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Ranking the Azorean Natural Forest Reserves for conservation using their endemic arthropods

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Abstract

Endemic arthropods were used to evaluate the conservation value of the 16 Natural Forest Reserves (NFRs) of the Azores (Macaronesia). For each of the 280 known Azorean endemic species of arthropods, a rarity index was calculated, using distribution and abundance data obtained from the literature. In addition, several scoring indices were used to rank the 16 NFRs. Frequency distributions of the rarity index indicated that there was a tendency for a greater proportion of the commonest species being represented in the NFRs in contrast with a lower representation of the rarest species. About 60% of the endemic arthropod species that were recorded from the NFRs are 'single NFR endemics', that is, are known from only one of the 16 NFRs. Species richness was considered to be a very good surrogate measure of the conservation value of the 16 NFRs under study. The fact that the six highest ranked NFRs (using a composite multi-criteria index) are located in different islands has some important conservation management implications; to preserve a large proportion of the Azorean arthropod biodiversity there is a need to protect sites in all islands. If the five highest ranked NFRs are correctly managed in terms of conservation, then at least 80% of the endemic arthropods known from the NFRs could be protected. Most of the tested taxa (Acari-Oribatei; Lepidoptera; Diptera; Coleoptera) are good surrogates of the overall total set of species present in the 16 NFRs when using a species richness index.

Introduction

This study focuses on the Natural Forest Reserves (NFRs) of the Azores, created under the Portuguese law n°27/88/A. This legislation established 16 protected natural areas distributed over seven islands (see Methods). There are few large undisturbed areas of native forest in the Azorean islands. The 16 NFRs include a great proportion of this important habitat and constitute a good sample of the available fragments of the original primitive 'Laurissilva'.

There is a wide variety of techniques which can be used to quantify the relative conservation value of natural areas (e.g., Spellerberg 1992; Collinson *et al.* 1995; Turpie 1995; Arita *et al.* 1997; Fox *et al.* 1997; Freitag *et al.* 1997; Kerr 1997; Kirchhofer 1997; Panzer & Schwartz 1998; Troumbis & Dimitrakopoulos 1998). The selection of methods depends largely on the goals and parameters of any given study (Turpie 1995). In the present case, we were interested in the biodiversity of the Azorean endemic arthropod species and their conservation status.

There are few studies which have attempted to assess the conservation status of arthropods in the

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Macaronesian islands (e.g., Meyer 1995; Geisthardt 1996; Lecoq 1996; Schmidt & Geisthardt 1996). The diversity and complexity of the arthropod fauna of the Azores is still incompletely known, It is clear from the available literature (see the comprehensive list of Borges & Vieira 1994) that some groups are better studied than others. It is, however, unclear if the relative proportion of available publications for each arthropod order reflects its relative species richness. There can be little doubt, for example, that some groups are poorly known because of their small size, taxonomic difficulties (e.g., Acari, Collembola, Diptera, Hymenoptera) or difficulties in sampling (e.g., cave and soil animals).

It seemed clear to the authors that significant progress in the study of the Azorean arthropod fauna had to start with a comprehensive revision of data on the distribution and abundance of the known species. In the present study, we have concentrated only on the Azorean endemic species, because endemic species have been widely used as indicators of the conservation value of natural habitats.

Importantly, the rarity status of each endemic Azorean arthropod species is in general unknown. There are several ways of giving a score of rarity to a species, either using algorithms (e.g., Freitag *et al.* 1997; Kirchhofer 1997) or applying a Rabinowitz-type rarity classification (e.g., Daniels *et al.* 1991; Kattan 1992; McIntyre 1992; Goerck 1997). Alternatively, the assignment of rare species could be made on the basis of abundance and/or range size as summarized in Gaston (1994).

Therefore, the aims of the present study are: (1) to compile an inventory of known Azorean endemic arthropod species; (2) to assign a rarity score to each endemic arthropod species; (3) and to rank each NFR in terms of its conservation value (using a range of techniques).

The authors are aware that precise data on the abundance and distribution estimates are not currently available for all the endemic arthropods from the Azores. Therefore, the results and conclusions here presented could be severely biased by variation in recording effort and, as such, should be considered as preliminary.

Methods

The sites

The 16 NFRs are listed with their associated code numbers in Table 1 and their locations within the seven islands concerned are shown in Figure 1. 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.

Table 1. List of the Natural Forest Reserves (NFRs) of the Azores. For each, name, area and minimum and maximum altitude are presented.

Code	Name	Island	Area (ha)	Altitude (m)
120	Cabeço do Fogo	FAI	37	400–529
121	Vulcão dos Capelinhos	FAI	196	0–170
122	Lagoa do Caiado	PIC	125	800–939
123	Mistério da Prainha	PIC	641	425–841
124	Caveiro	PIC	196	850–950
125	Caldeira da Graciosa	GRA	236	137–402
126	Caldeiras Funda e Rasa	FLO	442	350–600
127	Morro Alto e Pico da Sé	FLO	1556	300–400
128	Pico do Arieiro	SJG	37	800–958
129	Pico das Caldeirinhas	SJG	50	700–815
130	Picos do Carvão e da Esperança	SJG	167	800–1083
131	Atalhada	SMG	15	425–530
132	Graminhais	SMG	19	850–925
133	Pico da Vara	SMG	752	400–1103
134	Biscoito da Ferraria	TER	355	475–808
135	Serra de Stª Bárbara e M. Negro	TER	1083	550–1025

FAI – Faial; PIC – Pico; GRA – Graciosa; FLO – Flores; SJG – S. Jorge; SMG – S. Miguel; TER – Terceira.

The NFRs differ greatly in their areas (see Table 1) and habitats within them. On the island of Faial, 'Vulcão dos Capelinhos' (NFR 121) is a recent volcano (a historical eruption from 1957–58) made up of mainly lavicolous habitat. Caldeira da Graciosa (NFR 125) at the island Graciosa, is a volcanic caldera without any native vegetation, and covered with exotic forests and pasture. The three NFRs from S. Jorge (NFR 128, 129 and 130) are natural grassland fenced against grazing. All the other NFRs are dominated by the indigenous forest known as 'Laurissilva'. Semi-natural grassland (NFRs 122, 124, 126, 127, 132, 133, 134 and 135) and exotic forests (NFRs 133, 134 and 135) also occur in some of the NFRs.

Arthropod data

Data on the occurrence and abundance of each endemic species were obtained from a literature survey of all the known published entomological works dealing with Azorean arthropods. The recent entomological bibliography for the Azores of Borges and Vieira (1994) was especially useful. In addition, more recent works were obtained from bibliographical databases. For the Coleoptera and Araneae, unpublished data from one of the authors (P. Borges) was also used. Available information was collated in a database specially created in FILE MAKER 4.0.

The database

For each potential *taxon*, information was obtained about distribution in the nine Azorean islands, and number of records in each case. A record includes the

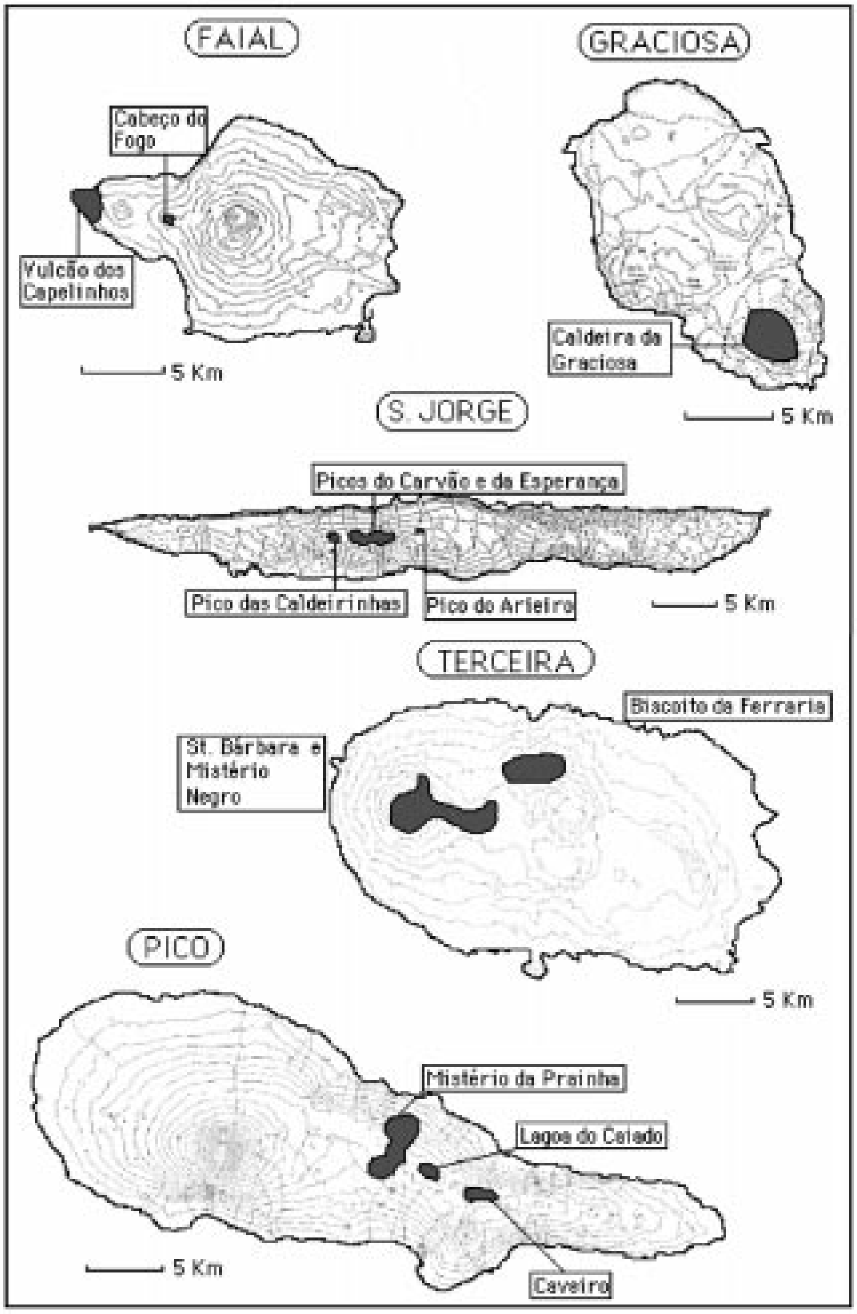

Figure 1. (Continued)

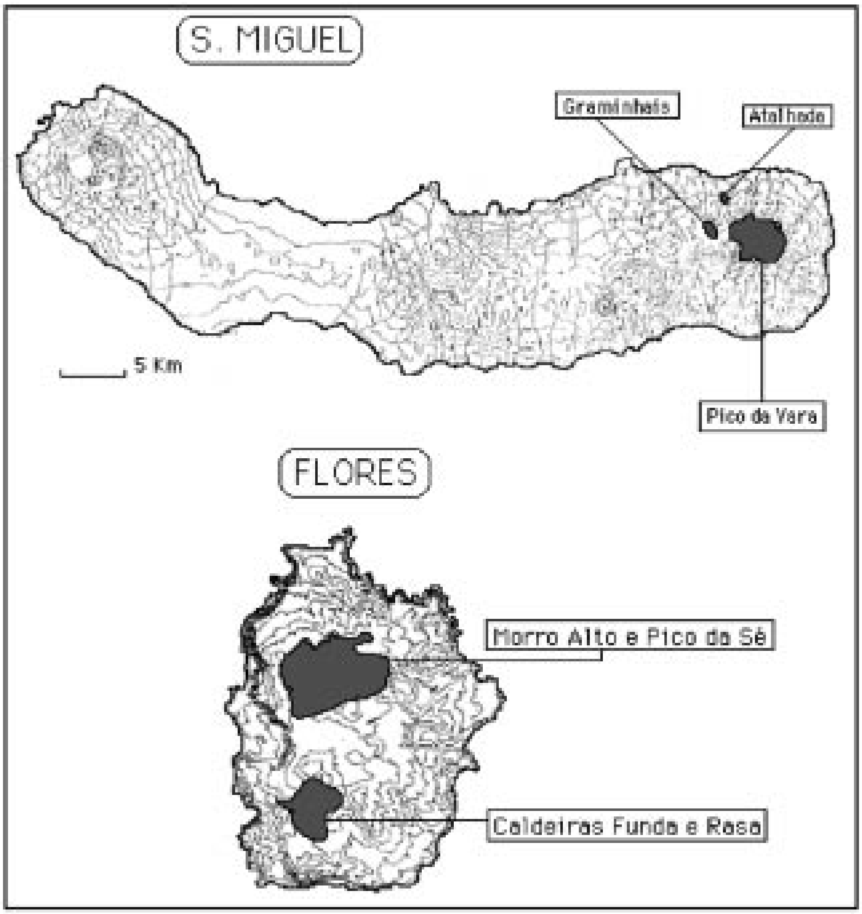

Figure 1. Location of the 16 Natural Forest Reserves (NFRs) in the Azorean islands.

locality, date, number of specimens collected and the host and/or habitat. In some cases, this information was incomplete. Where no information was available on the number of specimens sampled, it was assumed that only one specimen was collected. In cases where an author refers to 'lots of specimens', that information was included as such.

A total of 280 species, subspecies and varieties (varieties only in Diptera) were included in the database. For simplification, all 280 *taxa* will hereafter be referred to as species. This list was confined to those species endemic to the Azores. The wider Macaronesian endemics were not considered, because (by definition) they have a broader distribution, and are therefore less rare in terms of range size. For each species we calculated the following preliminary raw indices: number of known specimens, number of records, number of localities, number of islands, number of groups of islands and number of NFRs.

Species scores

To obtain a score of rarity for each arthropod species an index based on the rarity index (RI) of Kirchhofer (1997) was used. As the data available for the Azorean arthropods are different in type and quality to the data used by Kirchhofer (1997), his index was adapted, to generate the following function:

$$\mathrm{RI} = (L/\mathrm{TL_o}) + A + (I/9) + (\mathrm{GI}/3) + (\mathrm{NFR}/16)$$

RI – Rarity index;
L – Number of localities where a species was found;
$\mathrm{TL_o}$ – Total number of different localities for a particular order of arthropods;
A – Abundance score for a species given on a logarithmic scale as: 0 (only one specimen is known, the holotype), 1 (two to 10 specimens

known), 2 (11 to 100 specimens known), 3 (101 to 1000 specimens known), 4 (more than 1000 specimens or 'many');

I – Number of islands (out of the available nine) where a species occurs;

GI – Number of island groups (e.g., Western, Central and Eastern) where a species occurs;

NFR – Number of Natural Forest Reserves (out of the available 16) where a species occurs.

Kirchhofer (1997) defined 'extinct species' as those that were sampled in the last century but not recorded during the last 20–50 years. In what refers to the present data a slightly different concept was followed, i.e., 'a *taxon* not recorded during the last 50 years and historically associated with a site presently without native habitats.'

NFR scoring techniques

In order to rank the 16 NFRs, the following indices were applied:

Diversity

1. Species richness (S)
   S – the total number of species in a NFR.
   This gives greater value to the NFRs with more species.
2. Relative species richness (Srel.)

$$\text{Srel.} = S/\text{SI}$$

   S – the total number of species in a NFR.
   SI – the number of species known on the island of the NFR.
   This index gives greater value to those NFRs which contain a large proportion of the species known from its island.
3. Higher taxonomic diversity: Shannon's index (H')

$$H' = -\sum pi \ln pi,$$

   where pi is the proportion that the ith higher *taxon* (e.g., Coleoptera, Lepidoptera) contributes to the total number of species. This index gives greater value to a NFR with a large number of equally species rich orders (or classes), and lower value to a NFR dominated by species of a few higher taxa.
4. Higher taxonomic evenness (E)

$$E = H'/\ln O,$$

   H' – Shannon's index (as defined above).
   O – number of higher *taxa* (e.g., classes, orders).

Rarity

1. Mean rarity index (MRI) (Kirchhofer 1997)

$$\text{MRI} = \Sigma(\text{RI}i)/S$$

   RIi – the rarity index for the ith species.
   S – number of species.
   That is, the NFRs with the lowest MRI have the rarest endemic arthropod species assemblage. This index is equivalent to the SRI (species rarity index) of Collinson *et al*. (1995). In order to ensure that the index increases with increasing rarity the reciprocal form of the measure was adopted (1/MRI).
2. Hotspot species (Srare)
   To obtain a list of the rarest species, we ranked the 116 species present in the NFR in terms of their RI, and selected the 25% (29 species) with the lowest RI (see Gaston 1994).
   To obtain an index for each NFR, the number of those 29 species present in each NFR were counted. This is equivalent to designating hotspots of richness (e.g., Prendergast *et al*. 1993), but gives greater weight to the rarest species (Williams 1998).
3. Faunistic quality index (FQI) (from Panzer & Shwartz 1998)

$$\text{FQI} = \sqrt{(S)} * \sum(\text{RI}i/S)$$

   RIi – the RI for the ith species.
   S – number of species.
   This index gives greater value to the NFRs with more species and/or rare species.
4. Conservation value index (CVI) (adapted from Arita *et al*. 1996)

$$\text{CVI} = \left(\sum 1/\text{RI}i\right)/S$$

   RIi – the RI for the ith species.
   S – number of species.
   This index gives greater value to the NFR with more rare species (relative to the total number of species).

Multiple-criteria index

1. Importance value (IV) (adapted from Fox *et al*. 1997)

$$\begin{aligned} IV = \{&(\text{Snfr}/\text{Smax}) + (\text{H}'\text{nfr}/\text{H}'\text{max}) \\ &+ [(1/\text{MRInfr})/(1/\text{MRImax})] \\ &+ (\text{FQInfr}/\text{FQImax}) \\ &+ (\text{CVInfr}/\text{CVImax})\}/5 \end{aligned}$$

   Snfr – number of species in a NFR.
   Smax – maximum number of species found in a NFR.

H′nfr – Shannon's index of higher taxonomic diversity for a NFR.
H′max – maximum higher taxonomic H' obtained for a NFR.
1/MRInfr – reciprocal of the MRI for a NFR.
1/MRImax – maximum reciprocal of the MRI for a NFR.
FQInfr – faunistic quality index for a NFR.
FQImax – maximum FQI obtained for a NFR.
CVInfr – conservation value index for a NFR.
CVImax – maximum CVI obtained for a NFR.

This composite index has a maximum value of 1.

Statistical analysis

For contingency table analysis, the *G*-test was chosen, as the most reliable means of analysing frequency data (Crawley 1993).

Multiple regressions were performed using Excel 5.0 to obtain the minimal adequate model explaining the greatest variation. A maximal model was fitted, including all the available independent (= explanatory) variables. Model simplification was achieved by deleting non-significant terms from the model, until none could be removed without causing an increase in deviance with $p < 0.05$. The dependent (= response) variables were consistently logarithmically transformed in order to equalize variance and improve normality of errors. Transformation (logarithmic or square root) of the explanatory variables was used where necessary to improve normality of errors.

To adjust for multiple comparisons, we used a Bonferroni correction applied to each ANODEV table. A conservative correction was used, setting the significance level at $0.05/K$ (K = number of probabilities).

Results

The species

A total of 280 species of endemic Azorean arthropods were identified from the literature survey (see Borges *et al*. in prep.). Published faunal lists at order level are few, and some need urgent revision. Recent examples of published faunal lists are the works of Baz (1989) for the Psocoptera, Borges (1990) for the Coleoptera, Wunderlich (1991) for the Araneae, Eason and Ashmole (1992) for the Chilopoda-Lithobiomorpha, Gama (1992) for the Collembola, Sousa and Sakai (1997) for the Dermaptera and Vieira (1998) for the Lepidoptera.

The discovery curve presented in Figure 2 illustrates the considerable time taken to acquire this knowledge, as measured by the number of published descriptions of

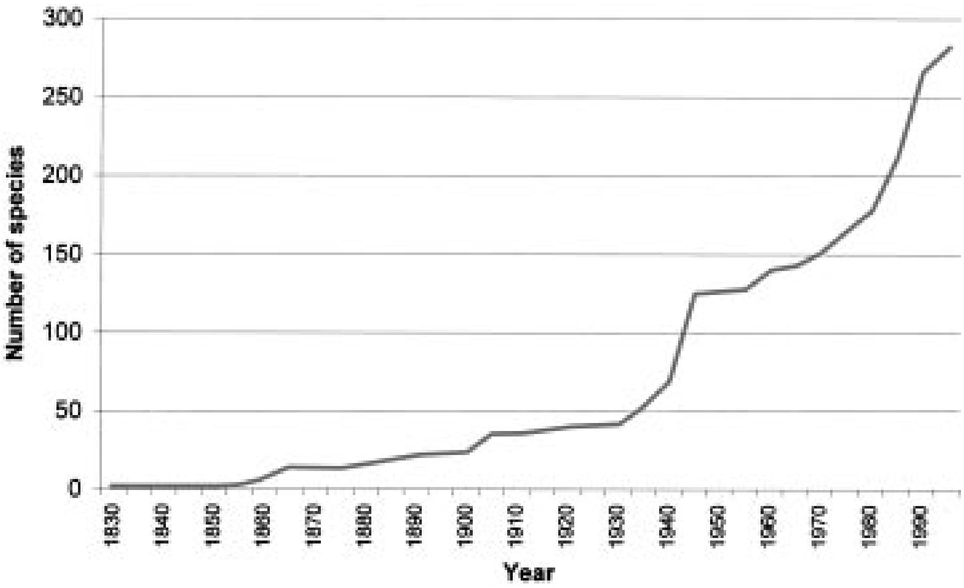

Figure 2. Cumulative species discovery curve for the endemic arthropods of the Azores. Data points are estimated for an interval of five years and are based upon published literature.

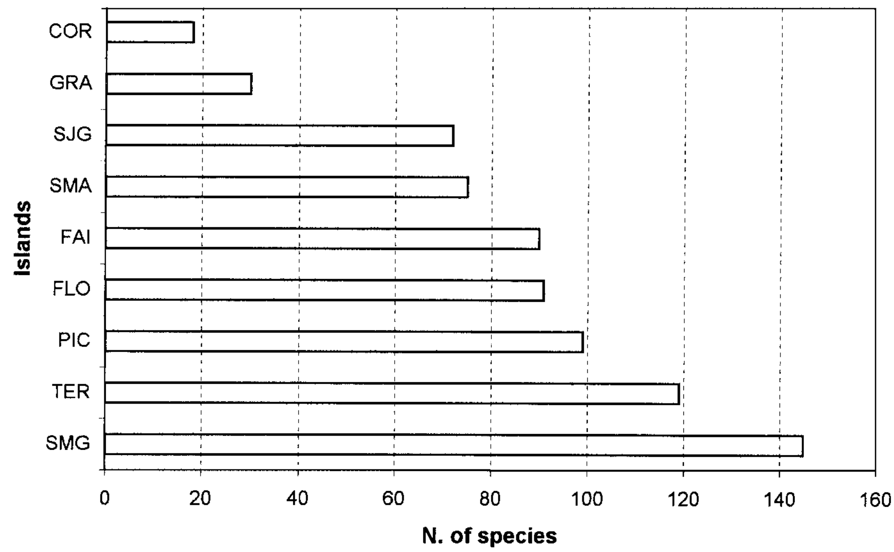

Figure 3. Number of endemic arthropod species in each of the nine Azorean islands. Islands are ranked by their richness in species.

endemic species. By 1950, only 45% of the species list had been recorded; and in 1980, only 63% of the species had been described. To reach 90%, the descriptions published between 1990 and 1995 need to be included.

The distribution of endemic species by island is shown in Figure 3. S. Miguel, Terceira and Pico have the higher numbers of recorded endemic arthropod species. The most speciose groups are the Coleoptera (64 spp.), Diptera (62 spp.), Acari (Oribatidae) (43 spp.), Lepidoptera (34 spp.) and Araneae (21 spp.).

The number of known Azorean endemic plant species (about 50 species; 17% of the indigenous flora) (Hansen, 1988) is a poor surrogate for the number of endemic arthropods in the nine Azorean islands ($y = 18.92 + 1.77x$; $r^2 = 0.30$; $p = 0.122$).

For the 280 endemic arthropod species, a ranked list of the 25% most rare species (in terms of RI) is presented in Table 2. The 68 species listed comprise 37% Coleoptera and 24% Diptera. From the pool of 280 species, 50% of the Diplopoda, 39% of the Coleoptera, 33% of the Pseudoscorpiones and 29% of the Hymenoptera are represented. The Lepidoptera (18%), Araneae (10%) and Homoptera (8%) are poorly represented.

The assemblage of rare species presented in Table 2 is not a linear sample of the available endemic species within each class or order. In fact, the relationship is curved (see Figure 4) and is well explained by the equation $\log y = 0.03 + 0.021 \log x + 0.37 \log x^2$ ($r^2 = 0.93$; $p < 0.0001$).

A total of 13 species were selected as potentially extinct (Table 3). Eight species are beetles (Coleoptera), four are moths (Lepidoptera) and one is a fly (Diptera). The island with most potentially extinct species is S. Miguel (five species).

The Natural Forest Reserves (NFRs)

Patterns in species composition and richness

A total of 116 endemic arthropod species were recorded from at least one NFR (listed in Appendix I). Only three of those species are included in the 25% most rare species across the nine islands of the Azores (see Table 2). The frequency distribution of the RI for the 280 pool of available endemic arthropods and for the 116 species present in the NFR is different ($G = 39.55$; d.f. $= 6$; $p < 0.0001$) (see Figure 5). The distribution of all endemic species is right-skewed (i.e., greater proportion of rare species) but the endemic species found in the NFRs follow a Gaussian curve, that is, a tendency for a greater representation of the intermediate classes of rarity. Only 20% of the species with RI less than 4 are represented in the NFRs.

Most of the 116 species (about 59%) are known from only one NFR and only 6% of the species occur in at least four NFRs (Figure 6). The number of species present in each NFR is not a linear sample of the pool of species available in the island where each RFN is located ($F_{1,14} = 0.04$, $p > 0.05$). However, the number of the rarest species (the 25% of species with the lowest RI, obtained by ranking the 116 species in the NFRs)

Table 2. Ranking of the endemic arthropods from the Azores using RI. For the same value of RI, the species are ranked first by alphabetical sequence of orders (or classes) and there after by alphabetical sequence of generic names. Only the 25% most rare species are listed.

RI	Species	Class/Order
0.44	*Onychiurus musae*	COLLEMBOLA
0.45	*Atheta (Geostibops) aptera*	COLEOPTERA
0.45	*Atheta (Hummleriella) azorica*	COLEOPTERA
0.45	*Holoparamecus azoricus*	COLEOPTERA
0.45	*Neocnemis occidentalis*	COLEOPTERA
0.45	*Phytosus schatzmayeri*	COLEOPTERA
0.45	*Trechus jorgensis*	COLEOPTERA
0.45	*Xantholinus longiventris miguelensis*	COLEOPTERA
0.45	*Eupithecia ogilviata*	LEPIDOPTERA
0.45	*Glyphipterix longistriatella*	LEPIDOPTERA
0.45	*Homoeosoma miguelensis*	LEPIDOPTERA
0.45	*Megaceraea incertella*	LEPIDOPTERA
0.45	*Tinea poecilella*	LEPIDOPTERA
0.46	*Brevipalpus* (new sp. ?)	ACARI-Oribatidae
0.46	*Euphthiracarus excultus*	ACARI-Oribatidae
0.46	*Hermanniella* sp. 1 (new sp.)	ACARI-Oribatidae
0.46	*Hermanniella* sp. 2 (new sp.)	ACARI-Oribatidae
0.46	*Hypovertex* sp. (new sp. ?)	ACARI-Oribatidae
0.46	*Metabelbella interlamellaris*	ACARI-Oribatidae
0.46	*Phthiracarus (Archiphthiracarus) falciformis*	ACARI-Oribatidae
0.46	*Steganacarus striculus insularis*	ACARI-Oribatidae
0.46	*Tenuipalpus* (new sp. ?)	ACARI-Oribatidae
0.46	*Cixius cavazoricus*	HOMOPTERA
0.46	*Clinocera (Kowarzia) azorica*	DIPTERA
0.46	*Exechia atlantis*	DIPTERA
0.46	*Exechia brinckiana*	DIPTERA
0.46	*Haplegis truncaticomis*	DIPTERA
0.46	*Hydrina agostinhoi pseudopelina*	DIPTERA
0.46	*Leptocera atrolimosa abnormalis*	DIPTERA
0.46	*Myaitropa florea nigrolanata*	DIPTERA
0.46	*Neosciara truncorum*	DIPTERA
0.46	*Rymosia azorensis*	DIPTERA
0.46	*Schoenomyza litorella major*	DIPTERA
0.46	*Sepsis mequignoni*	DIPTERA
0.46	*Sepsis nephodes*	DIPTERA
0.46	*Tetrapsila longipennis*	DIPTERA
0.46	*Trichonta floresiana*	DIPTERA
0.46	*Trichoscelis proximus*	DIPTERA
0.47	*Jaera insulana*	CRUSTACEA
0.47	Gen. sp. (undeterminated)	CRUSTACEA
0.52	*Melanozetes azoricus floresianus*	ACARI-Oribatidae
0.52	*Diplocentria acoreensis*	ARANEAE
0.52	*Savigniorrhipis grandis*	ARANEAE
0.53	*Angitia semiclausa*	HYMENOPTERA
0.53	*Atrometides nigerrimus*	HYMENOPTERA
0.57	*Caecilius dahli*	PSOCOPTERA
0.59	*Polydesmus ribeiraensis*	DIPLOPODA
0.78	*Microcreagrella caeca*	PSEUDOSCORPIONES
1.45	*Aromia thea*	COLEOPTERA
1.45	*Atheta (Nothotecta) caprariensis*	COLEOPTERA
1.45	*Bradycellus chavesi*	COLEOPTERA
1.45	*Calathus extensicollis*	COLEOPTERA
1.45	*Calathus carvalhoi*	COLEOPTERA
1.45	*Caulotrupis parvus*	COLEOPTERA
1.45	*Euconnus azoricus*	COLEOPTERA
1.45	*Geostiba melanocephala*	COLEOPTERA

Table 2. (Continued)

RI	Species	Class/Order
1.45	*Helops azoricus*	COLEOPTERA
1.45	*Hypera multifida*	COLEOPTERA
1.45	*Leptophloeus azoricus*	COLEOPTERA
1.45	*Sphaericus pinguis azoricus*	COLEOPTERA
1.45	*Tarphius acuminatus*	COLEOPTERA
1.45	*Tarphius serranoi*	COLEOPTERA
1.45	*Homoeosoma picoensis*	LEPIDOPTERA
1.46	*Calyptophthiracarus maritimus*	ACARI-Oribatidae
1.46	*Hermannia evidens*	ACARI-Oribatidae
1.46	*Vaghia* sp. (new sp.)	ACARI-Oribatidae
1.46	*Aleochara freyi*	COLEOPTERA
1.46	*Calathus vicenteorum*	COLEOPTERA
1.46	*Psylliodes vehemens azorica*	COLEOPTERA
1.46	*Trechus torretassoi*	COLEOPTERA
1.46	*Liriomyza triton*	DIPTERA

Table 3. List of potential extinct species. For each species, distribution between islands and RI is presented.

Species	SMA	SMG	TER	SJG	GRA	PIC	FAI	COR	FLO	Order	RI
Atheta azorica										COLEOPTERA	0.45
Eupithecia ogilviata							+			LEPIDOPTERA	0.45
Glyphipterix longistriatella			+							LEPIDOPTERA	0.45
Megaceraea incertella									+	LEPIDOPTERA	0.45
Neocnemis occidentalis	+									COLEOPTERA	0.45
Phytosus schatzmayeri		+								COLEOPTERA	0.45
Tinea poecilella		+								LEPIDOPTERA	0.45
Sepsis nephodes			+							DIPTERA	0.46
Aromia thea		+								COLEOPTERA	1.45
Bradycellus chavesi		+								COLEOPTERA	1.45
Calathus extensicollis						+				COLEOPTERA	1.45
Geostiba melanocephala		+								COLEOPTERA	1.45
Leptophloeus azoricus	+									COLEOPTERA	1.45
Total species per island	2	5	2	0	0	1	1	0	1		

occurring in each NFR is a linear sample of the number of species present in each NFR ($F_{1,13} = 20.45$, $p = 0.0006$) (Figure 7).

Ranking of the NFRs

Diversity

Four measures of diversity were applied to the data and gave quite different results. The two NFRs with the greatest endemic species richness (NFR-135 Terceira, with 41 species; NFR-127 Flores, with 35 species) (Table 4), were not ranked in the same order or position by three other diversity measures (see Table 4). In fact, the NFR from Flores was ranked first in terms of relative species richness, and NFR-125 (ranked 5th in terms of number of species) was second to it. The relative species richness index gives greater value to a NFR that has a greater proportion of the species available in its island. The first seven NFRs are from different islands.

In terms of higher taxonomic diversity NFR-135 remains pre-eminent, but NFR-127 from Flores is only the 5th (Table 4). This is a consequence of that NFRs being dominated by four classes or orders out of six. In terms of higher taxonomic diversity, two NFRs poorly ranked according to number of species score highly: the ‘Cabeço do Fogo’ from Faial and ‘Caldeira da Graciosa’ from Graciosa. Neither of these NFRs are dominated by any higher taxa (class or order) and

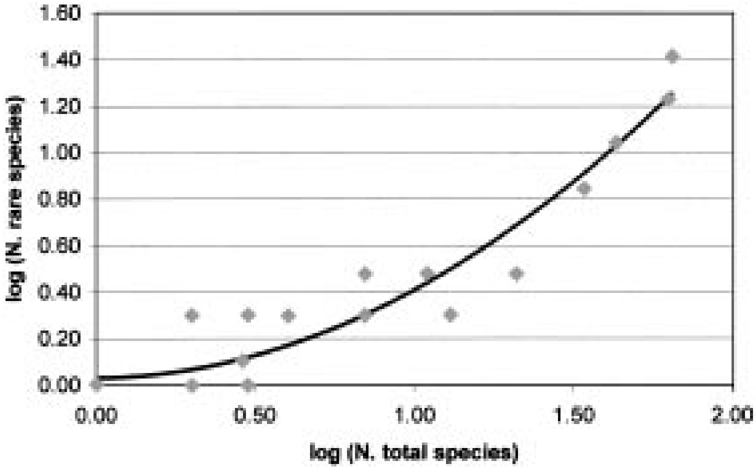

Figure 4. Relationship between the logarithm of the number of rare species and the logarithm of the number of total species of endemic arthropods for the 20 classes or orders (some of the points overlap).

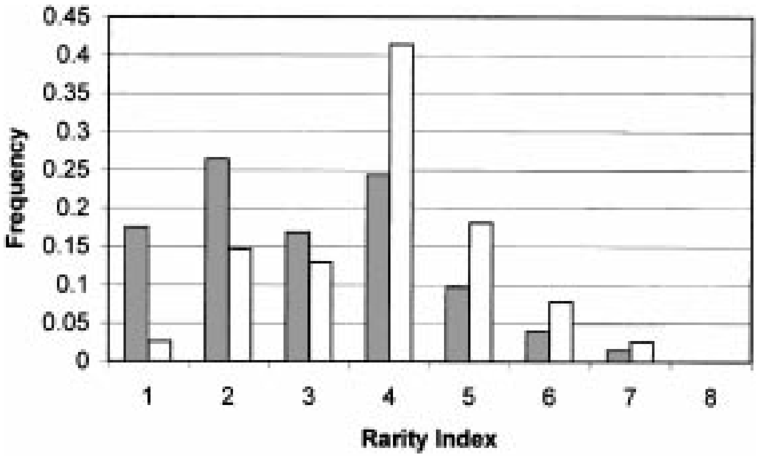

Figure 5. Frequency distribution of the RI for all the Azorean endemic arthropods ($S = 280$; filled bars) and for the species occurring in the NFR ($S = 116$; open bars).

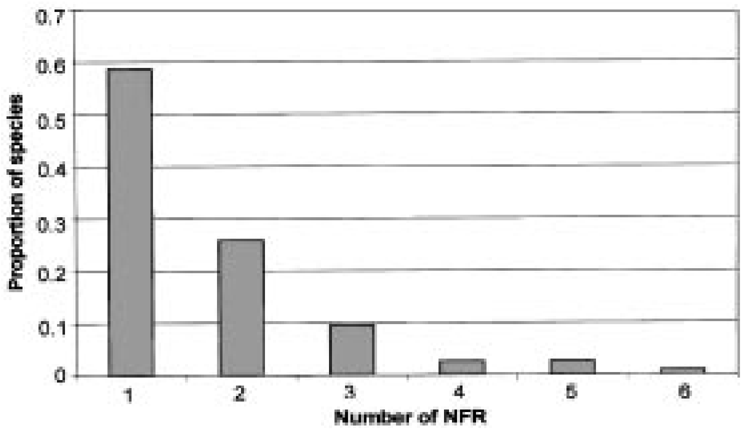

Figure 6. Frequency distribution of the number of NFRs in which each endemic arthropod species occurs.

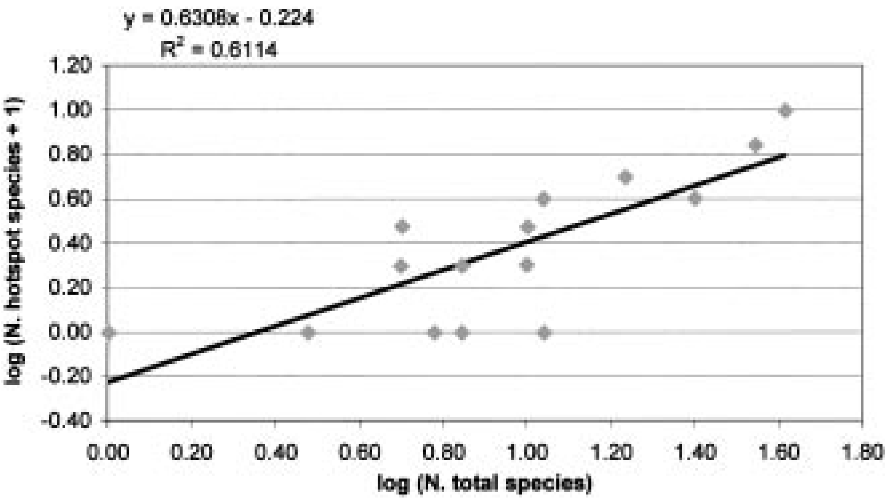

Figure 7. Relationship between the logarithm of the rarest and the total number of endemic arthropod species occurring in the 16 NFRs.

consequently also scored highly in terms of higher taxonomic evenness (Table 4). Remarkable is the fact that the four NFRs ranked first in terms of species richness are poorly ranked in terms of higher taxonomic evenness (see Table 4).

Rarity

The rarity score for each species (RI) was used as the starting point to assess the conservation value of each NFR (Table 4). The NFR with the highest reciprocal MRI has the rarest endemic arthropod species assemblage (NFR-135, followed by 126). It is notable that the three NFR from Pico are in the first six priority sites in terms of MRI (see Table 4).

The first six NFRs in terms of presence of hotspot species (25% cut-off point in the RI) (Table 4) were the same as those identified by species richness ranking with the exception of NFR-124 ('Caveiro', Pico). This conforms with the relationship shown in Figure 7 by which the number of hotspot species is a linear sample of the total species present in each NFR.

The ranking obtained for the NFRs using the FQI (Table 4) also followed the pattern obtained using species richness. This is a consequence of the FQI being weighted towards sites with more species.

The conservation value index (CVI) gives more weight to the presence of rare species, and the ranking of NFRs thus obtained has great potential value for setting conservation priorities (see Table 4). NFR-134 (Terceira) and NFR-124 (Pico), in spite of having few species, were ranked 2nd and 3rd respectively.

Multiple-criteria assessment of conservation value

In this study, we used an importance index that includes two of the previously used diversity indices, plus three of the rarity indices. The ranking of NFRs based on this multi-criteria index is presented in the last column of Table 4. Interestingly, the first four NFRs are the same (and in the same sequence) as those obtained by using the species richness index (first column of Table 4). Indeed, the first eight NFRs are the same as those obtained with the species richness index, although the 5th to 8th are not in the same sequence. In those first four NFRs, there are 78% (90 species) of the 116 endemic arthropod species recorded from the NFRs (Table 5). The first six NFRs, all occur in different islands, and the three NFRs from S. Jorge were all ranked together in a low priority position.

Indicator species

The MRI for the 16 NFRs using all taxa was not significantly positively correlated with the MRI for the 16 NFRs obtained with only the species of Lepidoptera, Acari-Oribatidae, Diptera, Coleoptera and Araneae (Table 6). The species richness for the 16 NFR using all taxa was significantly positively correlated with the species richness for the 16 NFRs obtained with only the species of Acari-Oribatidae, Lepidoptera, Diptera and Coleoptera (Table 7). The following is the minimal adequate model (parameters ± 1 SE): $\log \text{SRtotal} = 0.091\ (\pm 0.109) + 0.52\ (\pm 0.09) \log(\text{SR Acari} + 1) + 0.78\ (\pm 0.16) \log \text{SR Lepidoptera} + 0.44\ (\pm 0.13) \log(\text{SR Diptera} + 1) + 0.35\ (\pm 0.15) \log(\text{SR Coleoptera} + 1)$ ($r^2 = 0.92$; $p < 0.0001$).

Table 4. Ranking of the 16 NFRs (for a total of 116 endemic arthropod species) in terms of several indices – species richness (*S*), relative species richness (Srel.), Shannon's index of higher taxonomic diversity (H'), higher taxonomic evenness (*E*), reciprocal of the mean rarity index (1/MRI), number of hotspot species (Srare), faunistic quality index (FQI), conservation value index (CVI) and importance value (IV). The NFRs are listed in descending order of species richness.

NFR	Name	Island	Diversity							Rarity								Multi-criteria	
			S	Srel.		H'		*E*		1/MRI		Srare		FQI		CVI		IV	
135	Serra de St[a] Bárbara e M. Negro	TER	**41**	0.34	***3***	1.77	***1***	0.85	*8*	0.293	***1***	9	***1***	21.87	***2***	0.36	***4***	0.91	***1***
127	Morro Alto e Pico da Sé	FLO	**35**	0.38	***1***	1.56	***5***	0.87	*7*	0.253	*8*	6	***2***	23.42	***1***	0.30	*7*	0.82	***2***
133	Pico da Vara	SMG	**25**	0.17	***4***	1.63	***4***	0.84	*9*	0.249	*9*	3	***4***	20.05	***3***	0.28	*9*	0.74	***3***
122	Lagoa do Caiado	PIC	**17**	0.17	***5***	1.30	***6***	0.81	*11*	0.284	***5***	4	***3***	14.51	***5***	0.33	***6***	0.66	***4***
125	Caldeira da Graciosa	GRA	**11**	0.37	***2***	1.67	***3***	0.93	***4***	0.217	*14*	0	*11*	15.29	***4***	0.23	*14*	0.60	***6***
134	Biscoito da Ferraria	TER	**11**	0.09	*8*	1.07	*9*	0.97	***1***	0.245	*11*	3	***4***	13.53	***6***	0.41	***2***	0.60	***6***
120	Cabeço do Fogo	FAI	10	0.11	***6***	1.70	***2***	0.95	***3***	0.235	*12*	1	*8*	13.43	*7*	0.26	*11*	0.61	***5***
132	Graminhais	SMG	10	0.07	*10*	1.09	*8*	0.79	*12*	0.287	***4***	2	***6***	11.00	9	0.34	***5***	0.58	*8*
121	Vulcão dos Capelinhos	FAI	7	0.08	*9*	1.15	*7*	0.83	*10*	0.262	*7*	1	*8*	10.10	*10*	0.28	*8*	0.53	*10*
129	Pico das Caldeirinhas	SJG	7	0.10	*7*	0.00	*15*	0.00	*14*	0.225	*13*	0	*11*	11.77	*8*	0.23	*13*	0.37	*14*
123	Mistério da Prainha	PIC	6	0.06	*11*	1.01	*10*	0.92	***5***	0.265	***6***	0	*11*	9.26	*11*	0.27	*10*	0.50	*11*
126	Caldeiras Funda e Rasa	FLO	5	0.05	*12*	0.50	*13*	0.72	*13*	0.291	***2***	1	*8*	7.70	*13*	0.58	***1***	0.54	9
124	Caveiro	PIC	5	0.05	*13*	0.67	*11*	0.97	***1***	0.290	***3***	2	*6*	7.71	*12*	0.36	***3***	0.49	*12*
130	Picos do Carvão e da Esperança	SJG	3	0.04	*14*	0.64	*12*	0.91	***6***	0.246	*10*	0	*11*	7.04	*14*	0.25	*12*	0.40	*13*
128	Pico do Arieiro	SJG	1	0.01	*15*	0.00	*14*	0.00	*14*	0.185	*15*	0	*11*	5.42	*15*	0.18	*15*	0.24	*15*
131	Atalhada	SMG	0	0.00	*16*	—	*16*	—-	*16*	—	*16*	0	*11*	—	*16*	—	*16*	—	*16*

Table 5. Accumulated number of species of endemic arthropods in the NFRs using the ranking obtained in Table 4 with the species richness index.

Priority	NFR	Name	Island	*S*	New *S*	*S* Acum.	%
1	**135**	Serra de Stª Bárbara e M. Negro	TER	41		41	35.34
2	**127**	Morro Alto e Pico da Sé	FLO	35	27	67	57.76
3	**133**	Pico da Vara	SMG	25	13	80	68.97
4	**122**	Lagoa do Caiado	PIC	17	10	90	77.59
5	**125**	Caldeira da Graciosa	GRA	11	2	92	79.31
6	**134**	Biscoito da Ferraria	TER	11	3	95	81.90
7	**120**	Cabeço do Fogo	FAI	10	4	99	85.34
8	**132**	Graminhais	SMG	10	2	101	87.07
9	**121**	Vulcão dos Capelinhos	FAI	7	5	108	93.10
10	**129**	Pico das Caldeirinhas	SJG	7	1	109	93.97
11	**123**	Mistério da Prainha	PIC	6	3	112	96.55
12	**124**	Caveiro	PIC	5	1	113	97.41
13	**126**	Caldeiras Funda e Rasa	FLO	5	2	115	99.14
14	**130**	Picos do Carvão da Esperança	SJG	3	1	116	100.00
15	**128**	Pico do Arieiro	SJG	1	0	116	100.00
16	**131**	Atalhada	SMG	0	0	116	100.00

Table 6. Value of the MRI for the 16 NFRs: analysis of deviance (ANODEV) table for multiple regression with step-wise omission of non-significant terms, beginning from the maximal model. Each explanatory variable is the MRI calculated using only a particular taxon. Bonferroni correction ($p = 0.01$).

Explanatory variable	Deviance	*F*	Significance
Lepidoptera	1.032	4.07	n.s.
Acari-Oribatidae	0.441	1.74	n.s.
Diptera	0.318	1.29	n.s.
Coleoptera	0.379	1.62	n.s.
Araneae	0.047	0.18	n.s.

Table 7. Total number of endemic arthropod species in the 16 NFRs: analysis of deviance (ANODEV) table for multiple regression with step-wise omission of non-significant terms, beginning from the maximal model. Each explanatory variable is the species richness calculated using only a particular taxon. Bonferroni correction ($p = 0.01$).

Explanatory variable	Deviance	*F*	Significance (p)
Acari-Oribatidae	0.44	33.85	< 0.001
Lepidoptera	0.383	29.46	< 0.001
Diptera	0.275	21.15	< 0.001
Coleoptera	0.163	12.54	< 0.01
Araneae	0.072	5.54	< 0.05 (n.s.)

Discussion

Arthropods, and insects in particular, are considered as important potential tools in biodiversity assessments of natural areas (Howarth & Ramsay 1991; Samways 1993). As in most terrestrial habitats all over the world, arthropods are the most diverse animal group in the Azorean native habitats. Although this analysis was largely confined to a literature survey of incomplete records of the endemic arthropods, a total of 280 endemic species and subspecies were listed, which is almost six times the number of extant endemic vascular plants (see Hansen 1988). Furthermore, there was no evidence that most of the Azorean endemic arthropod species have been found and described; the results suggest that a species-discovery asymptote is far from being obtained (see Figure 2). This poses some difficulties for the reliability of the analysis, compounded by the facts that some islands have been more frequently visited than others (Borges 1992), and that some NFRs differ from others in accessibility.

In addition, the relative species richness of several orders studied here suggests that some groups have been particularly poorly studied (e.g., Diplopoda, Thysanoptera, Heteroptera, Homoptera and Hymenoptera). Some preliminary standardized field work recently performed in S. Maria and Terceira also showed that some undescribed species of spiders occur in the canopies of Azorean endemic trees (Borges and Vitorino in prep.). Moreover, the same type of survey in the same habitat revealed that some new taxa of whiteflies (Homoptera, Aleyrodidae) occur in the Graminhais NFR at S. Miguel (Polaszek, pers. comm.).

Moreover, there are taxonomic problems associated with some *taxa*; notably the Diptera, where only some of the varieties created by Frey (1945) were revised. There is also a need to confirm the subspecific status of the *Cixius* spp. (Homoptera, Cixiidae) and *Hipparchia* spp. (Lepidoptera). In other situations, species described in the last century or early in this century urgently need to be revised (e.g., the endemic Elateridae, Coleoptera). Given these caveats, most of the following discussion should be considered as tentative.

One of the most interesting results obtained here was that some arthropod orders have a higher proportion of rare species than predicted by a proportional sampling model. Rare Lepidoptera, Araneae and Homoptera are poorly represented relative to Diplopoda, Coleoptera, Pseudoscorpiones and Hymenoptera, which contain a high proportion of rarities in their pool of species. This result is also striking given that the Homoptera and Lepidoptera are phytophagous *taxa*, and could, therefore, be more prone to extinction through habitat destruction. The extant species are those that have survived human colonization of the islands, and are well adapted to the current distribution and area of natural habitats. Thus, the most vulnerable Lepidoptera, Araneae and Homoptera are probably already extinct.

The 13 extinct species identified by this study were not originally collected from sites in any of the current 16 NFRs. However, as some of the exact localities for these species were not recorded, it is possible that some were collected in remnants of native forest now within the NFRs.

The frequency distributions of the RI showed a tendency for a greater proportion of common than rare species to be represented in the NFRs. This may be explained by (a) an artefact of sampling, that is, rare species may occur in the NFRs but were not recorded as a consequence of their rarity, whereas common species were more easily found and recorded, or (b) the rarest species occur only in other localities and could not be protected using the NFR scheme. This type of result was obtained by Prendergast *et al*. (1993) for the U.K., Howard *et al.* (1997) for Uganda and Troumbis and Dimitrakopoulos (1998) for Greece, where many rare species do not occur in the most species-rich areas (‘hotspots’).

But, where are the rarest endemic arthropod species in the Azores? A survey in the database looking for the location of the 25% rarest species (Table 2) showed that three species are in the NFRs, 10 species were located in other types of protected areas, 17 species were either considered extinct (see Table 3) or their localities are unknown, eight species occur in caves located in unprotected areas, two species are lavicolous, three species are known from unprotected fragments of native forest, and the final 29 species were found only in man-made habitats. Therefore, 13 species (18%) were found in protected areas and 29 are threatened (41%). The species found in the man-made habitats are eventually able to survive in alternative habitats, but as most of them were recorded infrequently, they may also be at risk if they were in those places only as vagrant species, these few individuals representing the only survivors of habitat destruction.

About 60% of the endemic arthropod species that were recorded from the NFRs are ‘single NFR endemics’, that is, are known from only one of the 16 NFRs. This is not a consequence of the species being restricted to one island. In fact, 41 of the 68 species found in only one NFR occur in two or more islands. Therefore, the concentration of conservation management funds in few NFRs will provide protection for only a small fraction of the endemic arthropod fauna.

The four measures of diversity used to rank the 16 NFRs in terms of priority gave very different results. The ranking of NFRs obtained with the simple measures of species richness and relative species richness is of great conservation management value, since it is important to protect sites with more species (Bibby 1998). However, if the criterion is to preserve the sites with a more equal distribution of species per class and/or order, then the rank obtained with the higher taxonomic diversity index should be used.

There is some danger in considering diversity indices alone as conservation criteria for sites (Turpie 1995). In fact, the two priority NFRs in terms of higher taxonomic evenness (NFR-124 and 134) have only two (NFR-124) or three (NFR-134) rare endemic arthropod species and are poorly ranked in terms of presence of rare species.

The MRI is of great value because it is based on a diverse set of information for each species, including abundance and distribution at local and regional scales. The NFR-126 from Flores (with five species), NFR-124 from Pico (with five species), and NFR-132 from S. Miguel (with 10 species), in spite of not being particularly rich in species overall, are of high conservation value as a consequence of having an assemblage of rare endemic arthropod species. Remarkable is the persistence of the NFR-135 (Terceira) as the top NFR in terms of species richness and mean rarity score. On the other hand, one of the NFR ranked most highly in terms of taxonomic evenness (NFR-134) contains mostly common species and was poorly ranked in terms of MRI.

Of the NFRs highlighted for their MRI, of particular interest are the three sites from Pico, ranked 3rd, 5th and 6th. It seems that these three NFR are indispensable in the protection of a diverse assemblage of rare endemic arthropod species.

The final ranking obtained for the 16 NFRs was obtained using a composite multi-criteria index. Although a complex index may yield complex results, hindering interpretation (Spellerberg 1992; Turpie 1995), the ranking obtained here reproduced almost perfectly that obtained with the simple species richness index. One possible conclusion is that species richness is a very good surrogate of the conservation value of the 16 NFRs under study.

The fact that the first six NFRs are located on different islands has some important conservation management implications, that is, to preserve a large proportion of the Azorean arthropod biodiversity there is a need to protect sites on all islands. This makes sense, since there is a high proportion of island endemics. As shown in Table 5, if the first five RFNs are correctly managed in terms of conservation, then at least 80% of the endemic arthropods known from the RFNs could be protected.

The poor ranking of the sites from S. Jorge could be a consequence of the absence of native forest in the NFR of this island. The three NFRs are mainly composed of semi-natural grassland with no forest.

The investigation of the surrogacy power of the most diverse orders showed that, when using the species rarity index, none of the orders could be used to explain the overall pattern obtained with all 116 species occurring in the NFRs. This implies that, if using only some *taxa*, different sets of rankings for the 16 NFRs would be obtained.

However, the present results showed that most of the taxa studied (Acari-Oribatei; Lepidoptera; Diptera; Coleoptera) are good surrogates of the overall total set of species present in the 16 NFRs, when using the species richness index (contrary to results obtained by others, e.g. Kerr 1997). This implies that, if using a simple but informative diversity index, we may rank the Azorean NFRs in a similar way using only some of the arthropod *taxa*. The same type of result was obtained by Gaston (1996) and Carroll and Pearson (1998). This is an important result because in the next two years the authors aim to confirm the conservation importance of these 16 NFRs sites, performing a standardized sampling program directed to only some of the orders. It is hoped, then, to cover at least 53% of the listed 280 arthropod endemic species with the field sampling protocol.

Conclusions

The fact that most of the rarest endemic arthropod species are poorly represented in the NFRs may be considered of great concern. In fact, more reserves should be included in the same and/or other islands (e.g. S. Maria). In addition, a great effort should be made to survey all the NFRs with standardized methods to confirm the actual distribution and abundance of this assemblage of species.

However, even a common endemic arthropod species already belongs to the most important fraction of the Azorean arthropod fauna, which also includes native and introduced species. In addition, a better survey of the fauna of each NFR will surely reveal that they all constitute ‘hotspot’ and conservation priority sites in terms of species richness, higher taxonomic diversity and rarity. Since there is clearly at least one NFR per island of great importance, meaningful conservation management efforts should be applied to each island, in order to protect a maximum proportion of the endemic arthropod *taxa*. Therefore, we agree with Kerr (1997), that for invertebrates there is the need to preserve several small patches to protect rare, poorly known taxa.

However, if a ranking of NFRs is required, we strongly suggest a prioritization of sites, using the endemic arthropods, based on at least a diversity index (e.g. species richness) and a rarity index (see Ceballos *et al*. 1998). Therefore, the ranking of the 16 NFRs obtained with the importance value (IV) (last column of Table 4) might be appropriate. The ‘Laurissilva’ from the Azores is the habitat where a great proportion of the endemic arthropods occur. Protecting this vegetation type within the NFR scheme will be of particular relevance to the maintenance of the arthropod biodiversity of the archipelago.

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References

Arita, H.T., Figueroa, F., Frisch, A., Rodríguez, P. and Santos-del-Prado, K. (1997) Geographical range size and the conservation of Mexican mammals. *Conserv. Biol.* **11**, 92–100.

Baz, A. (1989) On a small collection of Psocoptera from Madeira with a check-list of Psocoptera of the Portuguese Macaronesia. *Bolm. Soc. Port. Ent.* **4**, 49–55.

Bibby, C.L. (1998) Selecting areas for conservation. In *Conservation Science and Action* (W.J. Sutherland, ed), pp. 176–201. Oxford: Blackwell Science.

Borges, P.A.V. (1990) A checklist of Coleoptera from the Azores with some systematic and biogeographic comments. *Bol. Mus. Mun. Funchal* **42**, 87–136.

Borges, P.A.V. (1992) Biogeography of the Azorean Coleoptera. *Bol. Mus. Mun. Funchal* **44**, 5–76.

Borges, P.A.V. and Vieira, V. (1994) The Entomological Bibliography from the Azores. II – The *Taxa*. *Bol. Mus. Mun. Funchal* **46**, 5–75.

Carroll, S.S. and Pearson, D.L. (1998) Spatial modeling of butterfly species richness using tiger beetles (Cicindelidae) as a bioindicator taxon. *Ecol. Applications* **8**, 531–93.

Ceballos, G., Rodríguez, P. and Medellín, R.A. (1998) Assessing conservation priorities in megadiverse Mexico: Mammalian diversity, endemicity, and endangerment. *Ecol. Applications* **8**, 8–17.

Collinson, N.H., Biggs, J., Corfield, A., Hodson, M.J., Walker, D., Whitfield, M. and Williams, P.J. (1995) Temporary and permanent ponds: An assessment of the effects of drying out on the conservation value of aquatic macroinvertebrate communities. *Biol. Conserv.* **74**, 125–33.

Crawley, M.J. (1993) *GLIM for Ecologists*. London: Blackwell Scientific Publications.

Daniels, R.J.R., Hegde, M., Joshi, N.V. and Gadgil, M. (1991) Assigning conservation value: A case study from India. *Conserv. Biol.* **5**, 464–75.

Eason, E.H. and Ashmole, N.P. (1992) Indigenous centipedes (Chilopoda, Lithobiomorpha) from Azorean caves and lava flows. *Zool. J. Linn. Soc.* **105**, 407–29.

Fox, B.J., Taylor, J.E., Fox, M.D. and Williams, C. (1997) Vegetation changes across edges of rainforest remnants. *Biol. Conserv.* **82**, 1–13.

Freitag, S., Van Jaarsveld, A.S. and Biggs, H.C. (1997) Ranking priority biodiversity areas: An iterative conservation value-based approach. *Biol. Conserv.* **82**, 263–72.

Frey, R. (1945) Tiergeographische Studien uber die Dipterenfauna der Azoren. I. Verzeichnis der bisher von den Azoren bekannten Dipteren. Iter entomologicum et botanicum ad insulas Madeirum et Azores anno 1938 a Richard Frey, Ragnar Stora et Carl Cedercreutz factum. *Soc. Scient. Fenn., Comm. Biol.* **8**, 1–114.

Gama, M.M. (1992) Collemboles des Açores. IV.*Algar* **3**, 41–8.

Gaston, K.J. (1994) *Rarity*. London: Chapman and Hall.

Gaston, K.J. (1996) Spatial covariance in the species richness of higher taxa. In *Aspects of the Genesis and Maintenance of Biological Diversity* (M.E. Hochberg, J. Clobert and R. Barbault, eds), pp. 221–42. Oxford: Oxford University Press.

Geisthardt, M. (1996) Lista Vermelha para os Coleópteros (Insecta, Coleoptera). *Cour. Forsch.-Inst. Senckenberg* **193**, 89–120.

Goerck, J.M. (1997) Patterns of rarity in the birds of the Atlantic Forest of Brazil. *Conserv. Biol.* **11**, 112–8.

Hansen, A. (1988) *Check-List, Azores (vascular plants)*. Unpublished.

Howarth, F.G. and Ramsay, G.W. (1991) The conservation of island insects and their habitats. In *The Conservation of Insects and their Habitats* (N.M. Collins and J.A. Thomas, eds) pp. 71–107. London: Symposium of the Royal Entomological Society of London, 15.

Howard, P., Davenport, T. and Kigenyi, F. (1997) Planning conservation areas in Uganda's natural forests. *Oryx* **31**, 253–64.

Kattan, G.H. (1992) Rarity and vulnerability: The birds of the Cordillera Central of Colombia. *Conserv. Biol.* **6**, 64–70.

Kerr, J.T. (1997) Species richness, endemism, and the choice of areas for conservation. *Conserv. Biol.* **11**, 1094–100.

Kirchhofer, A. (1997) The assessment of fish vulnerability in Switzerland based on distribution data. *Biol. Conserv.* **80**, 1–8.

Lecoq, M. (1996) Primeira Lista Vermelha para os Acrídeos (Insecta, Saltatoria). *Cour. Forsch.-Inst. Senckenberg* **193**, 87–8.

McIntyre, S. (1992) Risks associated with the setting of conservation priorities from rare plant species lists. *Biol. Conserv.* **60**, 31–7.

Meyer, M. (1995) The Lepidoptera of the Macaronesian Region. IV: Threatened endemic Macrolepidoptera in northern Macaronesia (Madeira, Azores). *Proceedings of the EIS Colloquium*, pp. 72–7.

Panzer, R. and Schwartz, M.W. (1998) Effectiveness of a vegetation-based approach to insect conservation. *Conserv. Biol.* **12**, 693–702.

Prendergast, J.R., Quinn, R.M., Lawton, J.H., Eversham, C. and Gibbons, D.W. (1993) Rare species, the coincidence of diversity hotspots and conservation strategies. *Nature* **365**, 335–7.

Samways, M.J. (1993) Insects in biodiversity conservation, some perspectives and directives. *Biodivers. Conserv.* **2**, 258–82.

Schmidt, G. and Geisthardt, M. (1996) Lista Vermelha para os Aracnídeos (Arachnida, Araneida). *Cour. Forsch.-Inst. Senckenberg* **193**, 77–85.

Sousa, A.B. and Sakai, S. (1997) Dermápteros (Insecta, Dermaptera) da Macaronésia, Faunística e Zoogeografia. *Bolm. Soc. Port. Ent.* **6**, 289–306.

Spellerberg, I.F. (1992) *Evaluation and Assessment for Conservation*. London: Chapman and Hall.

Troumbis, A.Y. and Dimitrakopoulos, P.G. (1998) Geographic coincidence of diversity threatspots for three taxa and conservation planning in Greece. *Biol. Conserv.* **84**, 1–6.

Turpie, J.K. (1995) Prioritizing South African estuaries for conservation: A practical example using waterbirds. *Biol. Conserv.* **74**, 175–85.

Vieira, V. (1998) Biogeografia dos Lepidópteros (Insecta, Lepidoptera) dos Açores. *Revista Biol.* **16**, 87–106.

Williams, P.H. (1998) Key sites for conservation, area-selection methods for biodiversity. In *Conservation in a Changing World,* *Integrating Processes into Priorities for Action* (G.M. Mace, A. Balmford and J.R. Ginsberg, eds), pp. 211–249. Cambridge: Cambridge University Press.

Wunderlich, J. (1991) Die Spinen-Fauna der Makaronesischen Inseln-Taxonomie, Ökologie, Biogeographie und Evolution. *Beiträge zur Aranealogie* **1**, 1–619.

Appendix 1. Ranking of the 116 endemic arthropod species occurring in the 16 NFRs using the RI. For the same value of RI the species are ranked by alphabetical sequence of classes or orders and thereafter by alphabetical sequence of genera.

RI	Species	Taxa
0.52	*Melanozetes azoricus floresianus*	ACARI-ORIBATIDAE
0.52	*Diplocentria acoreensis*	ARANEAE
0.52	*Savigniorrhipis grandis*	ARANEAE
1.52	*Peloptulus borgesi*	ACARI-ORIBATIDAE
1.52	*Steganacarus insulanus*	ACARI-ORIBATIDAE
1.52	*Minicia floresensis*	ARANEAE
1.52	*Xysticus cribratus*	ARANEAE
1.52	*Cedrorum azoricus caveirensis*	COLEOPTERA
1.52	*Ocydromus (Peryphus) derelictus*	COLEOPTERA
1.53	*Minicia* n. sp.	ARANEAE
1.53	*Chrysotus polychaetus* var. *minor*	DIPTERA
1.54	*Calathus lundbladi*	COLEOPTERA
1.66	*Chrysotus polychaetus* var. *intermedius*	DIPTERA
1.67	*Cixius azofloresi*	HOMOPTERA
1.67	*Meleboris (Nepiera) longicauda*	HYMENOPTERA
1.78	*Onychiurus sp.*	COLLEMBOLA
1.84	*Trigoniophthalmus borgesi*	DIPTERA
1.86	*Brachmia infuscatella*	LEPIDOPTERA
1.99	*Mycobates tridentatus*	ACARI-ORIBATIDAE
1.99	*Tritegeus* (n. sp.)	ACARI-ORIBATIDAE
2.02	*Ommatocepheus parvilamellatus*	ACARI-ORIBATIDAE
2.03	*Chrysotus polychaetus*	DIPTERA
2.05	*Pseudachipteria insularis*	ACARI-ORIBATIDAE
2.05	*Pseudanchomenus aptinoides*	COLEOPTERA
2.06	*Heminothrus (Heminothrus) oromii*	ACARI-ORIBATIDAE
2.52	*Carabodes azoricus*	ACARI-ORIBATIDAE
2.52	*Typhochrestus acoreensis*	ARANEAE
2.52	*Gietella faialensis*	COLEOPTERA
2.52	*Mniophilosoma obscurum*	COLEOPTERA
2.56	*Trechus terceiranus*	COLEOPTERA
2.58	*Lithobius obscurus mediocris*	CHILOPODA
2.66	*Hydrina agostinhoi*	DIPTERA
2.82	*Cixius azoricus*	HOMOPTERA
2.91	*Galumna* sp. (n sp.)	ACARI-ORIBATIDAE
2.91	*Noctua carvalhoi*	LEPIDOPTERA
3.04	*Parachipteria weigmanni*	ACARI-ORIBATIDAE
3.06	*Melanozetes azoricus sanctaemariae*	ACARI-ORIBATIDAE
3.07	*Lepidocyrtus* sp.	COLLEMBOLA
3.14	*Rugathodes acoreensis*	ARANEAE
3.16	*Ocydromus schmidti azoricus*	COLEOPTERA
3.19	*Melanozetes azoricus azoricus*	ACARI-ORIBATIDAE
3.28	*Emblyna acoreensis*	ARANEAE
3.30	*Macrocera azorica*	DIPTERA
3.30	*Xanthandrus azorensis*	DIPTERA
3.31	*Phlogophora cabrali*	LEPIDOPTERA
3.34	*Pilocepheus azoricus*	ACARI-ORIBATIDAE
3.37	*Savigniorrhipis acoreensis*	ARANEAE

Appendix 1. (Continued)

RI	Species	Taxa
3.38	*Heteroderes melliculus moreleti*	COLEOPTERA
3.39	*Dorycranosus angustatus*	ACARI-ORIBATIDAE
3.42	*Chaetophiloscia guemei*	CUSTACEA
3.43	*Pseudechinosoma nodosum*	COLEOPTERA
3.45	*Cerodonta bistrigata*	DIPTERA
3.46	*Limonia (Discobola) freyana*	DIPTERA
3.52	*Scutovertex* sp. (n. sp.?)	ACARI-ORIBATIDAE
3.52	*Isohelea griseipennis*	DIPTERA
3.57	*Orthocladius (Orthocladius) rivularis*	DIPTERA
3.57	*Hipparchia miguelensis*	LEPIDOPTERA
3.58	*Hermanniella incondita*	ACARI-ORIBATIDAE
3.59	*Pseudachipteria florensiana*	ACARI-ORIBATIDAE
3.59	*Phloeonomus azoricus*	COLEOPTERA
3.59	*Otiorhynchus trophonius azoricus*	COLEOPTERA
3.60	*Alestrus dolosus*	COLEOPTERA
3.61	*Cixius azoricus azoropicoi*	HOMOPTERA
3.62	*Cixius azopifajo azofa*	HOMOPTERA
3.62	*Cixius azoterceirae*	HOMOPTERA
3.64	*Atlantocis gillerforsi*	COLEOPTERA
3.65	*Cixius azopifajo*	HOMOPTERA
3.67	*Scoparia coecimaculalis*	LEPIDOPTERA
3.68	*Eudonia luteusalis*	LEPIDOPTERA
3.70	*Udea azorensis*	LEPIDOPTERA
3.71	*Acalles subcarinatus*	COLEOPTERA
3.73	*Cixius insularis*	HOMOPTERA
3.76	*Hipparchia azorina azorina*	LEPIDOPTERA
3.77	*Lepthyphantes acoreensis*	ARANEAE
3.80	*Gibbaranea occidentalis*	ARANEAE
3.85	*Lasaeola oceanica*	ARANEAE
3.89	*Sphaerophoria (Nesosyrphus) nigra*	DIPTERA
3.90	*Leucognatha acoreensis*	ARANEAE
3.92	*Xanthorhoe inaequata*	LEPIDOPTERA
3.93	*Liriomyza subartemisicola*	DIPTERA
3.94	*Pisaura acoreensis*	ARANEAE
3.95	*Neosciara rufipodex*	DIPTERA
3.95	*Psectrocladius sordidellus* var. *insularis*	DIPTERA
4.04	*Nothrus palustris azorensis*	ACARI-ORIBATIDAE
4.06	*Lepthyphantes miguelensis*	ARANEAE
4.07	*Tarphius tornvalli*	COLEOPTERA
4.09	*Agabus godmani*	COLEOPTERA
4.09	*Laparocerus azoricus*	COLEOPTERA
4.10	*Crotchiella brachyptera*	COLEOPTERA
4.23	*Pseudosinella ashmoleorum*	COLLEMBOLA
4.26	*Hydroporus guernei*	COLEOPTERA
4.27	*Galumna azoreana*	ACARI-ORIBATIDAE
4.32	*Humerobates pomboi*	ACARI-ORIBATIDAE
4.36	*Oxyethira dentata*	TRICHOPTERA
4.47	*Eudonia interlinealis*	LEPIDOPTERA
4.48	*Lithobius obscurus azoreae*	CHILOPODA
4.51	*Hipparchia azorina occidentalis*	LEPIDOPTERA
4.55	*Steganacarus hirsutus azorensis*	ACARI-ORIBATIDAE
4.59	*Damaeus pomboi*	ACARI-ORIBATIDAE
4.65	*Tarphius azoricus*	COLEOPTERA
4.95	*Xenillus discrepans azorensis*	ACARI-ORIBATIDAE
4.99	*Mesapamea storai*	LEPIDOPTERA

Appendix 1. (Continued)

RI	Species	Taxa
5.00	*Scoparia semiamplalis*	LEPIDOPTERA
5.00	*Scaptomyza impunctata*	DIPTERA
5.09	*Ensina azorica*	DIPTERA
5.10	*Phlogophora interrupta*	LEPIDOPTERA
5.16	*Chrysotus vulcanicola*	DIPTERA
5.19	*Cleora fortunata azorica*	LEPIDOPTERA
5.26	*Heteroderes azoricus*	COLEOPTERA
5.37	*Cyclophora azorensis*	LEPIDOPTERA
5.42	*Argyresthia atlanticella*	LEPIDOPTERA
5.44	*Scoparia aequipennalis*	LEPIDOPTERA
5.72	*Orchestia chevreuxi*	CRUSTACEA
6.16	*Simulium (Eusimulium) azorense*	DIPTERA
6.77	*Pardosa acoreensis*	ARANEAE
6.84	*Smittia (Pseudosmittia) azorica*	DIPTERA