes of Table Mountain National Park (TMNP) on the Cape Peninsula, South Africa (Fig. 1). TMNP protects 24 000 ha of the Cape Peninsula, including 80% of the Table Mountain chain (Helme and Trinder-Smith, 2006). The top and upper slopes of Table Mountain are characterised by the more abundant Peninsula sandstone fynbos, while the lower slopes of the mountain are characterised by Peninsula Granite Fynbos, which become endangered following urban development and agroforestry (Cowling et al., 1996). Natural Peninsula Granite Fynbos is characterised by Asteraceaous and Proteoid fynbos species (Mucina and Rutherford, 2006). Recovering granite fynbos vegetation growing on the sites of recently clear-felled pine plantations is characterised by younger fynbos plants and the remaining felled pine stumps and trunks. The study sites correspond to Peninsula Granite Fynbos and recently clear-felled pine plantation sites surveyed by Djock (2013), and previously included in a survey of TMNP invertebrates by Uys (2012). The two Peninsula Granite Fynbos sites acted as reference sites to which the composition of the Blattodea assemblages of six clear-felled pine sites, felled between 2003 and 2009, could be compared (Table 1).

2.2 Invertebrate sampling

Epigaeic invertebrates were sampled using pitfall traps by Djock (2013) in March 2013, and the by-catch used in this study. Pitfall catches represent a composite measure of the activity and abundance of surface-active fauna, rather than a true measure of relative abundance, and are therefore biased by species-specific activity levels and responses to habitat structure (Topping and Sunderland, 1992). Despite these caveats, pitfall trapping is commonly used to assess the composition of surface-active invertebrate assemblages.

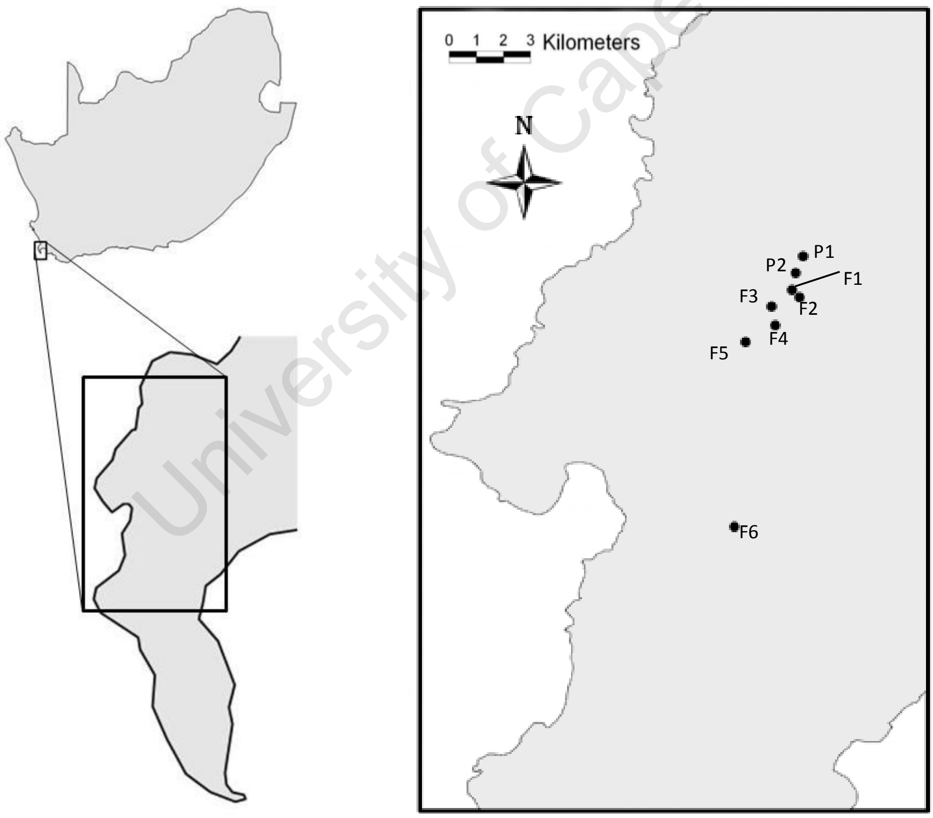

Figure 1: Map of sites sampled within Table Mountain National Park (right) on the Cape Peninsula (middle), South Africa (top left). F = granite fynbos reference sites, P = clear-felled pine sites of different ages since felling (see table 1).

Table 1: Location and description of study sites.

Site	Vegetation	Location	GPS coordinates		Altitude (m a.s.l)	Date of felling
F1	Granite fynbos	Kirstenbosch, Nursery Ravine	33^{o} 59' 03.2" S,	18^{o} 25' 28.4" E	330	n/a
F2	Granite fynbos	Kirstenbosch, Skeleton Gorge	33^{o} 59' 17.8" S,	18^{o} 25' 19.2" E	350	n/a
P1	Clear-felled pine	Cecilia, Rooikat Ravine	33^{o} 59' 42.9" S,	18^{o} 25' 21.6" E	320	May 2008
P2	Clear-felled pine	Cecilia, Rooikat Ravine	33^{o} 59' 46.0" S,	18^{o} 25' 20.8" E	300	Jan 2009
P3	Clear-felled pine	Cecilia, Spilhaus Ravine	34^{o} 00' 03.7" S,	18^{o} 24' 45.6" E	470	April 2008
P4	Clear-felled pine	Constantia Nek, Bridle Path	34^{o} 00' 19.6" S,	18^{o} 24' 45.4" E	330	April 2008
P5	Clear-felled pine	Contantia Nek, Steps	34^{o} 00' 31.6" S,	18^{o} 24' 19.4" E	280	July 2006
P6	Clear-felled pine	Tokai South, Prinkasteel	34^{o} 03' 59.9" S,	18^{o} 24' 09.8" E	230	July 2003

Traps consisted of clear plastic cups, 85mm in diameter and 120mm deep. At each of the eight sites, a total of twenty traps were arranged at 5 meter intervals along two transects. Of the twenty traps at each site, ten traps were half filled with 50% ethylene glycol solution and ten traps half filled with a 20% sucrose solution. The sugar-baited traps were used to specifically target ants for Djock's study, however they also produced a by-catch of other invertebrate species, including Blattodea and millipedes. Traps were left in the field, and collected after seven days. Collected specimens were preserved in 90% alcohol or frozen for later identification. Cockroaches and millipedes were removed from the by-catch and sorted to the level of morphospecies or species, where possible. Blattodea were identified using the photographic reference collection of Uys (2012) (see Appendix 2).

2.3 Habitat variables

At each of the eight sites, seven habitat variables were measured along each of four randomly placed 10 meter transects in order to explore possible factors responsible for difference to habitat suitability for Blattodea species. Total vegetation cover was visually estimated in a 1m x 1m plot at the start of each transect and the cover values averaged. The number of pine stumps and logs greater than 20cm in diameter lying within one meter of the transect were counted as measure of the remaining pine influence on the site characteristics. In order to estimate the degree to which alien vegetation had re-established within the recovering fynbos since the clear-felling of pine stands, the number of alien trees and saplings along and within one meter of the transect were counted and the base stem diameter measured using callipers. Four measures of leaf litter depth were made at each site by inserting a ruler vertically into the leaf litter, at the start of each randomly placed transect. Four 300ml soil samples per site were collected by removing surface litter and removing soil from 10cm depth. Soil samples were air dried at 25^{o}C for 1 week and passed through a 2mm sieve to remove coarse fragments. Sieved soil was prepared for analysis of pH and electrical conductivity by mixing a 10g soil sample with 20ml of distilled water and mixing for 12 hours. pH and electrical conductivity of the supernatant were measured using a pH and conductivity meter (Hanna Instruments, USA), respectively, and averaged across four samples for each site.

2.4 Data analysis

Clear-felled pine site P2 contained an usually low abundance of only 4 Blattodea individuals, attributable to possible sampling error, and was thus excluded from subsequent analyses. Unpooled catches from individual traps were only available for sites F1 and P2. As site P2 was excluded from analyses due to aforementioned reasons, it was not possible to compare sample-based species accumulation curves and species richness estimates between habits in order to determine whether sampling intensity had been sufficient. Due to the low number of replicates sites employed in this study (F = 2, P = 5), univariate descriptive statistics of abundance and richness were employed and interpreted qualitatively. Multivariate analyses of Blattodea assemblages were performed using PRIMER (v 6.1.11) (Clarke and Gorley, 2006) to investigate the differences in community composition between sites. Counts from twenty traps were summed to produce the abundance data for each site. Data were fourth root transformed, to down-weight the contribution of highly abundant species, and used to generate a Bray-Curtis similarity matrix (Clarke and Gorley, 2006). A non-metric, multidimensional scaling (NMDS) ordination was generated from the triangular Bray-Curtis similarity matrix in order to visualise the similarity in species presence and abundance between sites. Hierarchical clustering of Bray-Curtis similarities, using group-average sorting, was performed to produce a dendogram. (Clarke and Gorley, 2006).

Blattodea species characteristic of either granite fynbos or recovering clear-felled pine, and thus potential indicators of ecological change, were identified using two complementary approaches: The SIMPER analysis in PRIMER lists the percentage contribution of each species to the identity of an *a priori* defined group of sites. It also indicates which species contribute most to the dissimilarity in species composition between groups of sites, based on their relative abundance within each group. A complimentary approach to identifying bioindicator value is the Indicator Value method, developed by Dufrene and Legendre (1997). It incorporates measures of fidelity (relative frequency) and specificity (relative abundance) to produce and indicator value (IndVal) for each taxon in relation to *a priori* defined groups. A high indicator value is indicative of species with a high fidelity across a habitat type and high specificity for that habitat type. Such species possess useful characteristics for effective sampling and monitoring, and are thus viewed as useful tools for bioindication (McGeoch et al., 2002). As previously proposed by (McGeoch et al., 2002), an IndVal greater than 70% was considered a subjective benchmark for defining a 'characteristic' indicator species for each of the two habitats. The IndVal analysis was carried out in R (v 3.0.1) (R Core Team, 2013). Due to an insufficient number of replicate sites, Dufrene and Legendre's (1997) permutational significance test for IndVal was not performed. Species which were identified to be characteristic by both SIMPER and IndVal were considered to be suitable indicator species for their respective habitat type.

Multivariate analysis of habitat data was performed in PRIMER, following methods outlined in (Clarke and Gorley, 2006). A draftsman plot of all seven habitat variables was produced in order to identify variables with a high degree of collinearity. On the basis of a strong correlation ($\rho = 0.98$) between the alien tree abundance and alien tree stem diameter, stem diameter was removed from the analysis. The reduced set of variables was normalised and used to produce a triangular resemblance matrix of Euclidean distances, from which an NMDS ordination was produced to visually represent the variation in habitat conditions amongst sites. Blattodea community structure was related to the six remaining normalised environmental variables using the BIO-ENV and BEST procedures in PRIMER (Clarke and Ainsworth, 1993; Clarke and Gorley, 2006). The exploratory BIO-ENV procedure calculates the rank correlation between the biotic similarity matrix and different matrices of environmental variables in order to identify which suite of habitat variables best explain the variation in community structure.

3. Results

A total of 518 individuals from 10 Blattodea species, and 489 millipedes (all *Ommatoiulus moreletii*) were collected from the eight sampled sites (Table A1). The mean abundance of Blattodea was higher amongst the recently clear-felled pine sites than at the two fynbos sites, while measures of richness and diversity were comparable between habitat types (Table 2). *O. moreletii* was also more abundant at the recently clear-felled sites (Table 2). Blattodea species endemic to the Cape Peninsula (*Dipterum brinckae, Haplophoropyga unicolor, Saltoblattella montistabularis*) were not restricted to the fynbos sites, instead being most abundant at the clear-felled site P3, which was also characterised by the greatest abundance and species richness of Blattodea (Table A1).

The NMDS plot and cluster analysis revealed a weak separation in Blattodea community structure between habitat types, although there was no distinct clustering of sites in relation to habitat type or time since felling (Fig. 2). A stress value of 0.09 suggests that the NMDS ordination in two dimensions provides a good fit to the data and is therefore representative of the relationship between Blattodea communities (Clarke and Gorley, 2006). Site P5 was identified by cluster analysis as the most distinct site, separating it from all other sites at the 58% similarity level. The two fynbos sites which are clustered

Table 2: Mean values of Blattodea abundance, species richness and diversity and Portuguse millipede (*Ommatoiulus moreletii)* abundance from fynbos and clear-felled pines sites.

		Fynbos (n = 2)	**Clear-felled pine (n = 5)**
Blattodea	Abundance	27.5 (range: 27-28)	91.8 (range: 35-204)
	Richness	5 (range: 4-6)	6 (range: 5-8)
	Shannon-Wiener H	1.56 (range: 1.37-1.74)	1.71 (range: 1.54-1.87)
O. moreletii	Abundance	10.5 (range: 6-15)	81.8 (range: 35-113)

together with site P1 at the 79% similarity level are separated from the remaining pine sites (P3, P4, P6) at the 63% similarity level. The two fynbos sites are not considered to be more similar to each other than to site P1, with which they cluster together on the ordination and dendogram.

NMDS ordination of normalised habitat variables revealed a greater separation between habitat types, however also showed similarly large differences amongst clear-felled pine sites, which appear to be unrelated to the age of the site since clear-felling (Fig. A1). A stress value of 0.03 indicated a good fit of the ordination in two dimensions to the habitat data. BIO-ENV identified a combination of alien tree abundance, soil pH and felled pine stump abundance as the suite of habitat variables which correlated most strongly with Blattodea community composition ($\rho = 0.56$). A combination of alien tree abundance and soil pH provided similarly strong rank correlation with the biotic data ($\rho = 0.55$), which was more parsimonious. Furthermore, alien tree abundance was included in the top nine BEST results produced by the BIO-ENV procedure. This can largely be attributed to the absence of alien trees and saplings at either of the fynbos reference sites. The average abundance of alien trees and saplings recorded at clear-felled sites was 13.6 (range: 0-23), with only site P1 showing an absence of alien trees (Table A2).

Results from the SIMPER analysis are outlined in Table 3. *Temnopteryx phalerata* and the Cape Peninsula endemic *Haplophoropyga unicolor* were identified principal contributors to the 64.44 % similarity amongst fynbos sites and 76.29% similarity amongst clear-felled pine sites, respectively. Concordantly, neither species made a large contribution to the dissimilarity between fynbos and clear-felled pine. Blattodea species *Gen. nov. 1* was the second most important contributor to the dissimilarity between habitat types, and also as the third most important contributor to the similarity amongst fynbos sites. *Anallacta confusa* was the most important contributor to the separation of fynbos from clear-felled pine sites, as well as a notable contributor to the similarity among clear-felled pine sites.

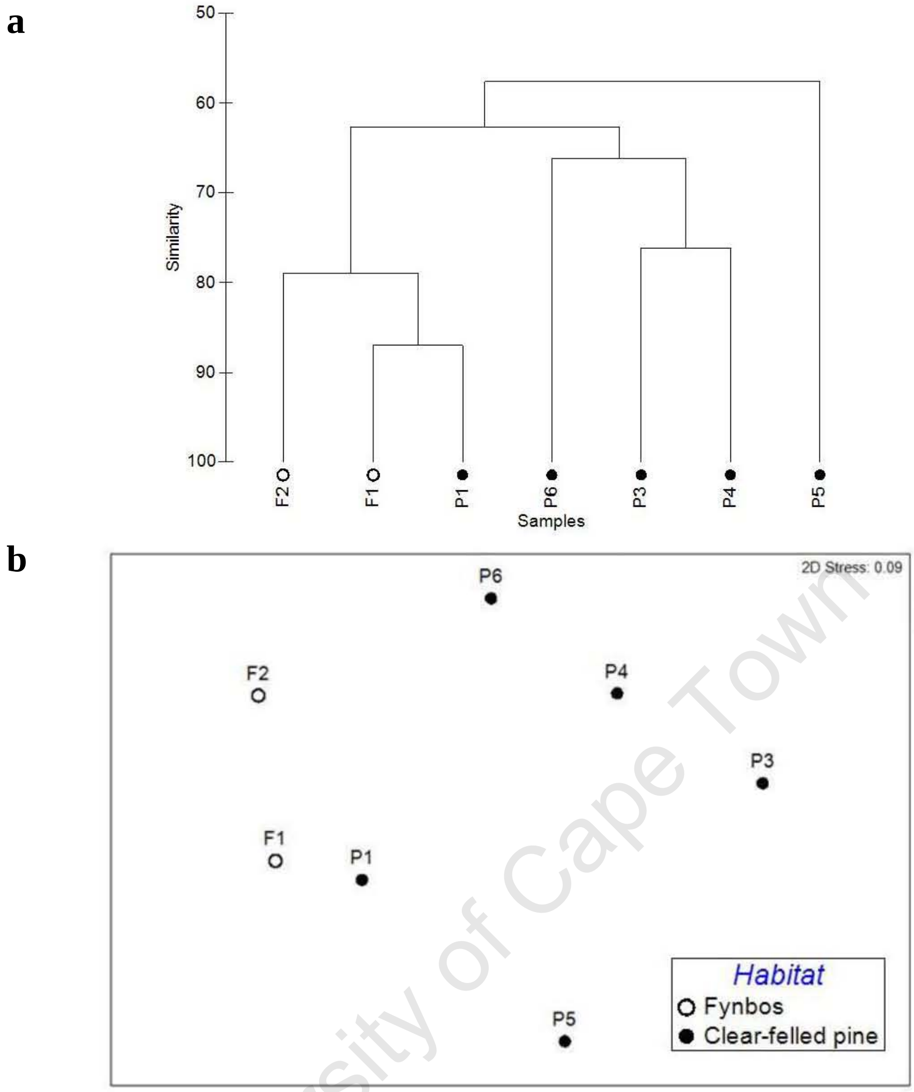

Figure 2: (a) Dendogram and (b) NMDS ordination of Bray-Curtis similarities between Blattodea communities at fynbos (F1 and F2) and recently clear-felled pine sites (P1-P6). Site P2 excluded from analysis due to low numbers and possible sampling error.

Indicator values (IndVal) of each species for their respective habitat types are summarised in Table 4. In concordance with the SIMPER results, the Blattodea species Gen. nov. 1, with an IndVal value of 81%, exceeded the 70% criterion to qualify as a ‘characteristic’ indicator species (McGeoch et al., 2002) of the fynbos habitat type. Among the clear-felled pine sites, *Anallacta confusa* had the highest IndVal value of 83%, and was also one of the few species specific to the habitat. Blattodea species sp. 1 and *T. Phalerata* also qualified as characteristic species for clear-felled pine, with IndVal measures greater than 70%. The remaining species did not have an indicator value exceeding the 50% criterion for qualification as ‘detector’ species, as proposed by (McGeoch et al., 2002).

Table 3: Contribution of the top three species to the similarity of Blattodea communities within habitat types, and separation between different habitat types, as identified by SIMPER analysis. Mean community similarity among sites within the same habitat and mean dissimilarity between sites from different habitats indicated in parentheses. * - Peninsula endemic

Habitat	Species	Avg.Sim/Dis	Contrib%	Cum %
Clear-felled pine (64.44%)	*Temnopteryx phalerata*	25.64	39.78	39.78
	sp. 1	15.25	23.66	63.45
	Haplophoropyga unicolor *	7.84	12.16	75.61
Fynbos (76.29%)	*Temnopteryx phalerata*	29.11	38.16	38.16
	Haplophoropyga unicolor *	17.59	23.06	61.22
	Gen. nov. 1	14.79	19.39	80.61
Clear-felled pine & Fynbos (35.74%)	*Anallacta confusa*	6.44	18.03	18.03
	Gen. nov. 1	4.76	13.33	31.36
	sp. 1	4.08	11.42	42.77

Avg.Sim/Dis average similarity/disimilarity, *Contrib%* contribution towards total average similarity per taxon, *Cum%* cumulative percentage total of all taxa towards average similarity.

Table 4: Mean abundances and Indicator values (IndVal) of Blattodea species habitat indicators. (>) 'Characteristic' indicator species with IndVal greater than 70% criterion. (*sensu* McGeoch et al., 2002). * - Peninsula endemic.

	Mean abundance	%IndVal	70% criterion
Granite Fynbos			
Gen. nov. 1	3.5	81	>
Xosablatta caffra	0.5	21	
Clear-felled pine			
Anallacta confusa	3	83	>
sp. 1	16.6	73	>
Temnopteryx phalerata	18.5	73	>
Bantua sp.	0.6	50	
*Haplophoropyga unicolor**	7.4	47	
*Dipterum brinckae**	2	38	
Pseudoderopeltis sp.	0.2	17	
*Saltoblattella montistabularis**	2.2	17	

4. Discussion

Recovery of Blattodea community composition

Alien pine plantations represent highly modified ecosystems, which are simplified, posses fewer functional redundancies and are consequently less resilient to perturbations than natural ecosystems (Laliberte et al., 2010). The flora and fauna of alien pine plantations are typically considered to be depauperate relative to the surrounding native communities (Ratsirarson et al., 2002; Aubin et al., 2008; Pryke and Samways, 2010; Magoba and Samways, 2012; Uys, 2012). Furthermore, alien pine plantations are thought to act as platform for the establishment and spread of alien invertebrates, such as the invasive argentine ant (*Linepithema humile*) and Portuguese millipede (*Ommatoiulus moreletii*), into surrounding native vegetation.

In this study, the composition of Blattodea communities occupying recovering fynbos habitats does not appear to be very distinct from those sampled within established Peninsula Granite Fynbos. Using a more comprehensive set of invertebrate taxa, the two granite fynbos sites sampled in this study have also previously been found to be clustered together, and distinct from both clear-felled and natural Peninsula sandstone fynbos sites (Uys, 2012). It should however be noted that, despite ensuring site independence by maintaining a minimum distance between sites, some of the apparent similarity between fynbos reference sites may be due to their geographical proximity. This was unavoidable, as very few patches of undisturbed Peninsula Granite Fynbos remain on the slopes of Table Mountain.

The variation in Blattodea community composition amongst sites also does not appear to be related to the age of the site since felling, agreeing with findings of Djock (2013) for ant communities at the same sites. Despite this, it appears that within 5-10 years of clear-felling, the recovering fynbos vegetation shows signs of being able to support a comparable richness and composition of Blattodea species. Despite apparent similarities in species richness and diversity, a greater abundance of Blattodea was recorded at all recently clear-felled sites, in contrast to (Pryke and Samways, 2009) who observed similar abundances of epigaeic invertebrates amongst natural and recovering granite fynbos sites, within 5 years of clear-felling. Clear-felled pine has been found to rapidly lead to the recovery of fynbos vegetation and epigaeic invertebrates, to a state which more closely resembles post-fire fynbos than mature fynbos (Pryke 2008). While fynbos vegetation is resilient to regular burning and able to fully recover after several fire cycles (Holmes and Richardson, 1999), it is unclear whether the timescales over which granite fynbos invertebrate communities may fully re-establish following the removal of pine stands mirrors the natural timescales of fynbos recovery following fire. The reference sites sampled in this study and by Uys (2012) are in close proximity to Kirstenbosch botanical garden and have thus been subject to fire-exclusion policies and the disruption of the natural disturbance regime. Consequently, senescence of mature fynbos vegetation and encroachment of fire-sensitive afromontaine forest have been observed. In the absence of regular disturbance by fire, reference sites may therefore not be truly representative of natural Peninsula Granite Fynbos plant and invertebrate communities.

Pryke and Samways (2010) posit that the high invertebrate diversity in fynbos largely stems from greater heterogeneity of abiotic physical characteristics between sites, leading to greater beta diversity than in the surrounding vegetation types. Ordination plots of Blattodea communities and habitat variables reflected similar patterns of heterogeneity between sites, providing some support for this argument. Due to the small sample size, it was not possible determine whether these differences were statistically significant. Qualitative interpretation of the ordinations and BIO-ENV results does however suggest that the presence of alien invasive trees and their signature on the habitat are associated with differences in community composition.

Ecological indicators of Peninsula Granite Fynbos and clear-felled pine

The goal of identifying ecological indicator species is to find taxa which are likely to be largely restricted to a set of habitat conditions and will therefore show changes in abundance in response to habitat conditions. This requires the composition of communities to be sufficiently distinct. Due to a large proportion of shared species, Blattodea community composition is not very distinct between habitats. The few species able to distinguish the habitat types are therefore likely to reflect subtle differences in habitat condition as perceived by the requirements of epigaeic invertebrates.

On the basis of the SIMPER results (Table 3), which place an emphasise relative abundance, *Analacta confusa*, Gen. Nov. 1 and sp. 1 contributed to the cumulative top 43% dissimilarity between habitat types. Species sp. 1 was further identified as a suitable ecological indicator due to its high contribution to the similarity amongst clear-felled pine. If monitoring of indicator taxa is going to be efficient, the target taxa should be present in sufficient abundances to be sampled easily. As a rarer indicator, *A. confuse* is more likely to encounter problems associated with insufficient sampling intensity than more abundant taxa. A more suitable indicator of clear-felled pine is provided by the more abundant sp. 1. In congruence with the SIMPER results, both species have IndVals greater than the 70% criterion (Table 4) and therefore qualify as 'characteristic' indicator species according to McGeoch's (1998) criterion. McGeoch et al. (2002) highlight that 'detector' species (IndVal > 50%), which are less habitat-specific, but still differ in their fidelity between different habitat types are inherently more useful for monitoring change as they are less likely to become vulnerable in habitat conditions become less favourable. Characteristic species, although useful for distinguishing a particular habitat state, may be too specific to effectively monitor ecological if they are only restricted to a single habitat state (McGeoch, 2002). Gen nov. 1 and *A. confusa*, which have the highest IndVals for granite fynbos and clear-felled pine but low abundances, respectively, may therefore represent species which are not able to tolerate habitat change, and would thus be unreliable indicators, if employed individually. Due to the aforementioned constraints associated with adequate sampling intensity, the patchy distribution of target taxa presents a major obstacle to the reliability of ecological indicators (Giller, 1996).

A further sign of recovery of the Blattodea community comes from the presence of endemic species. Both Cape Peninsula endemic cockroaches (*Dipteretrum brinckae* and *Hoplophoropyga unicolor*), previously recorded exclusively in granite fynbos by Uys (2012), also occurred on clear-felled sites. Furthermore, a third Peninsula endemic, *Saltoblattella montistabularis*, was recorded exclusively at one of the recovering fynbos sites. The presence of Peninsula endemics at clear-felled sites holds promise that as fynbos vegetation recovers it is able to retain more features of its natural state. The abundance of the alien Portuguese millipede (*O. moreletii*) however indicates that despite the recovery of fynbos vegetation, the ecological signature of pine still remains 10 years after its removal. Due to the lack of follow-up clearance, the recovering fynbos sites are still littered with felled pine logs, stumps and decaying plant material, as well as alien trees, providing a large source of additional plant biomass which is more atypical of native forest and pine stands than fynbos.

5. Conclusion and recommendations

Both native Peninsula Granite Fynbos and clear-felled pine stands support blattodea communities that are not very distinct with respect to richness and composition. Time since felling does not appear to be associated with the variation amongst clear-felled sites. Furthermore, Blattodea species endemic to the Cape Peninsula were recorded within both habitat types, providing a positive outlook on the ability of Peninsula Granite Fynbos communities to recover. The disturbance brought about by clear-felling of pine, together with the persisting ecological footprint of pine, appears to support a greater abundance of Blattodea and the alien Portuguese millipede (*O. Moreletii*). The potential for native communities to recover would be aided by the follow-up clearance of alien trees and saplings, and by the removal of pine stumps and logs.

The blattodea taxa with the best potential to act as an ecological indicator is sp. 1. Some caveats do arise, such as the differentiation of morphologically different life stages and sexes, as the indicator is only identified to morphospecies, Although morphospecies have been shown to be adequate surrogates for higher taxonomic ranks in studies involving more specious assemblages (Pik et al., 1999), it would be more effective to confirm the remaining taxonomic identities of the known Blattodea within TMNP. Blattodea community would also need to be sampled under different spatial and temporal conditions, in order to determine how robust the indicators are (McGeoch et al., 2002). This would allow indicator species data to be interpreted and applied with more confidence to the monitoring of Peninsula Granite Fynbos restoration.

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7. Appendix 1

Table A1: Blattodea and millipede** species recorded from pitfall traps at eight study sites in Table Mountain National Park. * – endemic to the Cape Peninsula. ** - alien species. Site P2 excluded from analyses due to low Blattodea abundance and possible sampling error. Individual pitfall trap data only available for sites F1 and P2.

Species	F1	F2	P1	P2	P3	P4	P5	P6
Pseudoderopeltis sp.	-	-	-	-	-	-	1	-
Haplophoropyga unicolor *	2	3	2	-	25	7	-	3
Temnopteryx phalerata	22	15	32	3	106	96	27	29
Anallacta confusa	-	-	-	1	6	4	4	1
Xosablatta caffra	1	-	-	-	-	4	-	-
Gen. nov. 1	1	6	1	-	3	1	-	-
*Dipterum brinckae**	1	-	1	-	8	-	1	-
Bantua sp.	-	-	-	-	1	1	-	1
Saltoblattella montistabularis *	-	-	-	-	11	-	-	-
sp. 1	1	3	8	-	44	22	8	1
No. of species	6	4	5	2	8	7	5	5
No. of individuals	28	27	44	4	204	135	41	35
Ommatoiulus moreletii **	15	6	35	59	89	108	113	64

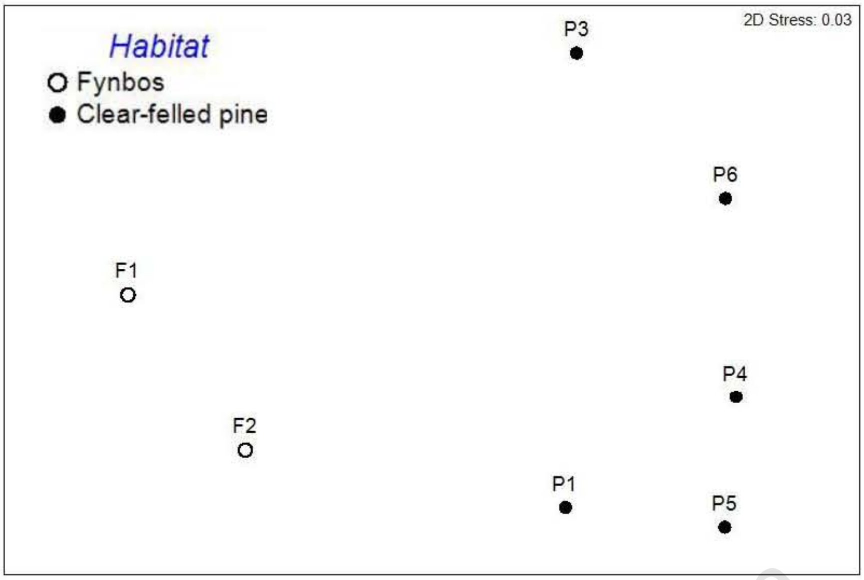


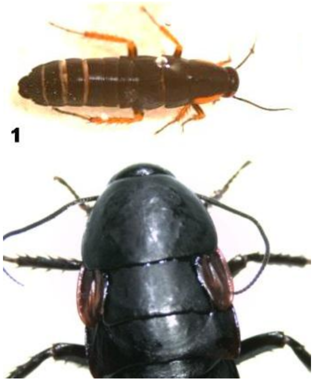
Figure A1: (a) NMDS ordination of normalised Euclidean distanceces between habitat variables at fynbos (F1 and F2) and recently clear-felled pine sites (P1-P6). Site P2 excluded from analysis due to low numbers and possible sampling error of Blattodea.

Table A2: Raw habitat data recorded at each of the eight study sites. * - Contribution of pines to total alien tree abundance (AllAliens). ** - Contribution of pines to total alien stem diameter (AllStemDiam).

Habitat Variable	F1	F2	P1	P2	P3	P4	P5	P6
%Cover	95	82.5	36.25	51.25	50	26.25	56.25	12.5
Pine stumps (> 20cm Diam)	0	0	13	11	30	14	7	33
Litter depth (mm)	20.75	18.75	11.25	17.75	20.25	10.75	10	15.25
Soil pH	5.42	5.85	5.7	5.76	4.86	5.31	5.6	5.32
Soil Conductivity (mS/m)	161.85	115.03	62.4	120.9	92.5	57.8	69.1	73.3
AllAliens	0	0	0	1	12	18	23	15
AllStemDiam(mm)	0	0	0	5	346	373	562	424
Pines*	0	0	0	0	11	13	16	0
PineStemsDiam (mm)*	0	0	0	0	20	268	331	0

Appendix 2

Photographic reference of Blattodea species. (PE – Cape Peninsula endemic)

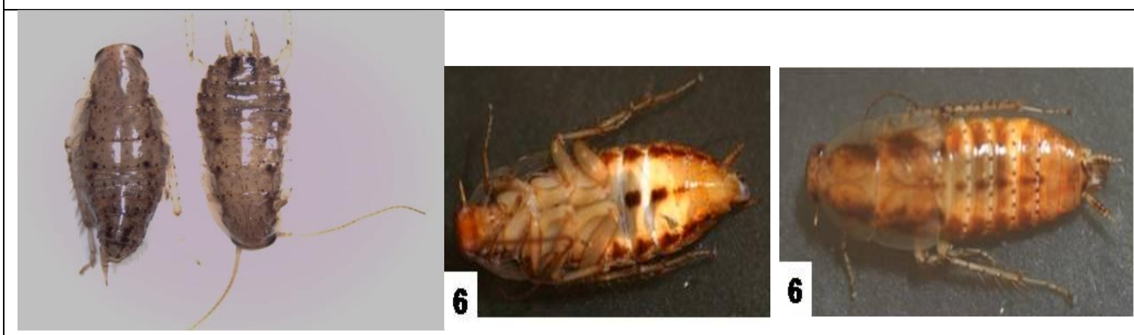


Pseudoderopeltis sp.

Haplophoropyga unicolor **(PE)**

Temnopteryx phalerata

Anallacta confusa



Xosablatta caffra

Gen. nov. 1


***Dipterum brinckae* (PE)**


Bantua sp.


***Saltoblattella montistabularis* (PE)**

sp.1