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22 Coral Reefs and Reef Islands of the Amirantes Archipelago, Western Indian Ocean

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Introduction

p0030 The Amirantes archipelago lies southwest of the extensive, shallow-water Seychelles Bank (maximum recorded depth of 65 m) in the western Indian Ocean and comprises a group of carbonate islands and islets extending over a distance of ~152 km, from 4°52′S (African Banks) to 6°14′S (Desnoeufs) (Figure 22.1). Most of the islands are sea-level coral reef platforms with varying degrees of subaerial sand cay and coral island development. They have evolved over the last 6,000 years since regional post-glacial sea level approached its present level [1]. Due to their remote nature, the islands remain largely undeveloped, with the exception of limited tourism infrastructure (i.e., single hotels) on four of the islands. The Amirantes Bank is an elongate structure, measuring ~180 × 35 km, deepest in its central zone (up to −70 m) with a marginal rim at water depths of 11–27 m. Approximately 95 km further south are the atolls of Alphonse and Bijoutier/St. François, which form the Alphonse Group. Of the 14 islands in the Amirantes archipelago, 13 were mapped, the exception being Desroches, a shallow submerged atoll, 19–21 km in diameter, lying 16 km east of the Amirantes Bank.

p0035 The climate of the western Indian Ocean is of a humid tropical type, with mean monthly temperatures always above 20°C and rainfall totals in excess of 700 mm. Seasonal and interannual climatic variability is determined by (1) the SE Asian Monsoon and the seasonal reversal of winds associated with it; (2) monsoon-related movements of the Inter-Tropical Convergence Zone; (3) changes in the position and intensity of the South Indian Ocean subtropical high pressure; and (4) variations in ocean circulation systems and sea surface temperatures. The surface ocean circulation of the West Indian Ocean is characterized by a subtropical, anticyclonic gyre to the south (between 40°S and 15°S) and reversing monsoon gyres to the north of 10°S, with the addition of large volumes of water (up to 15 Sv in June/July) from the Pacific Ocean through the Indonesian throughflow [2].

p0040 This case study presents the results of a collaborative expedition between the Cambridge Coastal Research Unit and the Khaled bin Sultan Living Oceans Foundation

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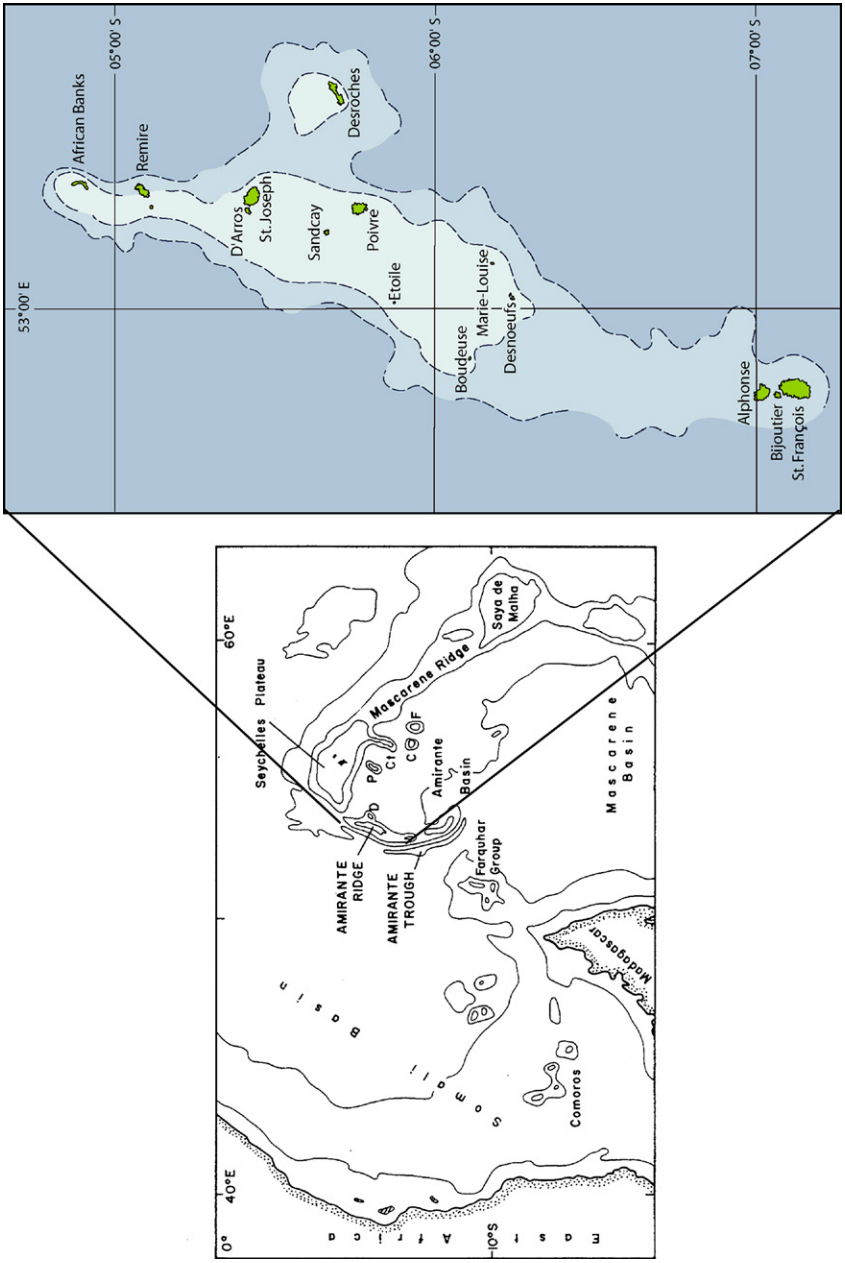
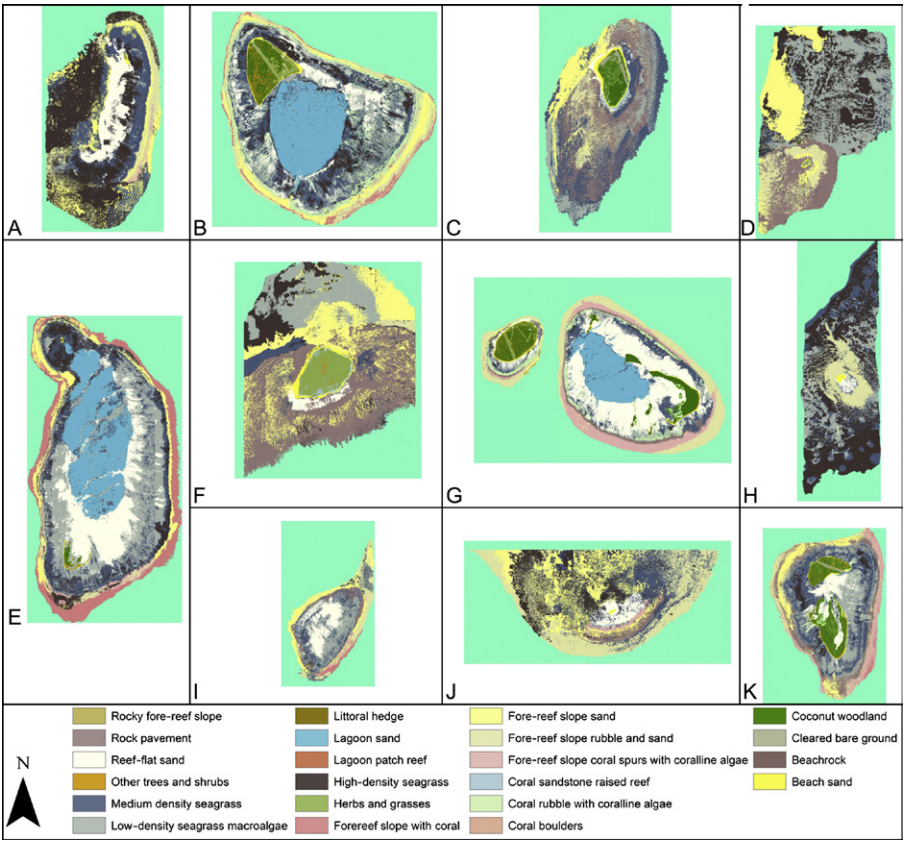


f0010 **Figure. 22.1** Regional setting of the Amirantes Ridge, western Indian Ocean (left), and the islands of the Amirantes archipelago (right); approximate bathymetric contours = 1 and 4 km. *Source:* Adapted from Ref. [3].



f0015 **Figure. 22.2** Habitat maps of the Amirante islands: (A) African Banks, (B) Alphonse, (C) Marie-Louise, (D) Boudeuse, (E) Bijoutier/St. François, (F) Desnoeufs, (G) D'Arros/St. Joseph, (H) Etoile, (I) Remire Reef, (J) Sand Cay, (K) Poivre.

in January 2005. Airborne remote sensing Compact Airborne Spectrographic Imager (CASI-2) imagery was acquired over the Amirantes Bank from which both the geomorphic and biological character of the 13 reef islands could be examined (Figure 22.2). This had a spatial resolution of 1 m and a spectral resolution of 19 wavebands. Biological assessments of benthic character in this study are supported by over 1,500 ground reference records of the terrestrial and marine environments. Further detail on production of the habitat maps and individual island descriptions can be found in the *Atlas of the Amirantes* [3].

s0015 Geomorphological Features

p0045 Of the seven reef types identified in the Seychelles [1], coral reef platform, atoll, and drowned atoll are present in the Amirantes [3]. The platform reefs can be subdivided

into three characteristic morphologies; those dominated by intertidal reef-flat sands (Type 1); those that overtop a rock platform (Type 2); and those that have undergone substantial sedimentary infill which support vegetated islands (Type 3).

p0050 *Type 1 coral reef platform* (African Banks, Remire Reef, Sand Cay and Etoile): In Type 1 platform reefs, the entire surface has been covered by intertidal reef-flat sands. There is no subaerial cay at Remire Reef, and the exposed land area at African Banks (North Island) is extremely small relative to the total area of the platform within the breaker zone (Table 22.1). Sand Cay and Etoile are very small (0.3 km^2) and, as repeat aerial photography shows, highly mobile sedimentary landforms, surrounded by extensive subtidal sand sheets and stabilized locally by seagrass beds. They appear to be positioned on localized highs in the pre-Holocene topography of the Amirantes Bank.

p0055 *Type 2 coral reef platform* (Marie-Louise, Desnoeufs, and Boudeuse): In the southern Amirantes archipelago, the Type 2 platform reef islands consist of raised reefs, bedded calcareous sandstones (often phosphatized), and beachrock ridges, which imply complex histories of landform development. These islands are surrounded by very narrow peripheral reefs (the area between the breaker zone and island marginal sands being only 0.08–0.24 km^2; Table 22.1) but sit on the margins of extensive and relatively shallow rock platforms, often incised with characteristic patterns of narrow, shallow, anastomosing channels. The subaerial islands thus occupy less than 10% of the total area classified from CASI imagery at Marie-Louise and Desnoeufs, and less than 1% at Boudeuse.

p0060 *Type 3 coral reef platform* (D'Arros and Poivre): At each of the two Type 3 platform reef islands, infilling of the platform surface has allowed the development of subaerial islands that exceed 2 km^2 in total area. The percentage cover of the area of the reef platform inside the breaker zone by islands is comparable to the Type 2 reefs, but habitat areas seaward of the breaker zone are much less extensive. Thus, the islands at D'Arros and Poivre account for a much greater proportion (38% and 13%, respectively) of the total area classified at these two locations (Table 22.1).

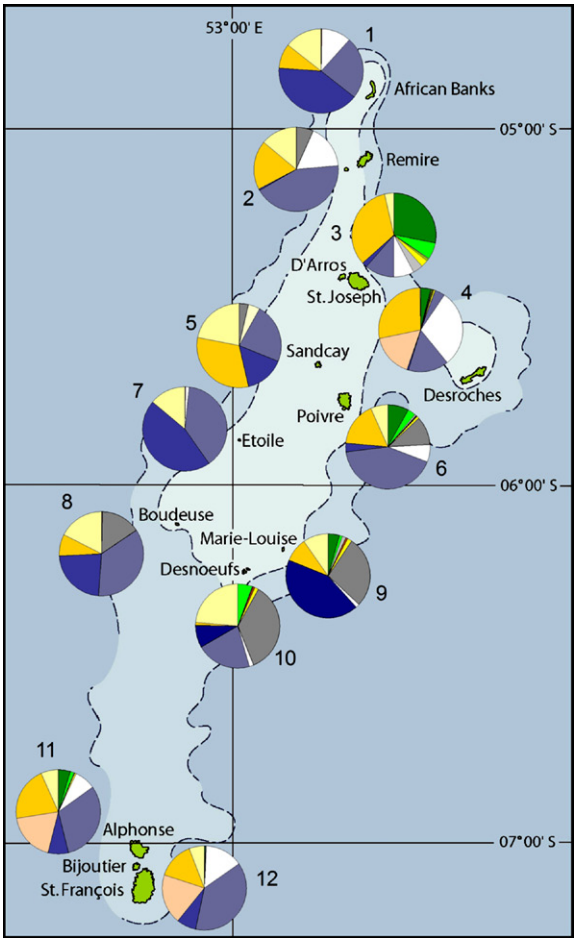
p0065 *Atolls* (St. Joseph, Desroches, Alphonse, and Bijoutier/St. François): The atolls are small by global standards [1]. They are characterized by wide reef-flats, typically occupying 50–60% of the reef platform inside the breaker zone (Table 22.1), shallow lagoons, and poor lagoon–ocean exchange. At St. François, the largest of the atolls, extensive sand sheets on the windward coast infill the lagoon. This process is more advanced at St. Joseph where the lagoon occupies only around 30% of the reef platform inside the breaker zone (Table 22.1) and has a maximum depth of 6.4 m.

p0070 *Submerged atoll* (Desroches): Although this was not included in the CASI analysis, it was classified for comparison from a Landsat TM image. The total area classified at Desroches was 189 km^2, making it more than twice as large as the largest sea-level atoll, Bijoutier/St. François, in the Alphonse Group. The atoll rim takes the form of a 1–3 km wide submerged reef platform, occupying 82 km^2 (43%) of the total classified area. The platform is found at depths of 4–7 m on its eastern and southern sides and at less than 3 m water depth on its northern edge. On the western margin, a narrow rim, with water depths of 4–8 m, is backed on its lagoonward side by a shelf at 15–18 m. The lagoon floor lies at between 23 and 27 m, much deeper

t0010 **Table 22.1** Morphological Statistics for the Atolls and Reef Platforms of the Amirantes

Atolls	Total Areas					Peripheral Reef Area as Proportion of Total Reef Platform Area	Lagoon Area as a Proportion of Total Reef Platform Area
	Overall Classified[a]	Reef Platform[b]	Peripheral Reef[c]	Land[d]	Lagoon		
St. Joseph	31.54	17.62	10.43	1.72	5.48	59.19	31.1
Alphonse	23.44	13.61	7.42	1.63	4.55	54.52	33.43
Bijoutier/St. François	71.33	37.99	19.48	0.46	18.05	51.28	47.51
Reef Platforms						Land area as proportion of total reef platform area	Land area as proportion of total classified area
African Banks (Type 1)	20.66	8.05	7.99	0.06		0.75	0.29
Remire Reef (Type 1)	19.30	11.61	11.61	0.00		0.00	0.00
Boudeuse (Type 2)	9.00	0.11	0.08	0.03		24.1	0.29
Marie-Louise (Type 2)	7.89	0.94	0.20	0.74		78.59	9.36
Desnoeufs (Type 2)	5.93	0.72	0.24	0.48		67.06	8.14
D'Arros (Type 3)	5.48	3.26	1.16	2.10		64.42	38.82
Poivre (Type 3)	20.24	14.67	12.01	2.66		18.13	13.14

Areas are delineated as follows:
[a] Overall classified: total area classified from CASI imagery and shown on island habitat maps.
[b] Reef platform: total area inside the breaker zone at each island, including area of any subaerial islands.
[c] Peripheral reef: area between the breaker zone and island marginal sediments and rocks.
[d] Land:area covered by terrestrial habitat categories.



f0020 **Figure. 22.3** Breakdown of habitat coverages of the reef islands of the Amirantes archipelago and surrounding reefs.

than the shallow lagoons seen at the three sea-level atolls (6.4–10.0 m), and the lagoon, at 57% of the total classified area, occupies a far greater area than at the other atolls (where the coverage is 17–25%).

s0020 Biological Features

p0075 The spatial distribution of habitat types by island location (Figure 22.3) shows that islands on the western margin of the Amirantes Bank are characterized by a restricted range of terrestrial and littoral habitats, whereas those on the eastern side

of the Bank show a greater range of habitats, particularly in subaerial environments. This may be because of their greater exposure to incident waves driven by the south-east Trade Winds, which encourage reef growth and subsequent island formation.

p0080 Seagrass was the most well-represented benthic cover type (13–84% cover), encompassing low-, medium-, and high-density communities. The dominant seagrass species were *Thalassodendron ciliatum* and *Thalassia hemprichii*. Fore-reef slope material, reef-flat sand, and lagoon sand were also abundant (Figure 22.3). Seagrass was abundant because the extensive reef-flats meet the habitat requirements of *Thalassia* and *Thalassodendron*. These include a marine environment, adequate rooting substrate, sufficient immersion in seawater, and illumination to maintain growth [4]. Like reef-flat sand and lagoon sand, seagrass beds adopt a lateral distribution of wide leaves that appear horizontally extensive when viewed from above, which is likely an adaptation for capturing light. Airborne remote sensing therefore lends itself well to mapping these coverages. Conversely, some of the habitats, such as beach sand and the fore-reef categories, were comparatively limited in the spatial extent of what was recorded because of their more vertical distribution, which could not be viewed as efficiently from above.

s0025 Surrogacy

p0085 Collectively, the maps illustrate considerable interisland habitat diversity across the Amirantes Bank. This variation reflects the presence or absence of elevated reef deposits of various kinds, related to past sea level and environmental histories on the Bank. In conjunction with this, more recent biophysical controls include the degree to which regionally variable wind and surface current fields determine windward versus leeward contrasts across individual islands. At the island scale, the habitat structure of seagrass patches on Etoile Cay has been related to incident wave power using a spatially explicit analysis of variance model [5], and the linearity of reef-flat patches of seagrass around the rim of Alphonse Atoll has been related to both the absolute amount of incident wave energy and the transfer of this energy over spur and groove morphological features on the upper fore-reef using a spatial multivariate regression model [6]. The combined influence of adjacent groove depths and incident wave power (modeled using linear wave theory) explained 81% of the variation in seagrass patch linearity across the overall Atoll habitat map. The estimated regression function read:

$$\begin{aligned}\text{Patch linearity} = &-0.234 + 2.584 \times 10^{-3^*}\,\text{wind factor} \\ &+3.93 \times 10^{-3^*}\,\text{groove depth}\end{aligned} \tag{22.1}$$

T-test values were 9.337 and 12.429 for the mean wind force and groove depth, respectively (561 degrees of freedom; $p < 0.001$), suggesting it to be highly likely that the estimated coefficients are different from zero.

s0030 ## Acknowledgments

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