VEGETATION MAPPING AND CLASSIFICATION IN MADAGASCAR (USING GIS): IMPLICATIONS AND RECOMMENDATIONS FOR THE CONSERVATION OF BIODIVERSITY

David J. Du Puy and Justin Moat.

Royal Botanic Gardens, Kew, Richmond, Surrey, TW9 3AB, England.
Tel.: (0)181 332 5237. Fax.: (0)181 332 5278.
E-Mail: D.Dupuy@rbgkew.org.uk & J.Moat@rbgkew.org.uk

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SUMMARY

A map of the ‘Remaining Primary Vegetation’ in Madagascar has been derived (Map 1) and divided into broad vegetation zones. It is based on the vegetation cover map of Faramalala (1988, 1995), produced from satellite imagery, and the classification of Humbert (1955). A map of the ‘Simplified Geology’, derived from Besairie (1964), has also been produced, with the geological categories grouped into broad rock types which are thought to have a strong influence on the vegetation they support and its species composition. These two base maps have been superimposed to show the extent and distribution of the remaining primary vegetation in Madagascar, classified firstly into broad vegetation ‘zones’ and secondly by the underlying geology into vegetation ‘types’(Maps 2 to 5; see also Du Puy & Moat, 1996). These maps have then been compared to the map of ‘Protected Areas’ (COEFOR/CI, 1993), and analysed using Geographical Information Systems (GIS). Histograms produced show the extent of the remaining primary vegetation (in km^2) classified according to the underlying geology, and the areas of each which fall within the current system of protected areas (Figs 1 to 5). These maps and data are discussed, and the major omissions in the current system of protected areas are highlighted. Conservation priorities are identified for vegetation types which are not currently protected or have only minimal protection, and the remaining areas of these vegetation types are mapped to show their current extent and distribution.

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INTRODUCTION

Madagascar is singled out by the international scientific and conservation community as one of the richest countries in the world in terms of biodiversity, endemism and range of habitats. Its flora is diverse and unique. Of approximately 10,000 native higher plant species, about 8,000 species are thought to be endemic to the island. As a comparison, Madagascar is about 2.5 times as large as Britain, which has about 1,200 species of which only 10 to 20 are endemic. The value of the flora of Madagascar, both to the local peoples and in a global sense, is potentially immense. Despite its importance, this flora is under serious threat. Over 80% of the island has already been stripped of its native vegetation cover (Fig. 1); the majority of this area is now very species-poor secondary grassland which is burnt annually and is subject to intense erosion. The heritage of biological diversity in Madagascar is probably under greater threat than in any other country. This unique diversity, combined with the threats to the remaining native vegetation, puts Madagascar amongst the highest conservation priority areas in the world.

In response to the Convention on Biological Diversity (resulting from the ‘Rio Summit’), a conservation strategy is being implemented as part of Madagascar’s Environmental Action Plan: part of this Action Plan is to increase the number of protected areas. Data on phytodiversity are rarely used in conservation planning, because of the paucity and incompleteness of information concerning the distribution and rarity of the vast majority of plant species. These data are time-consuming to acquire and, given the rapid rate at which primary vegetation is being destroyed, the only means of ensuring that informed decisions are made concerning the conservation of as many plant species as possible, is through methods of rapid biodiversity assessment. This paper presents one such method, which maps the remaining primary vegetation, and classifies it in a way which mirrors patterns of phytodiversity distribution. The extent of each vegetation type is quantified (in km^2), as is the amount of each type which is included within the current system of protected areas.

Recommendations concerning the conservation of phytodiversity in Madagascar are made on the basis of these analyses. For the first time, such recommendations are supported by statistical data. Priority areas are identified for further reserves which would optimise the range of vegetation types (and by implication the range of plant species) included in the system of protected areas. It should be recognised, however, that although a system of protected areas will offer theoretical protection to a portion of the remaining diversity, many species will inevitably be excluded. Areas with herbaceous or succulent vegetation, which may also be rich in endemic species (such as on the inselbergs and rocky outcrops of central Madagascar), are also missing from these analyses as the vegetation is too sparse to be recognised as primary vegetation in satellite images, and these rock outcrops are generally too small in area to be mapped on a national scale.

DERIVATION OF THE BASE MAPS '<u>REMAINING PRIMARY VEGETATION</u>' AND '<u>SIMPLIFIED GEOLOGY</u>', AND THE COMPOSITE MAP OF '<u>REMAINING PRIMARY VEGETATION CLASSIFIED BY THE UNDERLYING GEOLOGY</u>'

Field work has indicated that the species composition of vegetation alters radically with major changes in substrate. Different vegetation types, with distinct species compositions, occur on different rock types. It can be demonstrated that individual species are frequently confined to a particular rock type, or that they avoid one or more rock types (see below). A more informative vegetation map can therefore be produced by subdividing the broad primary vegetation zones into individual vegetation types on the basis of the rock type on which they occur, echoing the patterns demonstrated for individual species distributions.

The map of 'Remaining Primary Vegetation' (Map 1), initially derived from satellite imagery by Faramalala (1988, 1995), broadly maintains Humbert's (1955) main phytogeographic zones. These zones were slightly modified following Faramalala. A further modification is that the 'Sambirano' in the north-west was not recognised as a distinct zone but rather as a continuation of the 'evergreen humid forest: low altitude': it constitutes an area of high local endemism, perhaps due to the change in the underlying geology from the widespread 'basement rocks (metamorphic and igneous)' to the much more restricted 'sandstones' in this area (see Du Puy and Moat, 1996). The geology map of Besairie (1964) was digitised and then simplified into broad rock types which are thought to strongly influence the vegetation they support, resulting in the 'Simplified Geology' map (see Du Puy and Moat, 1996). These two maps were superimposed, resulting in the composite map of the 'Remaining Primary Vegetation, classified by the Underlying Geology'. This map provides new insights into the patterns of variation within the vegetation zones and the distributions of individual plant species, especially in western and southern Madagascar where the geology varies substantially (see Maps 3, 4 and 5).

These maps have already been published (Du Puy and Moat, 1996[1]), and the preparation of the 'Simplified Geology' map, the 'Remaining Primary Vegetation' map, the 'Remaining Primary Vegetation, classified by the Underlying Geology' map is documented there. The categories applied in each map are also outlined there, and are listed in Tables 1 and 2 for the two base maps. 7

[1] Copies of this paper and the three maps are available from the authors: a small copy of the 'Remaining Primary Vegetation' map is reproduced here (Map 1).

TABLE 1. CATEGORIES USED IN THE 'SIMPLIFIED GEOLOGY' MAP

Simplified Geology Types
SEDIMENTARY ROCKS:
Alluvial & lake deposits
Unconsolidated sands
Sandstones
Tertiary limestones + marls & chalks
Mesozoic limestones (incl. 'Tsingy') + marls
METAMORPHIC & IGNEOUS ROCKS:
Basement rocks (Metamorphic & Igneous)
Ultrabasics
Quartzites
Marbles (Cipolin)
Lavas (incl. Basalts & Gabbros)
OTHER CATEGORIES:
Mangrove Swamps

TABLE 2. CATEGORIES USED IN THE 'REMAINING PRIMARY VEGETATION' MAP

REMAINING PRIMARY VEGETATION 'ZONES'
EVERGREEN FORMATIONS (EAST AND CENTRE)
Coastal forest (eastern)
Evergreen, humid forest: low altitude (0-800 m)
Evergreen, humid forest: mid altitude (800-1800 m)
Evergreen, humid forest: lower montane (1800-200 m)
Montane (*Philippia*) scrubland (> 1800 m)
Evergreen, sclerphyllous (*Uapaca*) woodland (800-1800 m)
DECIDUOUS FORMATIONS (WEST AND SOUTH):
Coastal forest (western)
Deciduous, seasonally dry, western forest (0-800 m)
Deciduous, dry southern forest and scrubland (0-300 m)
OTHER CATEGORIES:
Mangrove
Marshland

EXTENT OF REMAINING PRIMARY VEGETATION, AND THE DEGREE OF PROTECTION PROVIDED BY THE CURRENT SYSTEM OF PROTECTED AREAS

Histograms showing the remaining area (in km^2) of primary vegetation in each vegetation zone (Fig. 2) and vegetation type (Figs 3 to 5) have been produced. Overlaying a map of the Protected Areas (COEFOR/CI, 1993) on the vegetation maps allows the amounts of protection for each vegetation zone and type to be shown on the histograms, and immediately demonstrates which zones and types are poorly represented within the current system of protected areas. The maps can then be re-examined to show where intact areas of primary vegetation suitable for conservation still exist (see Maps 3, 4 and 5). If reserves were set up on each significant vegetation type, then the system of reserves would include as wide a range of vegetation types as possible, and therefore the greatest possible diversity of species. This may be regarded as a form of rapid phytodiversity assessment, which gives a measure of plant diversity that can be used in the identification of conservation priorities.

A preliminary histogram has already been published (Fig. 2, and Du Puy and Moat, 1996) showing the areas of primary vegetation remaining within the main vegetation zones (derived from the map of ‘Remaining Primary Vegetation’, Map 1), and also indicating the areas which are included within the current system of protected areas. The ‘deciduous, dry, southern forest and scrubland’ was highlighted as being inadequately protected. In the present paper we are publishing further analyses of the maps, based on the ‘Remaining Primary Vegetation classified by the Underlying Geology’ map in particular, and are presenting the resulting implications for conservation planning and biodiversity management. The vegetation types which are shown in the histograms (Figs 2 to 5) to be least well represented within the current system of protected areas are discussed below, are illustrated in Maps 1 to 5, and are listed in the conclusion to the paper.

SPECIES RESTRICTED TO A SPECIFIC ROCK TYPE OR GROUP OF ROCK TYPES

It has been assumed in this study that different rock types will support vegetation containing different species, as is widespread in temperate vegetation. This implies that if a set of protected areas were set up which covered all the main vegetation types (i.e. all vegetation zones on the major rock types on which they occur), then as large a sample as possible of the phytodiversity would be included in the system of reserves. In the tropics the effect of rock type on species distribution may be obscured by deep weathering, such as occurs on the ‘basement rocks’ which form the backbone of upland Madagascar, where there are often deep beds of laterite, and also where sandstones are covered by eroded sand. We have used a database of the Papilionoid Legumes (*Leguminosae* subfam. *Papilionoideae*), containing about 7,000 collection points in c. 350 species, to look for evidence to support this hypothesis. This research continues, but preliminary results confirm that many species show distributions which coincide with the geological substrate: examples of species confined to one, or to a subset of the rock types are presented (Table 3). The strongest influence of rock type on species distribution appears to concern occurrence on limestone. Some species are confined to limestone, sometimes distributed uniquely on either ‘Mezozoic’ or ‘Teriary limestones’, while widespread species often appear on a range of rock types but not on limestone. The 'lavas (including basalts and gabbros)' also often support their own exclusive species, while others occur around but not on them (for instance those species with a broad distribution on the 'basement rocks' of the central plateaux which avoid the basalts of the Ankaratra Massif, and similarly for the areas of ancient lavas in the Mandrare River basin in southern Madagascar). The sandstone and unconsolidated sand categories often have species which are distributed on both categories, although certain species are confined to one or the other. Evidence is accumulating that other species occur exclusively on particular rock types, to varying degrees.

These maps have already helped to explain species distributions and centres of diversity and microendemism in the Papilionoid Legumes, and also in other groups, including both flora and fauna: they may well mirror the distribution patterns of biodiversity as a whole.

TABLE 3: NATIVE PAPILIONOID LEGUME SPECIES WITH DISTRIBUTION PATTERNS WHICH COINCIDE WITH THE UNDERLYING GEOLOGY

NATIVE SPECIES SHOWING A DISTINCT PREFERENCE FOR SEDIMENTARY ROCKS	
Unconsolidated Sands	*Cadia commersoniana, Canavalia rosea, Crotalaria edmundi-bakeri, Crotalaria androyensis, Dalbergia lemurica, Dicraeopetalum capuronianum, Galactia tenuiflora, Sakoanala madagascariensis*
Sandstones	*Crotalaria pervillei, Indigofera blaiseae, Kotschya perrieri, Pyranthus tullearensis, Tephrosia parvifolia, Tephrosia phylloxylon, Tephrosia isaloensis, Vaughania cerighellii, Vaughania dionaeifolia*
Sands (Unconsolidated Sands, Sandstones & Alluviums)	*Crotalaria anomala, Derris trifoliata, Erythrina madagascariensis, Indigofera compressa, Mundulea micrantha, Tephrosia pumila*
Tertiary limestones	*Crotalaria humbertiana, Crotalaria poissonii, Dicraeopetalum mahafaliensis, Ormocarpopsis tulearensis, Pearsonia madagascariensis, Vaughania mahafalensis, Vaughania humbertiana*
Mesozoic Limestones (incl. 'Tsingy')	*Crotalaria capuronii, Dalbergia glaberrima, Dalbergia humbertii, Dalbergia neoperrieri, Indigofera bemarahaensis, Mucuna gigantea, Neoharmsia madagascariensis, Pongamiopsis viguieri, Rhynchosia viscosa, Stylosanthes fruticosa, Tephrosia bibracteolata*
Limestones (both Mesozoic and Tertiary)	*Tephrosia perrieri*

(TABLE 3: CONTINUED)

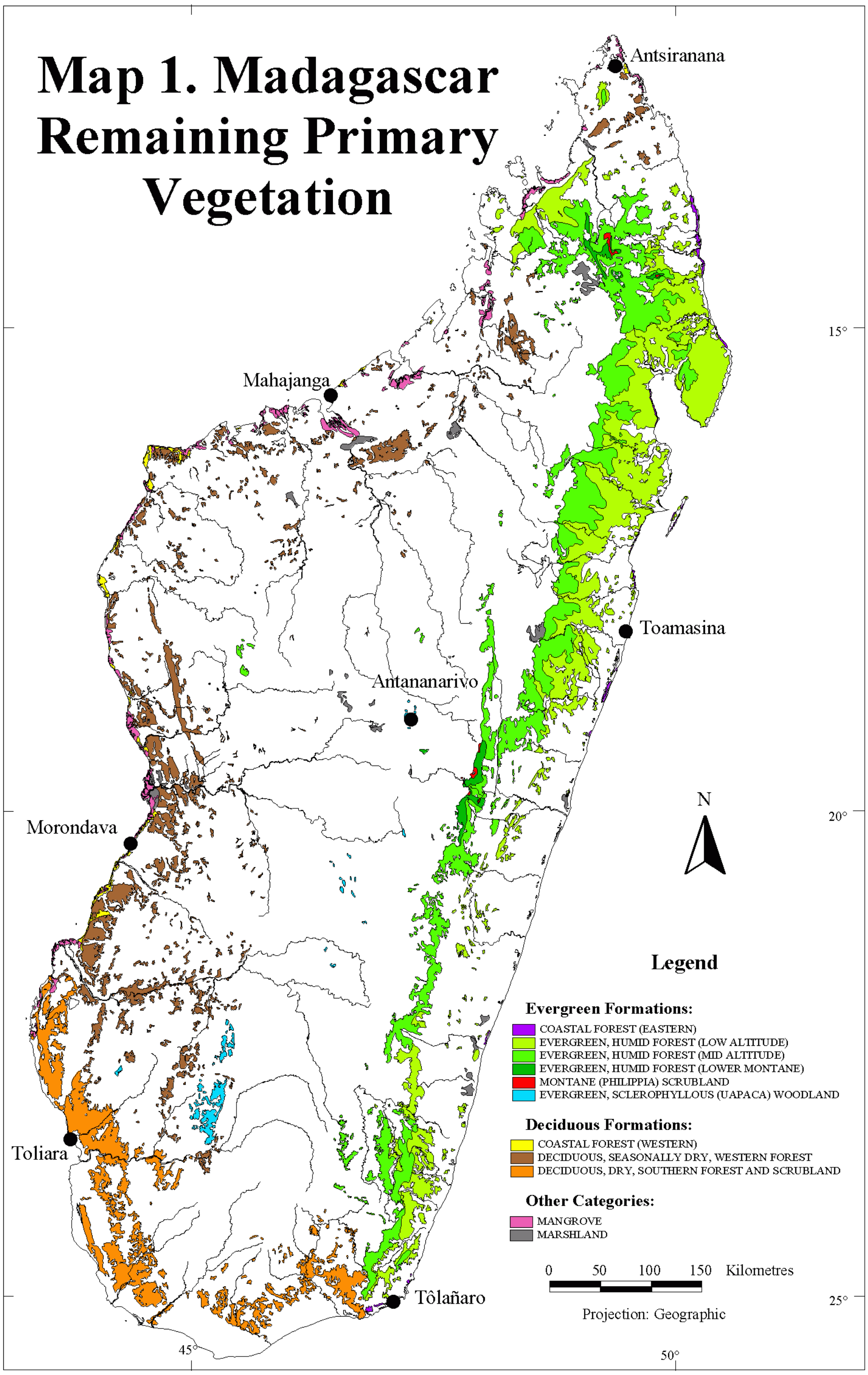
NATIVE SPECIES SHOWING A DISTINCT PREFERENCE FOR METAMORPHIC & IGNEOUS ROCK TYPES	
Basement Rocks (Metamorphic & Igneous Rocks, including Granites, Migmatites, Schists and Gneiss)	*Aeschynomene heurckeana, Argyrolobium pedunculare, Cadia ellisiana, Cadia pubescens, Cordyla haraka, Crotalaria diosmifolia, Crotalaria incana, Crotalaria uncinella, Crotalaria tanety, Crotalaria craspedocarpa, Dalbergia monticola, Dalbergia orientalis, Decorsea meridionalis, Eriosema procumbens, Eriosema parviflorum, Indigofera mangokyensis, Indigofera nummulariifolia, Indigofera arrecta, Kotschya strigosa, Leptodesmia congesta, Mundulea barclayi, Ormocarpopsis mandrarensis, Phylloxylon xylophylloides, Pyranthus pauciflora, Rhynchosia versicolor, Strongylodon madagascariensis, Vigna parkeri, Vigna angivensis, Zornia puberula*
Quartzites often asscoiated with Marbles (Cipolin)	*Argyrolobium itremoensis, Crotalaria ibityensis, Indigofera lyallii, Mundulea anceps, Tephrosia betsileensis, Indigofera itremoensis, Pyranthus ambatoana*
Lavas (incl. Basalts & Gabbros)	*Crotalaria ankaratrana, Dalbergia pseudobaroni, Indigofera thymoides, Indigofera pinifolia, Leptodesmia bojeriana, Leptodesmia perrieri, Pyranthus monantha, Tephrosia retamoides, Trifolium ankaratrense*

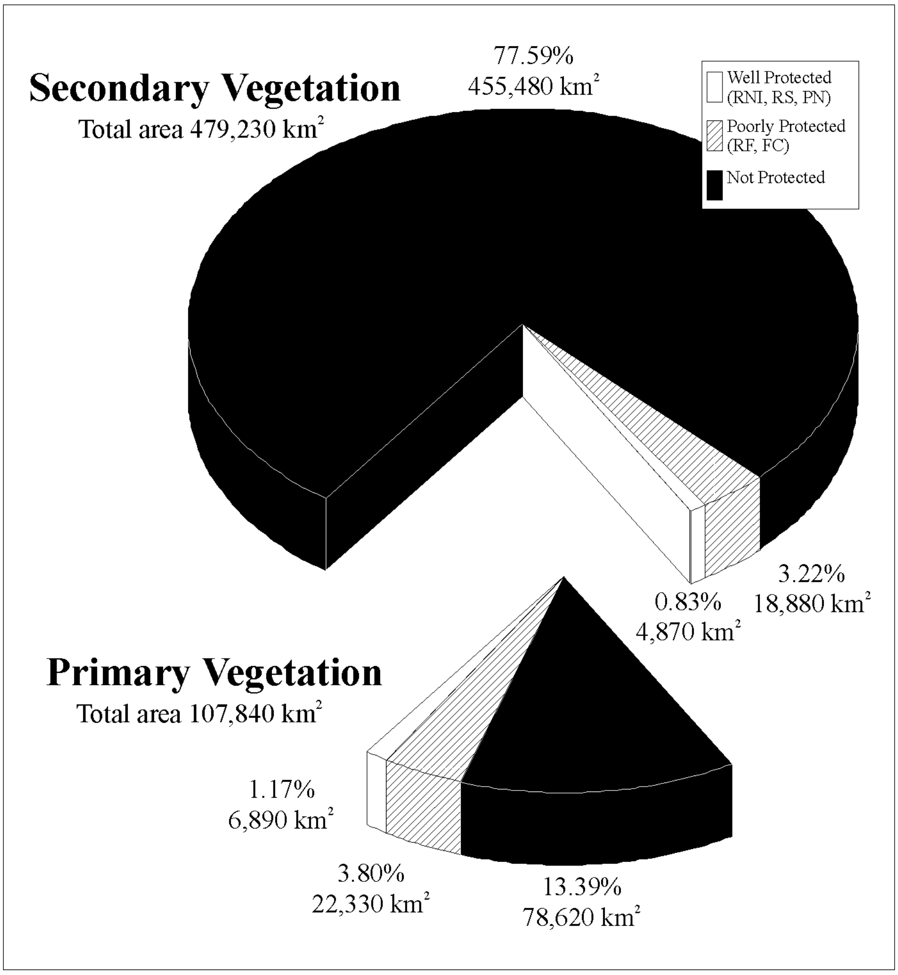
NATIVE SPECIES SHOWING NO ROCK TYPE PREFERENCE BUT A PRONOUNCED DISLIKE FOR A PARTICULAR GROUP OF ROCK TYPES	
Avoiding Basement Rocks	*Dalbergia peltieri, Dalbergia xerophila, Dalbergia trichocarpa, Dalbergia abrahamii, Erythrina variegata, Indigofera longeracemosa, Millettia richardiana, Millettia aurea, Ormocarpum drakei, Ormocarpum bernierianum, Rhynchosia baukea, Sakoanala villosa, Stylosanthes erecta*
Avoiding Lavas and Limestones	*Alistilus jumellei, Crotalaria mandrarensis, Crotalaria grevei, Ophrestia lyallii*
Avoiding Limestones	*Crotalaria fiherenensis, Crotalaria cornu-ammonis, Desmodium repandum, Dumasia villosa, Indigofera bojeri, Indigofera imerinensis, Mundulea laxiflora*

REMAINING AREAS OF PRIMARY VEGETATION WITHIN THE MAJOR VEGETATION ZONES, AND THEIR CURRENT PROTECTION

A histogram showing the areas (in km^2) of remaining primary vegetation within each vegetation zone (Fig. 2, and Du Puy & Moat, 1996) was produced by superimposing the map of ‘Protected Areas’ (COEFOR/CI, 1993) on the map of ‘Remaining Primary Vegetation’ (Map 1, and Du Puy and Moat, 1996). The categories of protection were divided into two levels, a higher ‘well protected’ category (including Réserves Naturelles Intégrales (RNI), Réserves Spéciales (RS) and Parcs Nationaux (PN), all now under the auspices of ANGAP), and a lower ‘poorly protected’ category (including Réserves Forestières (RF) and Forêts Classées (FC), under the auspices of DEF) which are, in general, forestry and forest exploitation areas, and have ‘suffered from enormous human pressures with the practice of ‘tavy’ [shifting agriculture] and an often illegal and abusive forest exploitation’ (translated from COEFOR/CI, 1993). The ‘protected areas’ referred to in this paper therefore only include the top three categories (RNI, RS, PN) which offer the best available protection to the vegetation within their boundaries, although lack of adequate funding, staffing and management means that the protection offered is often nominal and still very incomplete.

The map of ‘Remaining Primary Vegetation’ (Map 1) shows that only about 18% of the surface area of Madagascar is covered by primary vegetation (see Fig. 1). It should be noted, however, that the satellite images used to produce this map were taken during the 1970s (Faramalala, 1988), and that the present native vegetation cover is probably substantially reduced from this already low percentage. Further examination shows that only 6% of this remaining primary vegetation falls within the current system of protected areas (about 1.17% of the total surface area of Madagascar). Moreover, at least 40% of the vegetation within the current system of protected areas is indicated as secondary vegetation.


Map 1. Madagascar
Remaining Primary
Vegetation
Antsiranana
Mahajanga
Toamasina
Antananarivo
Morondava
Toliara
Tôlañaro
N
15°
20°
25°
45°
50°
Legend
Evergreen Formations:
COASTAL FOREST (EASTERN)
EVERGREEN, HUMID FOREST (LOW ALTITUDE)
EVERGREEN, HUMID FOREST (MID ALTITUDE)
EVERGREEN, HUMID FOREST (LOWER MONTANE)
MONTANE (PHILIPPIA) SCRUBLAND
EVERGREEN, SCLEROPHYLLOUS (UAPACA) WOODLAND
Deciduous Formations:
COASTAL FOREST (WESTERN)
DECIDUOUS, SEASONALLY DRY, WESTERN FOREST
DECIDUOUS, DRY, SOUTHERN FOREST AND SCRUBLAND
Other Categories:
MANGROVE
MARSHLAND
0 50 100 150 Kilometres
Projection: Geographic



Abbreviations: RNI - Réserves Naturelles Intégrales,
RS - Réserves Spéciales, PN - Parcs Nationaux,
RF - Réserves Forestières, FC - Forêts Classées

Figure 1. Proportion of Remaining Primary Vegetation to Secondary Vegetation in Madagascar and the percentages of these within protected areas.

EXTENSIVE VEGETATION ZONES

The histogram showing the remaining areas of primary vegetation within the major vegetation zones (Fig. 2) illustrates certain imbalances in the protection offered by the current system of protected areas. There are four vegetation zones which still have substantial areas of primary vegetation cover. Of these, the ‘deciduous, dry, southern forest and scrubland’ is the most outstanding example of inadequate protection; it has a far smaller proportion of primary vegetation within protected areas than the other major vegetation zones. There is clearly a strong case to be made for further protected areas to be placed within this southern zone, particularly since it contains a varied geology (see the discussion below) and a large number of endemic species and genera.

The other three major zones, ‘deciduous, seasonally dry, western forest’, ‘evergreen, humid forest: low altitude’ and ‘evergreen, humid forest: mid altitude’, all appear in this histogram (Fig. 2) to have a larger and more adequate proportion of their current area within protected areas. However, only the ‘evergreen, humid forest: mid altitude’ has as much as 10% of its remaining primary vegetation within protected areas.

The amount of protected vegetation within the ‘evergreen, humid forest: low altitude’ will increase when the new reserve on the Masoala Peninsula[2] is taken into account. Nevertheless, it is important to note that the area of ‘evergreen, humid forest: low altitude’ within protected areas is least at lower altitudes, and that from near sea level up to about 400 metres altitude the forest is both the most degraded and the least well protected. Forest destruction for charcoal and cultivation is proceeding extremely rapidly in these more accessible lowland areas. In fact, very little forest remains at the lowest altitudes, particularly in the southern half of Madagascar. A strong case can certainly be made for ensuring further conservation of ‘evergreen, humid forest’ at low altitudes, and particularly ensuring that forests on basalts and sandstones are adequately included (Fig. 3). The lowland forests from Vohemar to the Masoala Peninsula, around the Baie d’Antongil and near Mananara, and between Tôlañaro (Fort Dauphin) and Vangaindrano in the south, contain important stands of this rapidly diminishing forest type. The forest of Manombo (to the south of Farafangana) has been singled out in the IUCN Palm Conservation Action Plan (Beentje & Dransfield, 1996) as an area of high value, and it is certainly an important and rare example of lowland ‘evergreen, humid forest’ in the southern half of the island (see also the discussion of ‘coastal forest’ below).

Similarly, although the ‘deciduous, seasonally dry, western forest’ appears to have a relatively large degree of protection, most is focused on the vegetation on ‘Mezozoic limestone’. These limestone areas are of outstanding beauty containing the deeply eroded limestone karst, known locally as ‘tsingy’ (see discussion below)

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[2] Since submission of this article the formation of the new Masoala park has been formalised. This extremely large area (the largest protected area in Madagascar) provides a very significant contribution to the protection of the evergreen, humid forest at low altitudes.
This new park covers over 2,000 km^2 of primary forest, which is predominately (80%) ‘evergreen humid forest: low altitude’: nearly all on basement rocks, with very small areas on quartzites and lavas. The rest (20%) is made up of ‘evergreen humid forest: mid altitude’ on basement rocks.

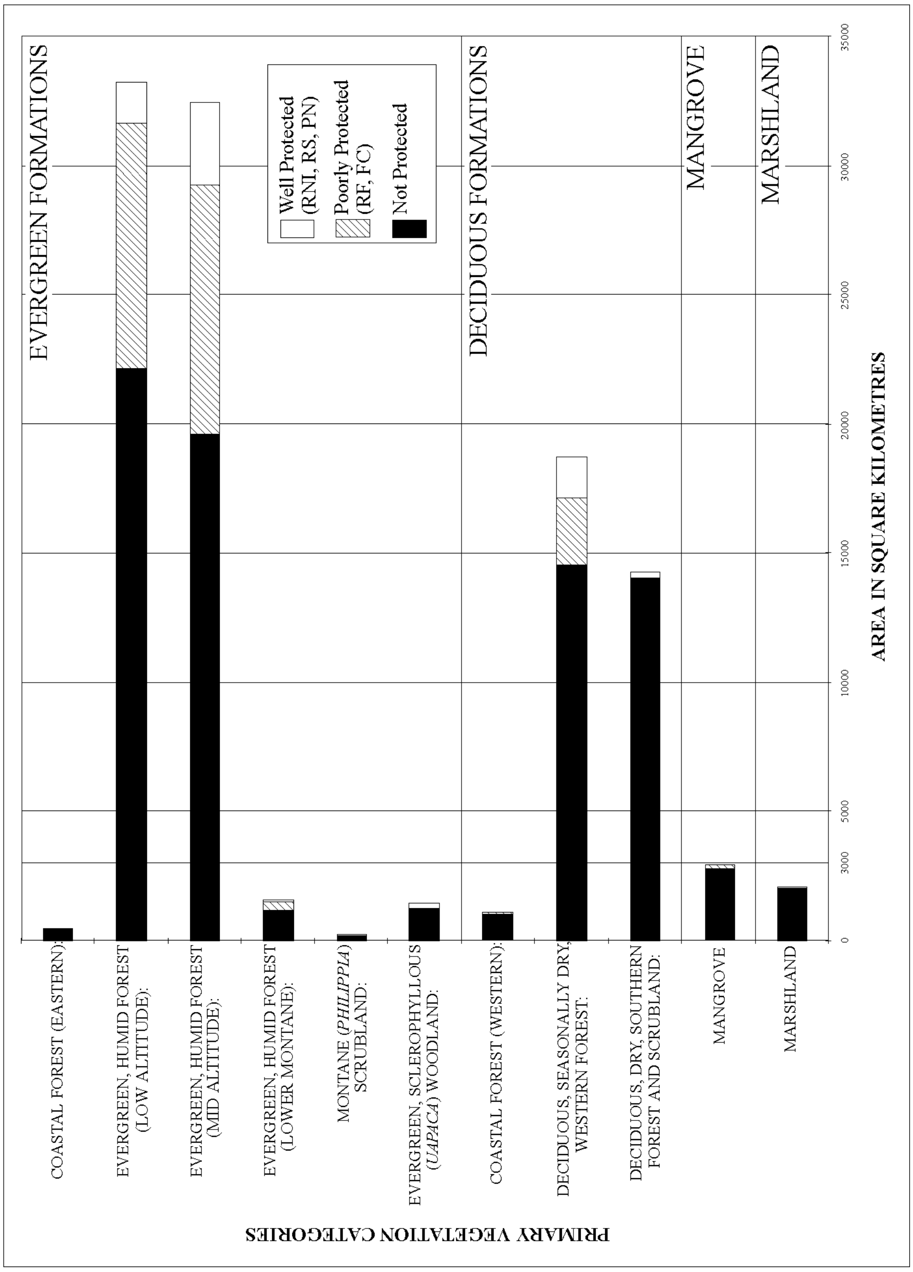


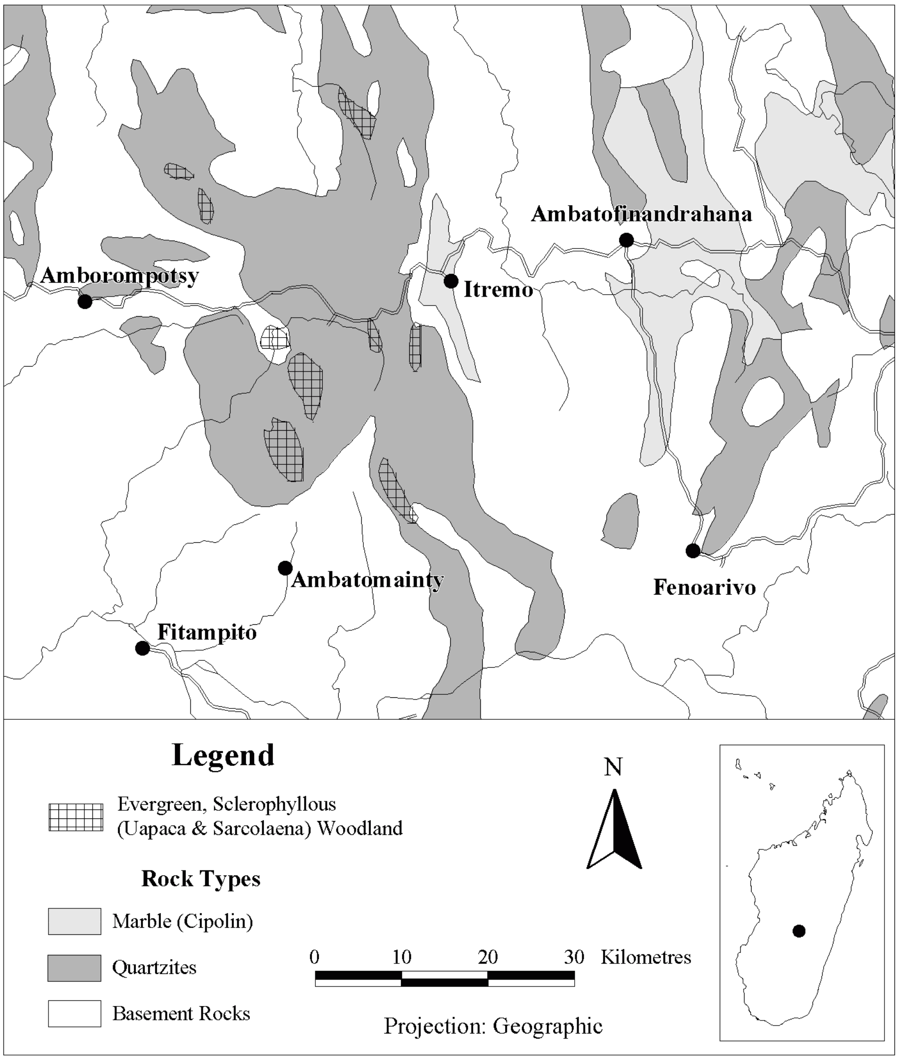
Figure 2. Areas of Remaining Primary Vegetation:
showing their Degrees of Protection.

RESTRICTED VEGETATION ZONES

The remaining vegetation zones (Fig. 2), which are restricted to small areas of remaining primary vegetation (all less than 3000 km^2), are of concern and should be considered as priority areas. Amongst these, the ‘coastal forest (eastern)’ and the ‘evergreen, sclerophyllous woodland’ dominated by *Uapaca bojeri* (Euphorbiaceae) merit particular mention for the need for conservation (see also Fig. 4).

The ‘coastal forest (eastern)’ zone has historically been under intense pressure as it is confined to the coastal plains of the east coast, where there are numerous towns and settlements which have used this forest for construction wood and charcoal, and it has been easily accessible by sea and along the canal which extends along the coastal plains (the ‘pangalan’). There are very few remaining patches of this forest (Map 1), mainly in scattered stands along the northern stretch of coast from Vohemar to the Bay of Antongil, and at other scattered localities further south including Fenoarivo Atn. (Tampolo), Isle Sainte Marie and Pointe à Larée, Ambila-Lemaitsu, Manakara and around Tôlañaro (Fort Dauphin) at Cap Sainte Luce and Ampetrika (Petriky). The areas around Tôlañaro are soon to be largely destroyed through mining: the coincidence of sands rich in titanium and the remaining forest remnants is remarkably high. The few remaining stands of forest are rich in locally endemic species, and have a very high diversity. Orchids, for example, are plentiful near sea level, and do not again form a large element of the flora until around the 600 m contour in the ‘evergreen, humid forest’ (see Bosser, *et al*., 1996). The threat of mining will remove a substantial proportion of the remaining primary forest in this zone and every effort is required to preserve as much as is possible. These forests in the south-east are of particular interest as they span the rapid transition zone from humid to dry vegetation and there are many highly localised species in the individual forest remnants.

The ‘evergreen, sclerophyllous (*Uapaca*) woodland’ (Map 1) is a distinctive vegetation which is almost the only remnant of the forest which is previously thought to have covered large areas of the southern half of the central plateaux. It has been modified by the annual grassland fires, and only persists due to the resistance of the *Uapaca* trees to these fires. It is generally species-poor, and is maintained for various ethnic reasons including native silk production (see Gade, 1985). Figure 4 shows that the majority occurs on sandstones, and that a substantial area is protected within the Isalo National Park (PN). However, the small cluster of remnants which occur on ‘quartzites’ in the Itremo Massif (Map 2) have a substantially different character, and form mixed stands with *Sarcolaena oblongifolia.* They are associated with a flora on the surrounding exposed rocks containing many endangered orchids (see Bosser, *et al*., 1996) and succulents (such as miniature *Aloe* and *Pachypodium* species and the last major stands known of the palm *Dypsis (Chryslidocarpus) decipiens*, all listed on Appendix I of CITES). Similarly, the ‘marbles (Cipolins)’ on the eastern flanks of the Massif contain their own unique flora which is highly threatened due to its very restricted nature and the concession of marble mining rights in the region. The whole of this area (Map 2) should be a priority for inventory and accurate mapping. The vegetation on the ‘quartzites’ and ‘marbles (Cipolin)’ in the Itremo Massif is of extremely high value and importance: this region, which is also of great beauty, certainly merits adequate protection.



Map 2. Itremo Massif area, showing the remaining areas of 'Evergreen, Sclerophyllous Woodland' and the occurrence of quartzite and marble ('Cipolin') rock types.

David Du Puy & Justin Moat.

REMAINING AREAS OF PRIMARY VEGETATION IN SOUTHERN AND WESTERN MADAGASCAR, SUBDIVIDED ACCORDING TO THE ROCK TYPES ON WHICH THEY OCCUR: IMPLICATIONS FOR THE PROTECTION OF BIODIVERSITY

DECIDUOUS, DRY, SOUTHERN FOREST AND SCRUBLAND

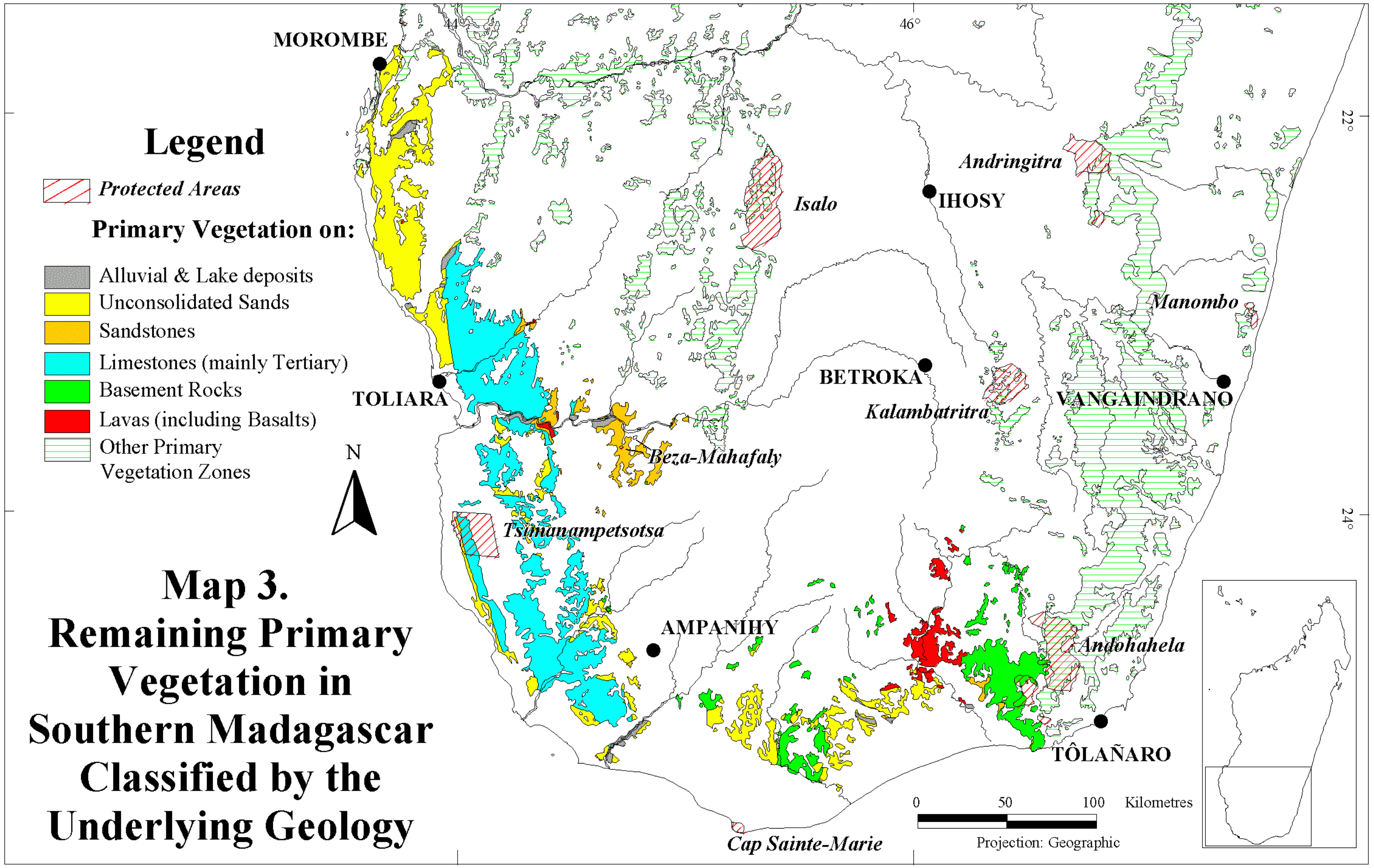
According to the histogram showing the remaining areas of primary vegetation within the major vegetation zones (Fig. 2, discussed above), of the four vegetation zones which still contain substantial areas of primary vegetation, the ‘deciduous, dry, southern forest and scrubland’ (Map 1) is of greatest concern, as there is only an extremely small proportion within current protected areas. Furthermore, if this zone is subdivided into different vegetation types according to the underlying geology (Fig. 5), it becomes apparent that three major rock types still support large areas of primary vegetation: ‘unconsolidated sands’, ‘Tertiary limestones’ and ‘basement rocks’. The distributions of these vegetation types are shown in Map 3, and are obviously major candidates for protection within reserves. The most appropriate localities for conservation can be chosen from amongst the areas indicated for each vegetation type.

The most poorly protected, and probably the most threatened vegetation type in this zone occurs on the unconsolidated sands (Map 3). The area accessible by the road to the north of Toliara (Tulear) has already been felled for charcoal, leaving only Mikea Forest, between Toliara (Tulear) and Morombe as the only remaining extensive area. Mikea forest is of great importance if the diversity of the southern zone is to be preserved. Another very localised area on sand, of high interest although restricted in size, occurs around Itampolo: the proximity of the Mahafaly Plateau and its escarpment in this region provides the potential for a reserve of great interest and diversity enclosing vegetation on two of the main rock types. The few remaining areas of this vegetation zone on sandstone are represented in the Beza Mahafaly reserve (Fig. 5, Map 3). This area is, nevertheless, extremely small and should be substantially extended.

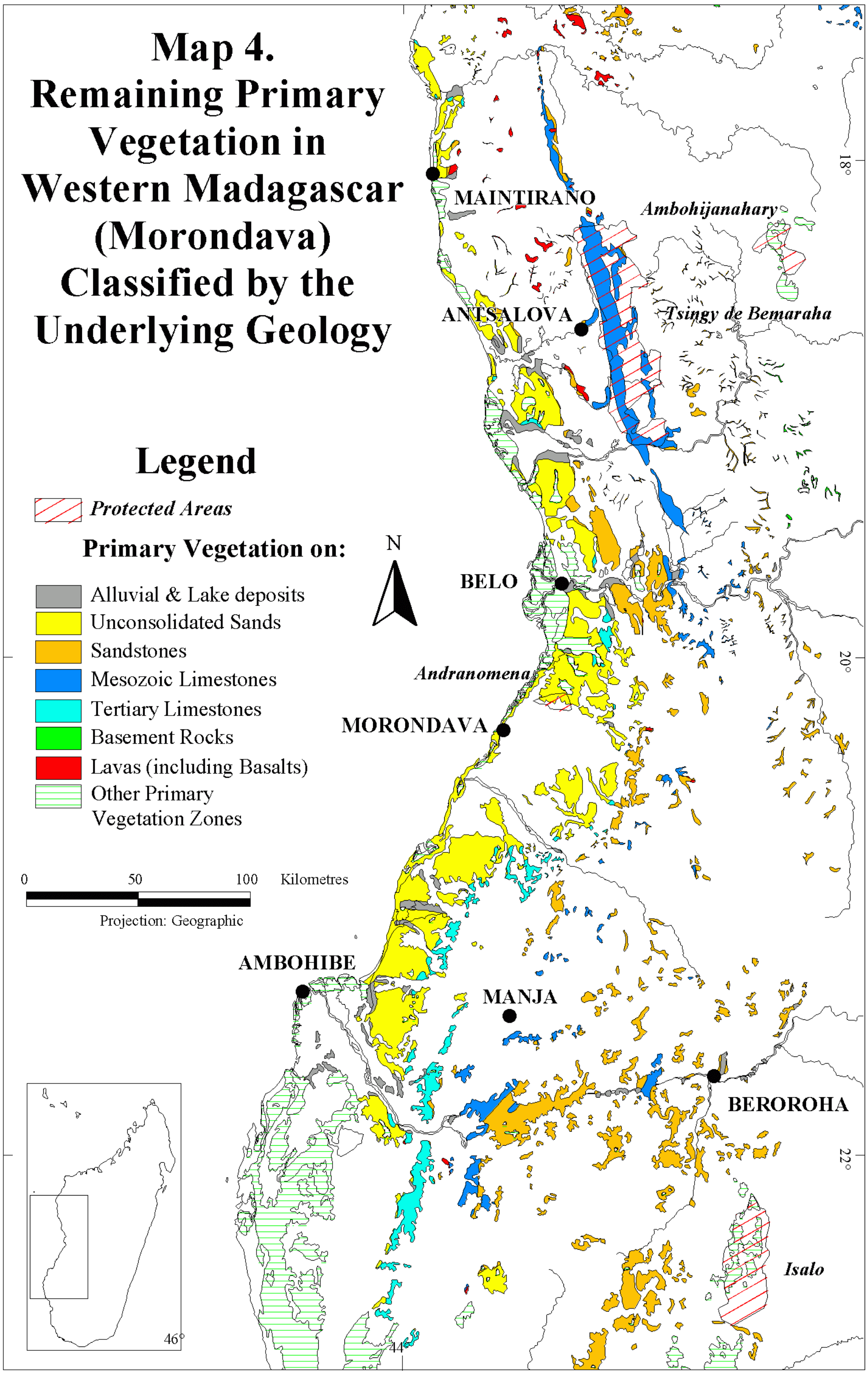
The ‘Tertiary limestones’ are represented in the ‘deciduous, dry, southern forest and scrubland’ zone, by the vegetation on the Mahafaly Plateau (Map 3): the Tsimanampetsotsa Reserve (RNI) provides an absolute minimum of protection. It is strongly recommended that other areas of the Mahafaly Plateau should be protected, and the area behind Tulear, including the escarpment edge towards Saint Augustin, offers an outstanding example which could be linked to a profitable tourist economy. Similarly, protection of the vegetation on the ‘basement rocks’ which occur along with ancient ‘lavas (basalts & gabbros)’ in the large crater-like basin of the Mandrare River should be extended: the Andohahela Reserve (RNI, parcelles 2 & 3) is in this area and provides protection for only a very small proportion.

DECIDUOUS, SEASONALLY DRY, WESTERN FOREST

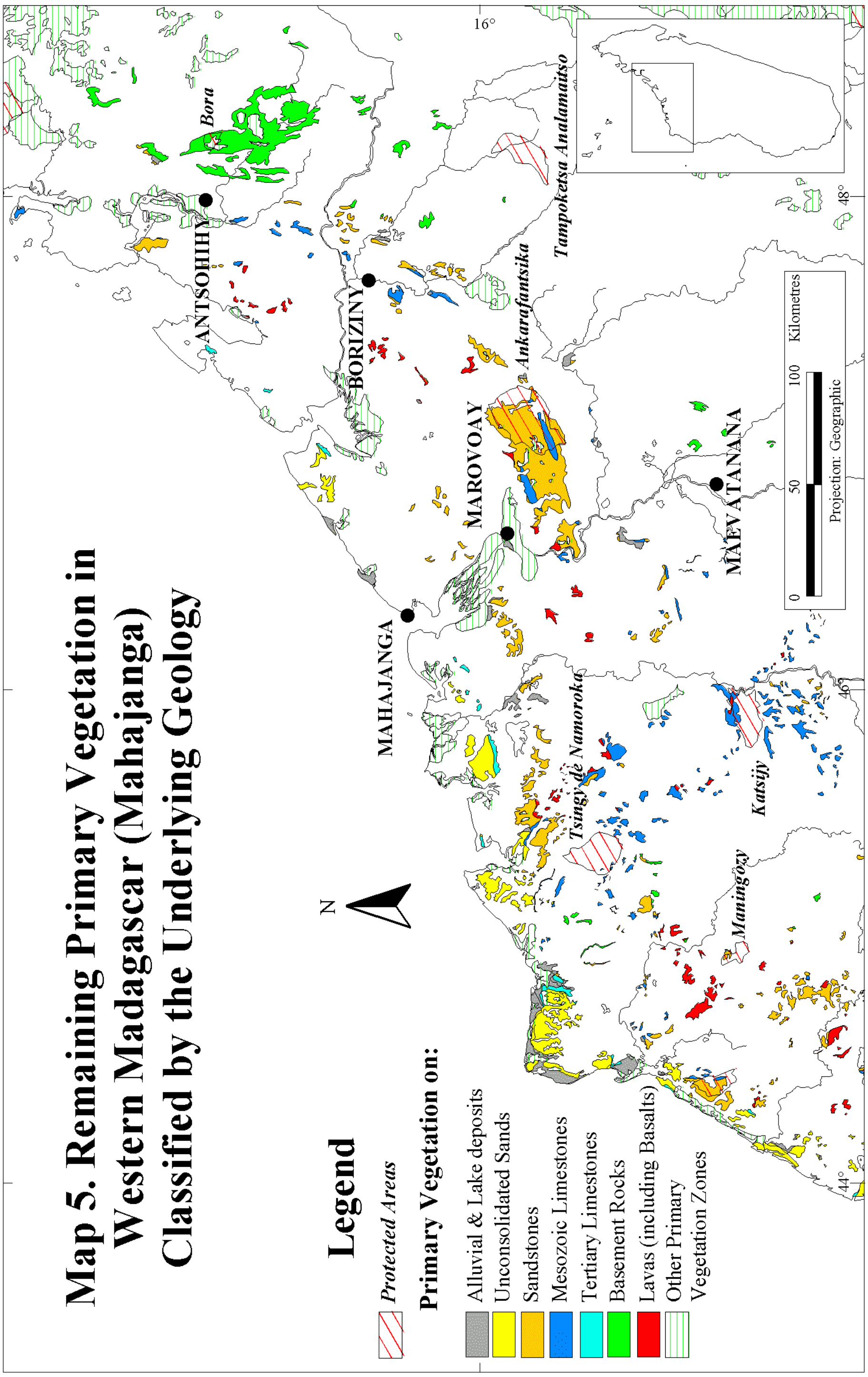
Although the histogram in Figure 2 shows a relatively large amount of protection within the ‘deciduous, seasonally dry, western forest’ (Map 1), it is evident, when this zone is subdivided by rock type (Maps 4, 5 and Fig. 5), that the large majority of this protection is of vegetation on the ‘Mesozoic limestones’. These are ancient Jurassic limestones, which have often become deeply eroded into spectacular ‘tsingy’ or limestone pinnacles traversed by canyons formed through the collapse of underground river systems. In fact, the vegetation in these areas is one of the least in need of active protection as the nature of the habitat renders it of little use for grazing, in little danger from grassland fires, and inaccessible to human exploitation due to the extreme difficulty of access, particularly where bare feet cannot tolerate the sharp rocks. However, within this western zone there still exists a large area of ‘deciduous, seasonally dry, western forest’ on ‘unconsolidated sands’ which has very little protection at present (Fig. 5), and which must be considered as a major candidate for the establishment of a protected area. There are substantial areas remaining of this vegetation type along the western coastal plains between Maintirano and Morombe (see Map 4), including the areas to the west of the Tsingy de Bemaraha, and the forests to the north of the Mangoky River. These forests are inaccessible and little known: they are key areas for which inventory work and botanical exploration are particularly required. The upgrading of the Forêt Classée of Marofihitra (north of Morombe), the extension of the Réserve Spéciale d’Andranomena (south of Morondava), and the protection of the forest to the west of the Bemaraha Massif could provide ideal opportunities for increased conservation of this habitat. A secondary category in this region, which is little known but also a strong candidate for protection is the forest on ‘basement rocks (igneous and metamorphic)’ which occurs to the south-west of the Tsaratanana Massif in NW Madagascar (Map 5). The remnant forest of Zombitsy (NW of Sakaraha, currently also a Forêt Classée), on sand over sandstone is also a unique area which, due to its proximity to the main road, is undergoing perhaps unparalleled rates of clearance, and is of immediate concern.



Map 3. Remaining Primary Vegetation in Southern Madagascar Classified by the Underlying Geology



Map 4.
Remaining Primary Vegetation in Western Madagascar (Morondava) Classified by the Underlying Geology
Legend
Protected Areas
Primary Vegetation on:
Alluvial & Lake deposits
Unconsolidated Sands
Sandstones
Mesozoic Limestones
Tertiary Limestones
Basement Rocks
Lavas (including Basalts)
Other Primary Vegetation Zones
0
50
100
Kilometres
Projection: Geographic
N
MAINTIRANO
Ambohijanahary
ANTSALOVA
Tsingy de Bemaraha
BELO
Andranomena
MORONDAVA
AMBOHIBE
MANJA
BEROROHA
Isalo
18°
20°
22°
44°
46°


Map 5. Remaining Primary Vegetation in Western Madagascar (Mahajanga) Classified by the Underlying Geology
Legend
Protected Areas
Primary Vegetation on:
Alluvial & Lake deposits
Unconsolidated Sands
Sandstones
Mesozoic Limestones
Tertiary Limestones
Basement Rocks
Lavas (including Basalts)
Other Primary Vegetation Zones
N
Bora
ANTSOHIHY
BORIZINY
Ankarafantsika
Tampoketsa Analamaitso
MAROVOAY
MAHAJANGA
MAEVATANANA
Tsingy de Namoroka
Katsijy
Maningozy
16°
48°
46°
44°
0
50
100
Kilometres
Projection: Geographic

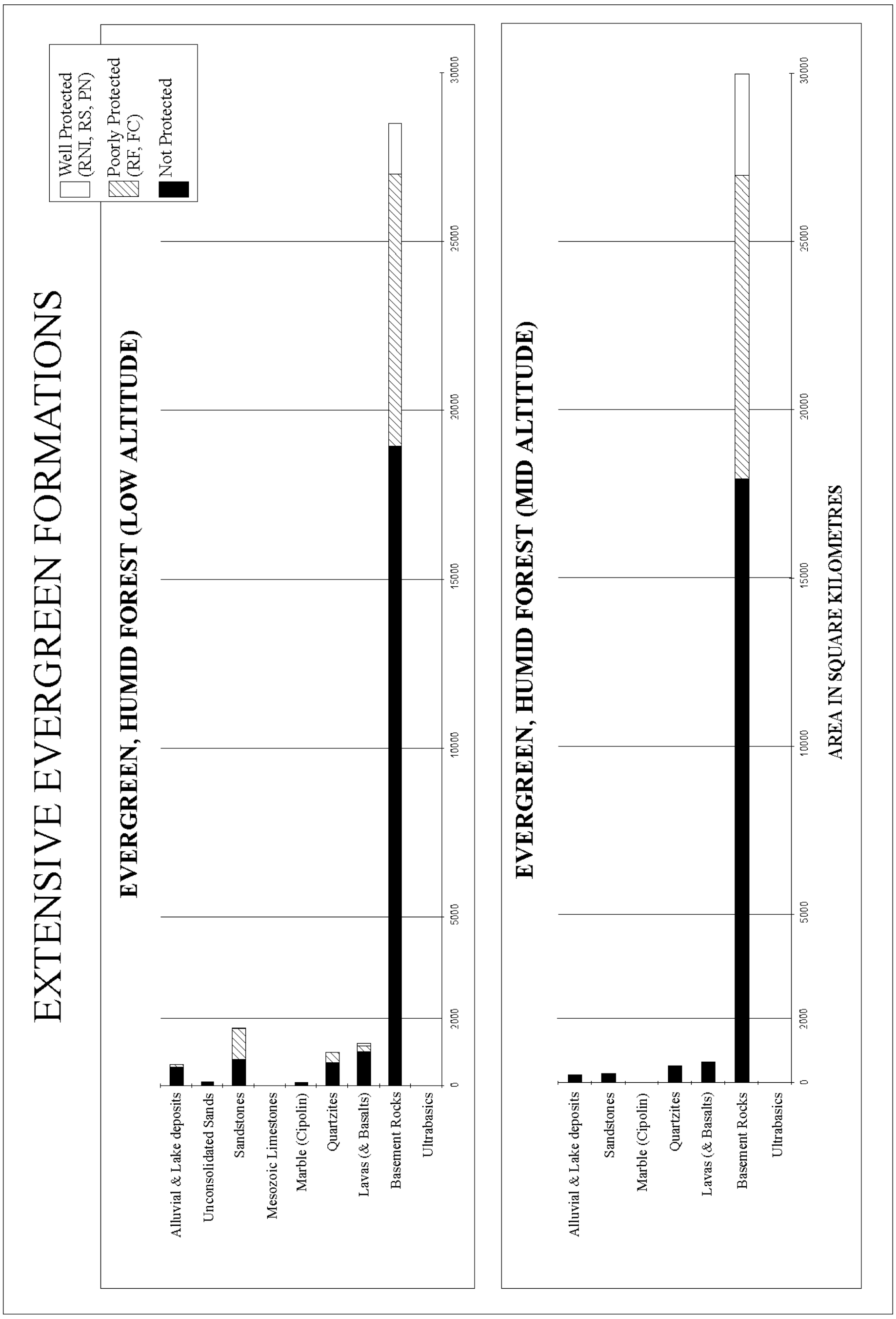


Figure 3. Areas of Extensive Primary Evergreen Formations:
Classified by the Underlying Geology
and showing their Degrees of Protection.

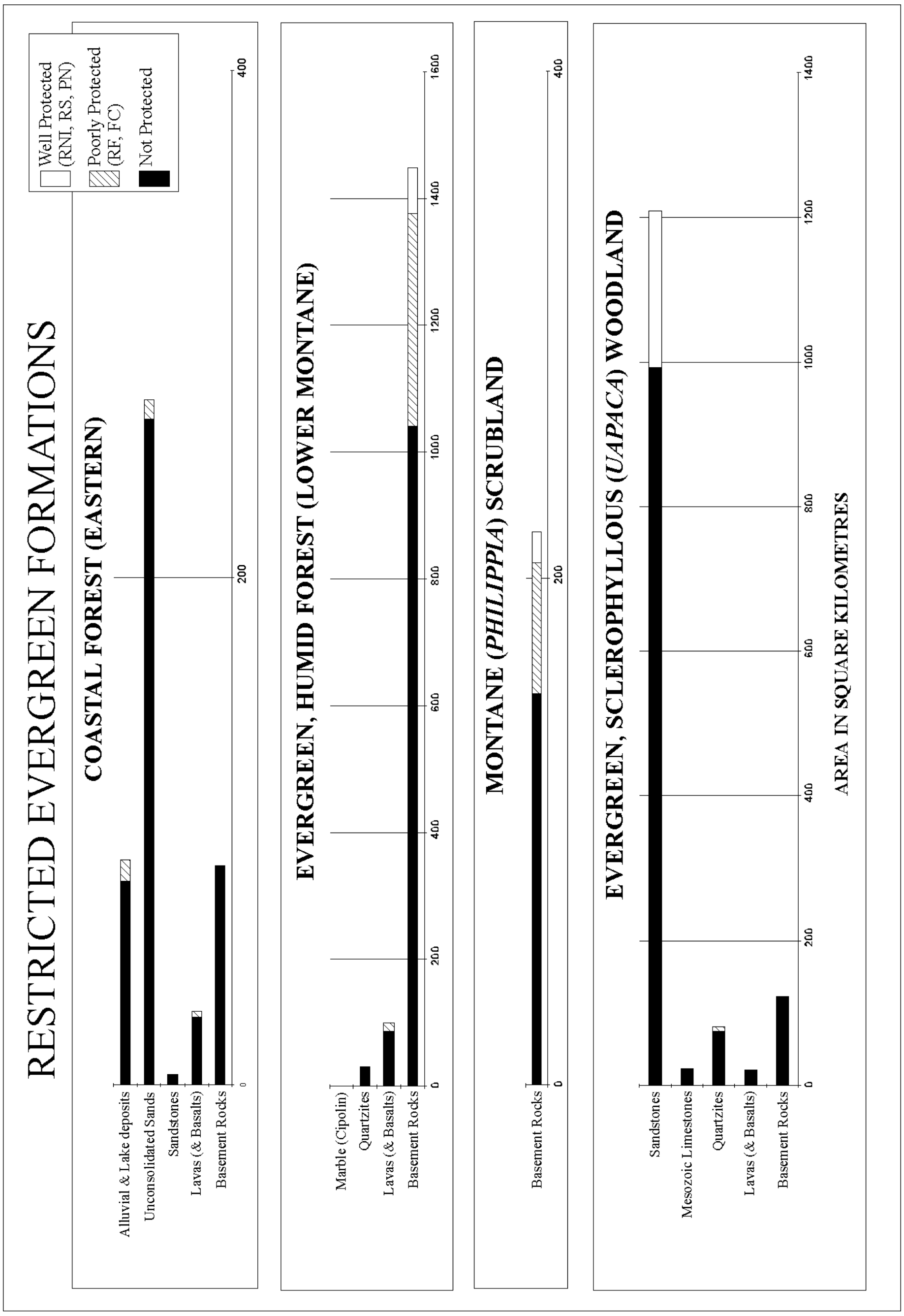


Figure 4. Areas of Restricted Primary Evergreen Formations:
Classified by the Underlying Geology
and showing their Degrees of Protection.

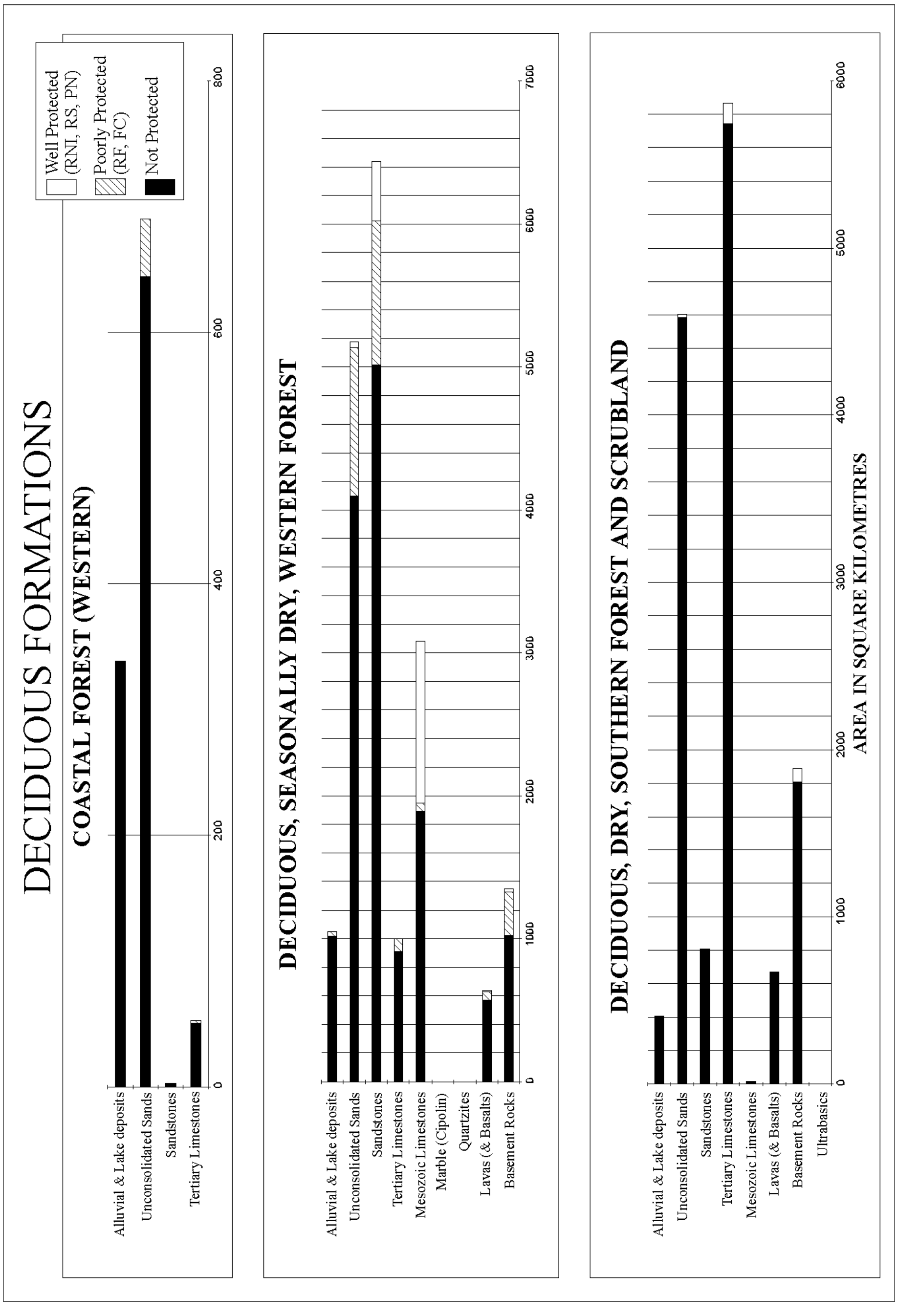


Figure 5. Areas of Primary Deciduous Formations:
Classified by the Underlying Geology
and showing their Degrees of Protection.

CONCLUSIONS

The maps presented here, and the histograms derived from them, can be interpreted as reflecting patterns of biodiversity distribution, and in particular plant diversity. If reserves were established in as many different vegetation types as possible (the vegetation types indicated by the vegetation zones subdivided by geological substrate), then the greatest possible diversity of species would be included in the protected areas. Some species distributions have already been shown to coincide with the geological categories used in this study, and it is probable that many more follow the same patterns.

The highlighted examples of the areas of importance for conservation in Madagascar are in no way exhaustive, but for the first time recommendations concerning conservation of plant diversity have been supported by statistical evidence. The main vegetation types identified within this study which are largely excluded from or are inadequately protected by the current system of protected areas are summarised below (not in order of importance):

- Deciduous, dry, southern vegetation (Map 3) on:
    1. Unconsolidated sands (Mikea Forest, Itampolo)
    2. Mesozoic limestones (Mahafaly Plateau)
    3. Sandstones (extension of the Beza Mahafaly reserve)
    4. Basement rocks and ancient Lavas and basalts (Mandrare River basin, north and west of Ifotaka)
- Deciduous, seasonally dry, western forest (Maps 4 and 5) on:
    5. Unconsolidated sand (coastal plains between Morombe and Maintirano)
    6. Basement Rocks (SW of the Tsaratanana Massif)
    7. Sandstones (Forest of Zombitsy)
- Evergreen, sclerophyllous (*Uapaca*) woodland on:
    8. Quartzites and marbles (‘Cipolins’), with associated succulent flora on exposed, non-forested areas (Itremo Massif, Map 2)
- Evergreen, humid forest at low altitude (Map 1):
    9. Particularly at lowest altitudes (Vohemar to the Masoala Peninsula an around the Bay of Antongil, Manombo and other areas described in the text)
- Eastern coastal forest (Map 1):
    10. All remaining remnants (described in the text, especially ensuring some protection for remnants in the south-east near Tôlañaro (Fort Dauphin)).

Traditional reserve boundaries, although often transgressed, are generally recognised locally. It is therefore recommended that, wherever possible, existing protected areas with a lower degree of protection should be upgraded and given more adequate protection rather than creating entirely new protected areas, for which it may be more difficult to gain local acceptance. Furthermore, protected areas can only offer true protection if adequate funds and personnel are made available and are assured for the future, and that the will to ensure continued protection is cultivated at a local and a national level.

We hope that this work will contribute to the planning of priorities for the conservation of biodiversity in Madagascar, particularly in the selection of areas suitable for the establishment of new reserves. The inclusion of habitats not currently covered by the existing series of protected areas will allow the conservation of as much of the island's phytodiversity as possible.

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