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Ranking protected areas in the Azores using standardised sampling of soil epigean arthropods

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Abstract. Nineteen areas in seven of the nine Azorean islands were evaluated for species diversity and rarity based on soil epigean arthropods. Fifteen out of the 19 study areas are managed as Natural Forest Reserves and the remaining four were included due to their importance as indigenous forest cover. Four of the 19 areas are not included in the European Conservation network, *NATURA 2000*. Two sampling replicates were run per study area, and a total of 191 species were collected; 43 of those species (23%) are endemic to the archipelago and 12 have yet to be described. To produce an unbiased multiple-criteria index (importance value for conservation, IV-C) incorporating diversity and rarity based indices, an iterative partial multiple regression analysis was performed. In addition, an irreplaceability index and the complementarity method (using both optimisation and heuristic methods) were used for priority-reserves analyses. It was concluded that at least one well-managed reserve per island is absolutely necessary to have a good fraction of the endemic arthropods preserved. We found that for presence/absence data the suboptimal complementarity algorithm provides solutions as good as the optimal algorithm. For abundance data, optimal solutions indicate that most reserves are needed if we want that at least 50% of endemic arthropod populations are represented in a minimum set of reserves. Consistently, two of the four areas not included in the *NATURA 2000* framework were considered of high priority, indicating that vascular plants and bird species used to determine *NATURA 2000* sites are not good surrogates of arthropod diversity in the Azores. The most irreplaceable reserves are those located in older islands, which indicates that geological history plays an important role in explaining faunal diversity of arthropods in the Azores. Based both on the uniqueness of species composition and high species richness, conservation efforts should be focused on the unmanaged Pico Alto region in the archipelago's oldest island, Santa Maria.

Introduction

Islands are isolated, and, as a consequence, they lack the 'rescue effect': only 'source' species can be maintained in ecological and evolutionary time (Rosenweig 1995). Moreover, this 'isolation effect' increases with the decrease of dispersal abilities of the considered *taxon* (Whittaker 1998). In fact, the high degree of endemicity of some islands implies that most islands should be considered as management units, as showed previously by Borges et al. (2000) for the Azores. Therefore, in oceanic archipelagos the ranking of sites will be almost inevitably an exercise of choosing between sites within each island, all islands having similar importance. Hence, due to within island endemics the conservation and management of archipelago reserves is considered more complicated (Curio 2002).

In the last 10 years, *NATURA 2000*, a European Commission conservation management scheme, was launched covering about 13% of the area of the Azores islands. Selected areas were chosen both for the protection of selected species of birds (special protection areas – SPAs; Portuguese ZPEs; $n = 15$) and for the protection of habitats and (non-bird) species (special areas of conservation – SACs; Portuguese SICs; $n = 23$). Nevertheless, no arthropod species were included in the list of priority species. The absence of arthropod species in the Azorean list of priority species is probably due to the lack of knowledge ('taxonomic impediment'; *sensu* Wilson 2000; Clarke 2001).

There is an increasing recognition that arthropod diversity is of central importance in assessing conservation priorities and targeting resources for conservation (see Collins and Thomas 1991; Gaston et al. 1993; Brown 1997; Anderson and Ashe 2000; Borges et al. 2000; Serrano, 2002; Tscharntke et al. 2002). However, comprehensive inventories of arthropods in island ecosystems are lacking (but see Andriamampianina et al. 2000), and are particularly important when information on non-vertebrates is non-existent to support conservation management policy.

In 1988, several Natural Forest Reserves (NFR) in the Azores archipelago were established by the Azorean Government in seven of the nine Azorean islands (S. Maria and Corvo excluded) as areas of geological, botanical and animal interest. The BALA Project, 'Biodiversity of Arthropods from the Laurisilva of the Azores', was launched in 1998 (see Borges et al. 2000) and funded by the Azorean Department of Agriculture and Fisheries for a broad arthropod biodiversity survey in 15 out of the 16 poorly studied NFRs, with particular emphasis on endemic fauna. Potentially interesting areas were also investigated during this survey. The collection of the necessary faunistic data on Azorean arthropods involved the cooperation of 24 researchers including ecologists, taxonomists and students. This study of Azorean arthropod biodiversity aimed to accomplish a standardised sampling of the arthropod fauna both at a local and regional scales in indigenous island ecosystems, each protected area being sampled with a constant transect size and a similar number of replicates. As the NFR have different areas and could be considered islands within true islands, this is one way of estimating the number of species when testing the species-area models (Holt 1992; Kohn and Walsh 1994; Borges and Brown 1999). Moreover, if the species-area equilibrium theory model fits the data, a given standard area should have more species on a large island than on a small island (Kohn and Walsh 1994; Rosenzweig 1995). Even if this small-scale sampling may not reflect large-scale landscape species richness in the studied NFRs ('γ diversity'), at least we will have an estimate of differences in diversity at small scales (transect) ('α diversity') and will be able to correct for uneven sampling common in literature records (see Borges et al. 2000).

Given the lack of knowledge on the distribution of Azorean endemic arthropod species and the limited funds available for their conservation, there is a need to set priorities for conservation. We followed a top-down approach for setting priorities (see Sutherland 2000), that is:

1. Fifteen areas were selected based on their inclusion on the NFR scheme and four other areas (reserves for simplification) based either on the addition of a new island or on the important native forest patches within an island.
2. Each area was ranked using a set of criteria such as diversity- and rarity-based indices, complementarity and irreplaceability analysis.
3. A list of reserves to be properly managed was suggested.

Therefore, the aim of this study was to examine the relative value of 15 NFRs and other four areas in seven of the Azorean islands as a management tool to improve the conservation of Azorean soil epigean arthropod biodiversity. We examined the following hypotheses:

1. At least one reserve per island will be highly ranked, that is, ranked in the top 10 areas (50% of the investigated areas) using an iterative partial regression analyses to produce a multiple-criteria index incorporating diversity- and rarity-based indices. This follows the assumption that the dispersal rates of species are low and consequently there is a high level of island-restricted endemism.
2. The restricted distribution of endemic species will imply that most areas are unique and largely irreplaceable. Consequently, most areas will be needed to ensure each species is included at least one time in a complementary based approach (using both optimisation and heuristic complementarity algorithms for both presence/absence and abundance data).
3. Original criteria used to define *NATURA 2000* conservation areas cannot provide basic information in community ecology and metacommunity data,

and thus cannot surrogate a scientifically consistent protocol to optimise arthropod species richness conservation.

With this work we intend to show that a standardised sampling program is of overwhelming importance for evaluation of protected areas and that the methodologies here followed have general applicability to conservation ecology studies.

Methods

Sites and experimental design

This study was conducted in the Azores, an isolated Northern Atlantic archipelago that comprises nine islands, as well as several islets and seamounts distributed from Northwest to Southeast, roughly between 37° and 40°N and 24° and 31°W. The Azorean islands extend for about 615 km and are situated across the Mid-Atlantic Ridge, which separates the western group (Flores and Corvo) from the central (Faial, Pico, S. Jorge, Terceira and Graciosa) and the eastern (S. Miguel and S. Maria) groups (Figure 1). All these islands have a

Figure 1. Locations of the 15 NFR plus four other areas in seven of the Azorean islands. Numbers correspond to those used in Table 1.

relatively recent volcanic origin, ranging from 8.12 Myr B.P. (S. Maria) to 300,000 years B.P. (Pico) (Abdel-Monem et al. 1975; Feraud et al. 1980; Nunes 1999). The temperate oceanic climate is characterised by high levels of relative atmospheric humidity, that could reach 95% at high altitude native forests and ensures slight thermal variations throughout the year. Frequent storms come from west, but the islands are also influenced by the 'Leste', a series of sand storms with origin in North Africa (Rodrigues 2001; Reis et al. 2002).

In this study a total of 15 NFRs distributed on seven of the nine Azorean islands were surveyed and are listed with their associated code numbers in Table 1 (see also Figure 1). The NFRs differ greatly in their areas and habitats within them. The predominant vegetation form is 'Laurisilva', a semi-tropical evergreen broadleaf and microphyllous (hereafter short-leaf) laurel type forest that originally covered most of Western Europe during the Tertiary (Dias 1996). Dominant trees and shrubs include short-leaf *Juniperus brevifolia* (Cupressaceae) and *Erica azorica* (Ericaceae), both endemics, the broadleaf species *Ilex perado azorica* (Aquifoliaceae) (endemic), *Laurus azorica* (Lauraceae) (native), and the shrub *Vaccinium cylindraceum* (Ericaceae) (endemic) (see Table 1). This type of forest is characterised by reduced tree stature (usually up to 5 m, rarely reaching 10 m), shaped by the shallow soil and sinuous terrain, which is raised up to tree tops in some points, and lowered 5–6 m below in others; high crown foliage density and thus low canopy openness; dense cover of moss and liverwort epiphytes. Some bryophytes also cover leaves in higher altitude humid forests. The soil is wet and highly acidic, pH decreasing with altitude ($n = 38$; $r = -0.47$; $p = 0.004$). Exceptions to this pattern occur in 'Vulcão dos Capelinhos' (FAI-VC) in the island of Faial, which is a recent volcano (a historical eruption from 1957–1958) made up of mainly lavicolous habitat, and in the three NFRs from S. Jorge that are made of semi-natural grassland fenced against cattle grazing. In order to have the native forest habitat represented in S. Jorge, two additional areas (Pico Pinheiro and Topo) were investigated (areas 11 and 12 in Figure 1). Two other areas were added for different reasons: in S. Maria island there is no NFR yet, but there is a proposal to include a small fragment of native forest at the top of Pico Alto (area 19; Figure 1); at Terceira a small area with a last remaining of native forest at low altitude (Matela) was also surveyed (area 15; Figure 1). Therefore, in six out of the seven islands, at least two areas were investigated (see Table 1).

In each of the 19 studied areas two independent transects were established. The sites were chosen in a random manner among the available forest patches within the studied areas, as long as they were accessible. In some cases, old paths were used to allow a better penetration to the core of the forest and to avoid border effects. Each transect had 150 m long and 5 m wide, and were established in different years (1999 and 2000). Whenever possible, a linear direction was followed, but frequently deviations were necessary due to uneven ground and very dense vegetation. In case of departure from a straight line, at least a same direction was kept, thus avoiding strong bias while setting the transect. A rope was used to mark each transect to facilitate its recognition

Table 1. List of the studied 15 NFR and four additional areas (*) with its code, name, island of occurrence (FAI = Faial; PIC = Pico; GRA = Graciosa; FLO = Flores; SJG = S. Jorge; SMG = S. Miguel; TER = Terceira), NATURA 2000 scheme, area, altitude (minimum and maximum), as well as the altitude and the list of the at least three dominant trees or shrubs in each of the two sampled transects (see also Figure 1 for location of the 19 reserves).

Name	Code	Island	NATURA 2000	Area (ha)	Altitude (m)	Dominant plants and altitude (m)
1. Morro Alto e Pico da Sé	FLO-MA	FLO	Yes	1558	300–915	(J; L; I; 625); (J; V; Myrs.; 700)
2. Caldeiras Funda e Rasa	FLO-FR	FLO	No	459	350–600	(E; V; 450); (J; I; V; 500)
3. Vulcão dos Capelinhos	FAI-VC	FAI	Yes	204	0–170	50; 105
4. Cabeço do Fogo	FAI-CF	FAI	Yes	54	400–529	(M; 425); (E; J; 510)
5. Mistério da Prainha	PIC-MP	PIC	Yes	643	425–841	(J; L; I; 525); (J; E; I; 800)
6. Lagoa do Caiado	PIC-LC	PIC	Yes	131	800–939	(J; E; Myrs.; 820); (J; I; V; 834)
7. Caveiro	PIC-C	PIC	Yes	199	850–950	(J; L; I; 900); (J; L; I; 920)
8. Pico das Caldeirinhas	SJG-C	SJG	Yes	62	700–815	720; 800
9. Picos do Carvão e da Esperança	SJG-E	SJG	Yes	178	800–1083	900; 920
10. Pico do Arieiro	SJG-A	SJG	Yes	40	800–958	830; 900
11. Pico Pinheiro (*)	SJG-P	SJG	Yes	293	600–780	(J; V; Myrs.; 630); (E; J; V; 670)
12. Topo (*)	SJG-T	SJG	Yes	2257	0–942	(J; I; V; 850); (J; I; V; 875)
13. Serra de Stª Barbara e M. Negros	TER-SB	TER	Yes	1274	550–1025	(J; V; Myrs.; 630); (J; I; Myrs; 760)
14. Biscoito da Ferraria	TER-BF	TER	Yes	391	475–808	(J; V; Myrs.; 530); (J; L; I; 600)
15. Matela (*)	TER-M	TER	No	25	350–393	(J; E; L; 350); (E; L; V; 430)
16. Graminhais	SMG-G	SMG	Yes	27	850–925	(J; L; V; 870); (L; I; V; 925)
17. Atalhada	SMG-A	SMG	No	15	425–530	(J; I; 425); (I; 450)
18. Pico da Vara	SMG-PV	SMG	Yes	742	400–1103	(E; C; 450); (J; L; I; 674)
19. Pico Alto (*)	STM-PA	STM	No	4	470–575	(E; L; P; 530); (E; L; V; 530)

(E = *Erica azorica*; L = *Laurus azorica*; P = *Picconia azorica*; V = *Vaccinium cylindraceum*; J = *Juniperus brevifolia*; I = *Ilex perado azorica*; C = *Clethra arborea*; Myrs. = *Myrsine africana*; M = *Myrica faya*).

during the trap recovery. Hence, despite the fact that the 19 reserves have very different areas, the same sampling effort was put into each reserve.

Arthropod sampling and identification

We collected epigean arthropods by using pitfall traps for at least a 2-weeks period in the summer of 1999 and 2000. For each reserve we sampled two transects, one per year. Pitfall traps consisted of plastic cups with a top diameter of 42 and 78 mm deep, dug into the ground so the lip of the cup was flush with the surface. Thirty traps were set up per transect: 15 traps filled approximately with 60 ml of a non-attractive solution (anti-freeze liquid) with a small proportion of ethylene glycol, and in 15 traps with the same volume of a general attractive solution (Turquin), which was made of dark beer and some preservatives (for further details see Turquin 1973). In both kinds of traps, a few drops of a liquid detergent was added to reduce surface tension. Traps were spaced at 5 m to each other, starting with a Turquin trap and alternating with the ethylene traps. With such a procedure, it was expected not only to survey the relative abundance of each species sampled (with non-attractive traps), but also to capture the maximum number of species (with attractive traps). Traps were protected from the rain by a white plastic plate, at about 5 cm above surface level and fixed to the ground by two pieces of wire. Finally, the arthropod samples were taken to the laboratory and transferred to ethanol 70% with glycerol 5%.

A total of 1140 samples were collected and available for sorting and identification (19 reserves × 2 transects × 30 pitfall samples). Arthropod identification was performed in several stages: (i) trained students (parataxonomists; Basset et al. 2000) sorted samples into morphospecies (or RTUs = recognisable taxonomic units, *sensu* Oliver and Beattie 1996) using a non-complete reference collection; (ii) a senior taxonomist (P.A.V. Borges) performed a detailed correction of each sorted sample, standardising identifications and adding new species or morphospecies for the reference collection; (iii) morphospecies were sent for proper identification to expert taxonomists (most authors); (iv) specimens properly identified were used to correct datasheets and reference collection before the second sampling year. Immature stages were also considered in the identification process. Due to its high proportion, the validation was performed mainly in the second stage of the identification process, based on previous experience of the taxonomist enrolled (see Borges 1997, 1999; Borges and Brown 1999, 2001). In spite of some recent criticism on the use of immature forms (Derraik et al. 2002), this was possible due to the low level of species richness. For instance, the assignment of spiders immature stages to species was particularly facilitated due to the existence of many monospecific genera. In fact, as showed by Borges et al. (2002) genera and families could be used successfully as surrogates of species richness for the Azorean arthropod fauna, even though in some few cases immature identification was not possible (e.g. Araneae – *Erigone* spp.; beetles).

Arthropods were classified to one of three colonisation categories: natives, endemics and introduced. In cases of doubt, a species was assumed to be native. Native species arrived by long-distance dispersal to the Azores and are also known in other archipelagoes and on the continental mainland. Endemic species are those that occur only in the Azores, as a result of either speciation events (neo-endemics) or extinction of the mainland populations (paleo-endemics). Introduced species are those believed to be in the archipelago as a result of human activities, some of them being cosmopolitan species.

Voucher specimens and all sorted data are housed in the reference arthropod collection at the Department of Agriculture of the University of the Azores ('Arruda Furtado Collection'). Not all arthropods collected were considered for this study due to non-availability of taxonomic expertise, particularly Hymenoptera and Diptera. The following groups were included in this: Arachnida (Araneae, Pseudoscorpiones, Opiliones); Chilopoda; Diplopoda and Insecta (Microcoryphia, Zygentoma, Blattodea, Dermaptera, Orthoptera, Psocoptera, Hemiptera, Thysanoptera, Plannipenia, Trichoptera, Coleoptera, Lepidoptera).

Data analysis

Species scores

Since the period of time in which the pitfall traps remained in the field varied among sites (between 14 and 20 days) and a few traps were found damaged in some of the transects, the number of individuals of each arthropod species or morphospecies (hereafter, species for simplification) were adjusted accordingly, and the activity-density (AD) of each species in each transect was defined as the number of specimens per trap per day.

A further data adjustment was done to define species rarity, needed for calculation of Hotspots of rarity (see below). For the calculation of a rarity index for each species we followed two steps:

(1) calculation of an importance value (IV) for each species in each transect based on species relative frequency and relative AD:

$$\mathrm{IV}_i = (n_i/\sum_{i=1}^{N} n_i F_i/\sum_{i=1}^{N} F_i)_{\mathrm{T}} + (n_i/\sum_{i=1}^{N} n_i + F_i \sum_{i=1}^{N} F_i)_{\mathrm{E}}$$

where n_i is the AD of the ith species; F_i, the proportion of traps where the species occurred and n, the total number of species recorded in Turquin (T) or ethylene (E) traps. Thus, this index (which range from 0 to 4) estimates the contribution of the ith species for the total activity and frequency of the arthropods recorded in a particular transect. In one transect the sum of all species IVs will be 4;

(2) to obtain a true estimate of species rarity-based on pitfall trapping we further eliminated from the analyses adult Lepidoptera, Plannipenia, Trichoptera and some specialised canopy arthropods (e.g. Cixiidae; some spider species). Canopy specialisation was determined based on samples obtained in the canopy in the same transects (P.A.V. Borges et al. unpublished data). With this approach we avoid pseudo-rare species (see Longino et al. 2002) that although being sampled by pitfall, occur in the soil as 'tourists' or were only occasionally attracted by the trap. Therefore, we calculated a rarity index only for true soil epigean species, species known to occur in dead wood and in herbaceous vegetation. As a result, a total of 191 species were selected, 43 (23%) of which are endemic from the Azores and are the ones that will be mainly used for reserve ranking (see Appendix 1).

For each *taxon* we calculated a rarity index (RI) adapted from Kirchhofer (1997) and Borges et al. (2000):

$$\mathrm{RI} = (\mathrm{IV}/\mathrm{IV}_{\max}) + (I/7)$$

where IV is the geometric mean of the IVs of the species at the transects where the species was found, $\mathrm{IV}_{\max}$ is the maximum value of IV obtained for the pool of species, I is the number of islands where a species was sampled out of seven possibilities. Using only the values of IV higher than 0 we avoid very low values of rarity and the artificial inflation of the number of rare species. This index has a maximum value of 2. A species was considered rare if it had a value inferior to 25% of the maximum RI obtained for a species (see Gaston 1994).

Prioritising reserves

For prioritising the 19 reserves two techniques were used: (i) indices for scoring conservation priorities based on comparative analyses; (ii) complementarity methods.

(i) Scoring method. Due to its simplicity a scoring approach was used with 11 different diversity- or rarity-based indices (see Appendix 2). However, as the seven measures of diversity and the four measures of rarity gave quite different results (Appendix 3) a multiple-criteria index was applied.

Multiple-criteria index: importance value for conservation (IV-C)

Species richness has been previously explicitly combined in a composite index with rarity (Fox et al. 1997; Borges et al. 2000) in order to cope with the information complementarities generated by individual indices. However, when different values or criteria are combined in a single index, it is difficult to know what the single value obtained from it represents (e.g. Curio 2002). Moreover, the different indices used to describe species diversity may not be unrelated, thus leading to the possibility of giving a higher weighting to a given facet of biodiversity (*sensu* Gaston 1996) (e.g., species richness) in the construction of the complex index. To avoid possible problems of collinearity, we first produced a Spearman correlation (r_s) matrix using the values of all calculated indices obtained for the 19 reserves. Four redundant indices (i.e. those highly correlated with another ones) were not considered for further analysis (S_{auct}; DF; R_{end}; RE).

However, there was some level of correlation among the rest of the variables. To avoid the effect of this collinearity, we have used partial regression analysis techniques (Borcard et al. 1992; Legendre 1993; Legendre and Legendre 1998), which allow the separation of the variability of a given predictor that is independent (i.e., non-related) from the variability of another variable, or set of variables. To do this, we applied generalised linear models (GLM) with natural logarithm link functions (McCullagh and Nelder 1989), in which the predictor is regressed against this variable, or group of variables, and the resulting residuals are retained as the independent term of the variable. In this particular case, we have developed iterative partial regression analyses, each time extracting the variability of a predictor that is independent of the formerly chosen indices. That is, after selecting a first index (A), which is used without any transformation in the IV-C calculations, we regressed the second one (B) against A, obtaining its residuals (rB). In successive steps, each index (e.g., C) is regressed against the formerly included (in this case, A and rB) in a multiple regression analysis, obtaining its residuals (rC). The first selected index to be used without any transformation was the total number of endemic species (S_{end}), since endemic species richness was considered to be of major importance. The other indices entered in the model by decreasing order of their r^2 values of a GLM regression of each index with S_{end}. Thus, the final IV-C composite index is as follows:

$$\begin{aligned}\text{IV-C} = [&(S_{end}/S_{end-max}) + (\text{R-FQ}_r/\text{R} - \text{FQ}_{r-max}) + (\text{R-H-r}/\text{R-H-r}_{max})\\ &+ (\text{R-SEI}/\text{R-SEI}_{max}) + (\text{R-S}_{total}/\text{R-S}_{total-max})\\ &+ (\text{R-FQ}_{ab}/\text{R-FQ}_{ab-max}) + (\text{R-CVI}/\text{R-CVI}_{max})]/7\end{aligned}$$

in which for a reserve the value of the residual variance (R) of each of the additional indices is divided by the maximum value (max) obtained within all reserves. For instance, the residuals of SEI were obtained after the following polynomial model: SEI $= a + b\, S_{end} + c\text{R-FQ}_r + d\text{R-H-r}$.

This composite index has a maximum value of 1 (for a detailed description of the indices see Appendix 2).

(ii) Complementarity. To obtain the minimum set of reserves that combined have the highest representation of species we applied the complementarity method (Williams 2001). We used two methods: (i) a heuristic suboptimal simple-greedy reserve-selection algorithm in an Excel Spreadsheet Macro. First, the site with the highest species richness was selected. Then, these species are ignored and the site with the highest complement of species (that is, the most species not represented in the previous selected site), and so on, until all species are represented at least once; (ii) optimal solutions were determined using a linear programming optimisation with C-Plex software (ILOG 2001).

The principle of the optimal solution was to minimise the number of sites selected having all species represented at least once. Runs were performed until all possible set of solutions were given. For this database, usually no more than four runs were needed. Comparing the sites selected in each possible solution gives us a measure of how often a specific site can be replaced by other, or instead, can be repeatedly selected in all possible solutions. In the optimal algorithm solution the final set of sites do not have a ranking as in the sub-optimal algorithm solution (for further details on the procedure see Rodrigues et al. 2000a). For detailed discussions on optimisation *versus* heuristic reserve selection algorithms see Moore et al. (2003).

Both methods were applied separately to both a dataset comprising only presence–absence data for the endemic arthropods in the 19 reserves and to the same species in 38 transects (2 per reserve) to have the minimum set of reserves or transects to represent all species at least once. The optimal algorithm was also applied for species abundance data, in order to represent at least a given percentage of the population of each species in the minimum set of 19 reserves or 38 transects (see Rodrigues et al. 2000a). Three cutoffs were used, 20% (low representation), 50% (medium representation) and 80% (high representation).

Reserve irreplaceability

Under disturbance we may ask which reserves are more irreplaceable, that is, that have the set of species more exclusive. For getting a score of the irreplaceability of each reserve we performed the following procedure (modified from Hughes et al. 2002): (i) the estimated number of endemic species in the Azores was obtained applying 'first order JACKKNIFE" (Colwell and Coddington 1995; Colwell 1997; Henderson and Seaby 2002): $S_{\max} = S_{\text{obs}} + a(n - 1/n)$, in which S_{obs} is the number of sampled endemic species, n is the number of reserves (19 in the present case) and a is the number of species found in only one reserve; (ii) to investigate how the number of species might change under different scenarios of reserve disturbance, we simply excluded the sample from each particular reserve and recalculated the JACKKNIFE estimate for the remaining 18 reserves once per reserve elimination; (iii) to obtain an index of irreplaceability, we calculated a relative error estimate, $\text{RE} = ((\text{Sn} - \text{Sn}_{\max})/\text{Sn}_{\max}) \times 100$, in which Sn is the number of species without one particular reserve and $\text{Sn}_{\max}$ is the overall estimated number of species.

Other analysis

To evaluate the completeness of the inventory using the software Species Diversity and Richness *version* 3.0 (Pisces Conservation) (see Henderson and Seaby 2002), we applied to the endemic species dataset an accumulation curve with site order randomised 100 times to obtain a mean species accumulation curve.

To evaluate the similarity between reserves in endemic species composition we used hierarchical, agglomerative cluster analysis. From the several possible available methods we used the Ward's method (with Euclidean distance), also known as minimum variance or error sums of squares clustering, in which, in each iteration, all possible pairs of groups are compared and the two groups chosen for fusion are those which will produce a group with the lowest variance (Software CAP. – Community Analysis Package v. 2.0; Pisces Conservation Ltd.; www.pisces-conservation.com).

Results

Species composition

We recorded 191 species of epigean arthropods in the 19 reserves. From those species, 43 (23%) are endemic to the Azores (Araneae = 16; Microcoryphia = 1; Thysanoptera = 1; Hemiptera = 2; Lepidoptera = 2; Coleoptera = 21), 76 are native and 72 introduced. Figure 2 shows that the 43 endemic species sampled are far from the asymptote, indicating that inventory completeness was not reached. A total of 12 species are undescribed, which implies that 28% of the sampled endemic species were not known before.

Concerning feeding guilds, 93 species are predators, 55 species are herbivores, 31 species are saprophagous and 12 species are fungivorous. From the 43

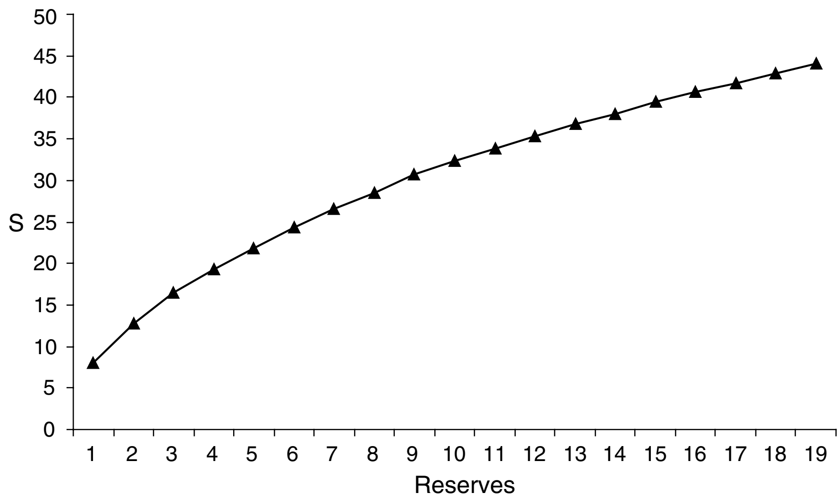

Figure 2. Average species accumulation curve for endemic arthropods in the 19 studied areas. The curve is the mean of 100 randomisations, in which the order of the areas was shuffled 100 times and the average calculated in order to produce a smoothed curve.

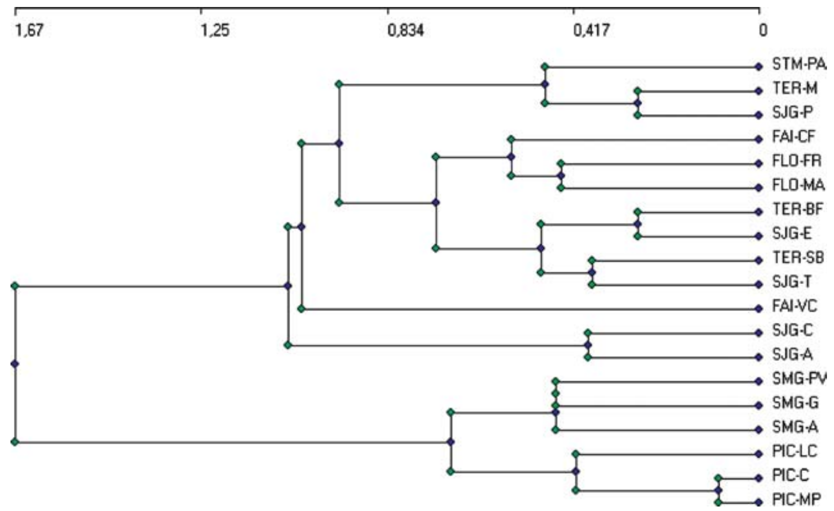

Figure 3. Dendrogram from a hierarchical cluster analysis for the 19 studied Azorean areas distributed on seven islands, using the presence–absence of endemic arthropod species. Linkage rule was Ward's method. The diagram plots the dissimilarity measure as the *x*-axis and reserves abbreviations are taken from Table 1.

endemic species, 23 are predators, 9 herbivorous, 8 fungivorous and 3 saprophagous. The richest taxonomic groups are Coleoptera (78 spp.), Araneae (41 spp.), Hemiptera (31 spp.) and Diplopoda (12 spp.), with a percentage of endemism of 39% for the Araneae, 27% for the Coleoptera, 6% for Hemiptera and 0% for Diplopoda.

The clustering of reserves based on presence–absence of endemic species is shown in Figure 3. The first division in the dendrogram separates all the six reserves from S. Miguel and Pico islands from all others. In most cases the highest similarities are for the reserves within each island. Some exceptions are related with the high similarity between the high altitude reserves of S. Jorge and Terceira: SJG-T and TER-SB; SJG-E and TER-BF; SJG-P and TER-M.

Reserve ranking

The two reserves with the greatest endemic species richness (STM-PA and PIC-MP, with 12 species) (Appendix 3) were ranked in first and 11th place respectively by the multiple criteria index (IV-C) (see Table 2). However, four reserves with lower rank in terms of endemic species richness (TER-BF, SJG-C, SJG-A, PIC-LC) were ranked in the first 10 based on the IV-C. This shows that, at least for those reserves, great part of the variation of this multiple-criteria index is explained by other indices unrelated to endemic species richness. Notably, in the first 10 reserves using the multiple-criteria index (IV-C),

Table 2. Ranking of the 19 reserves in terms of the multiple criteria index, Importance Value for Conservation (IV-C) (for other notations see Table 1).

Priority	NFR	Name	Island	NATURA 2000	IV-C
1	STM-PA	Pico Alto	SMA	No	0.71
1	SMG-PV	Pico da Vara	SMG	Yes	0.71
3	FLO-MA	Morro Alto e Pico da Sé	FLO	Yes	0.59
3	TER-BF	Biscoito da Ferraria	TER	Yes	0.59
5	FAI-CF	Cabeço do Fogo	FAI	Yes	0.58
6	SJG-C	Pico das Caldeirinhas	SJG	Yes	0.57
7	SMG-A	Atalhada	SMG	No	0.56
8	SMG-G	Graminhais	SMG	Yes	0.54
9	PIC-LC	Lagoa do Caiado	PIC	Yes	0.48
9	SJG-A	Pico do Arieiro	SJG	Yes	0.48
11	TER-SB	Serra de St^{a} Barbara e M. Negros	TER	Yes	0.47
11	PIC-MP	Mistério da Prainha	PIC	Yes	0.47
13	PIC-C	Caveiro	PIC	Yes	0.46
14	FLO-FR	Caldeiras Funda e Rasa	FLO	No	0.43
15	TER-M	Matela	TER	No	0.38
15	SJG-T	Topo	SJG	Yes	0.38
17	SJG-E	Picos do Carvão e da Esperança	SJG	Yes	0.37
18	SJG-P	Pico do Pinheiro	SJG	Yes	0.36
19	FAI-VC	Vulcão dos Capelinhos	FAI	Yes	0.32

two are not included in the *NATURA 2000* framework and one of the first (STM-PA) is also not a NFR. Noticeable is also the fact that all the reserves of the Oriental group of islands (S. Miguel and S. Maria) are in the first 10 ranked reserves using IV-C, and two of them are not included in the *NATURA 2000*. On the other hand, all islands have at least one reserve represented in the first 10 ranked reserves based on the IV-C, and the first six reserves are located within different islands.

Complementarity

Presence/absence data

Using presence/absence data, heuristic (suboptimal) and optimal solutions show that only 10 reserves (n = 19) are needed to have all endemic species represented at least once (Table 3). Moreover, all the seven islands have at least one reserve represented in the minimum complementary set of reserves (Table 3). Using the two replicates from each reserve, the minimum complementary set of transects includes the same reserves, with only four reserves being included twice for the suboptimal and optimal algorithms (Pico Alto (S. Maria), Pico da Vara (S. Miguel), Cabeço do Fogo (Faial) and Topo (S. Jorge)). In the optimal algorithm, the double representation of Topo (S. Jorge) may be replaced in other solution by the double representation of Graminhais (S. Miguel) (Table 3). Results of complementarity analysis

Table 3. Minimum complementarity set of transects (TRANS) within reserves and reserves (RESER) to have all the sampled endemic arthropod species represented at least once.

ISLAND	RESER	TRANS	N 2000	Transects within reserves (α diversity)					Reserves (γ diversity)				
				Suboptimal	Optimal algorithm				Suboptimal	Optimal algorithm			
				P/A data	P/A data	Abundance data			P/A data	P/A data	Abundance data		
				S		20%	50%	80%	S		20%	50%	80%
STM	PA	1	No	11	+	+	+	+	12	+	+	+	+
STM	PA	2	No	1	+	+	+	+					
SMG	PV	1	Yes	2	+	+	+	+	2	+	+	+	+
SMG	PV	2	Yes	1	+	+	+	+					
SMG	G	1	Yes	3	(+)		(+)	+	8	(+)	[+]	+	+
SMG	G	2	Yes		+	+	+	+					
SMG	A	1	No	7	+	+	+	+	3	+	+	+	+
SMG	A	2	No					+					
FAI	CF	1	Yes	2	+	+	+	+	3	+	+	+	+
FAI	CF	2	Yes	1	+	+	+	+					
FAI	VC	1	Yes			(+)	+	+			+	+	+
FAI	VC	2	Yes			(+)		+					
PIC	LC	1	Yes			[+]		(+)		(+)	(+)	(+)	+
PIC	LC	2	Yes				+	+					
PIC	C	1	Yes			[+]	+	+			(+)	+	+
PIC	C	2	Yes				+	+					
PIC	MP	1	Yes	3					3	+	+	+	+
PIC	MP	2	Yes		+	+	+	+					
FLO	FR	1	No					(+)		(+)		(+)	+
FLO	FR	2	No					+					

Table 3. Continued.

ISLAND	RESER	TRANS	N 2000	Transects within reserves (α diversity)					Reserves (γ diversity)				
				Suboptimal	Optimal algorithm				Suboptimal	Optimal algorithm			
				P/A data	P/A data	Abundance data			P/A data	P/A data	Abundance data		
				S		20%	50%	80%	S		20%	50%	80%
FLO	MA	1	Yes	4	[+]	+	+	+	5	+	+	+	+
FLO	MA	2	Yes		[+]		+	+					
TER	BF	1	Yes	1	+	+	+	+	1	+	+	+	+
TER	BF	2	Yes				(+)	(+)					
TER	SB	1	Yes				(+)	+			[+]	+	+
TER	SB	2	Yes				+	+					
TER	M	1	No				+	+				+	+
TER	M	2	No					+					
SJG	C	1	Yes	4				+	4	+	+	+	+
SJG	C	2	Yes		+	+	+	+					
SJG	E	1	Yes					+					
SJG	E	2	Yes										
SJG	A	1	Yes									+	+
SJG	A	2	Yes				+	+					
SJG	P	1	Yes					+					+
SJG	P	2	Yes				+	+					
SJG	T	1	Yes	2	(+)	+	+	+	2	+	+	+	+
SJG	T	2	Yes	1	+	+	+	+					

Results are presented for presence–absence (P/A) data for both suboptimal (with indication of number of species added) and optimal algorithms and for relative proportions of abundance (e.g. all species represented with at least 20% of their abundance summed across all sites) for the optimal algorithm. Selected transects or reserves in brackets, (+) or [+], are sites which can be replaced in other possible solution by other correspondent site (+) or [+]. The remaining selected sites, +, are irreplaceable. For other notations see Table 1.

(Table 3) also show that 50% of the reserves not included in the *NATURA 2000* framework are of great importance for the conservation of Azorean arthropod fauna.

Abundance data

Abundance data was only analysed using the optimal solutions. The number of transects and reserves needed in the minimum set increased with abundance threshold (Table 3). When including only 20% of the abundance of each endemic species the final solution is almost equivalent to presence/absence data for both transects and reserves. However, almost all transects ($n = 38$) and reserves ($n = 19$) are needed when 50% (24 transects and 16 reserves) and 80% of the abundance (33 transects and 18 reserves) is imposed (Table 3).

Considering a conservative 50% abundance threshold, three of the four reserves not included in the *NATURA 2000* framework are found to be irreplaceable for the conservation of sustainable populations of the Azorean arthropod fauna.

Irreplaceability

With the JACKKNIFE estimator, we estimated that 61 epigean endemic arthropod species belonging to the studied taxonomic groups should occur in the 19 reserves. Thus, we sampled 71% of the potential endemic species. Simulating the reduction of reserve area and eventual removing of reserves, we calculated an index of irreplaceability (Table 4), and the small reserve in S. Maria, Pico Alto, is by far the most irreplaceable reserve. Notably, the six reserves from the islands located in the two extremes of the Azorean archipelago (S. Maria, S. Miguel, Flores) are amongst the most irreplaceable. Moreover, a large fraction of the endemic arthropod diversity appears dependent of the preservation of two reserves not included in the *NATURA 2000* scheme (Pico Alto and Atalhada) (see Table 4).

Discussion

Lessons for the inventory process

In this study we aimed to quantify the relative value of island reserves using standardised sampling of arthropods. Even though this survey represents an extremely valuable contribution to the inventory of Azorean arthropods, as showed by the 12 new undescribed species found, the regional endemic arthropod species inventory in the studied areas was not complete, which strongly stresses the need for further sampling in all reserves. These results have encouraged us to continue with further campaigns in the same and additional habitats (e.g. canopy), which are being accomplished by the BALA project – 'Biodiversity of Arthropods from the Laurisilva of the Azores' (P.A.V. Borges

Table 4. The irreplaceability of each reserve based in 19 scenarios of reserve reduction or disapearence (see text for explanations).

Priority	Code	Name	Island	NATURA 2000	Irreplaceability
1	STM-PA	Pico Alto	SMA	No	18.57
2	SMG-PV	Pico da Vara	SMG	Yes	4.71
2	FAI-CF	Cabeço do Fogo	FAI	Yes	4.71
2	FLO-MA	Morro Alto e Pico da Sé	FLO	Yes	4.71
5	SMG-A	Atalhada	SMG	No	3.20
5	SJG-C	Pico das Caldeirinhas	SJG	Yes	3.20
7	TER-BF	Biscoito da Ferraria	TER	Yes	3.12
8	SMG-G	Graminhais	SMG	Yes	2.99
9	PIC-MP	Mistério da Prainha	PIC	Yes	1.61
9	FLO-FR	Caldeiras Funda e Rasa	FLO	No	1.61
11	FAI-VC	Vulcão dos Capelinhos	FAI	Yes	1.48
11	PIC-C	Caveiro	PIC	Yes	1.48
11	TER-SB	Serra de St^{a} Barbara e M. Negros	TER	Yes	1.48
11	TER-M	Matela	TER	No	1.48
11	SJG-A	Pico do Arieiro	SJG	Yes	1.48
16	SJG-T	Topo	SJG	Yes	0.11
17	PIC-LC	Lagoa do Caiado	PIC	Yes	0.02
17	SJG-E	Picos do Carvão e da Esperança	SJG	Yes	0.02
17	SJG-P	Pico do Pinheiro	SJG	Yes	0.02

et al. unpublished data). However, as we sampled the same part of the arthropod community in a standardised way throughout all transects the final dataset allows us to compare the relative value of all reserves for the representation of forest and semi-natural grassland epigean arthropod fauna.

Concerning the methods used, pitfall trapping usually carries some methodological problems that are well documented (reviewed in Adis 1979; Powell et al. 1996; Southwood and Henderson 2000), and it is commonly accepted that data collected by this method do not always reflect structure of invertebrate communities (Sunderland and Topping 1995) or species composition (Borges and Brown 2003). However, this study was carried out under logistically difficult circumstances on seven oceanic islands and at high altitude dense native forest sites where access was commonly difficult, and therefore, it required a fast to operate and reliable technique such as pitfall trapping. As the purpose of this study was to produce a regional comparison of arthropod biodiversity in poorly sampled areas (see Borges et al. 2000), we expect that a standardised application of the same method might result in comparable, unbiased errors throughout all sites.

Regional conservation assessment

Laurel forests covered vast areas of the islands before Human settlement and nowadays are reduced to few high-altitude areas. The NFR system includes most of the remaining areas of native forest in the Azores. Data from this study shows that a regional conservation approach, which value at least one indigenous forest area per island, will be required to conserve arthropod biodiversity in the Azores. This confirms a previous analysis using only literature data (Borges et al. 2000).

Based both on the uniqueness of species composition, irreplaceability of the fauna and high species richness, conservation efforts should focus on the Pico Alto area at Santa Maria island, a site still under evaluation to be included on the NFR scheme and not considered on the European Conservation network, *NATURA 2000*. This study shows that the selection of sites for special conservation purposes based only on a list of species of vascular plants or birds seems inadequate and leaves out important faunistic groups which are intrinsically related to community functionality and thus of conservation importance.

Geological history plays an important role in patterns of species richness and endemism in the Azores (Borges and Brown 1999), a pattern also confirmed by the current data, in which some of the most irreplaceable reserves are located in geologically old islands (S. Maria, S. Miguel and Flores). Therefore, the importance of speciation rates in islands of very different geological history and age should be taken into account when evaluating local and regional patterns of diversity in the Azores (see also Borges and Brown 1999). This highlights the importance of regional factors in community ecology and calls for a reconciliation between historical factors and diversity patterns (see Whittaker et al. 2001; Ricklefs 2004).

In spite of some recent criticism (see Prendergast et al. 1999; Heikkinen 2002), complementarity is nowadays a widely used technique for reserve selection, due mainly to the fact that it performs better than scoring techniques but also because limited funding is available for conservation (Faith and Walker 1996; Howard et al. 1998; Margules and Pressey 2000; Rodrigues et al. 2000b; Williams 2001). Moreover, there is also a recent debate on the relative value of optimisation complex methods *versus* heuristic simple reserve selection algorithms for complementarity (see Moore et al. 2003). When using presence/absence data, the minimum set of reserves to have all species represented at least once, sometimes fails to include very important sites in terms of conservation value (see Heikkinen 2002), a pattern also observed in the current study. In fact, using both suboptimal and optimal solutions very important sites like Vulcão dos Capelinhos (Faial), an important geological reserve, but most notably Caveiro (Pico) and Serra de St[a] Bárbara e M. Negros (Terceira), pristine reserves with some of the best, well-preserved indigenous forests from the Azores, were not included in the minimum complementarity set for preserving the Azorean endemic soil epigean arthropods. The reasons for this result are threefold: first, the use of only presence/absence data makes impossible the incorporation of important features like species abundance, an important surrogate of habitat quality and species persistence (see Araújo and Williams 2000, 2001); second, in species poor regions like the Azorean islands, most of the common within island endemic species occur throughout all the reserves of a particular island, and, consequently, some important reserves become redundant based on the simple complementarity approach. Third, using a single criterion may not allow us to cover all conservation goals. The reserve scheme here obtained fails to detect the geological uniqueness of Vulcão dos Capelinhos, and the pristine systemic conditions of Caveiro and Serra de St^{a} Bárbara e M. Negros forests. Thus, arthropod presence/absence data is not being able to cover all patterns of geology and laurisilva ecosystems variation.

However, when using abundance data with optimisation methods the final solutions are more in tune with the regional distribution of Azorean distribution of indigenous pristine *Laurisilva* forest, that is, most important reserves are needed for the inclusion of 50% of populations of endemic epigean arthropods. Consequently, the use of more complex algorithms in complementarity analysis gave more realistic solutions (see Margules and Pressey 2000; Rodrigues et al. 2000a, b). Here, it is important to take into account that, whilst complementarity in terms of species representation may not be able to detect several ecologically interesting sites, the use of an ecologically structured variable such as species abundances is most likely to success in detecting better ecological uniqueness. Therefore, only two out of 19 reserves are completely redundant in this new scenario, two in S. Jorge (five available). This exercise makes sense in terms of conservation biology, since for the persistence of species there is no guarantee that a single reserve in each island is enough for the persistence of within islands restricted endemic species. However, with this solution all the four reserves not included in *NATURA 2000* are needed for the conservation of Azorean arthropods.

We argue that if only the *NATURA 2000* sites are well managed then the consequences will be twofold. First, some important sites currently not properly managed will be invaded by exotic vascular plants as it is already occurring in Atalhada (S. Miguel), Matela (Terceira), Caldeira Funda (Flores) and to some extent in Pico Alto (S. Maria) with severe consequences for soil moss cover, an important component in the well-preserved Azorean indigenous forest. Second, the endemic arthropod populations restricted to unmanaged sites will be under permanent threat due to the 'out-of-sight effect', and future conflicts between conservation and development cannot readily be avoided. Replacement of indigenous forest or semi-natural pasture by any monoculture is still possible in private land in the Azores, which is a reason for some concern since most indigenous forest was already seriously fragmented due to traditional agriculture and the plantation of *Cryptomeria japonica*.

General applications of this study

Diversity- and rarity-based information was processed using partial multiple regression analysis to partition variation into its components, which is the most accurate way to avoid multicollinearity and redundancy (see Legendre and Legendre 1998; Graham 2003). This way, the possible bias due to the over-representation of a given facet of biodiversity in the indices used is accounted for. For the first time in conservation ecology studies we have applied a multiple-criteria index using such a procedure and the result was sound, since the final ranking of reserves followed a well-interpretable pattern and is in accordance with results obtained with the complementarity and irreplaceability analysis. We therefore encourage conservation ecologists to try similar approaches with other systems, clearly maximising the representation of different types of information and different combinations of diversity and rarity features. The refinement introduced here imposes that standardised sampling programs are used for evaluation of protected areas, since a great fraction of conservation studies rely on literature data gathered in different temporal and spatial scales, that could give biased results for the assessment of present conservation status.

Using a scoring technique that incorporates diversity and rarity information with partition of variation in combination with an optimal complementarity approach using abundance data, we hope that the final solution for the preservation of species within a reserve network could include all taxonomic distinctiveness, threat status, viable population sizes and rarity diversities in the region considered.

Conclusions

A large proportion of Azorean high nature-value landscape was evaluated using arthropods. The data analysed in this study are currently the only available standardised data on regional patterns in terrestrial invertebrate diversity for the Azores. The value of this information for setting conservation sites priorities in the Azores will largely be dependent on the value of arthropods for conservation managers, both by its own, and by its utility as indicators of the variations of a portion of total biodiversity. The current criteria for selecting conservation priority areas in the Azores are that those areas should be inside the already designed *NATURA 2000* or that they should be of regional environmental significance. We argue that neglecting the information presented in this paper will imply the loss of some very important sites, not yet properly managed, for the preservation of the Azorean biodiversity and ecosystem processes.

Three hypotheses were originally presented for the priority-reserve selection in the Azores based on the arthropod fauna: (1) at least one reserve per island will be highly ranked; (2) the restricted distribution of endemic species will imply that most areas are unique and largely irreplaceable; (3) *NATURA 2000* conservation areas alone cannot optimise arthropod species richness conservation in the Azores. There are three important conclusions: (1) we concluded that in fact at least one well-managed reserve per island is absolutely necessary to have a good fraction of the endemic arthropods preserved; (2) using an optimal complementarity algorithm with abundance data, an optimal solution implies that most reserves are needed for at least 50% of the populations are preserved; (3) moreover, *NATURA 2000* unmanaged reserves in the Azores play an important role in protecting a great proportion of Azorean endemic arthropods and are vital for the future persistence of restricted endemic species. Thus, Azorean endemic arthropod fauna could be preserved with only moderate effort in adding some small reserves to the already available conservation management framework.

We hope that this study represents only the first step towards generating enhanced quality data on the regional distribution of Azorean biodiversity, and a definite contribution towards increasing awareness and understanding of arthropod relevance for nature conservation.

Acknowledgements

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Appendix 1. List of endemic arthropod species of the 19 studied reserves, with the number of transects each species was sampled per reserve (see Table 1 for complete reserve names). F.H. = feeding habitus (F = fungivorous; H = herbivorous; P = predator; S = Saprophagous.

Morphospecies	Species name	F.H.	Family	FLO-MA	FLO-FR	FAI-VC	FAI-CF	PIC-MP	PIC-LC	PIC-C	SJG- C	SJG-E	SJG-A	SJG-P	SJG-T	TER-SB	TER-BF	TER-M	SMG-G	SMG-A	SMG-PV	STM- PA
	Arachnida																					
	Araneae																					
MF293	*Agyneta* n. sp.	P	Linyphiidae				1															
MF351	Gen. sp. (n. sp.)	P	Linyphiidae								1											
MF305	*Minicia picoensis* Wunderlich	P	Linyphiidae					1														
MF600	*Minicia* n. sp.	P	Linyphiidae								1		1									
MF421	*Walckenaeria grandis* (Wunderlich)	P	Linyphiidae												2	1						
MF585	*Agyneta* n.sp.	P	Linyphiidae	1							1		1		2							
MF312	*Diplocentria acoreensis* Wunderlich	P	Linyphiidae		1				1										1			
MF50	*Lepthyphantes acoreensis* Wunderlich	P	Linyphiidae		1			2	1	1	1	1	2	1	1		1	1		1		1
MF181	*Savigniorrhipis acoreensis* Wunderlich	P	Linyphiidae												1							
MF4	*Porrhomma* n.sp.	P	Linyphiidae					1								1			1			
MF313	*Agyneta* n. sp.	P	Linyphiidae	2																		
MF314	*Agyneta* n. sp.	P	Linyphiidae	2																		
MF17	*Pardosa acorensis* Simon	P	Lycosidae	2	2		2	2		2	2	2	2	1	2	1	2	2	1			2
MF281	*Orchestina* n. sp.	P	Oonopidae																	1		
MF526	*Neon* n.sp.	P	Salticidae	1			1						1		1							
MF5	*Rugathodes acoreensis* Wunderlich	P	Theridiidae	1				1		2		1			1	2	2		2	2	1	

Appendix 1. Continued.

Morphospecies	Species name	F.H.	Family	FLO-MA	FLO-FR	FAI-VC	FAI-CF	PIC-MP	PIC-LC	PIC-C	SJG- C	SJG-E	SJG-A	SJG-P	SJG-T	TER-SB	TER-BF	TER-M	SMG-G	SMG-A	SMG-PV	STM- PA
	Insecta																					
	Microcoryphia																					
MF144	*Trigoniophthalmus borgesi* Mendes et al.	S	Machilidae															1		1		
	Hemiptera																					
MF8	*Aphrodes hamiltoni* Quartau & Borges	H	Cicadellidae	2	2		1	2	2	2		1		2	2	1	2			1	1	2
MF496	*Nysius atlantidum* Horvàth	H	Lygaeidae				1															
	Thysanoptera																					
MF284	*Apterygothrips* n.sp. (?)	H	Phlaeothripidae																	1		
	Coleoptera																					
MF263	*Calathus lundbladi* Colas	P	Carabidae																		1	
MF346	*Cedrorum azoricus azoricus* Borges & Serrano	P	Carabidae														1					
MF297	*Pseudanchomenes aptinoides* Tarnier	P	Carabidae					1	1	1												
MF302	*Cedrorum azoricus caveirensis* Borges & Serrano	P	Carabidae					1		1												
MF76	*Tarphius rufonodulosus* Israelson	F	Colydiidae																			1
MF67	*Tarphius* n. sp. ?	F	Colydiidae																			2
MF490	*Tarphius acuminatus* Gillerfors	F	Colydiidae																		1	
MF64	*Tarphius serranoi* Borges	F	Colydiidae																			2
MF307	*Tarphius wollastoni* Crotch	F	Colydiidae	2	1																	

MF251	*Tarphius tornvalli* Gillerfors	F	Colydiidae					1	2	2									2	2	1	
MF300	*Tarphius azoricus* Gillerfors	F	Colydiidae					1	2	2									1	2	1	
MF70	*Tarphius pomboi* Borges	F	Colydiidae																			2
MF128	*Caulotrupis parvus* Israelson	H	Curculionidae																			1
MF46	*Laparocerus azoricus* (Drouet)	H	Curculionidae								1										1	
MF77	*Pseudechinosoma nodosum* Hustache	H	Curculionidae					1		2				1				1	1		1	2
MF285	*Agabus godmani* Crotch	P	Dytiscidae												1				1			
MF292	*Heteroderes melliculus moreleti* Tarnier	S	Elateridae			2	2															
MF244	*Alestrus dolosus*(Crotch)	H	Elateridae	1	2												1		2	2	2	
MF73	*Metophthalmus occidentalis* Israelson	S	Lathridiidae																			2
MF253	*Phloeonomus azoricus* Fauvel	P	Staphylinidae																1	1		
MF439	*Atheta dryochares*Israelson	P	Staphylinidae								1											
	Lepidoptera																					
MF90	*Cleora fortunata azorica* Pinker	H	Geometridae		1		1											1			1	1
MF19	*Argyresthia atlanticella* Rebel	H	Yponomeutidae	2	1	1	2	2	1	1			1	2	2	2	2	1	1	1	2	2

Appendix 2: List of the indices

Diversity based indices

Species richness (S), where S is equivalent to γ diversity, that is, the pooled number of species in a reserve based on two transects. Three S values were calculated: S_{end} = endemic species; S_{auct} = autochthonous species, that is, native plus endemic; S_{total} = all species including endemic, native and human introduced (anthropochorous) species.

Endemism rate (R_{end}).

$$R_{\mathrm{end}} = S_{\mathrm{end}}/S_{\mathrm{auct}}$$

An estimate of the proportion of the autochthonous fauna of arthropods that is endemic to the Azores, which gives more value to areas with high distinct phylogenetic patrimony.

Higher taxonomic diversity – families (DF). DF is the total number of families which contain endemic species. This index is used as a surrogate of genetic diversity, giving high value to reserves with more distinctive phylogenetic taxa.

Species richness faunistic quality index ($\mathrm{FQ_r}$).

$$\mathrm{FQ_r} = S_{\mathrm{auct}}/S_{\mathrm{total}}$$

Reserves composed only by native and endemic species will have a $\mathrm{FQ_r}$ of 1. This index gives higher rank to sites with few exotic species.

Abundance faunistic quality index (FQ_{ab}).

$$\mathrm{FQ}_{ab} = \sum \mathrm{IVauct}_i / \sum \mathrm{IVtotal}_i$$

where $\mathrm{IVauct_i}$ is the IV of the autochthonous (native or endemic) species i and $\mathrm{IVtotal}_i$ is the IV of the endemic, native or introduced species i. This index gives higher rank to sites with few specimens of alien species.

Rarity-based indices

Relative endemism (RE).

$$\mathrm{RE} = S_{\mathrm{excl}}/S_{\mathrm{end}}$$

where S_{excl} is the number of endemic species only sampled in a particular reserve and S_{end} is the overall number of endemic species sampled in this study. This index gives preference to reserves with restricted distributed endemic species.

Hotspots of rarity (H-r). Based on Gaston (1994), rare species were defined as those with a RI of less than 25% of the species that had the highest RI. To obtain an index for each reserve, the number of those rare species were counted. This is equivalent to designating hotspots of richness, but using only rare species, that is, hotspots of rarity.

Conservation value index (CVI) (adapted from Nilsson and Nilsson 1976 in Sutherland 2000).

$$\mathrm{CVI} = \left(\sum 100 \times \mathrm{IV}_i/\mathrm{IV}_{i\,\max}\right)/S_{\mathrm{end}}$$

where IV_i is the importance value of species i in a given reserve and $\mathrm{IV}_{i\max}$ is the maximum importance value of that species in all the reserves. A high value indicates that the reserve contains a high proportion of endemic species populations.

Site endemism index (SEI) (adapted from Rebelo and Siegfried 1992 in Sutherland 2000).

$$\mathrm{SEI} = \left(\sum k/a_i\right)/S_{\mathrm{end}}$$

where k is the number of reserves and a_i is the total number of reserves at which species i occurs. The calculation only includes the endemic species present (S_{end}). A high value indicates that the reserve contains many restricted species.

Appendix 3. Ranking of the 19 reserves in terms of several indices: total species richness (S_{total}); endemic species richness (S_{end}); autochthonous species richness (S_{auct}); endemism rate (R_{end}); higher taxonomic diversity – families (DF); species richness faunistic quality index (FQ_r); abundance faunistic quality index (FQ_{ab}); hotspots of rarity (H-r); relative endemism (RE); conservation value index (CVI); site endemism index (SEI). The reserves are listed in descending order of endemic species richness (S_{end}); ranks for all indices are given. For other notations see Table 1.

Priority	NFR	Name	Island	NATURA 2000	Diversity based indices														Rarity based indices							
					S_{end}	Rank	S_{total}	Rank	S_{auct}	Rank	R_{end}	Rank	DF	Rank	FQ_r	Rank	FQ_{ab}	Rank	H-r	Rank	RE	Rank	CVI	Rank	SEI	Rank
1	STM-PA	Pico Alto	SMA	No	12	1	53	1	34	2	0.35	7	8	3	0.64	14	0.50	17	6	1	0.50	1	63.78	2	10.48	1
2	PIC-MP	Mistério da Prainha	PIC	Yes	12	1	39	5	29	5	0.41	5	8	3	0.74	4	0.68	14	2	6	0.08	10	22.40	18	4.78	9
3	SMG-PV	Pico da Vara	SMG	Yes	11	3	48	3	35	1	0.31	10	8	3	0.73	6	0.72	12	3	4	0.18	5	57.95	4	6.17	6
4	SMG-A	Atalhada	SMG	No	11	3	38	7	26	8	0.42	4	10	1	0.68	12	0.71	13	4	3	0.18	5	54.69	6	6.58	4
5	SMG-G	Graminhais	SMG	Yes	11	3	34	10	28	6	0.39	6	9	2	0.82	2	0.75	8	2	6	0.00	11	51.41	9	4.38	10
5	FLO-MA	Morro Alto e Pico da Sé	FLO	Yes	10	6	32	13	21	11	0.48	2	8	3	0.66	13	0.82	3	2	6	0.20	4	53.48	8	6.58	4
7	SJG-T	Topo	SJG	Yes	10	6	24	19	17	18	0.59	1	7	9	0.71	9	0.81	4	3	4	0.10	9	45.04	13	5.46	7
8	PIC-C	Caveiro	PIC	Yes	10	6	26	17	23	10	0.43	3	8	3	0.88	1	0.77	6	1	11	0.00	11	51.13	10	3.20	17
9	FAI-CF	Cabeço do Fogo	FAI	Yes	8	9	49	2	34	2	0.24	17	8	3	0.69	11	0.53	16	2	6	0.25	3	36.27	16	7.47	3
10	FLO-FR	Caldeiras Funda e Rasa	FLO	No	8	9	41	4	30	4	0.27	14	6	11	0.73	5	0.58	15	0	16	0.00	11	20.87	19	3.50	14
11	SJG-C	Pico das Caldeirinhas	SJG	Yes	7	11	38	8	24	9	0.29	12	4	16	0.63	15	0.80	5	5	2	0.29	2	70.25	1	9.21	2
12	TER-BF	Biscoito da Ferraria	TER	Yes	7	11	39	6	28	6	0.25	15	7	9	0.72	8	0.83	2	1	11	0.14	7	44.97	14	4.18	11
12	PIC-LC	Lagoa do Caiado	PIC	Yes	7	11	28	14	21	11	0.33	8	5	13	0.75	3	0.77	6	1	11	0.00	11	56.77	5	3.28	16
14	SJG-A	Pico do Arieiro	SJG	Yes	6	14	33	12	20	14	0.30	11	4	16	0.61	16	0.89	1	2	6	0.00	11	45.46	12	3.81	12
15	TER-SB	Serra de St[a] Barbara e M. Negros	TER	Yes	6	14	26	17	19	16	0.32	9	5	13	0.73	5	0.74	10	1	11	0.00	11	62.21	3	3.58	13
16	TER-M	Matela	TER	No	6	14	38	8	21	11	0.29	12	6	11	0.55	17	0.39	18	1	11	0.00	11	45.55	11	3.31	15

17	SJG-P	Pico do Pinheiro	SJG	Yes	5	17	28	14	20	14	0.25	15	5	13	0.71	9	0.75	8	0	16	0.00	11	38.02	15	1.58	18
18	SJG-E	Picos do Carvão e da Esperança	SJG	Yes	4	18	34	10	18	17	0.22	18	4	16	0.53	18	0.73	11	0	16	0.00	11	33.03	17	1.50	19
19	FAI-VC	Vulcão dos Capelinhos	FAI	Yes	2	19	28	14	11	19	0.18	19	2	19	0.39	19	0.29	19	0	16	0.00	11	53.77	7	5.31	8

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