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Expedient Metrics to Describe Plant Community Change Across Gradients of Anthropogenic Influence

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Abstract Human influence associated with land use may cause considerable biodiversity losses, namely in oceanic islands such as the Azores. Our goal was to identify plant indicator species across two gradients of increasing anthropogenic influence and management (arborescent and herbaceous communities) and determine similarity between plant communities of uncategorized vegetation plots to those in reference gradients using metrics derived from R programming. We intend to test and provide an expedient way to determine the conservation value of a given uncategorized vegetation plot based on the number of native, endemic, introduced, and invasive indicator species present. Using the metric IndVal, plant taxa with a significant indicator value for each community type in the two anthropogenic gradients were determined. A new metric, ComVal, was developed to assess the similarity of an uncategorized vegetation plot toward a reference community type, based on (i) the percentage of pre-defined indicator species from reference communities present in the vegetation plots, and (ii) the percentage of indicator species, specific to a given reference community type, present in the vegetation plot. Using a data resampling approach, the communities were randomly used as training or validation sets to classify vegetation plots based on ComVal. The percentage match with reference community types ranged from 77 to 100 % and from 79 to 100 %, for herbaceous and arborescent vegetation plots, respectively. Both IndVal and ComVal are part of a suite of useful tools characterizing plant communities and plant community change along gradients of anthropogenic influence without a priori knowledge of their biology and ecology.

Keywords Plant community ecology · Indicator species · Change detection · R programming · Metrics

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Introduction

Anthropogenic influence is one of the major forces shaping ecosystems worldwide through land conversion from natural into homogenized herbaceous land (Foley et al. 2005). Land use change can negatively impact biodiversity and ecosystem balance, by reducing the number of species contributing for ecosystem function and ecosystem resilience to environmental and anthropogenic impacts, as well as by increasing species invasiveness, both in continental land (Hawksworth and Bull 2010; Laliberté et al. 2010) and in insular ecosystems (Castro et al. 2010; Kueffer et al. 2010). Identifying changes in land cover composition in the context of rising anthropogenic influence helps better understand the structural impact of human activities in species turnover following land conversion. Methodologies capable of monitoring these changes are increasingly popular (Bartha 2004; Winter 2012) and can contribute to a sustainable and strategic management of natural and artificial biotic communities, counteracting the decline of biodiversity (e.g., Engler et al. 2004; Peres et al. 2006; Dupouey et al. 2010).

For instance, the use of indicator species for analysis of biodiversity change or for defining conservation strategies is commonly reported and widely accepted (Paoletti 1999; Lindenmayer et al. 2000; Basset et al. 2004; Niemi and McDonald 2004; McGeoch 2006; Muramoto and Gliessman 2006; Pearsall 2007; De Cáceres et al. 2010). Vascular plants are good indicators of biodiversity change because of their structural importance in ecosystems, their relevance as keystone species in nutrient and carbon cycling, and their continuous presence in many terrestrial habitat types (Nordén et al. 2007; Zerbe et al. 2007; Billeter et al. 2008; Marignani et al. 2008; Aavik and Liira 2009; Odland 2009). Using indicator species to characterize vascular plant communities can reduce the time, cost, and difficulty associated with comprehensive community surveys (Hilty and Merenlender 2000; Nordén et al. 2007).

There is considerable work currently done using statistically derived indicator species to characterize communities (Podani and Csányi 2010; Urban et al. 2012; Vilches et al. 2013), namely plants (e.g.,Nimis et al. 1993; De-Keyser et al. 2003; De Cáceres et al. 2012). Although community classification based upon species sensitivity to habitat change is a powerful approach to detect ecological impacts to an ecosystem, the required prior expertise in the biology and ecology of a species can make this methodology difficult to implement.

We intend to test a quantitative metric, IndVal (Dufrene and Legendre 1997; De Cáceres et al. 2010), as an expedient tool to characterize plant communities, along a priori-defined gradients of anthropogenic influence (Marcelino et al., 2013), i.e., a herbaceous gradient of plant communities (corn, pasture, semi-natural pasture, natural meadows) and an arborescent gradient of plant communities (orchards, production forest, exotic woodland, native forest) based on indicator plant species. We then developed a new metric, ComVal, to measure the degree of similarity of an uncategorized vegetation plot to these reference plant communities, based on shared indicator species. Using this methodology, we expect to identify changes in land cover composition resulting from anthropogenic influence based on the presence/absence of indicator species. In addition, we attributed an ecological conservation category to the indicator species (e.g., endemic, native, introduced) in order to describe the composition of vegetation plots in terms of the presence of indigenous vs. non-indigenous biota.

This simple statistical methodology provides an accurate, cost effective, and expedient way to classify uncategorized vegetation plots, by inventorying only indicator species previously defined in reference communities. The new metric provides an additional tool to complement methodologies characterizing plant communities with limited a priori knowledge of their biology and ecology, such as cluster analysis using PC-ORD (McCune and Mefford 1999), TWINSPAN (Hill 1979), and COINSPAN (Carleton et al. 2009), as well as canonical correspondence analysis, redundancy analysis, and other methods using R packages (see Borcard et al. 2011).

The Azores islands are a good model system to test this methodology, considering the different conservation stages of the islands and the detailed information already available on biodiversity (Borges et al. 2010; Castro et al. 2010), namely plants (Silva and Smith 2004, 2006; Silva et al. 2009; Costa et al. 2014; Queiroz et al. 2014). We expect to find more native and endemic plant taxa as indicators of the more preserved communities and introduced or invasive plant taxa as indicators of the more altered and human influenced communities. The proposed new metric, ComVal, is expected to give a measure of similarity between reference community types and uncategorized vegetation plots, based on indicator species analysis, and of their conservation value.

Materials and Methods

Study Site

The archipelago of the Azores (36°35′–39°43′ N, 24°45′–31°17′ W) comprises nine volcanic islands, forming three main groups, on a WNW–ESE quadrant alignment across the Mid-Atlantic ridge. The Azores support a considerable variety of plant communities (Sjögren 1973; Dias 1996), namely several types of scrubland (coastal, mountain, pioneer), natural forest (e.g., Laurel forest, Juniper woodland), natural meadows (e.g., *Festuca*, *Holcus*, *Deschampsia*), coastal vegetation, and several types of wetlands. As a result, the Azores are recognized as important conservation hotspots (Myers et al. 2000; UNESCO World Heritage; Biosphere and Natura 2000 Networks).

Sampled islands were selected on the basis of the relative proportion of land cover allocated to agriculture (LAA,) and to natural communities (Island Natural Parks, INP, source: Costa et al. 2014) as follows:

Table 1 Description and characteristic plant species by community type

Code	Identification	Description	Characteristic plant species
Herbaceous communities			
MED	Natural meadow	Dominated by indigenous taxa, with low management intensity and low anthropogenic influence	*Holcus rigidus, Festuca* spp., *Deschampsia foliosa, Leontodon* spp., *Tolpis azorica*
SNPL	Semi-natural pasture (Low altitude)*	Dominated by annual populations of *Daucus carota* with low management intensity and low anthropogenic influence	*Daucus carota, Sporobolus indicus, Briza minor, Lotus subbiflorus*
SNP	Semi-natural pasture (High altitude)	Dominated by non-indigenous taxa, but including several indigenous taxa, with low management intensity and low anthropogenic influence	*Holcus lanatus, Agrostis castellana, Polytrichum commune, Ranunculus repens*
PAS	Artificial pasture	Dominated by introduced taxa, with high management intensity and high anthropogenic influence	*Lolium perenne, Bromus willdenowii, Trifolium repens, Poa* spp., etc. and many weeds
COR	Crop	Dominated by introduced taxa, with high management intensity, high anthropogenic influence, pesticide and fertilizer use	*Zea mays*, many agricultural weeds and ruderal plants
Arborescent communities			
NAT	Natural forest	Dominated by indigenous taxa, with low management intensity and low anthropogenic influence	*Laurus azorica, Juniperus brevifolia, Erica azorica, Ilex perado, Morella faya*
INV	Exotic woodlands	Dominated by non-indigenous invasive taxa, with low to medium management intensity and medium anthropogenic influence	*Pittosporum undulatum, Acacia melanoxylon, Eucalyptus globulus, Pinus pinaster, Solanum mauritianum*
CRY	Production forest	Dominated by introduced taxa, with high management intensity and high anthropogenic influence	Monocultural stands of *Cryptomeria japonica*
ORC	Orchard	Dominated by introduced taxa, with medium management intensity and medium anthropogenic influence	*Citrus sinensis, Mallus domestica, Prunus* spp., and many other crop, weed, ornamental or ruderal species

Habitats within each community typology (herbaceous or arborescent) are listed along an anthropogenic influence gradient from natural (top) to intense management (bottom)

* Semi-natural pastures, at low altitude, replaced Meadow habitats in Santa Maria and Terceira island due to the lack of sampling sites of the latter community type in these islands

SMG (São Miguel)—large proportion of land dedicated to pastureland (LAA = 61 %), low/medium proportion of natural habitats (INP = 19.1 %);
TER (Terceira)—large proportion of land dedicated to pastureland (LAA = 66.9 %), medium/high proportion of natural habitats (INP = 21.3 %);
PIC (Pico)—high proportion of land dedicated to pastureland (LAA = 50.33 %), medium/high proportion of natural habitats (INP = 35.3 %), considerable climatic range at the highest elevation in the archipelago, UNESCO World Heritage cultural landscapes);
FLO (Flores)—small proportion of land dedicated to pastureland (LAA = 17.7 %), high proportion of natural communities (INP = 43 %), UNESCO Biosphere Reserve);
SMR (Santa Maria)—high proportion of land cleared for agriculture (LAA = 56.7 %), although not all presently used; small proportion of natural habitats (INP = 17.3 %) but with relevant uniqueness conservation value, i.e., the oldest island in the archipelago).

Community types were defined based on the dominant species present, using the botanical expertise within the group and prior land cover characterization (Cruz et al. Cruz et al. 2007; Marcelino et al. 2013), aiming to cover the most comprehensive list of major plant community types on the Azores. It should be stressed that the community types sampled were not arbitrarily defined by the authors. They represent a broad range of communities that

Table 2 Conservation coefficient gradient categories (CC) for all plant taxa in the dataset

Species category	Category description	CC	References
TopMac	Priority for conservation in Macaronesia (keystone species in the Macaronesian region with ecological, social, and/or economic value)	9	b, c, d, f
TopAz	Priority for conservation in the Azores (keystone species in the Azorean region with ecological, social, and/ or economic value)	8	b, c, d, f
Threat	Under threat but not considered as priority (species with no social and/ or economic value)	7	a, c, d, f
End	Endemic (species endemic to one or more islands of the Azores)	6	a, c, f
Nati	Native (species native to one or more islands of the Azores)	5	a, b, c
Cult	Cultivated (species with considerable social and economical value for the Azores)	4	e
Cas	Casual (non-cultivated species with random distribution)	3	a
Natu	Naturalized (species with historical presence in the Azores, but not endemic nor native)	2	a, e
Inv	Invasive (introduced species with uncontrolled dispersal in the Azores)	1	e, h, g
TopInv	Priority for control in Macaronesia (introduced species with uncontrolled dispersal in the Macaronesian region)	0	e, h, g

Endemic species that are most threatened have the highest conservation value in the gradient. Species likely to displace native species have lower values. References: (a) Borges et al. 2010; (b) Martín et al. 2008; (c) Martín et al. 2010; (d) Silva et al. 2010; (e) Silva et al. 2008; (f) Marsh et al. 2007; (g) Silva and Smith 2004

have been described by several authors (for details see Marcelino et al. 2013 and Table 1) including: i) herbaceous gradient—corn fields as an example of a very common crop in the Azores; pastureland that presently covers about 65 % of the land in the Azores; semi-natural pastureland which represents a less intensive form of pasture; natural meadows, relics of pristine herbaceous formations as previously described for the Azores; ii) arborescent gradient—orchards, which were relatively common in the Azores in the past and usually include not only cultivated but also frequent escapes and naturalized plants; *Cryptomeria japonica* plantations which represent the most common production forest species but also include other non-cultivated elements; exotic woodland, a secondary forest dominated by introduced trees like *Pittosporum undulatum* which covers extensive areas; natural forests dominated by *Laurus azorica* and *Juniperus brevifolia*, as relicts of a once much more common formation. Those communities represent most of the main herbaceous and arborescent formations found in the Azores. We thus intended for a comprehensive but not exhaustive survey of all major vegetation types of the archipelago.

Sampling

In order to obtain the vascular plant richness for each community type, 100 × 100 m geo-referenced plots were sampled following the protocol of Silva and Smith (2006). Plants were assigned to categories based on published criteria (Table 2), ranging from species with top priority conservation status to top invasive species in the Macaronesian region. Plots were sampled by walking along two parallel transects, defined inside each community type, and recording all plant taxa using a semi-quantitative abundance index: 1) isolated plant; 2) plants scattered in the plot; 3) plants forming groups; 4) plants forming mixed stands with other taxa; 5) plants forming pure stands. Two replicates of the 8 habitat communities (4 herbaceous and 4 arborescent) were sampled for each island. Semi-natural pasture at low altitude (Table 1) replaced meadow habitats on Santa Maria and Terceira islands due to lack of this habitat type. The former were chosen as an additional comparison community to intensive pastures. Sampling effort was concentrated in the summer of 2009. All plant taxa were identified to species/subspecies level.

Data Analysis

Indicator Species Discrimination (IndVal)

To determine indicator species among the different communities, we used the R package 'indicspecies' (De Cáceres and Legendre 2009), available through Cran (http://cran.r-project.org/web/packages/indicspecies/). The package was written as a refinement of the IndVal method originally developed by Dufrene and Legendre (1997). The algorithm determines both species fidelity (restriction to a community type or group of community types) and consistency (consistent occurrence among sites within a given community type). In addition, a statistical metric, IndVal (ranging from 1–100), and a p value for all the species is determined (Supplementary material Tables S1 and S2). The algorithm then builds an IndVal tree ranking the indicator species based upon these values. Bootstrap confidence interval bounds (95 % percentile) are also computed in 'indicspecies' ($n = 100$ bootstraps). The arborescent gradient of community types was analyzed separately from the herbaceous gradient. The multipatt function with the IndVal option using communities as clusters was used to create the hierarchy. Only species significant at the $p < 0.05$ level were selected as indicator species.

Several limitations should be taken into consideration when using indicator species, namely the spatial and temporal scale for which a indicator relationship can be extrapolated (Niemi and McDonald 2004; Lindenmayer and Likens 2011), stochastic events and responses to environment variables (Carignan and Villard 2001; Diekmann 2003), and the presence of an accentuated biogeographical variation in species richness (Billeter et al. 2008). However, if those limitations are taken into account and providing that indicator species are also validated outside the scientific community in practical conservation work (Öster et al. 2008), indicator species can be accurately used.

Community Value Categorization (ComVal) by Similarity of Indicator Plant Composition

ComVal (Eq. 1) calculates the closeness of an uncategorized vegetation plot to a given priori reference community type based on the presence/absence of indicator species determined through the IndVal procedure. Calculations were made through an R script developed at Murray State University and available upon request.

ComVal ranges from 0 (no unique indicator species from the reference community type)–100 (includes all indicator species from the reference community type and no other indicator species from other community types) and can be calculated as

$$\mathrm{ComVal}_{ji} = \mathrm{C}_{ji} * \mathrm{D}_{ji} * 100 \qquad (1)$$

with C_{ji} as the percentage of pre-defined indicator species for the reference community *i* that is present in the sampled vegetation plot, *j*; and $\mathrm{D}_{ji} = \mathrm{N}_{ji}/\mathrm{T}_j$, where N_{ji} = number of indicator species for reference community type *i* found in the sampled vegetation plot *j*, and T*j* = total number of indicator species (for all reference communities) found in *j*. This process is repeated for all *i* community types of interest ($n = 1000$ bootstrap iterations).

Parameter C is a measure of how complete a sampled vegetation plot is, as to indicator species, relatively to a reference community type, and parameter D is a measure of fidelity, i.e., how often the community includes indicator species from other community types. When attributing a conservation category to indicator species, ComVal also provides an estimate of the vegetation plot value, allowing to calculate similarities with more or less anthropogenically influenced reference community types.

Predictive performance of ComVal in the assignment of uncategorized vegetation plots to pre-existing community types was evaluated using randomly defined validation datasets, independent from the ones used to determine indicator species, through bootstrapping in the R script. A random number of vegetation plots from each community type (≤½) were used to produce a training set. The global dataset was therefore divided into a *validation set 0* (communities treated as uncategorized vegetation plots, hence, not included in site classification based on indicator species) and a *training set 1* (categorized communities used to determine indicator species based on IndVal). Indicator species were determined from the training set, and then all communities (training and validation sets) were (re)classified to a community type through the ComVal results. The a priori community classification was then compared to the community classification obtained using ComVal metric for both the training and validation set to determine the accuracy in the classifications. All community types were included in the analysis to avoid biased community type classifications.

Results

Indicator Plant Species (IndVal)

Indicator species found using the R package 'indicspecies' (De Cáceres and Legendre 2009), which included the calculation of IndVal, where 69 ($p < 0.05$) out of 223 species in the arborescent gradient (Fig. 1) and 59 ($p < 0.05$) out of 189 species in the herbaceous gradient (Fig. 2). Hence, the list of indicator plant species required for the application of this classification methodology in uncategorized vegetation plots ranged from 4–45 species based on a given a priori-defined list of community typologies (see Figs. 1, 2). These species correspond to the taxa to be monitored for in uncategorized vegetation plots in detriment of monitoring all the plant taxa present at the site. As expected, cultivated indicator species with the highest IndVal significance occurred only in communities most strongly impacted by humans, i.e., orchard (Fig. 1) and corn (Fig. 2). Native plant taxa were never an indicator for these communities but rather for natural forest (Fig. 1), semi-natural pastures, and meadows (Fig. 2). Shared native indicator species were found in less anthropogenically disturbed communities of the herbaceous gradient (i.e., *Blechnum spicant*, *Potentilla erecta*, *Juncus effusus*, *Athyrium filix-femina*, *Sibthorpia europeia*, *Hidrocotyle vulgaris*). One top invasive species (*Hedychium gardnerianum*) and one threatened species (*Dryopteris azorica*) were shared indicators to all but the orchard community in the arborescent gradient (Fig. 1), whereas the invasive *Rubus ulmifolius* var. *inermis* was a shared indicator to all but corn and pasture communities in the herbaceous gradient (Fig. 2).

A trend in species change was evident along the comprehensive anthropogenic influence gradients sampled in

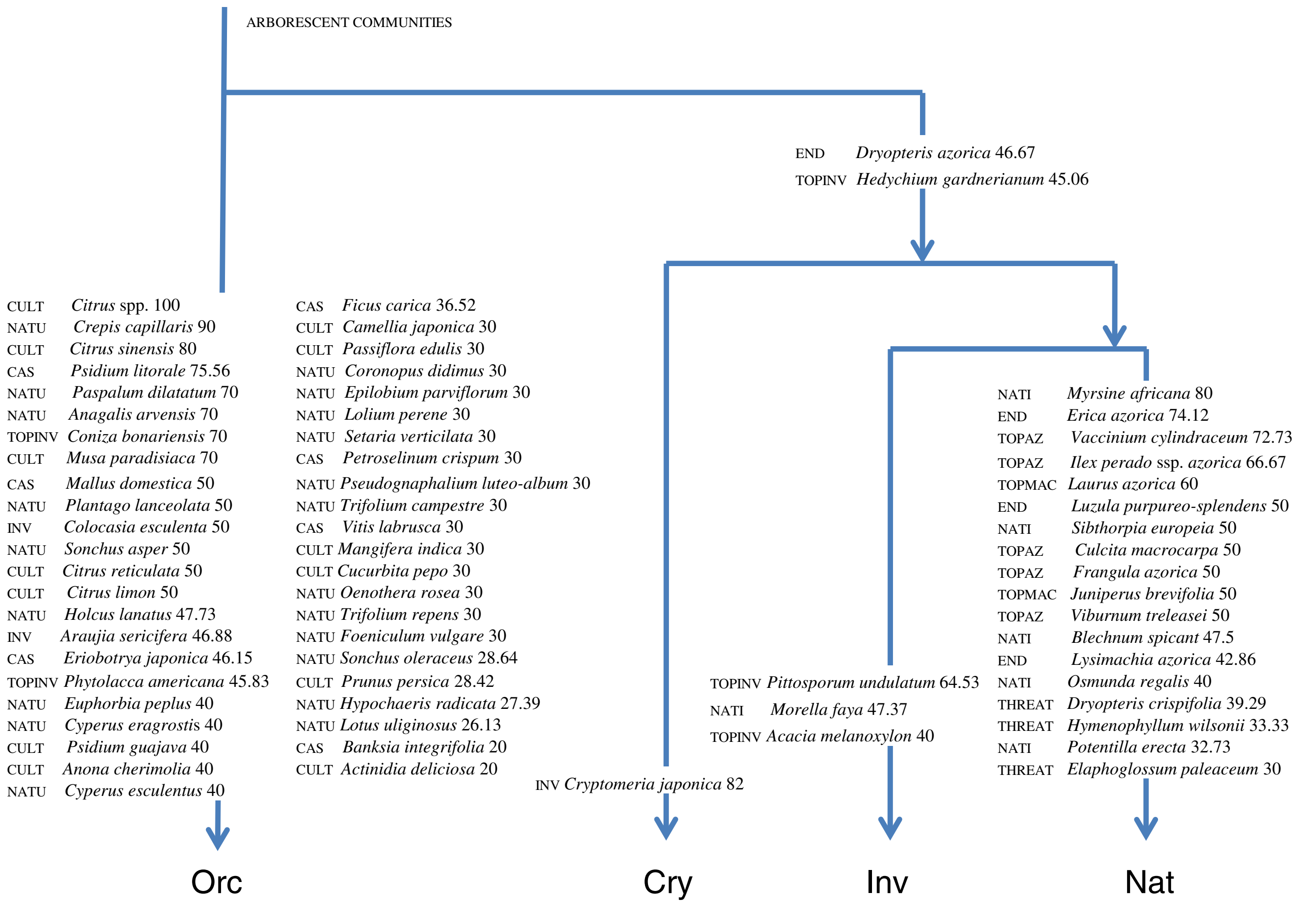

Fig. 1 Arborescent community indicator species ($p < 0.05$) ranked by indicator value (IndVal). Species that are at the nodes of the tree (i.e., community type) have the most fidelity to and consistency for that community type. *Orc* orchard, *Cry Cryptomeria* production forest, *Inv* exotic woodland, *Nat* natural forest. See Table 1 for community descriptions. The typology is based on an anthropogenic gradient with orchard communities being the most influenced and natural forest communities least influenced by humans. See Table 2 for explanation of species categories

this study (Table 3). An increase in the number of indicator species of cultivated, casual, invasive, or naturalized origin, as anthropogenic influence rose was observed mainly in the habitats of the arborescent types. For both landcover gradients, the least anthropogenically influenced habitats accounted for almost the entire set of species with attributes other than economical (i.e., top priority conservation for Macaronesia, top priority conservation for Azores, threatened, endemic, and native).

Community Value Discrimination (ComVal) by Similarity of Plant Indicator Composition

Community value discrimination for arborescent communities was accurate for more than 90 % of the cases. The metric ComVal correctly classified communities both used in training and in validation sets (Table 4). For exotic woodland forests, the proportion of correct classification decreased to 79 %, for the validation set. For herbaceous communities, the accuracy was also above 90 %, except for semi-natural pastures and pastures (66 and 77 %, respectively, in the validation sets).

Discussion

In this study, we used a broad gradient of herbaceous and arborescent anthropogenic influenced plant communities to assess the possibility of using indicator plant species to discriminate communities with different conservation values. This information could be a valuable tool in decision-making processes for land management and land use reconversion plans. Using a Bayesian approach, we had already found that the species spectra (i.e., the proportion of species with different conservation values) of a plant community significantly changed along the two gradients of anthropogenic influence (Marcelino et al. 2013). Similarly, using IndVal (i.e., species with highest fidelity and consistent presence per community type), we determined that indicator species with high conservation value for the

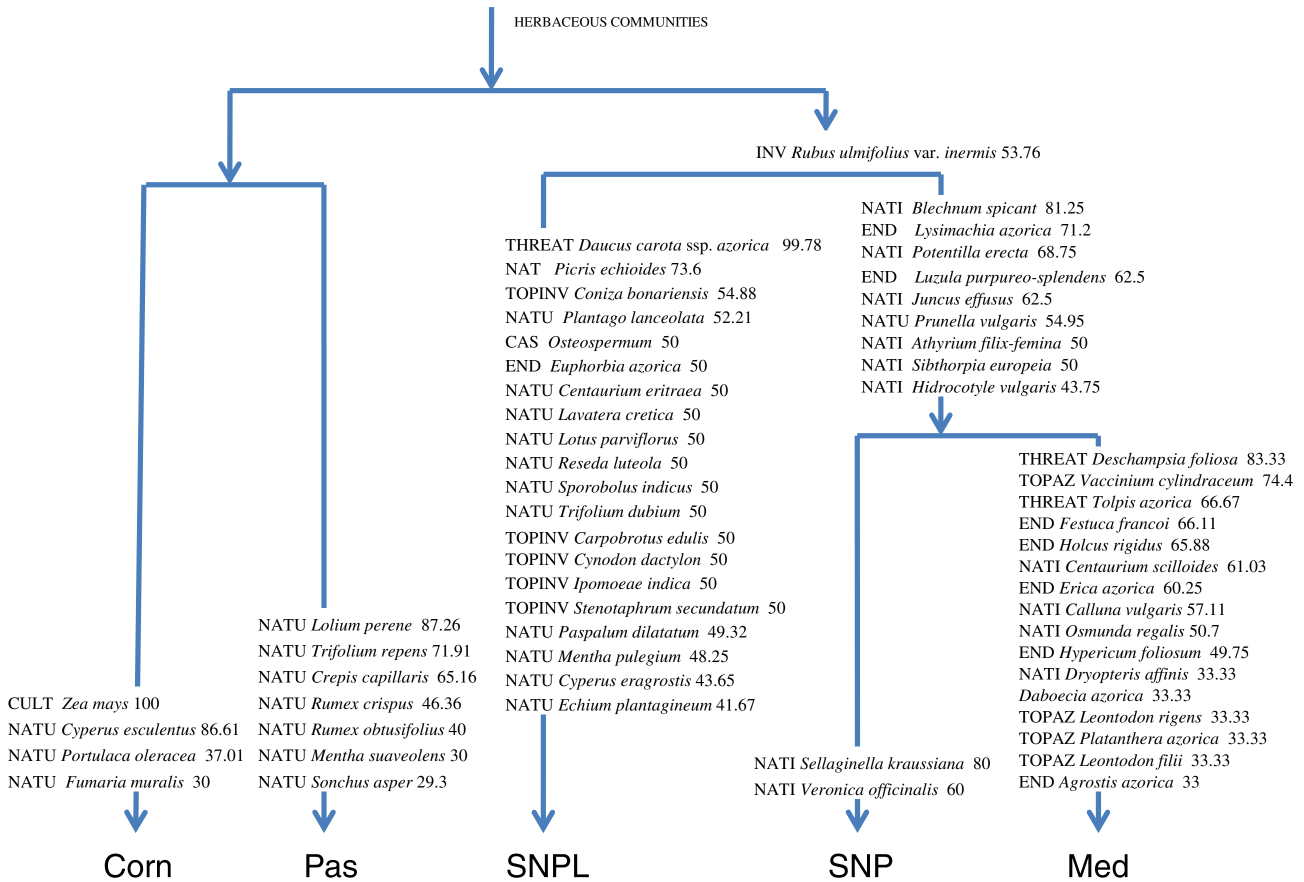

Fig. 2 Herbaceous community indicator species ($p < 0.05$) ranked by indicator value (IndVal). Species that are at the nodes of the tree (i.e., habitat type) have the most fidelity to and consistency for that community type. *Corn* corn, *Pas* pasture, *Snp* semi-natural pasture, *Snpl* semi-natural pasture lower elevation, *Med* meadow. See Table 1 for community descriptions. The typology is based on an anthropogenic gradient with corn communities being the most influenced and meadow communities least influenced by humans. See Table 2 for explanation of species category

Macaronesian region and for the Azores, as well as threatened, endemic, and native species were replaced by introduced species (mainly naturalized, casual, and invasive species), as anthropogenic influence rose. A larger proportion of indigenous species were found to have indicator value for more natural communities, while naturalized and cultivated plants showed indicator value for heavily anthropogenically influenced plant communities like corn fields, orchards, and pastures. Therefore, it was possible with IndVal to detect changes in the conservation category of indicator species, along the herbaceous and arborescent gradients of anthropogenic influence. Similar patterns can be deduced from other plant indicator studies. Schmidt et al. (2006) found indicator species classified as endangered in Norway's pure Spruce forests (*Picea abies*), but not in European beech forests (*Fagus silvatica*), nor in mixed *P. abies-F. sylvatica*. In addition, Aavik and Liira (2009) analyzed the response of nature-value indicator species (i.e., habitat specialists and rare weeds) to land use intensity in North-Eastern Europe and detected a drastic decrease in abundance of nature-value indicator species from forest and semi-natural grassland to agricultural fields and rotational grasslands.

ComVal determined the floristic closeness of vegetation plots which were not ecologically, economically, or socially characterized, to pre-existing characterized community types, based on indicator species. The accuracy assigning vegetation plots to a priori-defined community types was as a rule 90 % or above. Seldom, the correct assignment of sampled vegetation plots to reference community types was below the 90 % percentile bootstrap and was in those cases probably due to the existence of shared indicator species between community types. This was the case for exotic woodland sharing the indicator species *D. azorica* and the top invasive *H. gardnerianum* with both the production forest and the natural forest. This was also the case for semi-natural pastures and the less anthropogenically disturbed meadows which shared up to five native (*B. spicant*, *P. erecta*, *J. effusus*, *A. filix-femina*, and *H. vulgaris*), two endemic (*Lysimachia azorica* and *Luzula purpureo-splendens*) and one naturalized (*Prunella vulgaris*) indicator species.

Table 3 Number of indicator species within each of the species categories of the conservation coefficient gradient (from TopMac to Top Invasive. See Table 1 for acronyms)

	TopMac	TopAz	Threat	Endemic	Native	Naturalized	Cultivated	Casual	Invasive	Top Invasive
A ARBORESCENT COMMUNITIES										
Orchard	0	0	0	0	0	2	13	7	2	2
Cryptomeria	0	0	0	0	0	0	0	0	1	0
Invasive forest	0	0	0	0	1	0	0	0	0	2
Native forest	2	5	3	3	5	0	0	0	0	0
B HERBACEOUS COMMUNITIES										
Corn	0	0	0	0	0	6	2	0	0	0
Pasture	0	0	0	0	0	8	0	0	0	0
SNP	0	0	0	0	4	1	0	0	0	0
SNLP	0	0	1	1	4	11	0	1	0	5
Meadow	1	4	2	6	5	0	0	0	0	0

Specific indicator species can be found in Fig. 1 and Fig. 2. Gray contrast added to help readability. (A.) Arborescent communities and (B.) Herbaceous communities. Species types are presented along the conservation coefficient gradient from the most ecologically relevant (left) to most likely to impact native vegetation (right)

The drastic separation in indicator species composition between the least anthropogenic disturbed herbaceous community type, meadow, and the most disturbed herbaceous community types, corn and pastures, found through ComVal, corroborates the assumption that land conversion trajectories from unmanaged natural areas into intensive herbaceous land use are one of the major forces shaping ecosystems globally (Foley et al. 2005) and that the loss of natural and agricultural semi-natural land is a critical driver in the decline of unique plant richness (Liira et al. 2008). However, this might not be the case for arborescent community types where we observed a more gradual change in indicator species composition with shared taxa at both ends of the gradient (i.e., natural forests vs. production forests and orchards) and a common threatened indicator species for most of the communities. This might suggest that land management strategies aiming for the conversion of native areas into production forests, and orchards, might cause less drastic changes in indicator species composition, when compared to the plant indicator changes in herbaceous habitats. This finding also suggests that more attention should be given to indicator species that are unique to a plant community type or to combinations of indicator species (De Cáceres et al. 2012; Vilches et al. 2013).

A vast majority of methodologies strongly rely on species abundances and complex formulations (Schmidt et al. 2006; Zerbe et al. 2007) or comprehensive lists of species richness (Marignani et al. 2008; Aavik and Liira 2009) to characterize plant community types. ComVal was specifically designed to reduce sampling effort expediently assigning uncategorized vegetation plots to pre-existing community types, therefore, complementing pre-existing methodologies and allowing for comparisons across community types. ComVal provides both a means to reduce the number of species required to be identified in the field and reduces statistical noise generated by species not specifically associated with

Table 4 Percentage vegetation plots assigned to pre-defined community typologies (in gray) using two independent datasets, i.e., Validation set 0 (communities treated as uncategorized vegetation plots not included in ComVal classification) and Training set 1 (categorized communities used to determine ComVal)

Arborescent communities							*Herbaceous communities*						
	NAT	INV	CRY	ORC	NULL*	TOTALS		MED	SNPL	SNP	PAS	COR	TOTALS
Validation Sets (0)	**2622**	**2292**	**2485**	**2545**	**128**	**10072**	**Validation Sets (0)**	**1859**	**1171**	**1933**	**2575**	**2768**	**10306**
NAT	90	9	1	0	1	2490	MED	90	0	10	0	0	1466
INV	8	79	7	1	4	2539	SNPL	0	92	0	8	1	1067
CRY	7	2	90	0	1	2526	SNP	21	0	66	13	0	2599
ORC	0	0	0	100	0	2517	PAS	0	7	2	77	13	2630
							COR	0	0	0	5	95	2544
Training sets (1)	**7584**	**7211**	**7717**	**7476**	**215**	**30203**	**Training sets (1)**	**4717**	**3261**	**7235**	**7341**	**7778**	**30332**
NAT	97	3	0	0	0	7547	MED	100	0	0	0	0	4546
INV	3	92	3	0	2	7559	SNPL	0	100	0	0	0	2955
CRY	0	1	99	0	0	7614	SNP	2	0	93	5	0	7753
ORC	0	0	0	100	0	7483	PAS	0	4	0	91	4	7517
							COR	0	0	0	2	98	7561

Percentages based on 1000 bootstrap iterations. Habitat codes in Table 1

* Vegetation plots which equally fell in more than one community type were considered null

an expert delineated community type. The calculation of this metric is simple, and it can be expediently used by a technician in the field, surveying a community for solely indicator species of interest, a list that requires less training for field personnel and is most likely more time and cost effective to obtain than comprehensive lists of all the existing flora. Improving methodologies for decision-making processes of land use and conservation is strongly suggested for an effective management of resources (Pullin et al. 2004; Sutherland et al. 2004; Davies et al. 2014). This new method can provide tangible feedback to a manager, agency, or ecologist aiming to discern the ecological status of a given community (e.g., similarity to natural habitats or human influenced communities) and, therefore, a valuable tool in land use planning, change detection, conservation, and environmental impact assessments. In addition, the methodology could be used to evaluate long-term effects on community composition (e.g., climate change), depending on the establishment of permanent plots, and potentially be used to detect changes along other types of gradients (e.g., altitudinal, coastal, edaphic, etc.), contributing as a source of ecological data for the long-term conservation of remnants of natural areas and the management of ecosystems and land.

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References

Aavik T, Liira J (2009) Agrotolerant and high nature-value species – plant biodiversity indicator groups in agroecosystems. Ecol Indic 9:892–901

Bartha D (2004) Chances for a stand-level evaluation of the naturalness of forests. Allg Forst Jagdztg 175:8–13

Basset Y, Mavoungou JF, Mikissa JB, Missa O, Miller SE, Kitching RL, Alonso A (2004) Discriminatory power of different arthropod data sets for the biological monitoring of anthropogenic disturbance in tropical forests. Biodivers Conserv 13:709–732

Billeter R, Liira J, Bailey D, Bugter R, Arens P, Augenstein I, Aviron S, Baudry J, Bukacek R, Burel F, Cerny M, De Glust G, De Cock R, Diekotter T, Dietz H, Dirksen J, Dormann C, Durka W, Frenzel M, Hamersky R, Hendrickx F, Herzog F, Klotz S, Koolstra B, Lausch A, Le Coeur D, Maelfait JP, Opdam P, Robalova M, Schermann A, Schermann N, Schmidt T, Schweiger O, Smulders MJ, Speelmans M, Simova P, Verboom J, van Wingerden WK, Zobel M, Edwards PJ (2008) Indicators for biodiversity in agricultural landscapes: a pan European study. J Appl Ecol 45:141–150

Borcard D, Gillet F, Legendre P (2011) Numerical Ecology with R. Springer, New York, p 302

Borges PAV, Costa A, Cunha R, Gabriel R, Gonçalves V, Martins AF, Melo I, Parente M, Raposeiro P, Rodrigues P, Santos RS, Silva L, Vieira P, Vieira V (2010) A list of the terrestrial and marine biota from the Azores. Princípia, Portugal

Carignan V, Villard M-A (2001) Selecting indicator species to monitor ecological integrity: a review. Environ Monit Assess 78:45–61

Carleton TJ, Stitt RH, Nieppola J (2009) Constrained indicator species analysis (COINSPAN): an extension of TWINSPAN. J Veg Sci 7:125–130

Castro SA, Daehler CC, Silva L, Torres-Santana CW, Reyes-Betancort JA, Atkinson R, Jaramillo P, Guezou A, Jaksic FM (2010) Floristic homogenization as a teleconnected trend in oceanic islands. Divers Distrib 16:902–910

Costa H, Bettencourt MJ, Silva CMN, Teodósio J, Gil A, Silva L (2014) Invasive alien plants in the Azorean protected areas: invasion status and mitigation actions. In: Foxcroft LC, Pyšek P, Richardson DM, Genovesi P (eds) Plant invasions in protected areas: patterns, problems and challenges. Springer, Dordrecht

Cruz JV, Coutinho PAR, Fontiela J, Freire P (2007) Carta de Ocupação do Solo da Região Autónoma dos Açores. Ed. Secretaria Regional do Ambiente e do Mar, Direcção Regional do Ordenamento do Território e dos Recursos Hídricos (In Portuguese)

Davies AL, Colombo S, Hanley N (2014) Improving the application of long-term ecology in conservation and land management. J Appl Ecol 51:63–70

De Cáceres M, Legendre P (2009) Associations between species and groups of sites: indices and statistical inference. Ecology 90:3566–3574

De Cáceres M, Legendre P, Moretti M (2010) Improving indicator species analysis by combining groups of sites. Oikos 119:1674–1684

De Cáceres M, Legendre P, Wiser SK, Brotons L (2012) Using species combinations in indicator value analyses. Methods Ecol Evol 3:973–982

DeKeyser ES, Kirby DR, Ell MJ (2003) An index of plant community integrity: development of the methodology for assessing prairie wetland plant communities. Ecol Indic 3:119–133

Dias E (1996) Vegetação Natural dos Açores: ecologia e Sintaxonomia das Florestas Naturais (Natural Vegetation of the Azores: Ecology and Syntaxonomy of Natural Forests). dissertation, University of the Azores

Diekmann M (2003) Species indicator values as an important tool in applied plant ecology - a review. Basic Appl Ecol 4:493–506

Dufrene M, Legendre P (1997) Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecol Monogr 67:345–366

Dupouey JL, Dambrine E, Laffite JD, Moares C (2010) Irreversible impact of past land use on forest soils and biodiversity. Ecology 83:2978–2984

Engler R, Guisan A, Rechsteiner L (2004) An improved approach for predicting the distribution of rare and endangered species from occurrence and pseudo-absence data. J Appl Ecol 41:263–274

Foley JA, DeFries R, Asner GP, Barford C, Bonan G, Carpenter SR, Chapin FS, Coe MT, Daily GC, Gibbs HK, Helkowski JH, Holloway T, Howard EA, Kucharik CJ, Monfreda C, Patz JA, Prentice IC, Ramankutty N, Snyder PK (2005) Global Consequences of Land Use. Science 309:570–574

Hawksworth DL, Bull AT (2010) Plant conservation and biodiversity., Topics in biodiversity and conservationSpringer, The Netherlands

Hill MO (1979) TWINSPAN - a FORTRAN program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes. Section of Ecology and Systematics, Cornell University, New York, p 90

Hilty J, Merenlender A (2000) Faunal indicator taxa selection for monitoring ecossystem health. Biol Conserv 92:185–197
Kueffer C, Daehler CC, Torres-Santana CW, Lavergne C, Meyer J-Y, Otto R, Silva L (2010) Magnitude and form of invasive plant impacts on oceanic islands: a global comparison. Perspect Plant Ecol Evol Syst 12:145–161
Laliberté E, Wells JA, DeClerck F, Metcalfe DJ, Catterall CP, Queiroz C, Aubin I, Bonser SP, Ding Y, Fraterrigo JM, McNamara S, Morgan JW, Merlos DS, Vesk PA, Mayfield MM (2010) Land-use intensification reduces functional redundancy and response diversity in plant communities. Ecol Lett 13:76–86
Liira J et al (2008) Plant functional group composition and large-scale species richness in European agricultural landscapes. J Veg Sci 19:3–14
Lindenmayer DB, Likens G (2011) Direct measurement versus surrogate indicator species for evaluating environmental change and biodiversity loss. Ecosystems 14:47–59
Lindenmayer DB, Margules CR, Botkin DB (2000) Indicators of biodiversity for ecologically sustainable forest management. Conserv Biol 14:941–950
Marcelino JAP, Silva L, Garcia PV, Weber E, Soares AO (2013) Using species spectra to evaluate plant community conservation value along a gradient of anthropogenic disturbance. Environ Monit Assess 185:6221–6233
Marignani M, Vico E, Maccherini S (2008) Performance of indicators and the effect of grain size in the discrimination of plant communities for restoration purposes. Community Ecol 9:201–206
Marsh H, Dennis A, Hines H, Kutt A, McDonald K, Weber E, Williams S, Winter J (2007) Optimizing allocation of management resources for wildlife. Conserv Biol 2:387–399
Martín JL, Arechavaleta M, Borges PAV, Faria B (eds) (2008) TOP 100 - As cem espécies ameaçadas prioritárias em termos de gestão na região europeia biogeográfica da Macaronésia. Consejería de Medio Ambiente y Ordenación Territorial, Gobierno de Canarias
Martín JL, Cardoso P, Arechavaleta M, Borges PAV, Faria BF, Abreu C, Aguiar AF, Carvalho JA, Costa AC, Cunha RT, Fernandes FM, Gabriel R, Jardim R, Lobo C, Martins AMF, Oliveira P, Rodrigues P, Silva L, Teixeira D, Amorim IR, Homem N, Martins B, Martins M, Mendonça E (2010) Using taxonomically unbiased criteria to prioritize resource allocation for oceanic island species conservation. Biodivers Conserv 19:1659–1682
McCune B, Mefford MJ (1999) PC-ORD. Multivariate analysis of ecological data. Version 4. MjM Software Design, Gleneden Beach
McGeoch MA (2006) Bioindicators. Encyclopedia of environmetrics. Wiley, London
Muramoto J, Gliessman SR (2006) Use of bioindicators for assessing sustainability of farming practices. In: Pimentel D (ed) Encyclopedia of Pest Management. Marcel Dekker, Taylor & Francis Group, Boca Raton, pp 37–41
Myers N, Mittermeier RA, Mittermeier CG, da Fonseca GAB, Kent J (2000) Biodiversity hotspots for conservation priorities. Nature 403:853–858
Niemi GJ, McDonald ME (2004) Application of ecological indicators. Annu Rev Ecol Evol Syst 35:89–111
Nimis PL, Castello M, Perotti M (1993) Lichens as bioindicators of heavy metal pollution: a case study at La Spezia (N Italy). In: Markert B (ed) Plants as biomonitors. VCH Publishers, Chichester, pp 265–284
Nordén B, Paltto H, Götmark F, Wallin K (2007) Indicators of biodiversity, what do they indicate? - Lessons for conservation of cryptogams in oak-rich forest. Biol Conserv 135:369–379
Odland A (2009) Interpretation of altitudinal gradients in South Central Norway based on vascular plants as environmental indicators. Ecol Indic 9:409–421
Öster M, Persson K, Eriksson O (2008) Validation of plant diversity indicators in semi-natural grasslands. Agric Ecosyst Environ 125:65–72
Paoletti MG (1999) Using bioindicators based on biodiversity to assess landscape sustainability. Agric Ecosyst Env 74:1–18
Pearsall IA (2007) Carabid beetles as ecological indicators. In: Monitoring the effectiveness of biological conservation conference. Richmond, British Columbia, 2–4 November 2004, pp 389–399
Peres CA, Barlow J, Laurance WL (2006) Detecting anthropogenic disturbance in tropical forests. Trends Ecol Evol 21:227–229
Podani J, Csányi B (2010) Detecting indicator species: some extensions of the IndVal measure. Ecol Indic 10:1119–1124
Pullin AS, Knight TM, Stone DA, Charman K (2004) Do conservation managers use scientific evidence to support their decision-making? Biol Conserv 119:245–252
Queiroz RE, Ventura MA, Silva L (2014) Plant diversity in hiking trails crossing natura 2000 areas in the Azores: implications for tourism and nature conservation. Biodivers Conserv 23:1347–1365
Schmidt I, Zerbe S, Betzin J, Weckesser M (2006) An approach to the identification of indicators for forest biodiversity – the Solling mountains (NW Germany) as an example. Restor Ecol 14:123–136
Silva L, Smith CW (2004) A characterization of the non-indigenous flora of the Azores Archipelago. Biol Invasions 6:193–204
Silva L, Smith CW (2006) A quantitative approach to the study of non-indigenous plants: an example from the Azores Archipelago. Biodivers Conserv 15:1661–1679
Silva L, Land EO, Luengo JLR (eds) (2008) Invasive terrestrial flora & fauna of Macaronesia. TOP 100 in Azores, Madeira and Canaries. ARENA, Ponta Delgada
Silva L, Martins M, Maciel G, Moura M (2009) Flora Vascular dos Açores - Prioridades em Conservação. Associação Ecológica Amigos dos Açores, CCPA, Ponta Delgada
Silva L, Martins MC, Maciel GB, Moura M (2010) Azorean vascular flora., Priorities in ConservationAmigos dos Açores and CCPA, Ponta Delgada
Sjögren E (1973) Recent changes in the vascular flora and vegetation of the Azores islands. Mem Soc Brot 22:1–453
Sutherland WJ, Pullin AS, Dolman PM, Knight TM (2004) The need for evidence-based conservation. Trends Ecol Evol 19:305–308
Urban NA, Swihart RK, Malloy MC, Dunning JB (2012) Improving selection of indicator species when detection is imperfect. Ecol Indic 15:188–197
Vilches B, De Cáceres M, Sánchez-Mata D, Gavilán RG (2013) Indicator species of broad-leaved oak forests in the eastern Iberian Peninsula. Ecol Ind 26:44–48
Winter S (2012) Forest naturalness assessment as a component of biodiversity monitoring and conservation management". Forestry 85:293–304
Zerbe S, Schmidt I, Betzin J (2007) Indicators for plant species richness in pine (*Pinus sylvestris* L.) forests of Germany. Biodivers Conserv 16:3301–3316