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Beyond the green: Assessing quarry restoration success through plant and beetle communities

Running head: Assessing restoration success using multi-taxa

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Abstract

To assess the effectiveness of ecological restoration actions, outcomes must be evaluated and a multi-taxa approach can greatly improve the understanding of their success/failure. Since comprehensive biodiversity assessments are rarely possible, choosing taxa groups indicative of ecosystem structural and functional recovery is of major importance. Our goal was to evaluate the success of revegetation actions performed in a Mediterranean limestone quarry, using plants and epigean beetles as indicators. We compared their abundance, diversity and community composition between revegetated sites with 5, 13 and 19 years old and a natural reference. Total plant cover significantly increased with restoration age and quickly reached reference values. However, native woody species cover dropped in the oldest site, whilst non-native species became dominant. Beetles' abundance was always lower in restoration sites than in the reference, increasing with age, although not significantly. Both plant species' and beetle families' richness were lower in restoration sites and did not show any trend towards the reference values. Finally, using nonmetric multidimensional scaling, the composition of plant and beetle communities from restoration sites showed a clear separation from the reference. Restoration efforts have successfully increased total plant cover and the abundance of beetles in post-quarry sites, but considerable differences remain concerning communities' diversity and composition. These differences are probably largely related to the use of the non-native species *Pinus halepensis* in restoration plans, whose high cover in restoration sites greatly affects ecosystem structure, and most likely ecosystem functioning and related ecosystem services, causing divergence from the reference values and compromising restoration success.

Key words: Mediterranean, limestone quarry, chronosequence, multi-taxa, Coleoptera

Implications for Practice

- Practitioners may be misled by high plant cover in restoration sites, reducing disturbed areas visual impact but concealing major differences from the reference.
- Different responses of beetle and plant communities to restoration actions stressed how evaluating different taxa may provide complementary and more enlightening indication about ecosystem structural and functional recovery.
- Beetles identification to family level was sufficient to compare and detect differences between restoration' and reference's sites. This allows a rapid assessment of the community characteristics and a broader implementation of multi-taxa approaches.

Introduction

Mediterranean landscape has a long tradition of mining, especially in karst regions where there are many quarries in operation or abandoned, that require restoration actions (Gams et al. 1993). Open quarries are one of the most problematic areas to restore, since their exploration requires removing all topsoil and associated biota, drastically modifying the original topography and causing a major visual impact (Correia et al. 2001; Clemente et al. 2004; Lima et al. 2016; Mavrommatis & Menegaki 2017). Spontaneous colonization ("passive restoration") has been reported to efficiently create early successional stages, many times with important conservation status (e.g. Baasch et al. 2012; Tropek et al. 2012; Prach & del Moral 2015). However, total recovery of these highly degraded areas may take hundreds of years (e.g. Cullen et al. 1998; Correia et al. 2001) and this situation may be aggravated by local environmental stress conditions. Under Mediterranean climate, water scarcity and high temperatures limit plant establishment and are major constraints to ecosystem recovery (Correia et al. 2001; Le Houerou 2000). If faster recovery is required to prevent further degradation or e.g. reduce visual and ecological impact, active restoration may be necessary to help re-establish plant and animal communities (Prach & del Moral 2015).

For some time, ecological restoration frequently aimed at soil and few plant species recovery, as the basis of the trophic chains and to rapidly reduce the visual impact was rapidly reduced, while other plant and animal species were expected to spontaneously colonize from the surrounding areas (Young 2000; Longcore 2003; Majer 2009; Suding 2011). However, different taxa communities play different roles and may have distinct recovery trajectories that may compromise restoration efforts success, as has been reported for plant and animals (e.g. Majer JD et al. 2007; Woodcock & McDonald 2008; Babin-Fenske & Anand 2010). It is important to evaluate how effective restoration actions actually are (Suding 2011; Wortley et al. 2013; Gann et al. 2019), but there are still few studies combining more than one taxonomic group (Neri & Sánchez 2010; Nunes et al. 2016). Furthermore, restoration outcome evaluation in the short-to-medium term is essential to, when necessary, adopt adaptive management actions or reformulate restoration strategies, in order to ensure that initial goals are achieved and that restoration efforts are cost-effective (Bakker et al. 2018; Suding 2011). Still, medium-term monitoring and the use of a positive reference, representing the pre-existing ecosystem, are still less common (Wortley et al. 2013; Nunes et al. 2016).

A successful restoration is based on key attributes that ensure general ecological outcomes such as vegetation structure, species diversity and abundance, and ecological processes (Ruiz-Jaén & Aide 2005; Wortley et al. 2013; Gann et al. 2019). Biological diversity and abundance are primary objectives of ecological restoration and are therefore the most common measures used to assess restoration success (Ruiz-Jaén & Aide 2005; Wortley et al. 2013). The contribution of animal communities to the functioning and self-sustainability of restored ecosystems is essential (Young 2000; Nichols & Nichols 2003; Walker & del Moral 2003; Majer 2009; Audino et al. 2014), so multi-taxa studies should be used for a better understanding of restoration success and cost-effectiveness. However, monitoring all animal groups in restored areas is most often not logistically feasible (Young 2000; Audino et al. 2014). This constrain may be overcome by selecting a group of organisms that serve as bioindicators, i.e. taxa that indicate environmental conditions, and may therefore be used in identifying ecological characteristics or monitoring the effects of habitat management (Gerlach et al. 2013).

Beetles (Insecta: order Coleoptera) have been widely proposed as bioindicators because they are typically sensitive to ecosystem changes and microclimatic conditions, most species are easily sampled with high abundance catchments in short time periods and broadly distributed, include different trophic levels, and their taxonomy and ecology are relatively well known (New 2010; Gerlach et al. 2013). As an important component of terrestrial ecosystems, beetles provide a set of ecological functions, many of them critical in the restoration process, such as nutrient cycling, soil turbation, fertilization, secondary seed dispersal, and biological control of parasites (Walker & del Moral 2003; New 2010; Gerlach et al. 2013). Also, beetles have been shown to resemble arthropods overall response to restoration (Bisevac & Majer 2002; Longcore 2003). Thus, beetle assemblages can both indicate and influence the success of restoration efforts (New 2010; Audino et al. 2014). Still, biodiversity assessment of insects is time-consuming and taxonomically demanding, which is often not practicable for monitoring purposes (Babin-Fenske & Anand 2010; Cardoso et al. 2011). A higher taxa approach has been suggested as an alternative to species-level identification, with identifications at family-level sufficient to detect changes in distribution patterns of communities (Báldi 2003; Lovell et al. 2007; Babin-Fenske & Anand 2010; Cardoso et al. 2011), while order-level may fail to detect changes (Longcore 2003).

Our main objective was to evaluate the restoration success of a Mediterranean limestone quarry through the combined study of plants and epigean beetles. To achieve this goal, we used a “space-for-time” approach, where sites with different intervention ages were used as a proxy of the effect of time since intervention on the ecosystem. Despite some methodological concerns about this approach (e.g. differences in sites’ soil and aspect, changes in rehabilitation technology; Majer 2009), chronosequences use is common in restoration studies (e.g. Audino et al. 2014; Boscutti et al. 2017) and quarry sites were chosen to try to minimize these confounding factors. By comparing sites with different ages since revegetation with a natural maquis reference, we hypothesized that the abundance and diversity of plant species and beetle families will increase with time since restoration, and that their values, as well as their communities' composition, will progress towards the values of the reference ecosystem. We expect that this integrative work will provide insights on restoration trajectories followed by different relevant taxa, and on their possible interdependence, after the implementation of restoration actions to recover a severely degraded ecosystem – a limestone quarry – under Mediterranean climate, contributing to improve restoration planning and management in similar contexts.

Methods

Study area

The study was conducted in a limestone quarry in a natural park, located in southwest Portugal (SECIL, SA – Outão quarry, 38°29'44.57"N; 8°56'53.19"W). The climate is sub-humid Mediterranean with an average annual temperature of 16,4°C and average annual precipitation of 670 mm (Setúbal). The bedrock is mainly limestone, with *terra rossa* accumulated in fissures and holes. Rock extraction is conducted from the top of the mountain downwards, creating a series of platforms and vertical walls with approximately 20m width/height. Intervention in the platforms starts as soon as an area is cleared, thus creating a chronosequence of platforms since the early 1980s. Intervention consisted in placing a 1m layer of quarry's marl spoils and planting (0.8 - 1.2 ind/m^2) of woody species. These included native evergreen sclerophyllous species, selected from the adjacent natural vegetation, and non-native species (for planted species list see Table S1 – Supporting information). The latter, namely *Pinus halepensis*, were planted to mitigate initial visual impact and act as nurse species, and they should be removed while restoration sites are still under management. The study was performed in three restoration sites with different ages since plantation: 5, 13 and 19 years (Fig. S1 – Supporting information). The surrounding natural community was selected as a reference site, representing the desired end point of restoration (Fig. S1). The reference area ranged from rupestrian to Mediterranean maquis formations, with a maximum height of 5m, dominated by evergreen sclerophyllous shrubs and small trees.

Vegetation and ground assessment

Vegetation was sampled from April to May 2007 using fifteen 3 x 3m square plots per site, placed at regular intervals along a 200m transect (Kent & Coker 1994). In each plot, vascular plant species were identified to the species level, and the percentage cover (visual estimation for the whole plot) and density (number of individuals per plot) of woody species was assessed, as well as the cover of herbaceous species altogether, rocks and litter accumulation on the soil surface. To assess the density of herbaceous species, three smaller squares with 0.5 x 0.5m placed within each plot were used (a total of 45 squares per site). Species identification followed The Angiosperm Phylogeny Group (2016). When species-level identification was not possible, due to the limited availability of identifying characters, plant specimens were classified into morphospecies.

Beetle assessment

Beetles were sampled using pitfall traps, following methods described in New (1998). Traps consisted of plastic containers 15cm deep and 9cm wide at rim level, covered with a ceiling supported 2.5-3cm above the ground level. Ethylene glycol was used as preservative and traps were filled to at least one-third of the cup's volume. In each site, three stations of five traps were placed along the same transect used for vegetation sampling, separated by 80m and traps spaced by 2m. The content of each trap was collected twice a month from April to June 2007. Adult specimens of beetles (Insecta: Order Coleoptera) were sorted and identified to family level following Vanin and Ide (2002). Total captures per station (sum of the five traps) were considered in the data analysis.

Data analysis

Plant and beetle diversity were assessed by estimating the Shannon-Wiener diversity index and the Pielou's evenness index at species (plant) and family (beetles) levels (Magurran, 2004). We used general linear models (n = 15 for a plants, n = 3 for beetles) to test for differences between sites': (i) plant and beetle taxonomic richness, diversity and evenness; ii) cover of vegetation (total), herbaceous and woody species, planted native and non-native species, and non-native spontaneous species; (iii) cover of leaf litter and rocks; and (iv) beetle abundance. Multiple post hoc pairwise comparisons between sites were made for all the response variables previously mentioned (i-iv) with "glth" function (multcomp R package) (Hothorn et al. 2008). To assess the variation in species (plants)/families (beetles) composition between sites, non-metric multidimensional scaling (NMDS) ordination was performed separately for the plant and beetle communities, based on (i) plant species density and (ii) beetles abundance per plot, using the function “metaMDS” of R Package vegan (Oksanen et al. 2018). Square root transformed data were submitted to Wisconsin double standardization (species are first standardized by maxima and then sites by site totals). Bray-Curtis distance measure was used to measure the distance/similarity between sites. Ordination stress statistic was used as a measure of goodness of fit. The coefficients of determination (r2) between original plot distances and distances in the final ordination solution were calculated to assess how much variability in plant and beetles community composition was represented by the NMDS axes (McCune, Grace & Urban 2002). All statistical analyses were conducted in R (R Core Team 2018).

Results

A total of 104 plant species were identified in the study site, including 37 woody and 67 herbaceous species (Table S2). Plant species richness and diversity were significantly lower in restoration sites compared to the reference site (Table 1). In restoration sites, woody species richness showed no change with restoration age, while herbaceous species significantly decreased their richness and diversity from 5 to 13 and 19 year restoration old sites (Table 1). Concerning beetles, a total of 2,056 specimens from 37 families were collected (Table S3). Beetle family richness was significantly lower in restoration sites compared to the reference (Table 1). Contrasting with vegetation patterns, no significant differences were found in beetle diversity and richness with restoration age (Table 1).

Total plant cover was higher than 70% across all sites (Fig. 1a). Older restoration sites were significantly different from the younger one, and showed a total plant cover similar to the reference site (Fig. 1a). Summed cover of woody species increased with restoration age, as well as litter cover, the latter significantly higher in 19 years old restoration site, compared to the reference (Fig. 1a). Cover of herbaceous species (all natural colonizers) decreased with restoration age (Fig. 1a). Concerning only woody species, the cover of species used in the restoration process was responsible for most of the woody cover (over 70%) and increased with age (Fig. 1b). However, native species cover, both used in the restoration as well as spontaneous colonizers, dropped in the older site, in contrast with non-native species that achieved its maximum cover there (Fig. 1b). Beetle mean abundance, although showing an increasing trend with restoration age (112% from 5 to 19 years), did not differ significantly between restoration sites nor from the reference site (Fig. 1a).

The main gradients in plant and beetle communities' composition were described by the first two axes of the non-metric multidimensional scaling ordinations (NMDS) based on plant species density and beetle family abundance, with final stress values of 0.22 and 0.14, respectively (Fig. 2). The first two axes accounted for most of the variance in both cases (35,6% and 10,0% for plants, and 39,0% and 12,6% for beetles, axis 1 and axis 2, respectively).The first axis of plant community NMDS discriminated between restoration sites and the reference site (Fig. 2a). The second axis of plant community ordination identified a gradient of restoration age, but the sites partially overlap (Fig. 2a).

Beetle NMDS also showed a clear separation between the reference and the restoration sites (Fig 2b). Considering both axis of the NMDS, beetle community composition in 13 and 19 year old restoration sites were more similar, contrasting with the younger restoration site and with the reference site, which also differed from each other (Fig. 2b). Neither the plant nor the beetle communities' composition in restoration sites seemed to show a distinct progression towards the reference site with restoration age.

Discussion

In our study area, revegetation efficiently contributed to the rapid recovery of plant cover in the quarry area, as seen by other authors (e.g. Correia et al. 2001; Watts & Gibbs 2002; Ruiz-Jaén & Aide 2005; Boscutti et al. 2017). However, there were differences in structural components from the reference site, more conspicuous in the older restoration site. This is mostly owned to a switch in planted species cover along the restoration chronosequence, marked by a decrease in native species cover coupled with an increase in cover of the introduced non-native species *Pinus halepensis* with restoration age. Although *P. halepensis* does not occur in the reference, this species has been extensively used in the Mediterranean Basin region, as a nurse species facilitating the establishment of other species and as an engineer species rapidly changing the environment, and also for a rapid visual impact mitigation due to its fast-growing characteristics (Maestre et al. 2003; Maestre & Cortina 2004; Pausas et al. 2004). The use of *P. halepensis* in restoration plans, alongside with the harsh edaphoclimatic conditions in the quarry site, may compete with native species and contribute to delay succession and divert the evolution of the plant community from the intended target (Correia et al. 2001; Maestre et al. 2003; Bellot et al. 2004; Maestre & Cortina 2004; Nunes et al. 2014).

Nevertheless, planted sclerophyllous species were quite successfully established, although with much lower cover in the older restoration site. These species were previously selected for their presence and abundance in the surrounding natural sites, which is an important factor in promoting restoration sustainability and success (Vallejo et al. 2006; Prach et al. 2015). Yet, species such as the shrub *Quercus coccifera*, one of the most abundant species in the reference site and planted in the restoration sites, lacked relevant cover in all restoration sites.

The mentioned differences, along with successional processes, led to a clear separation between the plant community composition of the restoration sites and of the reference site. Most of the herbaceous species that have higher density in the younger restoration site were annual, while perennial herbs dominated in the reference, a common successional replacement (e.g. Khater et al. 2003; Bonet & Pausas 2004; Boscutti et al. 2017). Moreover, the cover of shrubs associated to early stages of succession in Mediterranean ecosystems, e.g. *Cistus* spp. (Correia et al. 2001), was higher in restoration sites than in the reference site, as happened with species characteristic of disturbed sites, e.g. *Dittrichia viscosa* (Khater et al. 2003). Additionally, the presence of rock outcrops in the reference, typical of this type of mountain bedrock, promoted the presence of herbaceous rupestrian species, whilst in the restoration sites the cover of rocks was always small. Assuming propagule availability is not a problem at the quarry sites, which is contiguous to the reference areas, different conditions (more favorable to native species colonization and establishment) or more time may be needed to enable the recovery of plant composition (Correia et al. 2001; Ruiz-Jaén & Aide 2005; Prach et al. 2015; Řehounková et al. 2016).

The number of epigean beetle families was similar in all restoration sites, and, simultaneously, no significant changes were found in their diversity and abundance with restoration age (Gibb & Cunningham 2010). Among other factors, mobility and habitat requirements affect animals ability to colonize restored sites (Nichols & Nichols 2003). Restoration efforts shaped the plant community and most certainly changed the microclimatic conditions, influencing beetles colonization and establishment (Watts & Gibbs 2002; Davis et al. 2003; Longcore 2003; New 2010). Although other authors have found that changes in beetle communities of restored sites were more related to vegetation characteristics (e.g. increase of vegetation cover and complexity) than site age by itself (Watts & Gibbs 2002; Longcore 2003; Topp et al. 2010), in our case we cannot separate both effects. Nonetheless, the growing dissimilarity in vegetation characteristics between restoration sites and the reference site may be hindering changes in beetles abundance, diversity and composition towards the reference values. The fact that beetle community composition in the 13 an 19 years old sites seemed more similar, may suggest that after some time changes in composition take longer to carry on. Also, restoration efforts may have facilitated the colonization from the surrounding areas, but changes at substrate level take much longer time to occur and may be also preventing a clear discrimination in beetle's diversity along the chronosequence (Davis et al. 2003; Longcore 2003).

The reference's higher beetle abundance and diversity may also be related to a more heterogeneous habitat at ground level, regardless of being a much less disturbed site. Rocks, litter, logs and debris amount may influence epigean beetle communities by supplying refuges from predation and facilitating foraging and presence of preys (Watts & Gibbs 2002; Lassau et al. 2005). The reference's rock outcrops resulted in higher areas of rock, that do not exist in the restoration sites due to a homogeneous introduction of substrate prior to plantation. Also, epigean beetles are sensitive to structural and chemical properties of leaf litter (Scheu et al. 2003; Pontégnie et al. 2005), so alterations in its quality may have also influenced the beetle assemblages. The increased cover of *P. halepensis* in restoration sites led to an accumulation of pine needles on the ground not observed in the reference, where litter is dominated by evergreen sclerophyllous species (personal observation). Habitat modifications due to conifer plantations, as well as changes from native overstorey to non-native, have been shown to have a negative effect on epigean beetles abundance and richness (Wiezik et al. 2007). Moreover, separation between the restoration sites and the reference site was in part associated with the higher abundance of fungivorous families (e.g. Leiodidae, Lathridiidae and Cryptophagidae) in the latter, most probably related with a higher fungi biomass in maquis areas (Correia et al. 2001).

This study has stressed how measures of plant and beetle communities complement each other, and can contribute to a better understanding of the success of restoration practices and their interdependence. Both communities provide several ecosystem functions, which change in type and amount according to communities' composition. Therefore, a major divergence from the reference ecosystem may also entail differences in ecosystem services provision (e.g. carbon sequestration, nutrient cycling, pest control, seed dispersal) with consequences at the landscape level, compromising the long-term restoration success.

Although the direct effect of *P. halepensis* has not been assessed in this study, this species had probably a large negative effect on both plant and beetle communities. A better knowledge of this interaction is necessary to understand its effects, and management of restoration areas is needed to prevent further dissimilarities from the reference. Practical measures from the quarry management side have already been taken regarding this species, which is no longer part of this quarry's restoration plantation scheme, and its density has been reduced in some revegetated quarry areas.

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Tables and Figures

Table 1. Plant species and beetle families' richness and diversity per site (mean ± standard deviation). Species/family richness per square/station (S), Shannon-Wiener's diversity index (H'), and Pielou's evenness index (J') in restoration sites (5, 13 and 19 years old) and in natural surrounding vegetation (Reference). Differences between sites are denoted with a different letter (see Table S4 for statistical results).

		5 years	**13 years**	**19 years**	**Reference**
Plants	S total	15.00 ± 2.33bc	13.53 ± 3.52b	9.87 ± 1.92a	17.13 ± 2.92c
	S woody species	7.73 ± 1.58ab	9.13 ± 2.95a	6.07 ± 1.44b	8.80 ± 2.18a
	S herb species	7.27 ± 1.39a	4.40 ± 1.84b	3.80 ± 1.52b	8.33 ± 3.74a
	H'	1.62 ± 0.25ab	1.47 ± 0.35a	1.41 ± 0.36c	1.82 ± 0.26b
	J'	0.60 ± 0.09a	0.58 ± 0.13a	0.62 ± 0.16a	0.64 ± 0.08a
Beetles	S	15.00 ± 2.00a	14.33 ± 2.08a	16.00 ± 1.00a	23.00 ± 2.00b
	H'	1.64 ± 0.26a	1.33 ± 0.21a	1.44 ± 0.39a	2.12 ± 0.04a
	J'	0.61 ± 0.09a	0.50 ± 0.06a	0.52 ± 0.15a	0.68 ± 0.03a

Figure captions

Figure 1. Plant cover and beetles abundance: (a) Mean abundance of beetles (number of individuals per station, *n* = 3, bars, right y-axis), and mean total cover of vegetation, herbaceous species, woody species, litter and rock (%, *n* = 15, symbols, left y-axis), per site (5, 13 and 19 years old restoration sites and reference site); (b) mean cover of native species used in the restoration, native species not used in the restoration (spontaneous colonizers) and fast growing species used in the restoration (%, *n* = 15, symbols, left y-axis), per site (5, 13 and 19 years old restoration sites and reference site). Different letters represent significant differences between sites (see Table S4 for statistical results).

Figure 2. Non-metric multidimensional scaling (NMDS) ordination diagrams of the sampled sites based on (a) plant species density (number individuals/m^2; *n* = 15); (b) beetle families' abundance (number individuals/trap station; *n* = 3). Hulls represent different sites (5 years, 13 years, 19 years restoration sites and reference site). For species and families coding see Table S2 and S3.

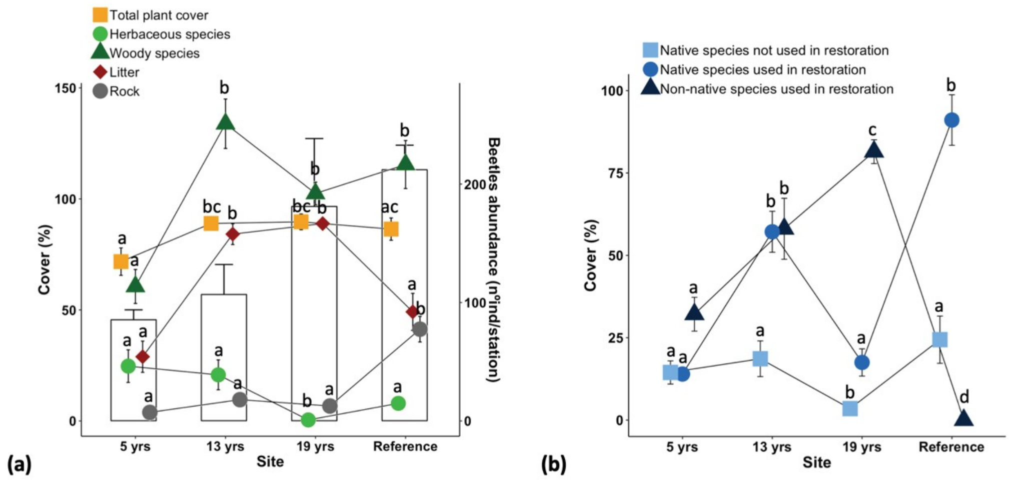
Total plant cover
Herbaceous species
Woody species
Litter
Rock
Cover (%)
150
100
50
0
Beetles abundance (nºind/station)
200
100
0
5 yrs
13 yrs
19 yrs
Reference
Site
(a)
Native species not used in restoration
Native species used in restoration
Non-native species used in restoration
Cover (%)
100
75
50
25
0
5 yrs
13 yrs
19 yrs
Reference
Site
(b)

Figure 1

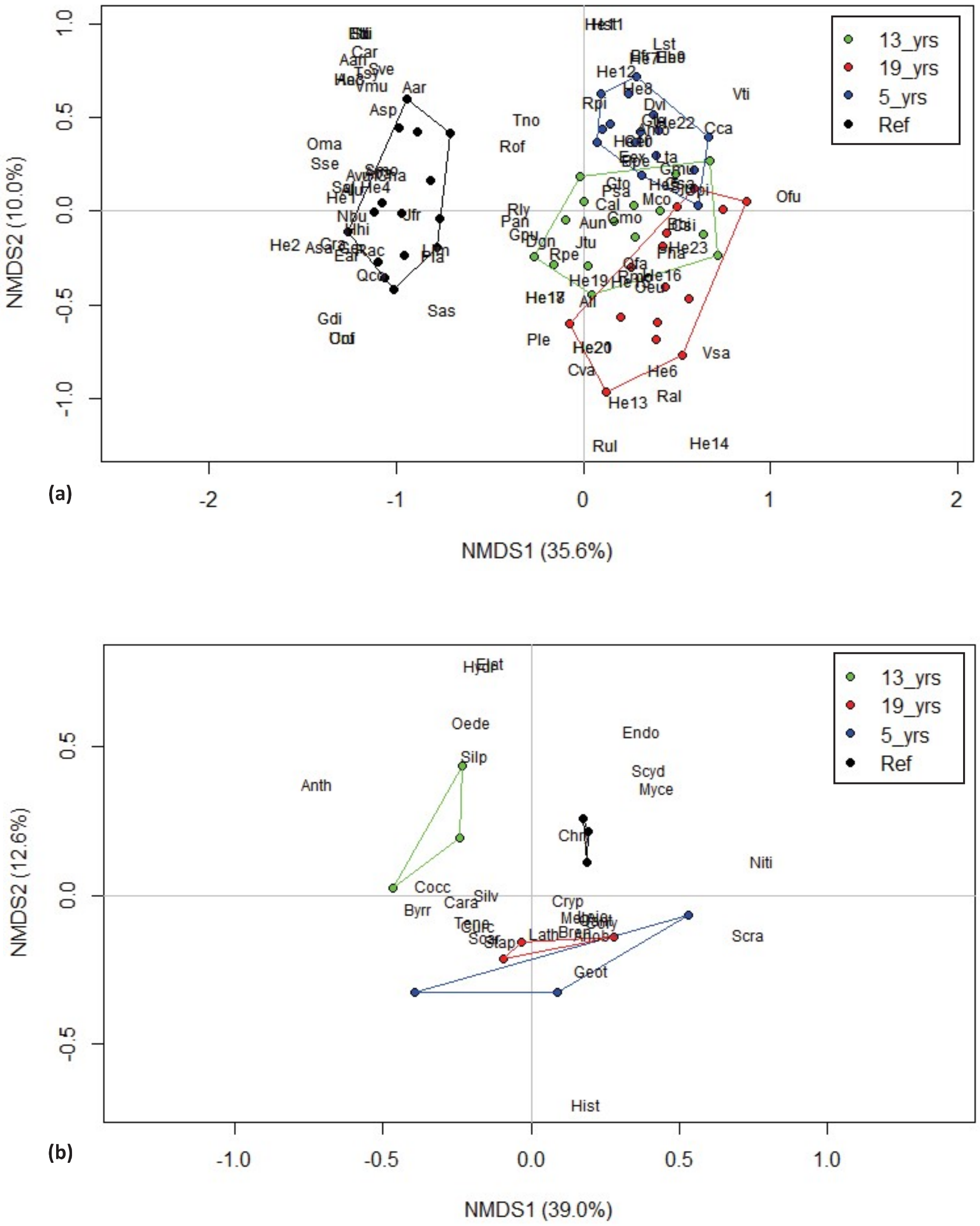(a)
NMDS1 (35.6%)
NMDS2 (10.0%)
-2
-1
0
1
2
-1.0
-0.5
0.0
0.5
1.0
13_yrs
19_yrs
5_yrs
Ref
Car
Aar
Sve
Vmu
Aar
Asp
Oma
Sse
He4
He1
Nbu
Vhi
Ufr
He2
Rac
Ear
Lim
Pla
Qco
Sas
Gdi
Tno
Rof
Rly
Pan
Gpu
Dgn
Rpe
Jtu
Aun
Cal
Psa
Gmo
Mco
Gto
He18
He19
He16
Oeu
All
Ple
He20
Cva
He13
He6
Ral
Vsa
He14
Rul
He23
Pha
Ofu
Vti
Cca
Lst
He12
He8
Rpi
Dvi
He22
Epe
Lta
(b)
NMDS1 (39.0%)
NMDS2 (12.6%)
-1.0
-0.5
0.0
0.5
1.0
-0.5
0.0
0.5
13_yrs
19_yrs
5_yrs
Ref
Elat
Hydr
Oede
Silp
Anth
Endo
Scyd
Myce
Chry
Niti
Cocc
Byrr
Cara
Silv
Tene
Curc
Scar
Stap
Lath
Cryp
Brac
Geot
Scra
Hist

Figure 2