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Worldwide conservation hotspots for Soricomorpha focusing on endemic island taxa: an analysis at two taxonomic levels

Giovanni Amori[1,*], Federica Chiozza[2], Carlo Rondinini[2], Luca Luiselli[3]

[1]CNR–Institute of Ecosystem Studies, Viale dell'Università 32, 00185 Rome, Italy
[2]Department of Biology and Biotechnology, Sapienza Università di Roma, Viale dell'Università 32, 00185 Roma, Italy
[3]Centre of Environmental Studies Demetra, Eni Environmental Department, via Olona 7, 00198 Rome, Italy

ABSTRACT: Identifying conservation priorities is crucial in the modern world, and biodiversity hotspots have been vital instruments in better defining the main areas requiring conservation. This paper analyzes distribution patterns of threatened Soricomorpha genera and species to evaluate whether the current biodiversity hotspots network really covers these taxa. We also analyze the Soricomorpha species that are endemic to islands worldwide in order to define the main islands in terms of both endemic species richness and threatened species richness. At the genus level, all threatened taxa are represented within hotspots, whereas 18% of the threatened species (particularly in the Afrotropics) do not occur in any biodiversity hotspot. Approximately 35% of island endemic species are threatened, particularly in the Oriental region. Most of the threatened endemics are found within forest habitats. Both mainland (Cameroon and Congo) and island (particularly Andamans, Sri Lanka, Bioko) forest ecosystems deserve the particular attention of conservation organizations. In addition, basic research on the ecology, taxonomy, and distribution of threatened Soricomorpha species (particularly in the tropical regions) is urgently needed.

KEY WORDS: Hotspots · Soricomorpha · Conservation · Endemicity · Islands

INTRODUCTION

Identifying conservation priorities is crucial in the modern world where human activities have a strong impact on the natural environment and resources (Wilson 1992, Myers 1998). An important dilemma for conservationists has hence been to define which areas are the most immediately important for conserving biodiversity (Wilson 1992, Myers et al. 2000, Mittermeier et al. 2004). Brooks et al. (2006) identified 9 major institutional templates of global biodiversity conservation prioritization, with most of these templates prioritizing highly irreplaceable regions: some are reactive (prioritizing high vulnerability) and others are proactive (prioritizing low vulnerability). Some proposals for systematic conservation of priority areas are based on biogeographic units, which are typically defined *a priori* by specialist perception of the distribution of biodiversity (Brooks et al. 2006), as, for example, the ecoregions (Olson & Dinerstein 1998).

One of the 9 templates advised by Brooks et al. (2006) is the biodiversity hotspots approach (Myers et al. 2000, Stuart et al. 2004). This approach defines 34 'biodiversity hotspots, which hold especially high numbers of endemic species and which together cover ~2.3% of the Earth's land surface (Stuart et al. 2004). When biodiversity hotspots take endemic spe-

*Email: giovanni.amori@uniroma1.it

cies richness into consideration, the emerging patterns can be extremely useful because, although it has been demonstrated that the correlation between global richness and endemism is low, aggregating regions into appropriate hotspots selected for high levels of endemism captures far more species than single unaggregated regions (Lamoreux et al. 2006). Each hotspot faces extreme threats and has already lost at least 70% of its original natural vegetation (Myers et al. 2000). Over 50% of the world's plant species and 42% of all terrestrial vertebrate species are endemic to the 34 biodiversity hotspots (Myers et al. 2000, Stuart et al. 2004). Nonetheless, biodiversity hotspots have also been criticized for several reasons, including the fact that they do not consider phylogenetic diversity and/or do not give adequate representation of taxa other than vascular plants (Kareiva & Marvier 2003).

A majority of endemic taxa around the world are found on islands, where they are particularly vulnerable to changes in biotic factors (Sala et al. 2000). Although the general link between endemicity rate, island ecosystems and threatened status is widely recognized by the international community of conservationists, there is still very scarce quantitative information for many animal groups, including small mammals (Amori et al. 2008). This is particularly unfortunate if we consider that small mammals (rodents and insectivores) account for 50% of the total number of mammal species (n = 5416), with 2277 rodent and 428 insectivore species (Wilson & Reeder 2005). In addition, many of these species are threatened with extinction (Amori et al. 2011a).

Another important point to be considered is that identification of biodiversity hotspots was based on taxa other than small mammals, particularly insectivores (Myers et al. 2000, Stuart et al. 2004). Hence, it is interesting to evaluate how small mammals may fit with the already defined hotspots and how they can contribute towards emphasizing the relevance of the various hotspots for biodiversity conservation.

In this paper, we analyze patterns of distribution across zoogeographic regions of threatened Soricomorpha species in order to evaluate whether the current biodiversity hotspots network really covers this taxon. We also focus our attention on the species that are endemic to islands. In particular, we define the main islands in terms of endemic species and threatened species richness. Our data are aimed at international relevance for better defining global conservation strategies for soricomorphs, particularly since these species are rarely considered in conservation management, being non-charismatic and usually scarcely studied in the field (Amori & Gippoliti 2000).

MATERIALS AND METHODS

We extracted data for insectivores from the International Union for Conservation of Nature (IUCN) Red List presence record (Soricomorpha according to Wilson & Reeder 2005; available at www.iucn.redlist.org) occurring throughout the world. We excluded from the analysis the allochtonous species.

Biodiversity hotspots were selected according to Myers et al. (2000) and Stuart et al. (2004); threatened soricomorph diversity at the genus level was evaluated according to the criterion of Amori & Gippoliti (2000), where a threatened genus was that for which all extant species were listed as Critically Endangered, Endangered or Vulnerable by the IUCN (2010). For threatened species, we used the IUCN lists (2010). Soricomorph nomenclature followed Wilson & Reeder (2005). In this regard, it is necessary to consider that soricomorphs do not have a global distribution, being absent from Australia, Papua-New Guinea and South America. Hence, our study deals only with the biodiversity hotspots situated outside these major regions (Churchfield 1990).

For each zoogeographical region (i.e. Nearctic, Neotropical [excluding South America], Palearctic, Afrotropical, Oriental, and Australian [excluding Australia and Papua-New Guinea; henceforth Australasian]), we considered whether the distribution range of each threatened genus/species matched, at least partially, with one or more of the biodiversity hotspots. We assessed the overlap between threatened taxa distribution and biodiversity hotspots using the species distribution polygons (GIS shapefiles) available in IUCN (2010) using ArcGIS software. If at least 5% of a species' range overlapped with any biodiversity hotspot, we considered that the taxon was covered by that biodiversity hotspot; otherwise, the threatened taxon was considered disjunct from hotspots. Chi-squared tests were used to explore whether the frequencies of threatened taxa within and outside of biodiversity hotspots differed significantly either globally or at a zoogeographical region level. Alpha was assessed at 5%. Statistics were performed using STATISTICA v6.0 software. Chi-square tests were calculated using the observed-versus-expected option as available in STATISTICA.

RESULTS

Distribution of threatened taxa within and outside of biodiversity hotspots

The distribution of species richness of soricomorphs throughout the world revealed peaks in the Central African rainforest and Southeast Asia (Fig. 1). Overall, 9 out of 45 soricomorph genera (20 %) were threatened worldwide, all of which were found within biodiversity hotspots (Table 1). Of the 45 genera, 17 (37.7 %) had at least 1 threatened species. Of 428 soricomorph species, 81 (18.9 %) were threatened; of these 14 (17.3 %) did not occur within biodiversity hotspots, and 67 (82.7 %) did. Hence, among the threatened species occurring throughout the world, the proportion of those occurring within hotspots was significantly higher than those occurring outside of biodiversity hotspots ($\chi^2 = 34.68$, df = 1, $p < 0.00001$). If we analyze the data by zoogeographic region (Table 2), a significantly higher proportion of threatened species ($\chi^2 = 43.3$, df = 9, $p < 0.0001$) occurs within rather than outside of biodiversity hotspots (Fig. 2). However, there was considerable variation among regions: indeed, whilst nearly all threatened species are included in biodiversity hotspots in the Palearctic, Oriental and Neotropical regions, ~30 % of the Afrotropical threatened species are not found within biodiversity hotspots, particularly those occurring in the Congolese and southern Cameroonian forests (Fig. 2).

Table 1. Threatened soricomorph genera included within biodiversity hotspots as defined by Myers et al. (2000) and Stuart et al. (2004)

Genus	Distribution	Zoogeographical region
Desmana	Russia, Ukraine, Kazakhstan	Palearctic
Feroculus	Sri Lanka	Oriental
Galemys	Spain, France, Portugal	Palearctic
Neohylomys	Hainan Island (China)	Oriental
Podogymnura	Philippines	Oriental
Ruwenzorisorex	Burundi, Rwanda, Democratic Republic of Congo, Uganda	Afrotropical
Solenodon	Cuba	Neotropical
Solisorex	Sri Lanka	Oriental
Surdisorex	Kenya	Afrotropical

Distribution of threatened taxa in relation to island endemicity

Table 3 lists all species of soricomorphs endemic to islands, including their IUCN category. A total of 68 species are endemic to islands, with the Oriental regions housing the majority of them (Fig. 3a). The main islands in terms of number of endemic taxa were: Japan, the Philippines, Sri Lanka and Sulawesi (Fig. 3b). Of the endemic taxa occurring on these islands, 7.3 % were Critically Endangered (CR), 22.1 % Endangered (EN), and 5.9 % Vulnerable (VU). Overall, 35.3 % of the soricomorphs endemic to islands were threatened. The proportion of endan-

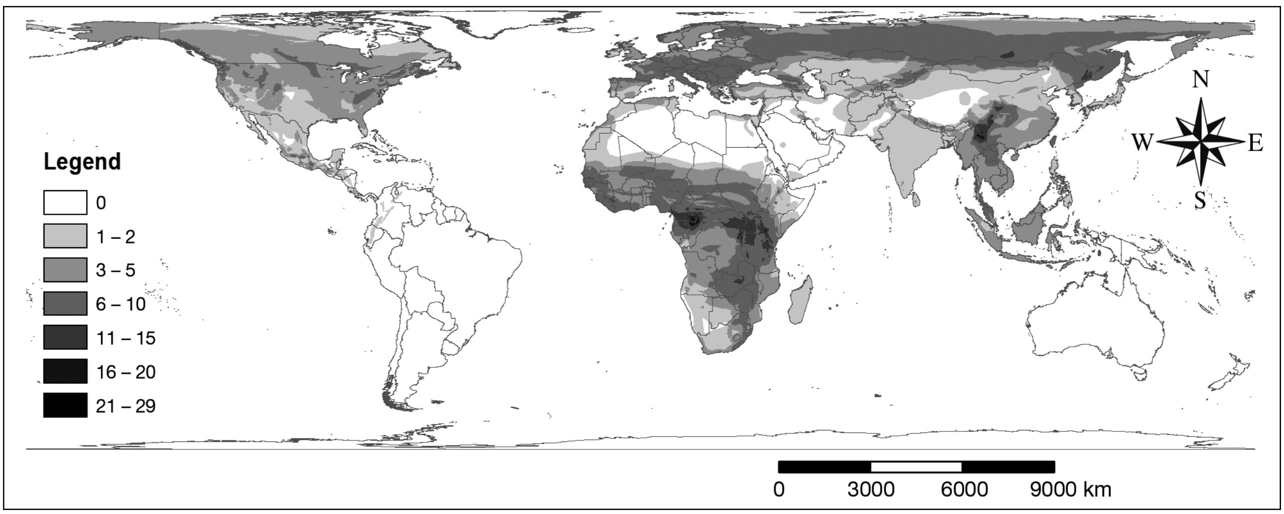

Fig. 1. Species richness of soricomorph species worldwide. Shading shows number of species known to occur in the respective regions

Table 2. Threatened soricomorph species occurring in biodiversity hotspots (definition of hotspots follows Myers et al. 2000 and Stuart et al. 2004). DRC: Democratic Republic of Congo. CR: Critically Endangered; EN: Endangered; VU: Vulnerable; (?): presence uncertain

Family	IUCN Status	Species	Distribution	Zoogeographical region	Presence in hotspots
Solenodontidae	EN	*Solenodon cubanus*	Cuba	Neotropical	Yes
	EN	*Solenodon paradoxus*	Hispaniola	Neotropical	Yes
Soricidae	EN	*Chimarrogale phaeura*	Borneo	Oriental	Yes
	CR	*Congosorex phillipsorum*	Tanzania	Afrotropical	Yes
	VU	*Crocidura allex*	Kenya, Tanzania	Afrotropical	Yes
	CR	*Crocidura andamanens*	Andaman Island	Oriental	Yes
	EN	*Crocidura ansellorum*	Zambia, DCR, Angola	Afrotropical	No
	EN	*Crocidura baileyi*	Ethiopia	Afrotropical	Yes
	VU	*Crocidura baluensis*	Borneo	Oriental	Yes
	EN	*Crocidura bottegoide*	Ethiopia	Afrotropical	Yes
	EN	*Crocidura canariensis*	Canary Islands (Spain)	Palearctic	Yes
	EN	*Crocidura desperata*	Tanzania	Afrotropical	Yes
	VU	*Crocidura eisentrauti*	Cameroon	Afrotropical	No
	VU	*Crocidura fumosa*	Kenya	Afrotropical	Yes
	VU	*Crocidura glassi*	Ethiopia	Afrotropical	Yes
	CR	*Crocidura harenna*	Ethiopia	Afrotropical	Yes
	EN	*Crocidura hikmiya*	Sri Lanka	Oriental	Yes
	VU	*Crocidura hispida*	Andaman Island	Oriental	Yes
	CR	*Crocidura jenkinsi*	Andaman Island	Oriental	Yes
	VU	*Crocidura kivuana*	DCR	Afrotropical	No
	EN	*Crocidura lanosa*	DCR, Rwanda	Afrotropical	No
	VU	*Crocidura lucina*	Ethiopia	Afrotropical	Yes
	VU	*Crocidura macmillani*	Ethiopia	Afrotropical	Yes
	VU	*Crocidura manengubae*	Cameroon	Afrotropical	Yes
	EN	*Crocidura miya*	Sri Lanka	Oriental	Yes
	EN	*Crocidura negrina*	Philippines	Oriental	Yes
	CR	*Crocidura nicobarica*	Nicobar Islands	Oriental	Yes
	VU	*Crocidura orientalis*	Java	Oriental	Yes
	EN	*Crocidura orii*	Ryukyu Islands	Palearctic	Yes
	EN	*Crocidura phaeura*	Ethiopia	Afrotropical	Yes
	EN	*Crocidura picea*	Cameroon	Afrotropical	Yes
	EN	*Crocidura stenocepha*	DCR, Uganda	Afrotropical	No
	EN	*Crocidura tansaniana*	Tanzania	Afrotropical	Yes
	EN	*Crocidura tarella*	DCR, Uganda	Afrotropical	No
	EN	*Crocidura telfordi*	Tanzania	Afrotropical	Yes
	EN	*Crocidura thomensis*	Sao Tome	Afrotropical	No
	CR	*Crocidura trichura*	Christmas Island (Australia)	Oriental	Yes
	EN	*Crocidura usambarae*	Tanzania	Afrotropical	Yes
	CR	*Crocidura wimmeri*	Ivory Coast	Afrotropical	Yes
	VU	*Crocidura zimmermanni*	Crete (Greece)	Palearctic	Yes
	EN	*Cryptotis endersi*	Panama	Neotropical	Yes
	VU	*Cryptotis gracilis*	Costa Rica	Neotropical	Yes
	VU	*Cryptotis griseoventris*	Mexico, Guatemala	Neotropical	Yes
	VU	*Cryptotis magna*	Mexico	Neotropical	Yes
	EN	*Cryptotis mera*	Panama	Neotropical	Yes
	CR	*Cryptotis nelsoni*	Mexico	Neotropical	Yes
	VU	*Cryptotis obscura*	Mexico	Neotropical	Yes
	VU	*Cryptotis phillipsii*	Mexico	Neotropical	Yes
	EN	*Feroculus feroculus*	Sri Lanka	Oriental	Yes
	EN	*Myosorex blarina*	DRC, Uganda	Afrotropical	No
	CR	*Myosorex eisentrauti*	Bioko	Afrotropical	Yes
	EN	*Myosorex geata*	Tanzania	Afrotropical	Yes
	EN	*Myosorex kihaulei*	Tanzania	Afrotropical	Yes
	VU	*Myosorex longicaudatus*	South Africa	Afrotropical	Yes
	EN	*Myosorex okuensis*	Cameroon	Afrotropical	Yes
	EN	*Myosorex rumpii*	Cameroon	Afrotropical	No
	VU	*Myosorex zinki*	Tanzania	Afrotropical	Yes

Table 2 (continued)

Family	IUCN Status	Species	Distribution	Zoogeographical region	Presence in hotspots
Soricidae	VU	*Notiosorex villai*	Mexico	Neotropical	Yes
	VU	*Ruwenzorisorex sunco*	Burundi, Rwanda, DRC, Uganda	Afrotropical	No
	EN	*Solisorex pearsoni*	Sri Lanka	Oriental	Yes
	VU	*Sorex macrodon*	Mexico	Neotropical	Yes
	VU	*Sorex milleri*	Mexico	Neotropical	Yes
	EN	*Sorex pribilofensis*	Saint Paul Island (Alaska)	Nearctic	No
	CR	*Sorex sclateri*	Mexico	Neotropical	Yes
	CR	*Sorex stizodon*	Mexico	Neotropical	Yes
	CR	*Suncus aequatorius*	Kenya, (Tanzania?)	Afrotropical	Yes
	EN	*Suncus dayi*	India	Oriental	No
	EN	*Suncus fellowesgordoni*	Sri Lanka	Oriental	Yes
	EN	*Suncus mertensi*	Flores (Indonesia)	Oriental	Yes
	VU	*Suncus montanus*	India, Sri Lanka	Oriental	Yes
	EN	*Suncus zeylanicus*	Sri Lanka	Oriental	Yes
	VU	*Surdisorex norae*	Kenya	Afrotropical	Yes
	VU	*Surdisorex polulus*	Kenya	Afrotropical	Yes
	VU	*Sylvisorex camerunensis*	Cameroon, Nigeria	Afrotropical	Yes
	EN	*Sylvisorex howelli*	Tanzania	Afrotropical	Yes
	EN	*Sylvisorex isabellae*	Bioko	Afrotropical	Yes
	VU	*Sylvisorex lunaris*	Burundi, Rwanda, DRC, Uganda	Afrotropical	No
	EN	*Sylvisorex morio*	Cameroon	Afrotropical	No
Talpidae	VU	*Desmana moschata*	Russia	Palearctic	Yes
	VU	*Galemys pyrenaicus*	Spain, France, Portugal	Palearctic	Yes
	EN	*Mogera etigo*	Japan	Palearctic	Yes

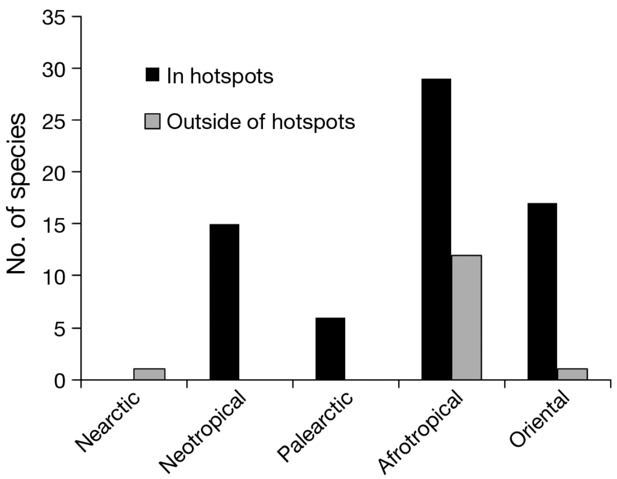

Fig. 2. Number of threatened soricomorphs species within and outside of biodiversity hotspots as defined by Myers et al. (2000) and Stuart et al. (2004) according to geographic regions

gered soricomorphs was significantly higher among species endemic to islands than among species non-endemic to islands (χ^2 test, df = 1, p < 0.01). The islands hosting the greatest number of endangered species were Andamans, Sri Lanka, and Bioko (Table 3).

DISCUSSION

At the genus level, this study confirms that biodiversity hotspots as currently defined (see Myers et al. 2000, Stuart et al. 2004) fully cover the diversity of threatened genera. This is important, of course, in terms of conservation, especially because other studies on small mammals showed a remarkable disjunction between threatened genera diversity and biodiversity hotspots (Amori et al. 2011b). In the case of rodents, however, most of the threatened genera found outside biodiversity hotspots occur in Papua-New Guinea (Amori et al. 2011b), where soricomorphs are not present. On the other hand, <1 out of 5 threatened species are not represented in biodiversity hotspots. This mismatch between threatened species and biodiversity hotspots occurs in particular in the Afrotropical region (mainly Congo and Cameroon) where soricomorphs are often linked to rainforest habitats (Amori & Luiselli 2011) that are currently suffering from severe fragmentation and exploitation (e.g. Davis & Philips 2009), as for example, in the case of *Sylvisorex* spp. (Nowak 1999). We therefore suggest adding Congolese and Cameroonian forests to the list of biodiversity hotspots, at least for soricomorphs, in order to increase the effective-

Table 3. Soricomorph species endemic to islands, including their distribution and IUCN status. LC: Least Concerned; DD: Data Deficient; Is.: Island(s). See Table 2 for other definitions

Family	IUCN status	Species	Distribution
Soricidae	LC	*Anourosorex yamashin*	Taiwan
	EN	*Chimarrogale phaeura*	Borneo
	LC	*Chimarrogale platycephala*	Japan
	DD	*Chimarrogale sumatrana*	Sumatra
	DD	*Chodsigoa sodalis*	Taiwan
	CR	*Crocidura andamanens*	Andaman Is.
	VU	*Crocidura baluensis*	Borneo
	LC	*Crocidura beatus*	Philippines
	LC	*Crocidura beccarii*	Sumatra
	LC	*Crocidura brunnea*	Java, Bali
	EN	*Crocidura canariensis*	Canary Is. (Spain)
	LC	*Crocidura dsinezumi*	Japan
	LC	*Crocidura elongata*	Sulawesi
	LC	*Crocidura foetida*	Borneo
	DD	*Crocidura grandis*	Philippines
	LC	*Crocidura grayi*	Philippines
	EN	*Crocidura hikmiya*	Sri Lanka
	VU	*Crocidura hispida*	Andaman Is.
	LC	*Crocidura hutanis*	Sumatra
	CR	*Crocidura jenkinsi*	Andaman Is.
	LC	*Crocidura lea*	Sulawesi
	LC	*Crocidura lepidura*	Sumatra
	LC	*Crocidura levicula*	Sulawesi
	LC	*Crocidura maxi*	Indonesia
	DD	*Crocidura mindorus*	Philippines
	EN	*Crocidura miya*	Sri Lanka
	DD	*Crocidura musseri*	Sulawesi
	EN	*Crocidura negrina*	Philippines
	CR	*Crocidura nicobarica*	Nicobar Is.
	LC	*Crocidura nigripes*	Sulawesi
	VU	*Crocidura orientalis*	Java
	EN	*Crocidura orii*	Ryukyu Is.
	LC	*Crocidura palawanens*	Philippines
	LC	*Crocidura paradoxura*	Sumatra, (Java?)
	LC	*Crocidura rhoditis*	Sulawesi
	LC	*Crocidura sicula*	Sicily
	LC	*Crocidura tanakae*	Taiwan
	DD	*Crocidura tenuis*	Timor
Soricidae	EN	*Crocidura thomensis*	Sao Tome
	CR	*Crocidura trichura*	Christmas Is. (Australia)
	DD	*Crocidura vosmaeri*	Bangka (Indonesia)
	LC	*Crocidura watasei*	Japan
	VU	*Crocidura zimmermanni*	Crete (Greece)
	LC	*Episoriculus fumidus*	Taiwan
	EN	*Feroculus feroculus*	Sri Lanka
	CR	*Myosorex eisentrauti*	Bioko
	EN	*Solisorex pearsoni*	Sri Lanka
	LC	*Sorex hosonoi*	Honshu (Japan)
	LC	*Sorex jacksoni*	St Lauren Is. (USA)
	DD	*Sorex leucogaster*	Paramushir (Russia)
	EN	*Sorex pribilofensis*	Saint Paul Is. (Alaska)
	LC	*Sorex shinto*	Japan
	DD	*Suncus ater*	Borneo
	EN	*Suncus fellowesgordoni*	Sri Lanka
	DD	*Suncus hosei*	Borneo
	LC	*Suncus madagascariensis*	Madagascar, Comoros
	EN	*Suncus mertensi*	Flores (Indonesia)
	EN	*Suncus zeylanicus*	Sri Lanka
	EN	*Sylvisorex isabellae*	Bioko
Solenodontidae	EN	*Solenodon cubanus*	Cuba
	EN	*Solenodon paradoxus*	Hispaniola
Talpidae	DD	*Euroscaptor mizura*	Japan
	LC	*Mogera imaizumii*	Japan
	NT	*Mogera tokudae*	Japan
	DD	*Mogera uchidai*	Ryukyu Is.
	LC	*Mogera wogura*	Japan
	LC	*Dymecodon pilirostris*	Japan
	LC	*Urotrichus talpoides*	Japan

ness of potential worldwide conservation of these neglected mammals.

Although our study revealed that the current biodiversity hotspots network covers nearly all the diversity of threatened soricomorph genera and species, this does not necessarily mean that these biodiversity hotspots have proper conservation area networks and that soricomorphs are adequately protected. As an example, Sarkar et al. (2008) assessed the Mesoamerica, Chocó, and Tropical Andes biodiversity hotspots and found that existing protected areas do not perform well in protecting the Red List species in these regions.

Another aspect highlighted by our study is that a considerable diversity of soricomorph taxa occurs only on islands, with a higher proportion of threatened taxa being endemic to islands. This result is important in terms of conservation because it shows that about one-third of the soricomorphs endemic to islands may be at serious risk of extinction if their remaining island habitats are altered. In this regard, particular attention should be paid to the conservation of mature forests on the Andaman Islands (for *Crocidura andamanens*, *C. hispida*, *C. jenkinsi*), on Sri Lanka (*C. hikmiya*, *C. miya*, *Feroculus feroculus*, *Solisorex pearsoni*, *Suncus fellowesgordoni*, *Suncus*

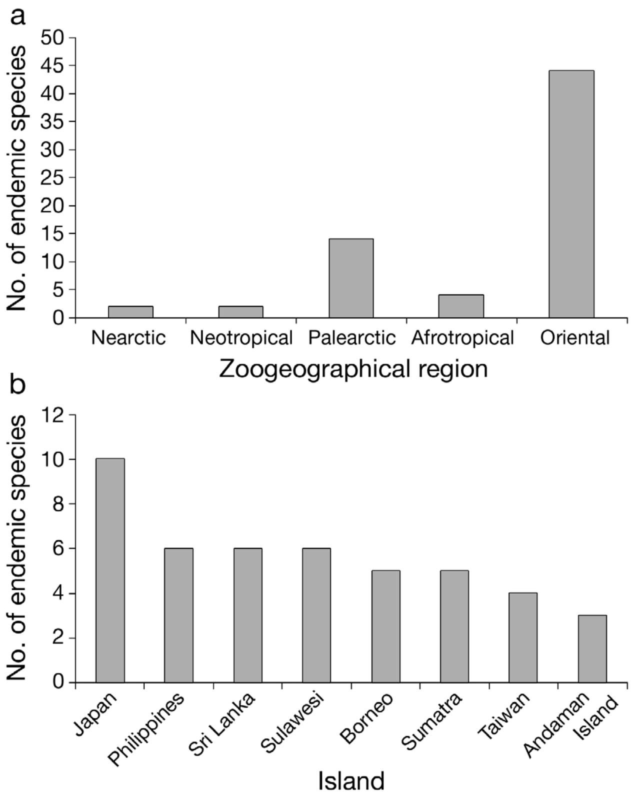

Fig. 3. Distribution of number of endemic soricomorph species by (a) zoogeographical region and (b) specific islands

zeylanicus), and Bioko (*Myosorex eisentrauti, Sylvisorex isabellae*).

In conclusion, although our study confirms that biodiversity hotspots covered the diversity of threatened soricomorphs quite satisfactorily (at least at the genus level), it should be noted that both mainland (Cameroon and Congo) and island (particularly the Andaman Islands, Sri Lanka, Bioko) forest ecosystems deserve particular attention from conservation organizations if soricomorphs are to be effectively maintained worldwide. In addition, the data available so far on soricomorphs are very preliminary and fragmentary (Stone 1995); hence, we strongly invite the scientific community to perform careful baseline studies on the ecology, taxonomy, and distribution of these mammals, particularly in the tropical regions, where species diversity is greater but less is known about the biology of these mammals.

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