Short Communication

Updated estimates of biotic diversity and endemism for Madagascar

Steven M. Goodman and Jonathan P. Benstead

Abstract Madagascar is a critical priority for international conservation efforts, based on almost unparalleled levels of endemism, species diversity, and human threat. Field research conducted over the past two decades has greatly expanded knowledge of the island's biota, making it difficult for any single research team to maintain up to date estimates of biodiversity and endemism across taxonomic groups. The recent publication of *The Natural History of Madagascar*, a synthesis by nearly 300 contributors from a wide range of disciplines, provides the means to update these estimates. Here, we summarize biodiversity information presented in the volume by providing revised estimates of species richness, endemism, and state of knowledge of a wide variety of taxonomic groups occurring on the island.

Keywords Biodiversity, conservation priorities, endemicity, hotspots, islands, Madagascar.

Measures of species diversity and levels of endemism are two important components in determining conservation priorities around the world. In numerous countries and biomes, particularly in tropical areas, biological exploration is still at an initial descriptive stage. In these areas ongoing field inventories for a variety of organisms, combined with systematic studies, are rapidly modifying previous estimates of biotic diversity, especially those concerning endemism and species richness.

Based on almost unparalleled levels of endemism, species diversity, and human threat, Madagascar is among the most critical global priorities for conservation action, and has been designated one of the world's most important biodiversity hotspots (Myers *et al*., 2000; Groombridge & Jenkins, 2002). This island nation, with a surface area of 594,150 km^2, retains only an estimated 10% of the natural habitats that existed before human colonization *c.* 2,000 years ago. The past 20 years have seen considerable growth in biological research on the island, including the exploration of unknown or poorly known areas and subsequent taxonomic studies of collected specimens.

For a country such as Madagascar, with its remarkable and poorly known levels of biotic diversity and endemism, the various measures used in hotspot analyses are in constant need of revision. However, given the remarkable level of new species now being described across a wide variety of taxonomic groups, it is difficult for any single research team to maintain up to date figures for the island. The recalculation of these values depends on the hundreds of specialists working on the island's biota. The recent publication of *The Natural History of Madagascar* (Goodman & Benstead, 2003), a synthesis by nearly 300 contributors from a wide range of disciplines, provides the means to update these estimates. Here, we provide revised figures of species richness, endemism, and state of knowledge of a wide variety of taxonomic groups on Madagascar (Table 1).

For most marine organisms occurring within Malagasy waters the current state of knowledge is still insufficient to estimate species richness. There appear, however, to be few local marine endemics. Previous estimates of the vascular plant diversity on the island are 10,000–12,000 species (Koechlin *et al*., 1974; Phillipson, 1994; Schatz *et al*., 1996), with rates of endemism of *c*. 85%. A recent revision of the tree and large shrub flora revealed levels of endemism of this portion of the flora of *c*. 96% (Schatz, 2000). On the basis of the plant groups covered in *The Natural History of Madagascar* (*c.* 3,000 species, or *c.* 25% of the known flora), endemism is 83%. This averaged figure includes ferns, only 45% of which are endemic species. When ferns are removed from this estimate, vascular plant endemism rises to 92%.

Total species richness for the macroinvertebrate groups covered in the book is slightly more than 5,800 species, of which 86% are endemic to the island. Several speciose groups of invertebrates are not covered in the volume (e.g. the majority of beetle families) and this estimate of species richness is probably at least an order

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Table 1 Estimates of species richness, endemism and state of knowledge of Malagasy plants and animals. Data are from *The Natural History of Madagascar* (Goodman & Benstead, 2003), and sources (author names and associated page numbers) within that work are cited.

Taxonomic group	Species richness[1]	Endemism	State of knowledge	Source
Marine[2]				
Fishes (including elasmobranchs)	*c.* 1,110	very low	well known	Cooke *et al.*, p. 179
Porifera (sponges)	>300	none	well known	Cooke *et al.*, p. 179
Cnidaria (corals & anemones)	>400	very low	reasonably well known	Cooke *et al.*, p. 179
Octocorallians (soft corals, sea fans, etc.)	222	62 regional endemics[3]	reasonably well known	Cooke *et al.*, p. 179
Hexacorallians (hard corals)	208	some regional endemism	reasonably well known	Cooke *et al.*, p. 179
Mollusca (molluscs)	*c.* 1,500	some regional endemism	poorly known	Cooke *et al.*, p. 179
Crustacea (crustaceans)	*c.* 800	some regional endemism	poorly known	Cooke *et al.*, p. 179
Echinoderma (echinoderms)	*c.* 400	>80 regional endemics	reasonably well known	Cooke *et al.*, p. 179
Marine algae	*c.* 200	not stated	reasonably well known	Cooke *et al.*, p. 179
Chelonidae (sea turtles)	5	none	well known	Ratsimbazafy, p. 210
Cetacea (whales & dolphins)	25[4]	none	reasonably well known	Rosenbaum, p. 213
Pinnipedia (seals)	2	none	reasonably well known	Rosenbaum, p. 213
Sirenia (dugongs)	1	none	well known	Rosenbaum, p. 213
Non-marine plants				
Aquatic plants	338	128 (38%)	poorly known	Andrianasetra Ranarijaona, p. 250
Bacillariophyceae (diatoms)	134[5]	some endemic	poorly known	Spaulding & Kociolek, p. 276
Pteridophyta (ferns & allies)	586[6]	265 (45%)	reasonably well known	Rakotondrainibe, p. 282
Annonaceae	89	83 (93%)	reasonably well known	le Thomas & Aymonin, p. 316
Myristicaeae	10	10 (100%)	reasonably well known	Sauquet, p. 319
Moraceae (*Ficus*)	25	15 (60%)	reasonably well known	Dalecky *et al.*, p. 322
Bombaceae (*Adansonia*)	7[7]	6 (85–100%)	well known	Baum, p. 339
Sapotaceae	84	81 (96%)	reasonably well known	Gautier, p. 342
Leguminosae	573	459 (80%)	reasonably well known	Labat & Moat, p. 346
Melastomataceae	321	318 (99%)	reasonably well known	Almeda, p. 375
Euphorbiaceae	*c.* 700	mostly endemic	poorly known	Hoffmann & McPherson, p. 379
Anacardiaceae	41	38 (93%)	reasonably well known	Randrianasolo, p. 398
Balsaminaceae	149	149 (100%)	reasonably well known	Rahelivololona *et al.*, p. 402
Gentianaceae	67	62 (93%)	reasonably well known	Wohlhauser *et al.*, p. 409
Scrophulariaceae	79	40 (51%)	reasonably well known	Fischer, p. 417
Rubiaceae	*c.* 650	637 (98%)	poorly known	Davis & Bridson, p. 431
Arecaceae (palms)	170	167 (98%)	reasonably well known	Dransfield & Beentje, p. 448
Pandanaceae (*Pandanus*)	99	99 (100%)	reasonably well known	Callmander & Laivao, p. 460
Poaceae, Bambuseae (bamboos)	34	34 (100%)	poorly known	Dransfield, p. 467, pers. comm.
Totals[8]	*2,984*	*2,463 (83%)*		
Non-marine invertebrates				
Gastropoda (terrestrial snails)	671	671 (100%)	reasonably well known	Pearce, p. 529
Scorpiones (scorpions)	40	40 (100%)	reasonably well known	Lourenço, p. 575
Araneae (spiders)	459	390 (85%)	reasonably well known	Griswold, p. 579
Ixodida (ticks)	27	25 (93%)	reasonably well known	Klompen, p. 588

Table 1 (Continued)

Taxonomic group	Species richness[1]	Endemism	State of knowledge	Source
Atyidae (freshwater shrimps)	27	20 (74%)	well known	Short & Doumenq, p. 603
Palaemonidae (freshwater shrimps)	13	5 (39%)	reasonably well known	Short & Doumenq, p. 603
Parastacidae (freshwater crayfish)	6	6 (100%)	well known	Crandall, p. 608
Potamonautidae	12	12 (100%)	reasonably well known	Cumberlidge & v. Sternberg, p. 612
Diplopoda (millipedes)	160	123[9] (77%)	poorly known	Enghoff, p. 617
Collembola (springtails)	69	64 (93%)	poorly known	Betsch, p. 627
Ephemeroptera (mayflies)	>100[10]	100 (*c.* 100%)	reasonably well known	Elouard *et al.*, p. 639
Odonata (dragonflies & damselflies)	181	132 (73%)	reasonably well known	Donnelly & Parr, p. 645
Plecoptera (stoneflies)	12	12 (100%)	poorly known	Elouard, p. 661
Megaloptera (fishflies & alderflies)	4	4 (100%)	poorly known	Penny, p. 662
Neuroptera (lacewings)	163	119 (73%)	reasonably well known	Penny, p. 663
Coleoptera				
Cicindelidae (tiger beetles)	203	201 (99%)	reasonably well known	Cassola, p. 669
Scarabaeidae, Melolonthinae, Enariini (scarab beetles)	148	148 (100%)	reasonably well known	Andriamampianina, p. 677
Siphonaptera (fleas)	24	21 (88%)	reasonably well known	Duchemin *et al.*, p. 687
Diptera (true flies)	1,796	1,437 (80%)	poorly known	Irwin *et al.*, p. 692
Blephariceridae (net-winged midges)	9	9 (100%)	poorly known	Courtney, p. 702
Culicidae (mosquitoes)	178	80 (45%)	poorly known	Duchemin *et al.*, p. 708
Simuliidae (black flies)	27	22 (82%)	reasonably well known	Elouard, p. 715
Tabanidae (horse flies)	75	71 (95%)	reasonably well known	Chainey, p. 721
Therevidae (stiletto flies)	21	21 (100%)	reasonably well known	Irwin, p. 730
Trichoptera (caddisflies)	*c.* 500[11]	*c.* 99%	reasonably well known	Gibon, pp. 740
Lepidoptera (butterflies & moths)	4,530	unclear	reasonably well known	Lees & Minet, p. 748
Papilionoidea & Hesperioidea (true butterflies)	300	211 (70%)	reasonably well known	Lees *et al.*, p. 762
Hymenoptera				
Heterogynaidae, Ampulicidae, Sphecidae, Crabronidae (apoid wasps)	190	158 (83%)	reasonably well known	Pulawski, p. 793
Formicidae (ants)	393[12]	379 (96%)	poorly known	Fisher, p. 811
Totals[13]	*5,808*	*4,976 (86%)*		
Freshwater fishes	143	93 (65%)	poorly known	Sparks & Stiassny, p. 849
Land vertebrates				
Amphibia (frogs)	199	197 (99%)	reasonably well known	Glaw & Vences, p. 883
Reptilia (reptiles)	340	314 (92%)	poorly known	Raxworthy, p. 934
Aves (birds)	209[14]	109 (52%)	reasonably well known	Hawkins & Goodman, p. 1019
Mammalia (non-volant mammals)	101	101[15] (100%)	poorly known	Goodman *et al.*, p. 1181
Mammalia (bats)	30	18 (60%)	poorly known	Eger & Mitchell, p. 1287
Totals	*879*	*739 (84%)*		

Table 1 (Continued)

[1]Does not include introduced species
[2]Totals for marine groups are not provided, as a number of entries are approximations.
[3]Refers to the western Indian Ocean and East African coast
[4]Includes confirmed sightings/specimens and suspected occurrences
[5]Refers to 'forms' including species and geographic forms. In many cases species were described from Quaternary deposits and it is not known if they are extant.
[6]Includes species and varieties
[7]One species may be naturalized
[8]Excludes figures for aquatic plants, diatoms, and Euphorbiaceae
[9]A considerable proportion of the non-endemic species are synanthropic and presumably introduced to Madagascar. Thus, the real level of endemism is higher than indicated here.
[10]More than 90 species of which have been described since 1990
[11]As of 1994 only 52 species were described from the island. The figure of 500 species is the known fauna, most of which remains to be described.
[12]Valid species and subspecies named to date
[13]Excludes Lepidoptera, with the exception of Papilionoidea and Hesperioidea
[14]Includes breeding species; the total avifauna of the island, including migrants, is 283 species.
[15]The status of *Potamochoerus* on Madagascar is unclear; here it is considered introduced.

of magnitude lower than the real figure. This is the first modern estimate we are aware of for endemism rates across a wide variety of Malagasy invertebrate groups. However, given that such an important percentage of this fauna remains to be discovered and described, this estimate should be considered as an approximation only.

The vertebrate fauna of the island has received most attention from the conservation community. The data we report here include 879 land vertebrates, of which 739 (84%) are endemic. For terrestrial animals rates of endemism are 92–100%, while those for flying animals (bats and birds) are 52–60%. Our estimates of species richness and endemism for certain vertebrate groups differ from previous estimates (e.g. Myers *et al*., 2000) for three reasons: (1) we only include animals native to Madagascar and exclude known or presumed introduced species, (2) numerous new species to science have been recently described, and (3) the neighbouring islands of the Mascarenes, Comoros, and Seychelles were included in previously published estimates.

The data presented here further highlight Madagascar as a critical component of the global biological heritage. An overwhelming majority of species occur in the original and widely differing forest formations of the island, and these are the regions in need of conservation action. As of mid 2002 Madagascar had 46 legally protected areas, comprising *c*. 17,000 km^2 or 3% of the island's land area (Randrianandianina *et al*., 2003). In late 2003, during the World Parks Congress in Durban, South Africa, the President of Madagascar, Marc Ravalomanana, declared that Madagascar would increase its protected area coverage to 60,000 km^2 over the next 5 years. Addition of insufficiently represented habitats to this protected areas system and the planned bolstering of the current network are amongst some of the most important conservation priorities for this island nation.

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