

Setting Conservation Priorities – A Key Biodiversity Areas Analysis for the Seychelles Islands

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Abstract: Key Biodiversity Areas (KBAs) are areas identified as being important for the conservation of biodiversity due to the presence of threatened species or habitats, or particularly high levels of biodiversity. They are a useful concept for setting site conservation priorities, combining other categories such as biodiversity hotspots, Important Bird Areas and 'ecoregions'. An analysis of the terrestrial KBAs of the Seychelles islands based on comprehensive biodiversity assessments identifies 48 sites of conservation importance. A high proportion of the land area of Seychelles is designated as protected areas, however, the KBA analysis indicates that this needs to be expanded by a further 47km². The KBAs are threatened by development (6 sites), sea-level rise (13 sites) and unpredictable climate change (16 sites). Habitat degradation caused by invasive species is the most significant threat to the largest number of KBAs, affecting all 48 sites with invasive species dominating the plant communities in 15 sites. There is an urgent requirement for future conservation in Seychelles to combine effective legal protection of KBAs with large-scale habitat restoration.

INTRODUCTION

Setting conservation priorities has been the subject of intense discussion over the past 30 years. It is widely accepted that priorities for site selection must be established to maximise the effectiveness of limited conservation resources and to minimise biodiversity loss. However, there has been little agreement over how to undertake such prioritisation [1]. The main methods have included biodiversity hotspots [1, 2], specific areas of biological richness such as Important Bird Areas (IBA) [3] and Important Plant Areas (IPA), areas with threatened species [5] and representative ecosystems ('ecoregions') [6]. The concept of Key Biodiversity Areas combines all these priority setting measures, forming a single useful framework [7]. A recent analysis of the current state of biodiversity of the Seychelles islands allows KBAs to be identified for the islands using taxonomic diversity, threat ranking and the more subjective measures of IBAs and IPAs. This analysis enables comparisons between the effectiveness of the component measures in determining priorities for protection.

The 115 Seychelles islands cover over a million square kilometres in the western Indian Ocean (Fig. 1), lying within the Madagascar region biodiversity hotspot. 7,200 species of animal, plant and fungi have been recorded from the islands, including several famous species such as the Aldabra giant tortoise *Dipsochelys dussumieri* (Gray) and the coco-de-mer palm *Lodoicea maldivica* (Gmel.)Pers. Endemism is comparatively high at between 50-88% for different animal groups [8-11] in general and approximately 45% for plants [12].

A large proportion of genera are endemic and there is one endemic family of tree, represented by the critically endan-

gered jellyfish tree *Medusagyne oppositifolia* Baker (Medusagynaceae) and an ancient endemic family of frogs (Sooglossidae). The great significance of the biodiversity of the Seychelles islands was first recognised by Professor John Stanley Gardiner of Cambridge University who organised and led the Percy Sladen Memorial Expedition to the Indian Ocean in 1905. The remarkable number of new species found in 1905 inspired Gardiner to organise a second expedition specifically to the Seychelles islands. The combined effort of these two expeditions remains the largest research effort to concentrate on the region. The Indian Ocean Biodiversity Assessment 2000-2005 (IOBA) marked the centenary of the Gardiner expeditions by surveying the biodiversity of the Seychelles islands [13]. This covered all 32 of the granitic islands, a range of the coral islands in the Amirantes, and Aldabra and the southern atolls. This programme assessed the diversity of all multicellular terrestrial and freshwater organisms, rather than relying on indicators. The results of this assessment are presented here as the first Key Biodiversity Areas analysis for an entire archipelago in the Western Indian Ocean region.

METHODS

Biodiversity Assessment

The collecting methods used in the Indian Ocean Biodiversity Assessment and evaluation of the effectiveness of collecting are described elsewhere [13]. For most taxa collections are considered to provide an accurate assessment of the biodiversity of the islands. Fungi, tardigrades, nematodes and mites remain inadequately sampled, current data providing a comparative assessment rather than a full evaluation of diversity.

KBA Measures

KBAs have been defined on the basis of containing globally threatened species, restricted range species with small global ranges, congregatory species or biome restricted

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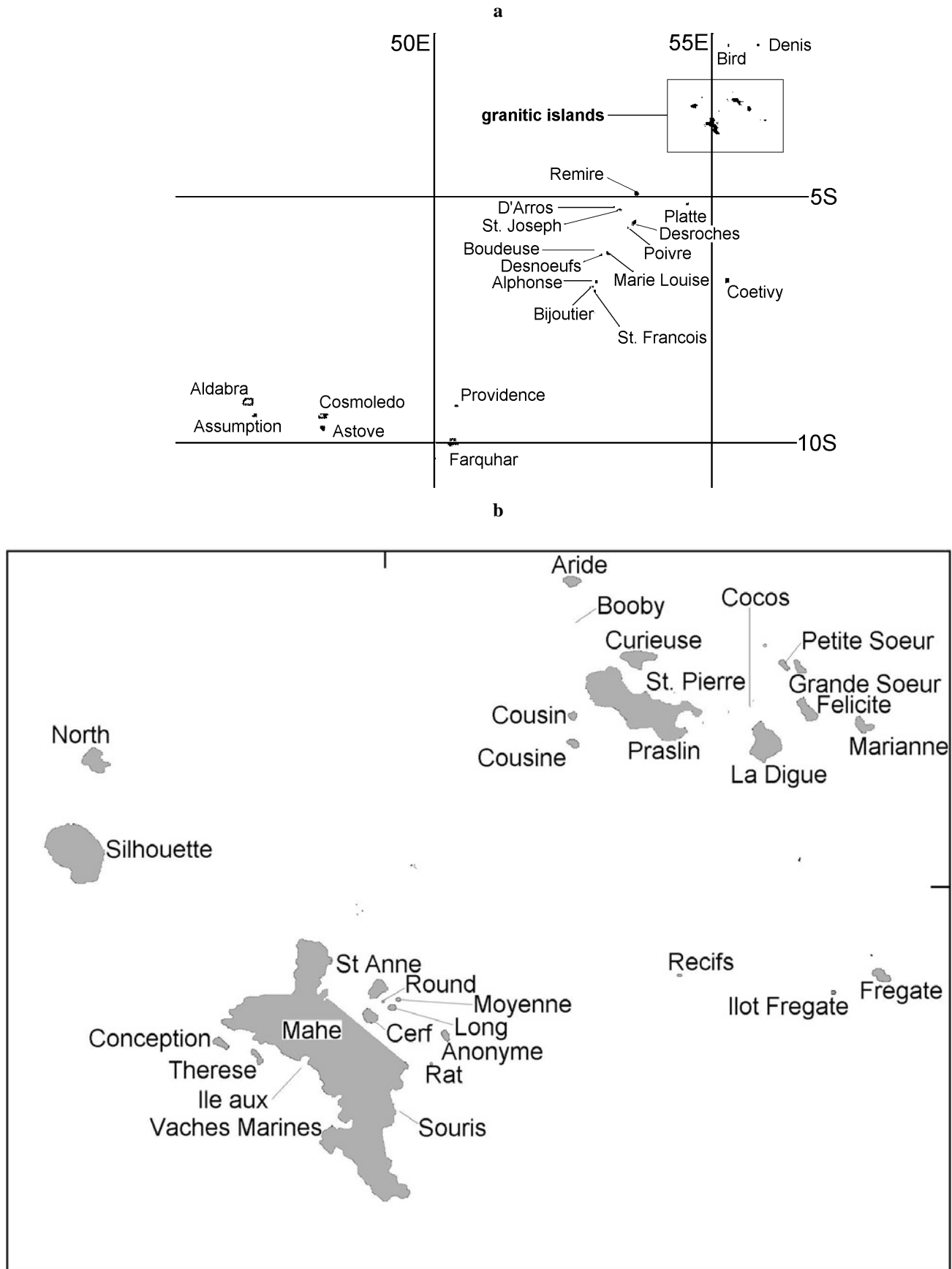


Fig. (1). Islands of the Seychelles group. a) all islands in the group; b) detail of the granitic islands.

Table 1. Important Plant Areas of Seychelles

Island	Important Plant Areas	Critically Endangered Taxa	Endangered Taxa	Species Richness	Priority Habitats
Mahé	Anse Major to Cap Ternay	<i>Medusagyne oppositifolia</i>		-	-
	Bernica	<i>Medusagyne oppositifolia</i>		-	-
	Rivière Grand St. Louis			-	-
	Morne Seychellois - Morne Blanc	<i>Drypetes riseleyi</i> <i>Gastonia lionneti</i> <i>Gastonia sechellarum</i> var. <i>contracta</i> <i>Grisollea thomasseti</i> <i>Psathura sechellarum</i> <i>Rapanea sechellarum</i> <i>Vateriopsis sechellarum</i>	<i>Camptosperma sechellarum</i> <i>Canthium sechellense</i> <i>Craterispermum microdon</i> <i>Gastonia sechellarum</i> var. <i>sechellarum</i> <i>Glionnetia sericea</i>	>10% montane forest	Montane forest
	Mare aux Cochons			>10% high altitude marsh	High altitude marsh
	Grand Bois	<i>Vateriopsis sechellarum</i>			
	La Reserve		<i>Camptosperma sechellarum</i> <i>Craterispermum microdon</i>		
	Montagne Planeau		<i>Gastonia sechellarum</i> var. <i>sechellarum</i>		Montane forest
	Mont Sebert	<i>Medusagyne oppositifolia</i>	<i>Secamone schimperiana</i>		
	Port Launay			Rich mangroves	magroves
	Police Bay				Lowland marsh
Silhouette	Jardin Marron	<i>Grisollea thomasseti</i>	<i>Gastonia sechellarum</i> var. <i>sechellarum</i>	Rich Typical sub-montane	
	Mont Dauban - Mont Pot a Eau	<i>Grisollea thomasseti</i> <i>Psathura sechellarum</i> <i>Rapanea sechellarum</i> <i>Schefflera procumbens</i>	<i>Canthium sechellense</i> <i>Glionnetia sericea</i>		Montane forest
	Gratte Fesse slopes	<i>Grisollea thomasseti</i> <i>Trilepisium gynandrum</i>	<i>Canthium sechellense</i> <i>Gastonia sechellarum</i> var. <i>sechellarum</i>		
	<i>Pisonia sechellarum</i> forest	<i>Grisollea thomasseti</i> <i>Psychotria silhouettae</i> <i>Schefflera procumbens</i>	<i>Pisonia sechellarum</i>	>10% hygrophilic sub-montane	
	Anse Mondon valley	<i>Grisollea thomasseti</i> <i>Psychotria silhouettae</i>	<i>Gastonia sechellarum</i> var. <i>sechellarum</i>		
	Grande Barbe				Lowland marsh
	South coast	<i>Drypetes riseleyi</i>	<i>Craterispermum microdon</i> <i>Gastonia sechellarum</i> var. <i>sechellarum</i>	>10% lowland	

(Table 1). Contd.....

Island	Important Plant Areas	Critically Endangered Taxa	Endangered Taxa	Species Richness	Priority Habitats
	La Passe	<i>Carissa edulis</i>			
	Mare aux Cochons	<i>Carissa edulis</i> <i>Grisollea thomasseti</i>			
	South eastern glacis	<i>Carissa edulis</i> <i>Drypetes riseleyi</i>			
Praslin	Praslin National Park & Fond Ferdinand	<i>Drypetes riseleyi</i>	<i>Craterispermum microdon</i> <i>Gastonia sechellarum</i> var. <i>sechellarum</i> <i>Secamone schimperiana</i>		
	Northern-eastern rocky coast		<i>Secamone schimperiana</i>		
La Digue	Mare Soupape				Lowland marsh
	Mont La Digue		<i>Gastonia sechellarum</i> var. <i>sechellarum</i>		
	Curieuse	<i>Gastonia sechellarum</i> var. <i>curiosae</i>	<i>Secamone schimperiana</i>		
	Felicite		<i>Gastonia sechellarum</i> var. <i>sechellarum</i>		
	Aride & Booby	<i>Rothmannia annae</i>			
	Aldabra	<i>Maillardia pendula</i>			

assemblages [7]. In the Seychelles context globally threatened species distributions are well known (at least for the small proportion of species currently assessed for the IUCN Red List). All endemic species would qualify as 'restricted range' species and the quantitative criterion of a site including 5% or more of the population of such a species [7] may be too broad in this context. Accordingly this criterion is used to designate a KBA only if a site contains at least 95% of the range and/or population of an endemic species. Seychelles is visited by relatively few migratory species. With the exception of a small number of palaeotropical Lepidoptera the migratory species are all birds, accordingly the congregatory species are included within the existing IBA listings. Biome restricted assemblages are poorly defined, in Seychelles plant communities on inselbergs have been characterised [14] and a characterisation of forest communities is underway. Until communities have been quantitatively characterised it will not be possible to identify such restricted assemblages, and this criterion has not been used here.

Biodiversity Hotspots and Biodiversity Rich Sites

The biodiversity hotspot concept developed by Myers in 1988 [15] and implemented by Conservation International in 2000 [2] has proven to be a valuable tool in highlighting areas of particular conservation significance. These areas are defined on the basis of on vascular plant species richness (>1,500 species) and threat levels (having lost at least 70% of its original habitat). These criteria are not directly applicable to small areas but the principles of the concept can be used to identify biologically rich sites. Such sites can easily be identified within the Seychelles islands due to the com-

plete survey of all aspects of biodiversity provided by the IOBA. In this assessment biologically rich sites have been defined as areas of exceptionally high biodiversity (more than 140 species of any taxonomic group in a 500x500m grid square) isolated from other areas by at least 250m of lower diversity habitat. In some cases, contiguous areas of high biodiversity have been subdivided due to clear habitat divisions, reflected in the distribution of species making up the diversity. Two sites with high recorded diversity were excluded as both sites (Cascade and Anse Royale – Anse aux Pins on Mahé, with 759 and 161 species respectively) have been extensively modified by urban development or agriculture and currently support low levels of native biodiversity.

Important Bird Areas and Important Plant Areas

Important Bird Areas have been defined for Seychelles [15] based on the presence of threatened birds of significant congregations of migratory species. These areas were used in the present analysis.

An analysis of Important Plant Areas has not been published for Seychelles although the data for this have been compiled (Table 1). Three criteria are used [4]:

- Threatened species – site contains at least 5% of a globally threatened species, or the 5 'best sites' for the species. Here the Angiospermae and Pteridophyta assessments for Critically Endangered and Endangered species submitted to the IUCN Red List in 2007 are used.

- b) Species richness – site contains at least 10% of a defined habitat type or is one of 5 ‘best sites’ in terms of species richness. Habitats are here defined as:
- 1) montane forest
 - 2) sub-montane forest
 - 2.1) typical sub-montane forest
 - 2.2) hygrophilic sub-montane forest
 - 3) lowland forest
 - 4) marsh
 - 4.1) high altitude marsh
 - 4.2) lowland marsh
 - 4.3) mangrove
 - 5) glacia rock (inselbergs)

- c) Priority threatened habitats – site contains at least 5% of a threatened habitat. Habitats considered threatened in Seychelles comprise montane forest (threatened by climate change) and marsh habitats (threatened by development).

Alliance for Zero Extinction Sites

The Alliance for Zero Extinction lists three sites for Seychelles based on the presence of over 95% of the population of a globally threatened vertebrate, conifer or cycad species in a particular area [5].

Minimum Protected Area Network

The minimum protected area network is the minimum area needed to protect all endemic species. This was identified by first identifying all species which were restricted to single 250x250m grid squares. These representing the only known locality for the most restricted endemic species. To

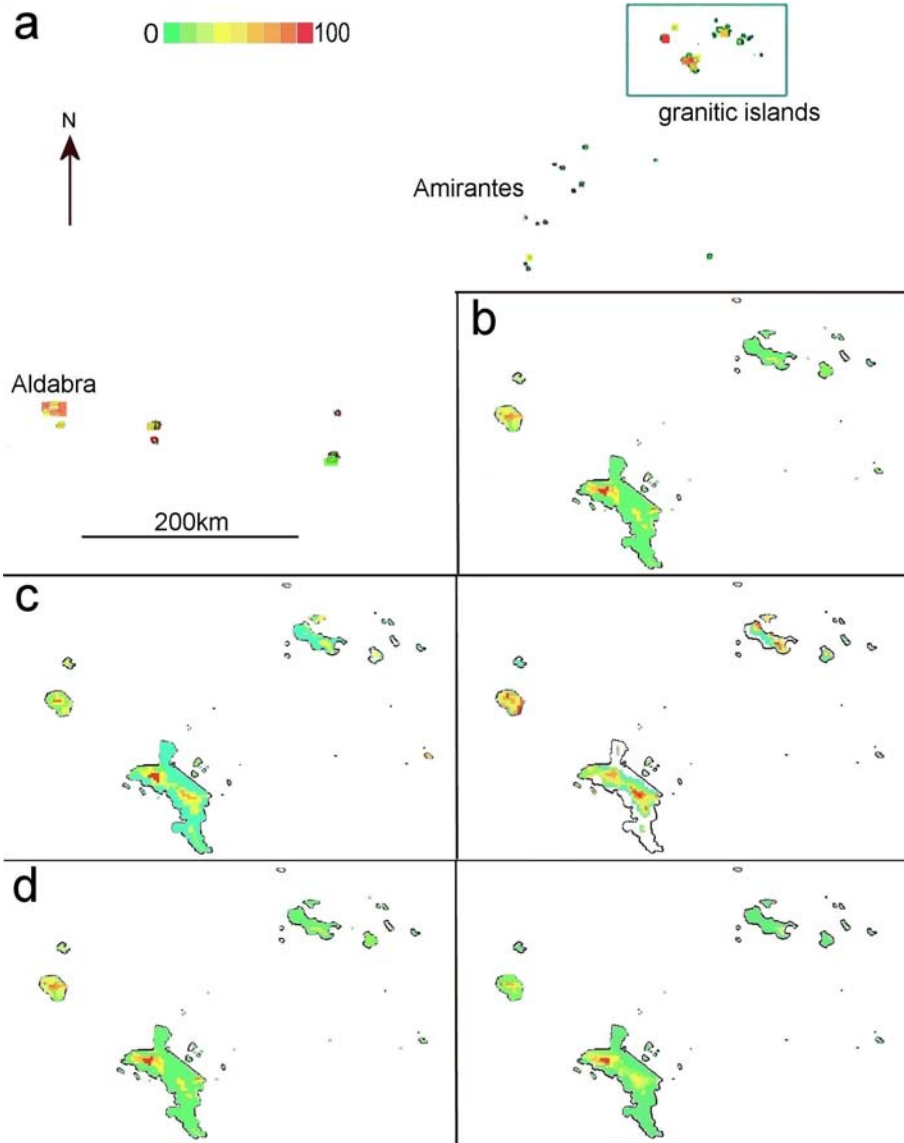


Fig. (2). Biodiversity rich sites in the Seychelles islands. Each grid square is coloured according to the % of the maximum species number recorded from lowest 10% (green) to the highest 10% (red). **a)** Total biodiversity for all islands (maximum species richness 909 species); **b)** total biodiversity for granitic islands only (maximum 909 species); **c)** plants (left – 204 total, right - 130 endemic); **d)** vertebrate and invertebrate animals (left - 874 total, right - 597 endemic).

this set of priority areas were added the grid squares with the highest levels of species richness. These were added progressively until all endemic species were included.

Threat Status

A qualitative evaluation of threat levels facing the KBAs was undertaken by categorising the threat posed by development, sea-level rise, climate change and invasive species. An indication of ecological dynamism was also provided. Ongoing or planned development affecting a significant part of the site or important components of biodiversity within a site were assigned a 'high' threat level. Lower level development was scored as 'moderate'. Existing development without plans for further expansion was categorised as 'low'. Sea-level rise was considered a risk to areas less than 1m

above sea level, sites with at least 50% of their land area below this level were considered 'high' risk, less than 50% at risk was considered a 'local' risk. Climate change threats were categorised as risk imposed by changes in rainfall and/or cloud cover. Invasive species were considered to be a 'high' threat to a site if they comprised at least 60% of the tree canopy, 'moderate' if 21-59% and 'low' if less than 20%. Data on levels of invasion are published elsewhere [17, 18].

RESULTS

Of the animal phyla Platyhelminthes, Annelida, Nematoda and Rotifera, and the insect classes Neuroptera, Thysanoptera, Mallophaga and Siphonaptera, and the Pauropoda in the Myriapoda and Schizomida and Scorpiones in the

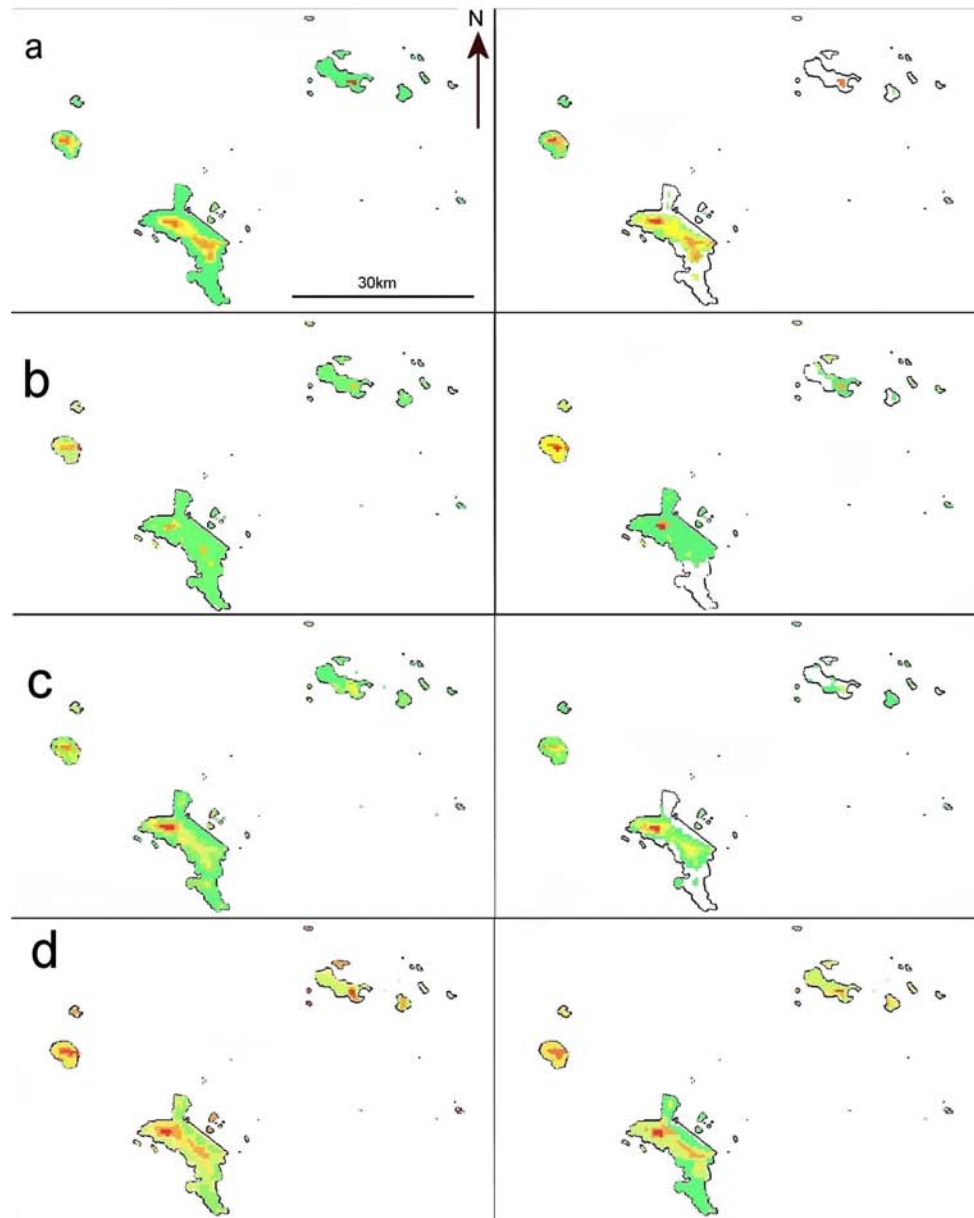


Fig. (3). Biodiversity rich sites in the granitic islands of Seychelles for different animal groups. Left column – native species, right column – endemic species. **a)** Mollusca (maximum species number 18 total, 18 endemic); **b)** Chelicerata (101 total, 52 endemic); **c)** Insecta (699 total, 476 endemic); **d)** Vertebrata (26 total, 20 endemic). Taxa where fewer than 10 endemic species were found in each grid square are not shown. Colour as in Fig. (2).

Chelicerata were excluded as no site had more than 5 species of any of these phyla which are all low diversity in the islands.

The biodiversity rich sites are shown in Figs. (2, 3); for clarity only the granitic islands are shown in detail. Species numbers are extremely low in the coral islands with fewer than 20 species of any taxon in any grid square. The exception is Aldabra atoll where two grid squares contain 23-45 plant species and 97-96 insect species. Plants used in designation of Important Plant Areas are summarized in Table 1. The distribution of sites identified as KBAs by different criteria are shown in Fig. (4) and detailed in Table 2.

Correlations Between Taxa

The same biodiversity rich sites were identified for all taxa (Fig. 2). The importance of these sites for different taxonomic groups was evaluated with Spearman's rank correlation. For each taxonomic group all sites were ranked by richness and comparisons made between groups. Significant correlations ($r' > 0.3$, $P_{2,43} < 0.01$) were found in all comparisons, indicating that all taxonomic groups share the same general distribution patterns. In order to test whether taxa shared more than just general distribution patterns cross-taxon congruence in complementarity was evaluated by comparing the correspondence between the biodiversity rich

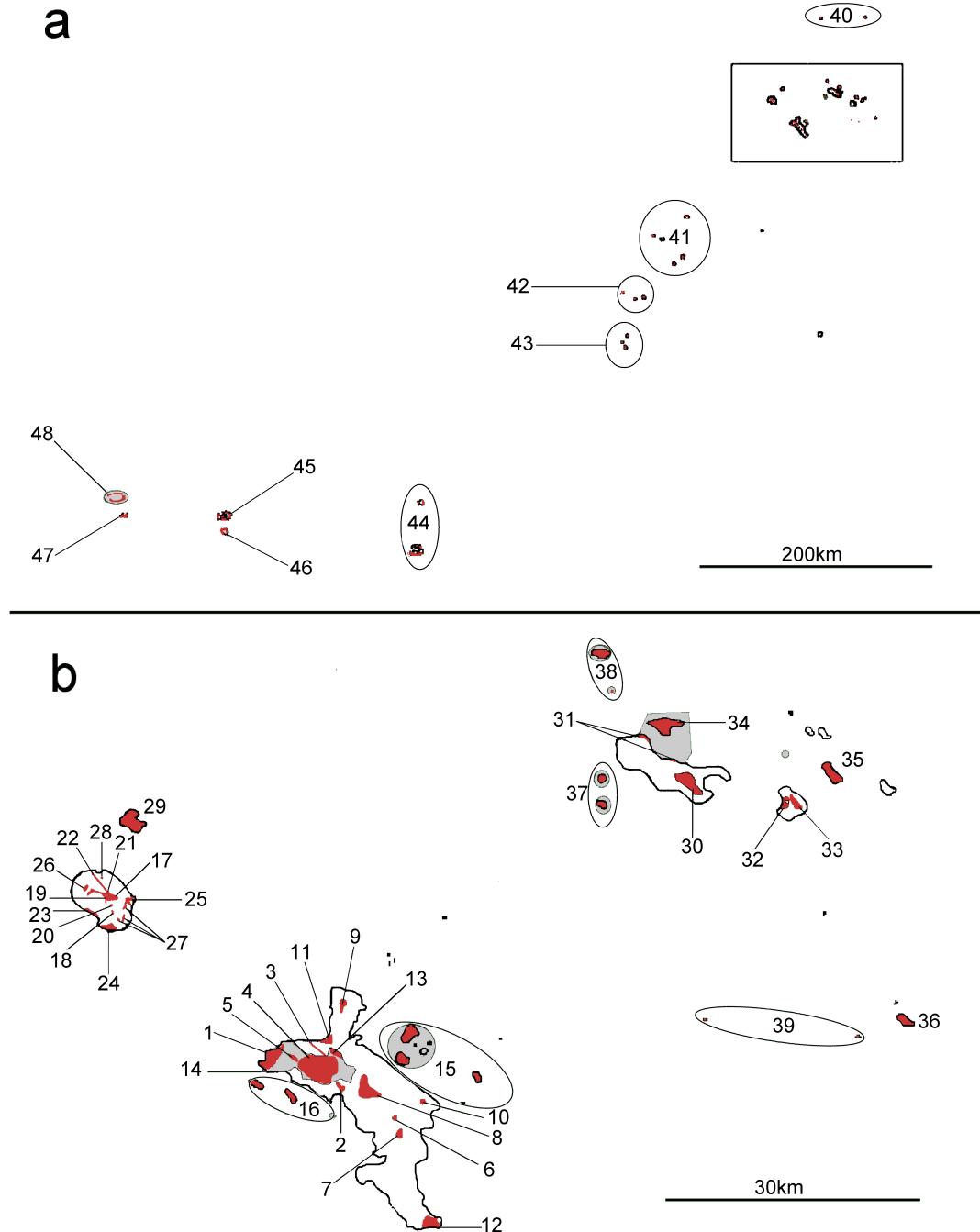


Fig. (4). Distribution of Seychelles KBAs. **a)** all Seychelles islands, box represents granitic islands; **b)** granitic islands. KBAs are shown in red and numbered from Table 1. Existing protected areas are shaded grey.

Table 2. Criteria Assigning KBAs. Two Protected Sites are Not Listed: Mamelles and Ilot Fous Bird Reserves Support Seabird Populations, However these are Currently Small and do Include Significant Populations of any Species Not Found on other Islands

	Island	KBA	Protected Area	Biodiversity Richness (rank)	IBA	IPA Criteria	AZE Sites	Minimum Protected Area Network
1	Mahé	Anse Major - Cap Ternay	Morne Seychellois NP	20		A		C
2		Bernica		24		A		C
3		Rivière Grand St. Louis		15	Mahé highlands			A
4		Morne Seychellois - Morne Blanc	Morne Seychellois NP	1	Mahé highlands	A, B, C	+	A
5		Mare aux Cochons	Morne Seychellois NP	8	Mahé highlands	B, C		A
6		Grand Bois		25	Mahé highlands	A		C
7		La Reserve		11		A		C
8		Montagne Planeau		9	Mahé highlands	A, C		C
9		Montagne Glacis		40	Montagne Glacis			-
10		Mont Sebert		21	Mahé highlands	A		A
11		Beau Vallon		31				-
12		Police Bay		37		C		-
13		Trois Freres - Morne Pilot	Morne Seychellois NP	4		A		A
14		Port Launay	Ramsar site	38		B, C		-
15	East coast islands		St. Anne Marine NP, Seche BR	12				B
16	West coast islands		Ile aux Vaches BR	44	Conception			-
17	Silhouette	Jardin Marron		6	Silhouette	A		A
18		Mont Corgat		14	Silhouette	A		
19		Mont Dauban - Mont Pot a Eau		3	Silhouette	A, C		A
20		Gratte Fesse slopes		13	Silhouette	A		A
21		<i>Pisonia sechellarum</i> forest		18	Silhouette	A, B		A
22		Anse Mondon valley		16	Silhouette	A		C
23		Grande Barbe		28	Silhouette	C	+	
24		South coast		41	Silhouette	A, B		
25		La Passe		7	Silhouette	A	+	A
26		Mare aux Cochons		5	Silhouette	A		A
27		South eastern glacis		19	Silhouette	A		A
28		Belle Vue		32	Silhouette			
29	North			27				A
30	Praslin	Praslin National Park - Fond Ferdinand	Praslin NP	10	Praslin NP	A		A
31		Northern-eastern rocky coast		42		A		-
32	La Digue	Mare Soupape	La Vev SR	-	La Digue	C	+	C

(Table 2). Contd.....

	Island	KBA	Protected Area	Biodiversity Richness (rank)	IBA	IPA Criteria	AZE Sites	Minimum Protected Area Network
33		Mont La Digue		35	La Digue	A	+	-
34		Curieuse	Curieuse MNP	34		A		A
35		Felicite		26		A		A
36		Fregate		29	Fregate			A
37		Cousin & Cousine	SR	23	Cousin, Cousine			A
38		Aride & Booby	SR	17	Aride	A		A
39		Recifs & Ilot Fregates		-				B
40		Bird & Denis		30	Bird			A
41	North Amirantes	Remire, African Banks, Poivre, Desroches, Etoile, D'Arros	African Banks BR	39	D'Arros, African Banks			A
42	South Amirantes	Marie Louise, Boudeuse, Etoile, Desnoeuvs	Etoile & Boudeuse BR	-	Marie Louise, Boudeuse, Etoile, Desnoeuvs			-
43		Alphonse & St. Francois atoll		-	Provisional*			-
44	Providence & Farquhar	Providence, Bancs de Providence, St. Pierre		42	Islets of Farquhar			B
45		Cosmoledo		21	Cosmoledo			A
46		Astove		34				B
47		Assumption		32				A
48		Aldabra	Aldabra SR	1	Aldabra	A	+	A

Abbreviations - Protected areas: BR – Bird Reserve, MNP – Marine National Park, NP – National Park; Minimum protected area network: A – restricted range endemic species site, B – restricted range non-endemic species site, C – additional sites.

* Alphonse & St. Francois atoll were listed as a 'shadow' site in the Seychelles IBA list due to the suspected presence of internationally important migratory congregations of shorebirds and terns [16]. This has now been confirmed [20].

sites with expectations from random sets [19]. The level of significance of the correspondence was evaluated using replicated goodness of fit G-statistics. In all comparisons significant correspondence was found ($G > 60.01$, $P_{2,43} < 0.05$), supporting the finding that the distribution patterns of all taxa are comparable.

DISCUSSION

Conservationists require high quality biodiversity and geographical information in order to protect the most important sites. A high proportion of the land surface of Seychelles is protected but much of this has been defined on the basis of historical convenience or by the presence of a small number of species. Effective conservation requires a more reliable scientific basis that was available when these reserves were created in the 1960s and 1970s. For the first time this analysis illustrates exactly where the biodiversity rich sites are and how these relate to existing protected areas.

Alternative approaches for identifying conservation areas have produced the current protected area system in Seychelles based on the presence of species of particular interest (principally birds) but without comprehensive consideration of all biodiversity. The KBA analysis for the Seychelles islands identifies 48 sites of conservation importance. This includes all current protected areas and an additional 36 un-

protected sites (194km² protected and 46.7km² unprotected). Of the unprotected sites 12 are in areas already planned for protection (all sites on Silhouette), 3 sites (4 islands) are private property managed as reserves (North, Fregate, Bird and Denis islands), 16 need legal protection (Bernica, Rivière Grand St. Louis, Grand Bois, La Reserve, Montagne Planeau, Mont Sebert, Police Bay; West coast islands, Praslin north-eastern coast, Mont La Digue, Felicite, Alphonse & St. Francois, Cosmoledo, Astove, Assumption, Farquhar). 2 are private property in development areas for which legal protection may be impractical and special conservation agreements may be needed (Mahé: Beau Vallon, Montagne Glacis)

Six sites are currently facing heavy development pressures (ongoing or proposed development) which need immediate action (Silhouette – La Passe, Grande Barbe and slopes of Gratte Fesse; Alphonse, Desroches and Farquhar. Additional threats are expected from climate change with sea-level habitats being at risk from sea-level rise and montane forest vulnerable to changes in rainfall patterns and cloud cover [21]. The former is a major issue to all the coral island KBAs whilst the latter affects the high altitude areas of Mahé (Morne Seychellois and Montagne Planeau) and Silhouette (Mt. Dauban) (Table 2). The effects of climate change are unpredictable for the Seychelles islands as the land area is

too small to be reliably modeled by either global or regional climate models [21]. For the KBAs to be able to adapt to these unpredictable changes the ecosystems in each KBA and in surrounding habitat need to be as dynamic as possible. The species richness and priority threatened habitat criteria of the Important Plant Areas capture the most viable areas of the main habitat. However, even these areas are affected by very high levels of invasion by introduced plant species. It is probable that there will be synergistic impacts of invasion and climate change causing at least some deterioration in even the most dynamic sites. There is an urgent requirement for future conservation in Seychelles to combine effective legal protection of KBAs with large-scale habitat restoration.

The above discussion demonstrates that a comprehensive KBA analysis is practical for small geographical areas with relatively low diversity. Global biodiversity conservation requires the implementation of comprehensive KBA analysis for all geographical regions and at all scales. For larger areas analysis of the distributions of all species may not be practical in the foreseeable future. The use of selected taxa as approximate indicators of biodiversity may be required. The present study found that all major taxonomic groupings (e.g. animal phyla) shared the same distribution of biodiversity rich sites. This means that using surrogate indicators may be a valid approach for these islands. Such indicators should cover as wide a range of taxonomic and functional groups as possible (e.g. both vertebrates and molluscs, two groups that show extremes of vagility) to minimise bias. This finding contradicts many recent studies which report little overlap of distribution of species richness patterns between different taxonomic groups [22, 23]. These studies are carried out at a much larger geographical scale (often continental) and the difference may be primarily due to scale. Across large geographical scales major environmental gradients will be found and different taxa will respond to those gradients differently. For the Seychelles islands the main environmental gradients are the correlated ones of rainfall and altitude, in this relatively simple system correspondence of distribution patterns is to be expected. Further studies should be carried out in other areas to determine whether this is a peculiarity of these islands or a general feature of small geographical scales. Analysis of KBAs and implementation of the findings are urgent pre-requisites for conservation at a time of ecological change.

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