Atlas of the Amirantes

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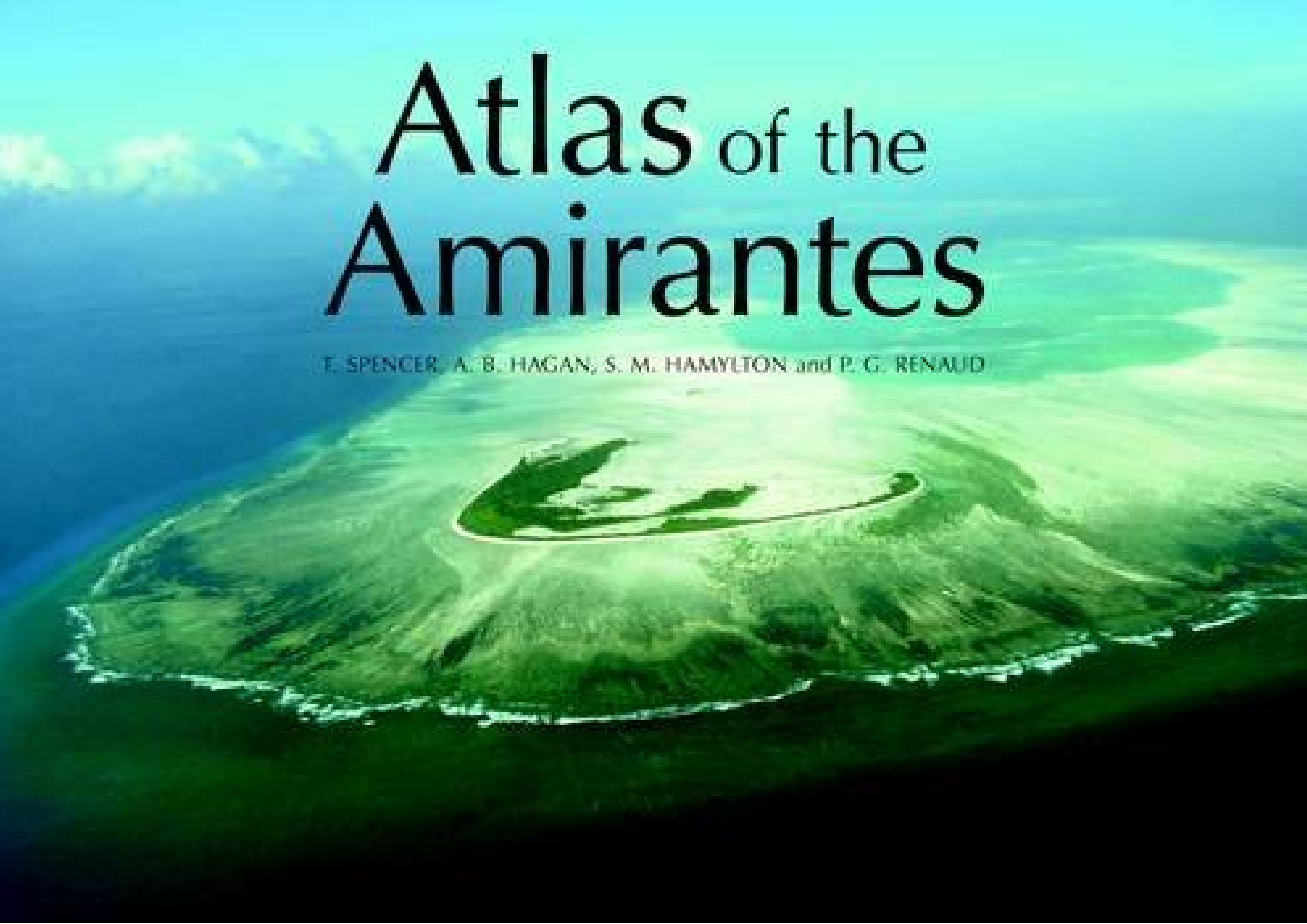

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SCMRT-MPA

Unit for Landscape Modelling

CCRU

Contents

Preface

This collection of habitat maps of the coral islands, reefs and shoals of the Amirantes Archipelago, Western Indian Ocean, is the result of a collaborative research project between Khaled bin Sultan Living Oceans Foundation, Cambridge Coastal Research Unit and Unit for Landscape Modelling, University of Cambridge and Seychelles Centre for Marine Research and Technology – Marine Parks Authority. The project was centred around a research cruise to the southern Seychelles which utilised M.Y. *Golden Shadow*, kindly loaned by Prince Khaled bin Sultan to the Living Oceans Foundation for use during the expedition, 10–28 January 2005.

The Republic of Seychelles (5°-10°S; 45°-56°E) comprises 42 granitic islands and 74 coralline islands. The total land area of 455 km^2 lies within an Exclusive Economic Zone (EEZ) of 1,374,000 km^2. The Amirantes Group comprises a total of 24 islands and islets (including the atolls of St. Joseph and Poivre), stretching ~155 km from 4°53'S (African Banks) to 6°14'S (Desnoeufs). The atoll of Desroches lies to the east of the main Amirantes Ridge and 95 km further south are the atolls of Alphonse and St. François which form, with Bijoutier, the Alphonse Group. 13 of the 14 islands were mapped, the exception being Desroches. However, in the interests of completeness, we have generated a habitat map based on Landsat imagery for this locality.

The area selected for survey was large and thus not amenable to detailed ground mapping over a relatively short field visit. However, the sites were ideally suited to extensive, high resolution airborne mapping. This was achieved using a CASI (Compact Airborne Spectrographic Imager) sensor onboard the seaplane *Golden Eye*. As a secondary goal, the terrestrial vegetation was also mapped, although the choice of CASI bands (targeted for marine work) was such that the reliability of the terrestrial mapping is lower than that of the marine work. Whilst the *Golden Eye* collected aerial imagery, scientific personnel onboard M.Y. *Golden Shadow* were involved in an extensive exercise collecting ground-reference data. Both marine and terrestrial environments were sampled using a variety of techniques, including visual observations, photographs and video transects. Full details on the remote sensing techniques and field survey methods used can be found later in this Atlas (see below and Appendix 1).

It is hoped that the information contained herein will be incorporated into marine ecosystem management plans in the Republic of Seychelles, providing guidance to decision makers on the level, and prioritisation of, conservation and management required at particular sites. In addition, these maps will form a baseline against which to assess the impacts of near-future global environmental change in this area.

It is important, however, to treat these maps as living documents. We hope that they will be taken into the field whenever the opportunity arises and checked against what is seen and recorded on the ground. The authors will be delighted to incorporate new and revised information into the ongoing revision of the maps contained in this Atlas.

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Geology of the Western Indian Ocean

Ocean basin seafloor topography and tectonic history

The Western Indian Ocean covers an area of over 20 million square kilometres and is dominated by three major bathymetric features[1]. Illustrated in Figure 1 (east to west), these are:

1. the **Chagos – Laccadive Ridge**, stretching over 2,000 km south from the western margins of the Indian subcontinent. Seen in the islands of the Laccadives, Maldives and Chagos archipelago, this is the product of high volume volcanism at the Reunion hotspot;
2. the **Indian Ocean mid-oceanic ridge system**, 7,000 km in length and typically lying 3,000 m above the flanking basins. The ridges are segmented by large numbers of transverse fracture zones (appearing black in Figure 1), often perpendicular to the ridge axis and supporting an axial valley characterised by typical seafloor spreading rates of 50 – 90 mm a^{-1}. This system of ridges, which all meet at a triple junction near the island of Rodrigues (600 km east of Mauritius), comprises the Central Indian Ocean Ridge, the divergent tectonic plate boundary between the African Plate and the Indo-Australian Plate which extends northward to a junction with the large-scale Owen Fracture Zone SE of Socotra; the deep (5,600 m below sea level) and slow-spreading (15 mm a^{-1}) Southwest Indian Ocean Ridge, which separates the African Plate to the north from the Antarctic Plate to the south; and the Southeast Indian Ocean Ridge, which forms the boundary between the Indo-Australian Plate to the north and the Antarctic Plate to the south;
3. the **Mascarene Plateau**, a region of extensive shallow banks (20 - 90 m water depths) and shoals (appearing white in Figure 1), separated by deep passages, extending over 1,500 km from the Seychelles Plateau (area of 31,000 km^2) at 4°S to 18°S. From north to south, the Plateau incorporates the Ritchie Bank (5,800 km^2), the Saya de Malha Bank (40,000 km^2), the Nazareth Bank (26,000 km^2) and the Saint Brandon Bank or Cargados Carajos Shoals (10,000 km^2).

These three features dissect the region into a series of seven isolated basins, reaching water depths of 5,500 m in the Central Indian Ocean and SE of Madagascar. In the area of particular interest in this Atlas, the Somali Basin, to the NW of the Amirantes, lies at 5,100 m below sea level with seafloor ages of 66 Ma (million years); to the SE, the Mascarene Basin lies at a depth of 4,900 m and exhibits seafloor ages of 76 Ma. Within these basins is evidence of internal seafloor spreading, tectonic extension and intrusive volcanism, including the still-active shield volcano of Mount Karthala on Ngazidja, Comoros Archipelago in the Mozambique Channel (see Figure 4 below). The large, rugged island of Mauritius, 875 km east of Madagascar, is composed of three major basaltic lava flows ranging in age from 7-8 Ma to 0.2 Ma; the hotspot now lies beneath the volcanically-active island of Reunion, 200 km to the SW.

This patterning of the Indian Ocean seafloor dates back to the Late Jurassic break-up of the Gondwanaland supercontinent[2]. This has left a legacy of fault-dominated shelf margins along the eastern flank of the African continent, including Madagascar, and around the Indian subcontinent. Around 160 Ma (million years ago) India, Madagascar and Antarctica broke away from the African continent, forming the Somali Basin; between 130 and 115 Ma, seafloor spreading ceased between India/Madagascar and Africa, although the coherent continental block of India/Madagascar separated from Antarctica (Figure 2a). Between 100 and 95 Ma, India separated from Madagascar, taking with it the Seychelles microcontinent and the embryonic Mascarene Plateau (Figure 2b). By 85 Ma, this separation began to generate i) the 'pull-apart' Amirante Basin to the north (in a manner similar to the opening of the Red Sea between Africa and Arabia) and ii) the incipient Mascarene Basin to the south, created by axial spreading (Figures 2c and d). The evolving wedge of new seafloor by progressive southerly rotational extension, and the anti-clockwise rotation of India as it moved away from Madagascar, was countered by an opposing rotational compression to the north (Figure 2e). It is these tectonic dynamics, and their change over time, which can explain the geometry of the Amirante ridge/trough complex[3-5]. This plate tectonic arrangement persisted until *ca.* 64 Ma when, with the establishment of the Carlsberg Spreading Ridge, a further rifting stage separated India from the Mascarene Plateau and the Mauritius/Reunion volcanic chain (Figure 2f). The Carlsberg Ridge now forms the northern section of the present Central Indian Ocean Ridge. Finally, the continued northerly migration of India, at rates of between 7.7 - 16.0 cm a^{-1}, ultimately led to its collision with continental Asia between 55 and 50 Ma.

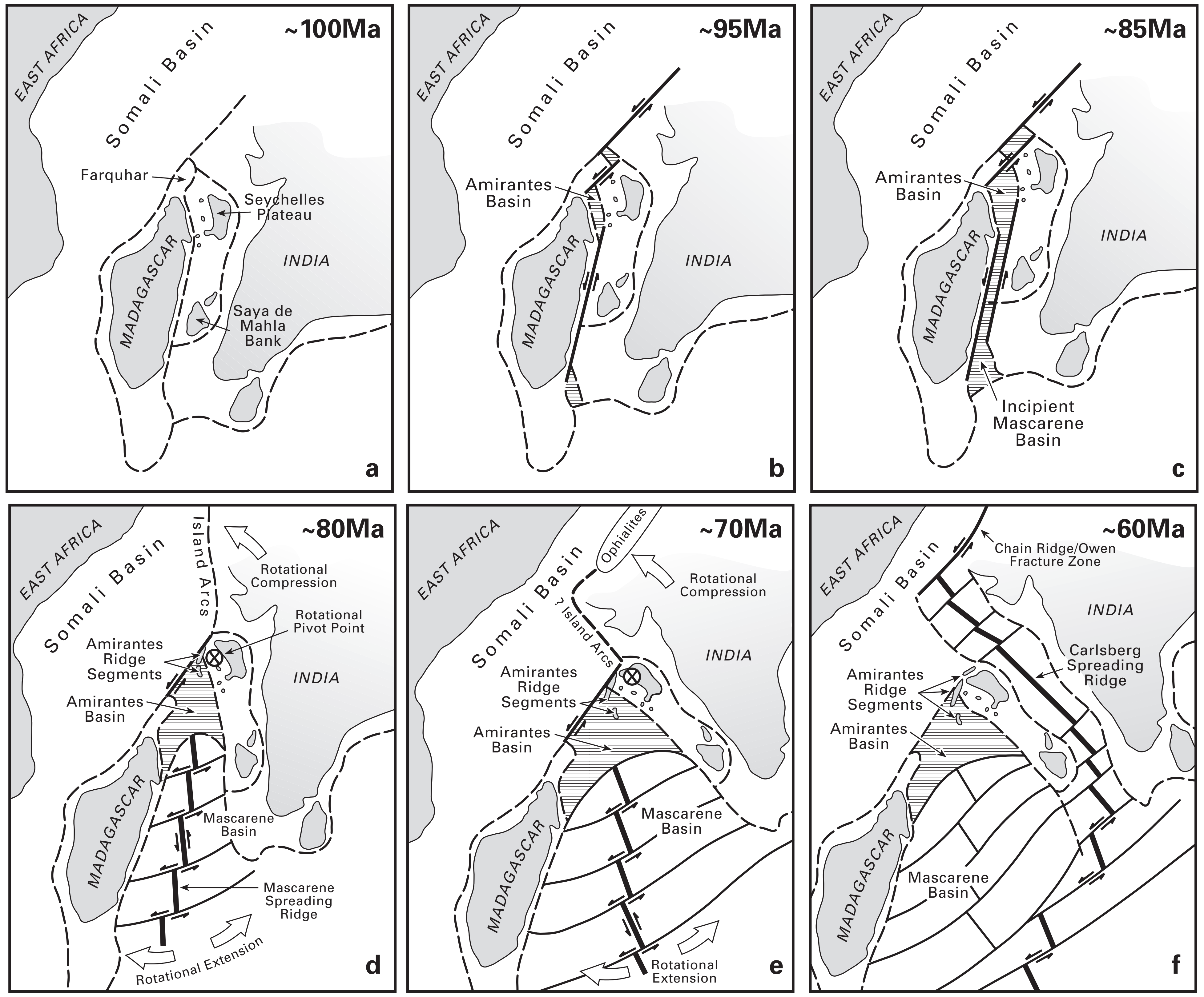
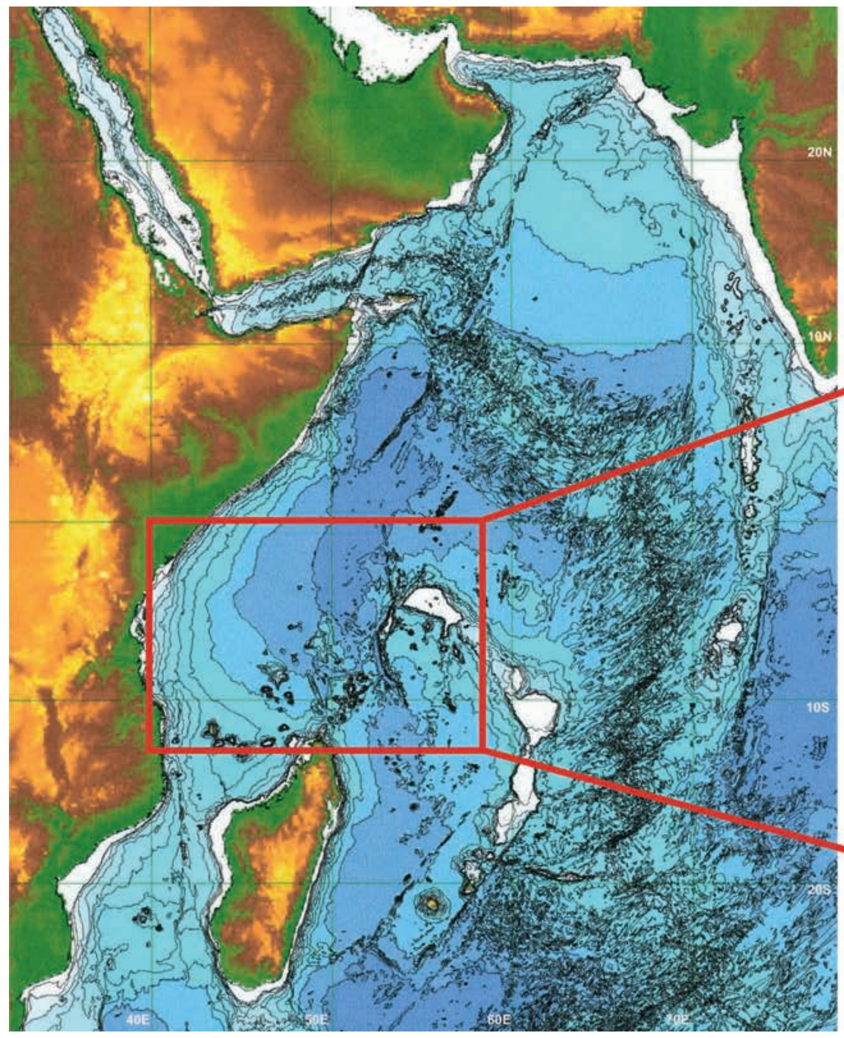


Figure 2: Palaeogeographic evolution of the Seychelles – Madagascar rift and drift and the development of the Amirante Basin, Mascarene Basin and Amirante ridge/trough complex (after Plummer, 1996).

One of the characteristics of the type of rifting seen in the Western Indian Ocean is that separation is often initiated at several locations, resulting in the detachment of relatively small fragments of continental material which may, with further phases of rifting and seafloor spreading, come to be surrounded by deep ocean floor. One such outlier is the Seychelles Plateau, an area of 43,000 km^2 where granitic rocks are variously exposed in 24 islands[6]. The pre-Cambrian granites on Mahé and Praslin – La Digue can be differentiated in terms of colour and composition but appear contemporaneous in age, at 755 – 748 Ma (range: 808 – 703 Ma)[7]. They show strong NW-SE and E-W joint sets, with the former paralleled by broadly contemporaneous doleritic dykes. In addition, further doleritic dykes are also present in these two island groups; on Praslin they have been dated to 69 – 74 Ma. Volcanics from boreholes drilled on the Reith Bank, Owen Bank and Seagull Shoals at the western tip of the Seychelles Plateau show broadly coincident ages of 78 – 71 Ma and it has been suggested that all these rocks are the product of magma extrusion along fault planes associated with the development of the Amirante Ridge. Finally, the island group of Silhouette – Ile du Nord, on the northwest of the Plateau, are characterised by more alkaline volcanic rocks dated to 63 – 60 Ma[8], strongly correlating with the final rifting



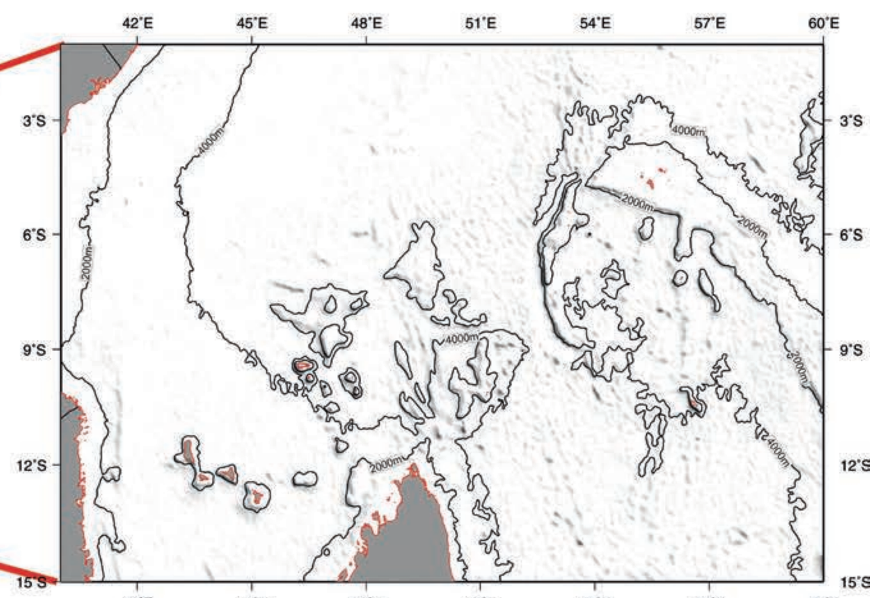


Figure 1: Principal bathymetric features of the Western Indian Ocean (courtesy of AJ Evans, National Oceanography Centre, Southampton, UK) (1) Chagos – Laccadive Ridge; (2) Indian Ocean mid-oceanic ridge system; and (3) Mascarene Plateau

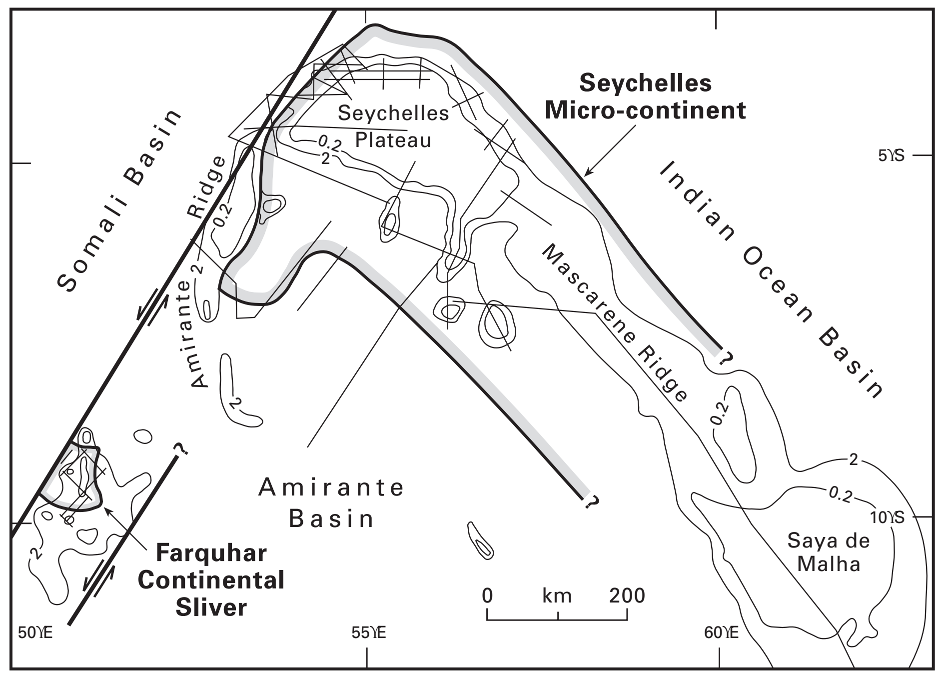


Figure 3: Extent of the Seychelles and Farquhar microcontinental slabs (after Plummer, 1996)

phase of the Seychelles from India, the development of the Carlsberg Ridge and with the eruption of the extensive flood basalts of the Deccan Traps of India where volcanic activity peaked between 60 and 65 Ma[9].

It has generally been assumed that the extent of the Seychelles microcontinent is limited to the Seychelles Plateau, with Constant Bank, Fortune Bank and the islands of Platte, Desroches, and Coetivy (for locations see Figure 4) being of later volcanic origin. However, the gathering of seismic data and satellite gravity data since the late 1970s has shown that continental crust extends well beyond the limits to the Seychelles Plateau (Figure 3). Whilst basalts have been encountered in drill holes at the SW corner of the Plateau, and between the Seychelles Plateau and the Saya de Malha Bank, these deposits are themselves underlain by thick sedimentary sequences of at least Middle Triassic (245 – 228 Ma) age. It is not clear how far to the east these sequences extend; it has been variously claimed, on the one hand, that volcanic rocks underlie the Saya de Malha Bank or, on the other hand, that pre-Tertiary sediments extend as far south as the St Brandon Bank at 15ºS. Furthermore, seismic data in the vicinity of the Providence Bank, Farquhar Group, has revealed the presence of a further isolated fragment - or sliver - of pre-Tertiary continental crust to the SW of the Seychelles Plateau (Plate 3)[10].

Geology of the Amirante ridge/trough complex

The Amirante ridge/trough complex abuts the northwestern margin of the Seychelles Plateau and then extends to the south over a total distance of approximately 500 km. The system has a width of 75 – 100 km and a vertical relief between ridge crest and ocean basin floor which can exceed 5,000 m. Geophysical measurements suggest a volcanic ridge developed within oceanic crust with only a thin sedimentary cover.

Although superficially the planform and bathymetry of the Amirante system suggests an inactive island arc / subduction trench[11], the lack of an accretionary wedge on the eastern margin, the composition of the underlying basalts (tholeiitic rather than andestic) and geoidal and gravity measurements all fail to support this interpretation. Rather, the Amirante Ridge is the product of tectonic and volcanic activity at the transition between compressive and extensional regimes, adjacent to a rotational pivot, that, as described above, took place between around 95 and 64 Ma and particularly in the period between 71 – 78 Ma[3].

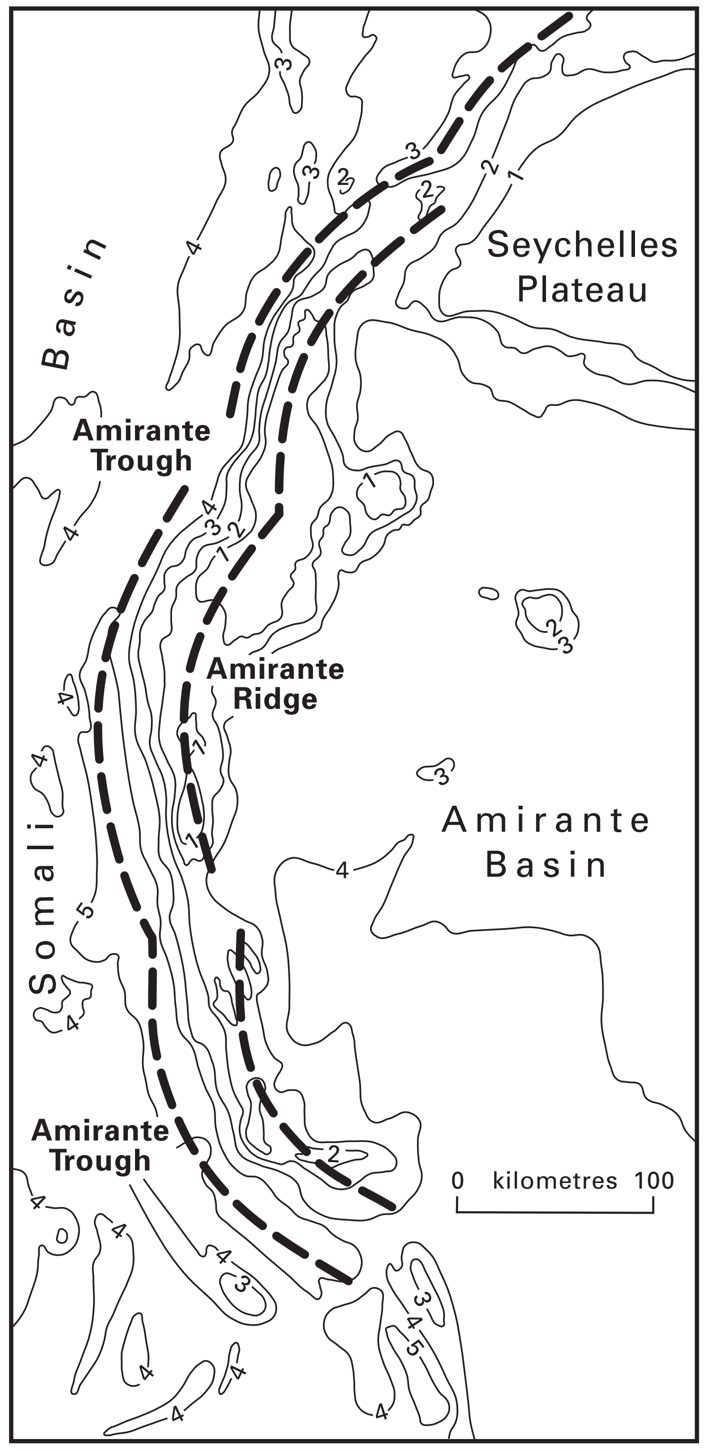


Figure 5: Detailed bathymetry (water depth contours in kms) over the Amirante ridge/trough complex, showing a series of 4 arcuate segments (after Plummer, 1996).

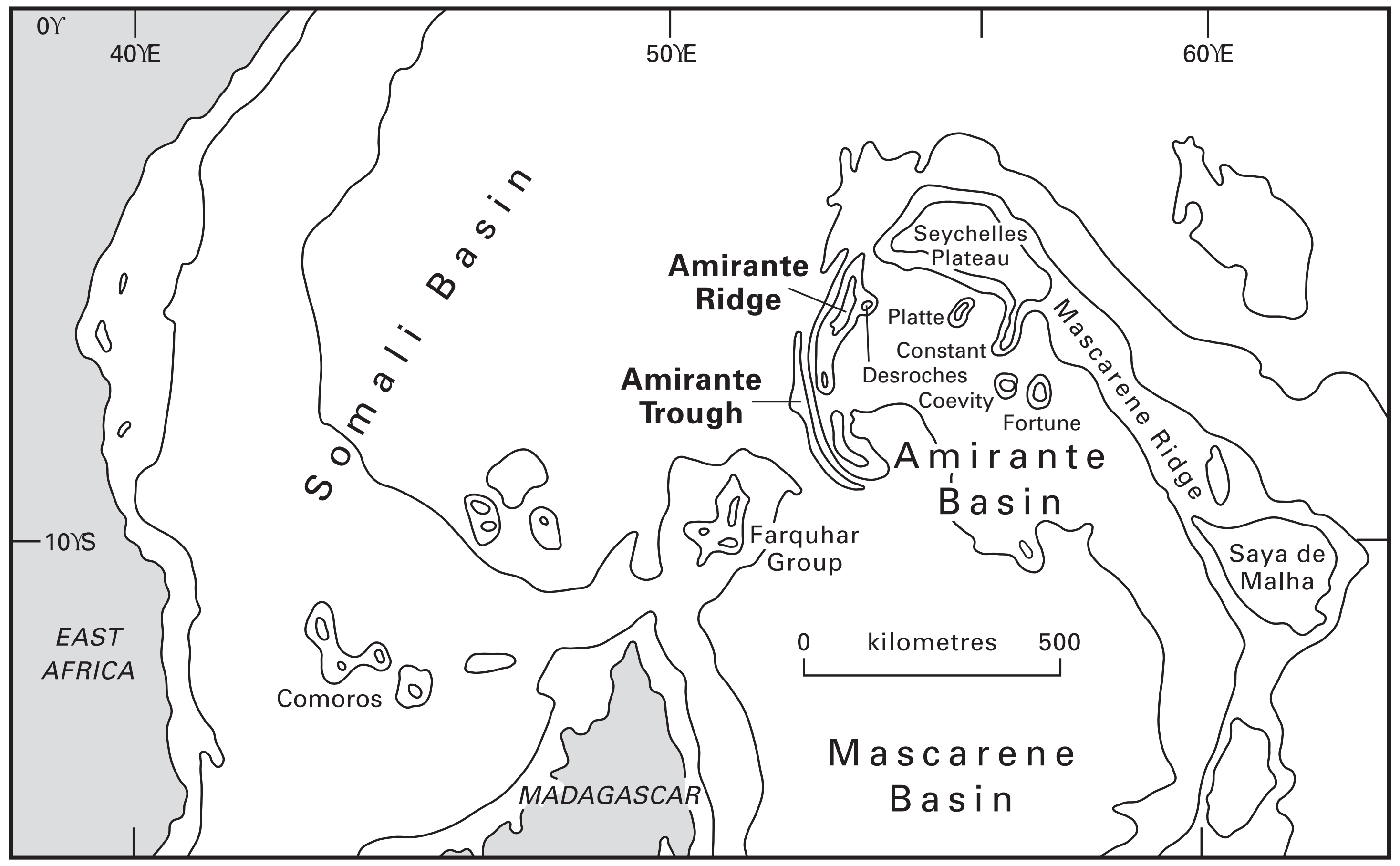


Figure 4: Location map of the Amirante ridge/trough complex in relation to the Mascarene Plateau (Seychelles Plateau / Mascarene Ridge / Saya de Malha), Madagascar and East Africa.

A closer look at the planform of the Amirante archipelago (Figure 5) suggests that the ridge is in fact made up from a series of four, eastward concave segments. The trough, adjacent to the western side of the ridge, also appears to be an amalgam of smaller segments. The four segments appear to have developed progressively from south to north, representing periodic shifts in the position of the rotational pole. The central section can be dated to 84 Ma, from a basalt sample retrieved from the western flank of the ridge[12]; this age is consistent with the presence of overlying pelagic oozes of Late Cretaceous age[13]. The segment to the north, immediately SW of the Seychelles Plateau, has been assigned an age of 71 – 75 Ma, and the most northerly arc, abutting the NW margin of the Plateau, to some time after 73 Ma.

Bathymetry of the Seychelles Bank and Amirantes Archipelago

The geological unit of the Seychelles Plateau, described above, is also known as the Seychelles Bank, a shoal area of 31,000 km2 (Figure 4, Figure 6). It is characterised by water depths of 65 - 44 m, with a discontinuous marginal rim, encrusted with coralline algae rather than coral growth, reaching to within 27 - 11 m of sea level. The southern face of the Bank is terraced at –75 m and there is a platform at –32 to –40 m. Bank sediments are typically very fine to coarse bioclastic sands (0.06 – 0.7mm), with the coarser sediments being found in shallower water[14]. Some forty granitic islands and islets sit on the Bank[6]. The larger islands are characterised by rugged, mountainous interiors, with peaks reaching 914 m on Mahé, the largest island (area of 145 km^2), 867 m on Silhouette (19.6 km^2) and 427 m on Praslin (35 km^2). Landscapes on these islands are characterised by smooth, often fluted, bare rock surfaces (glacis) and lower slopes filled with red lateritic soils, surrounded by raised deposits (plateau) and sea level wetlands[15]. Fringing reefs are of variable width and continuity, being best developed on Mahé and Praslin where they reach widths of 2,870 and 1,300 m respectively; reef fronts, restricted by the shallow waters of the Bank, are typically only 20 m high[16-19]. At Ste. Anne, typical of the smaller granitic islands, the fringing reef varies in width from 100 to 330 m. Small patches of raised fringing reefs are known from Mahé, Praslin, Curieuse and Silhouette; maximum elevations of these deposits from the first three of these localities lie 5.9 – 9.3 m above Mean Low Water Springs. Reefal materials from both Mahé and Praslin have been dated at 140 ± 30 ka (thousand years), making these deposits contemporaneous with the raised reef limestones of the southern Seychelles[20]. The Bank also supports a number of low sand cays on sea level coral reefs, including Bird and Denis Islands on its northern edge[21]. The reef platforms on these islands are characterised by calcarenites and phosphatic sandstones[15]. In addition, there are a number of islands to the south of the Seychelles Bank / Plateau (Figure 4). Platte is a small platform reef at the northern end of an extensive submerged atoll (including the La Perle reef), 62 km south of the Seychelles Bank and surrounded by water depths in excess of 1,500 m. To the east, the regional bathymetry (Figure 6) suggests a ridge extending from the Le Constant Bank, at the SE margin of the Seychelles Bank, through Coetivy to the Agalega Islands at 10°25'S, a distance of ca. 500 km, although water depths between Le Constant Bank and Coetivy and between Coetivy and the Agalega Islands in places exceed 2,000 and 3,000 m respectively. Coetivy (Figure 4) is a linear sand cay with sand dunes and phosphatic calcarenites on the eastern side of a shallow bank, typically 36 m deep with a marginal rim at –25 to –20 m. 55 km to the east of Coetivy lies the shallow Fortune Bank (Figures 4 and 6).

The Amirantes Bank, to the SW of the Seychelles Bank, is an elongate structure, measuring approximately 180 km by 35 km, deepest in its central zone (up to

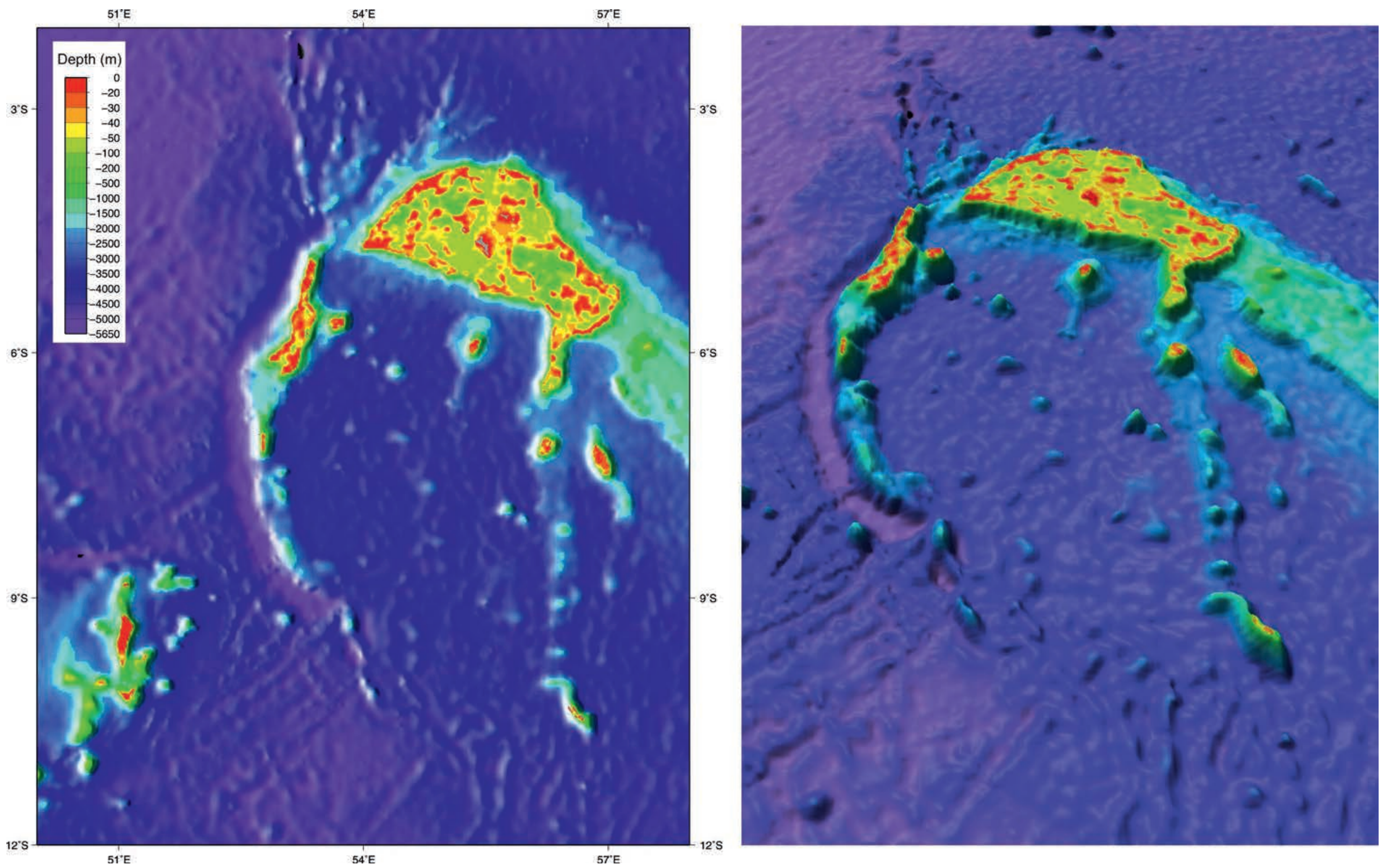


Figure 6: Bathymetry of the Seychelles Bank, southern outlying islands, Amirantes Archipelago, Farquhar Group and Agalega Islands (courtesy of AJ Evans, National Oceanography Centre, Southampton, UK).

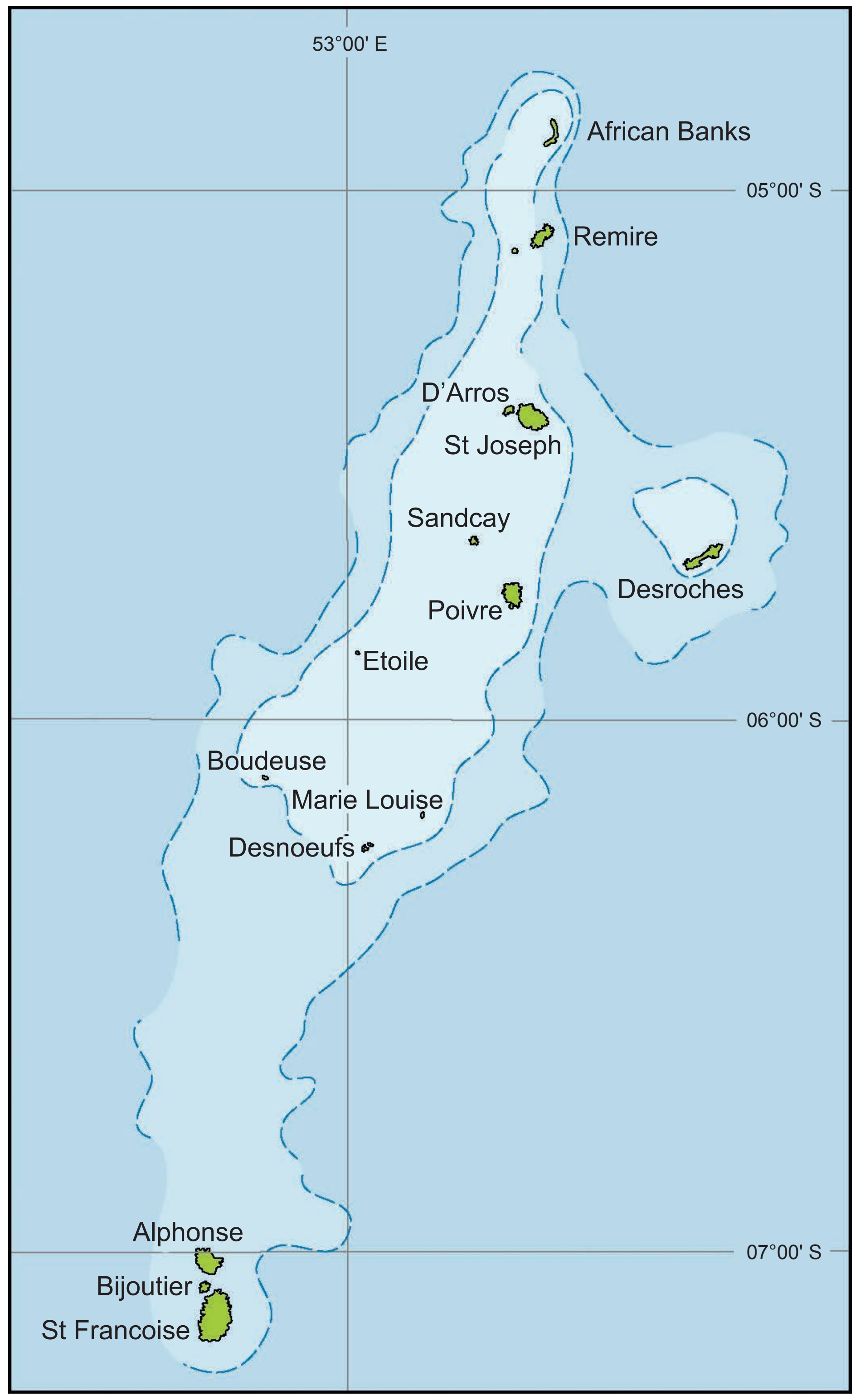


Figure 7: The Amirantes Bank

–70 m) with a rim at –11 to –27 m, comparable to that of the Seychelles Bank. With the exceptions of Etoile and Boudeuse, the reef platforms lie towards the eastern margin of the Bank. Structurally, the ridge continues to the atolls of Alphonse and Bijoutier / St. François, although these islands are separated by a distance of ca. 80 km with intervening water depths of up to 2,000 m. South of St. François, water depths rapidly reach in excess of 3,000 m, although there is a further dog-legged ridge structure, with water depths of ca. 1,000 m, 65 km to the south between 7°40 S and 8°40 S. Desroches is a shallow submerged atoll, 19-21 km in diameter lying 16 km to the east of the Amirantes Bank[22]. There is a sounding of 1,598 m between Desroches atoll and the Bank.

Water depths in the Somali Basin to the west of the Amirantes are typically 4,200 - 4,700 m but reach a maximum of 5,100 m. To the east, water depths in the Amirantes Basin are ca. 3,700 m. Deep ocean floor sediments throughout the area are dominantly foraminiferal and coccolith oozes[23]. They are fine-grained, with high carbonate contents (including coral and algal-derived sediments in sediment aprons around islands) but with low levels of amorphous silica and organic carbon.

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The Indian Ocean is the least-studied of the world's great oceans and differs significantly from the Pacific and Atlantic Oceans in two major respects. Although predominantly in the Southern Hemisphere, it is bounded to the north by large land masses which include the Himalayas and the Tibetan Plateau and has a climate significantly affected by the East African Highlands. The second unique feature is the role of one of the most remarkable climate systems on Earth, the SE Asian Monsoon, with its annual cycle of reversing surface winds.

Climate of the Western Indian Ocean

In the Western Indian Ocean, the climate is controlled by i) the SE Asian Monsoon and the seasonal reversal of winds associated with it; ii) monsoon-related movements of the Inter-Tropical Convergence Zone (ITCZ); iii) changes in the position and intensity of the South Indian Ocean subtropical high pressure; and iv) variations in ocean circulation systems and sea surface temperatures.[1-3] In the Northern Hemisphere summer (May - October) atmospheric pressure is low over Arabia and the Indian subcontinent and high over southern Africa, with strong anticyclonic conditions centred at 29-30°S. The SE Trades dominate over the whole of the southern western Indian Ocean, recurving to form the SW Monsoon north of the Equator. The dry, stable air associated with this period gives low rainfall totals, although the constancy of the SE Trades, and the length of this dry season, varies considerably across the region.

In the Northern Hemisphere winter (December-March) high pressure develops over the landmasses to the north. A pronounced intertropical trough develops at 10-15°S and anticyclonic conditions weaken and move to 33-35°S. The NE Trades characterise the northern Indian Ocean, becoming the NW Monsoon south of the Equator in the region of the Seychelles. In the transition periods (April and November) winds tend to be light and variable and intertropical troughs lie close to the Equator and over the Seychelles. Typically, the transition periods and the NW monsoon constitute the rainy season in the north of the Mascarene Plateau / Seychelles Plateau region.[1, 4]

Figure 1 shows seasonal variations in wind power density, derived from microwave measurements recorded on the QuikSCAT satellite platform, over the Indian Ocean.[5] For the region of the Seychelles (3°S; 56°E – 9°S; 46°E) note the low wind power densities (wind power density is proportional to U^3, where U = windspeed) in the northern winter months and the strength of the SE Trades in the northern summer, with particularly strong jet flow (and associated wind shadow) around Cape d'Ambre, northernmost Madagascar.

Oceanography of the Western Indian Ocean

The surface ocean circulation of the Western Indian Ocean is characterised by a subtropical, anti-cyclonic gyre to the south (between 40–15°S) and reversing monsoon gyres north of 10°S. In addition, large volumes of water, around 5 Sv (February) to 15 Sv (June/July) (where 1 sverdrup (Sv) = 106 m3 s^{-1}), enter the Indian Ocean from the Pacific Ocean at low latitudes through the Indonesian throughflow.[3] Ultimately, some of this water enters the southward flowing Agulhas Current along the coast of SE Africa; where this current retroflects and heads back into the Indian Ocean south of Africa, rings are shed which carry large volumes (~ 10 Sv) of warm and salty Indian Ocean water into the South Atlantic Ocean.[6] There are many 3-D complexities also, but the discussion of equatorial undercurrents, deep jets and vertical propagating signals lies beyond the scope of this review.

The northern boundary of the subtropical gyre is formed by the South Equatorial Current, a 100 - 200 m thick layer of relatively low salinity water (reflecting its source region of heavy convective rainfall in the eastern equatorial Indian Ocean). Driven by the SE Trades, typical current speeds of 0.25 m s^{-1} with an estimated transport of 50 Sv.[3,7] In its westward passage it must pass over, or through, the Mascarene Plateau, accelerating to current speeds of 0.5 m s^{-1} as it is squeezed by the topography. Recent research suggests that *ca.* 50% of the flow is concentrated in the deep channel between the Saya de Malha and Nazareth Banks (Figure 2), with a secondary concentration of flow between the St. Brandon Bank / Cargados Carajos and Mauritius.[7] Some of the transport probably spills onto the Plateau, especially nearer the Equator where the effect of the Earth's rotation is weaker.

After passing through and over the Plateau, the South Equatorial Current reforms, with current speeds of 0.3 m s^{-1}, before dividing around the island of Madagascar. Around 60% of the flow moves north around Cape d'Ambre, at near surface speeds of 0.7 m s^{-1}, and 40% southwards.[8]

Close to the Equator and in the Northern Hemisphere, the direction of surface currents is determined by the prevailing winds. During the Northern Hemisphere summer (Figure 3), the northern branch of the South Equatorial Current is displaced northwards, as far as 6°S and thus into the region of the Amirantes Archipelago. It feeds into the East African Coast Current, which in turn supplies the northward flowing Somali Current.[3] Any flow that does not go north moves through the Mozambique Channel[6], organized each year into 4-5 large scale (300 km across) anticyclonic eddies, moving south at 4.5 cm s^{-1}. The cross-equatorial winds associated with the Somali Current force strong coastal upwelling (organised into a temporally variable series of gyres (from south to north): the 'Southern Gyre'; the 'Great Whirl' and; the 'Socotra Eddy'; Figure 3) and a dramatic cooling of sea surface temperatures. The Southwest Monsoon Current, south of Sri Lanka, flows eastwards during this season.[9]

By comparison, the East African Coast Current meets the southward-flowing, near-surface Somali Current during the Northern Hemisphere winter in a confluence zone at 2-4°S (Figure 4). The two flows then supplying an eastward-

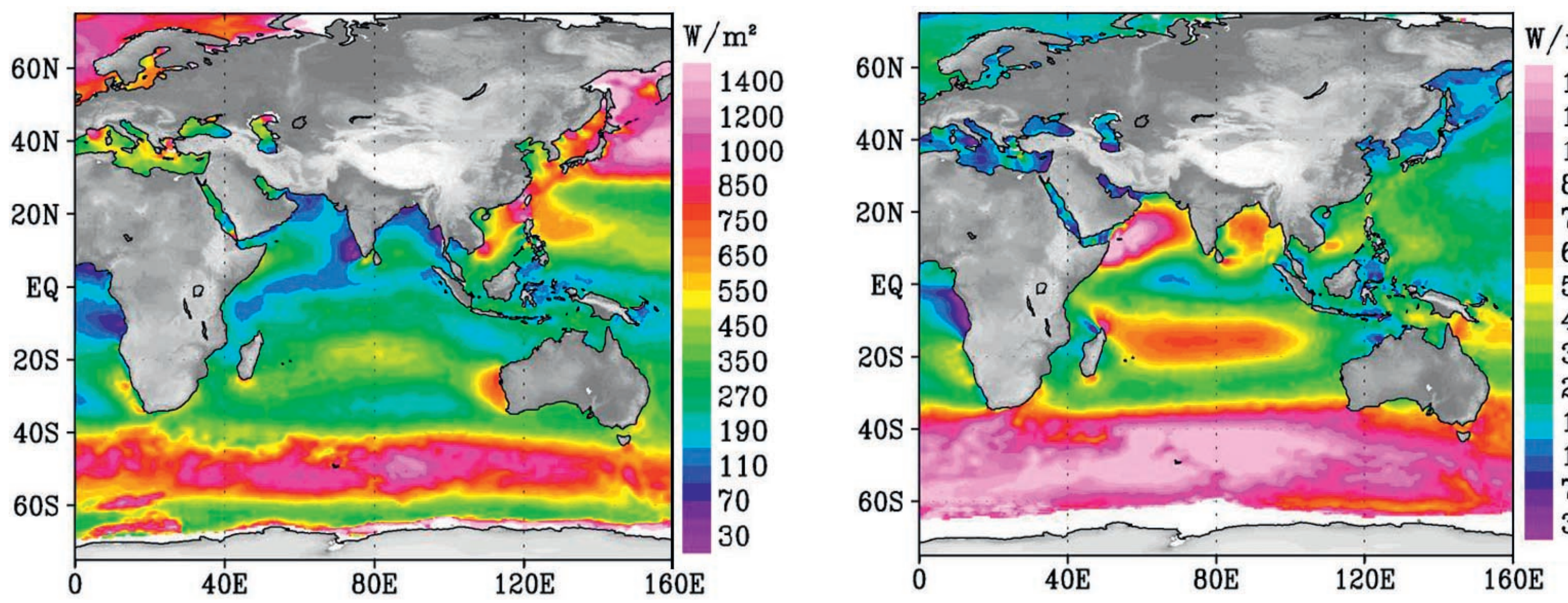


Figure 1: QuikSCAT wind power density a) Dec/Jan/Feb 2000-2007 b) Jun/July/Aug 2000-2007 (after Liu *et al.*, 2008)

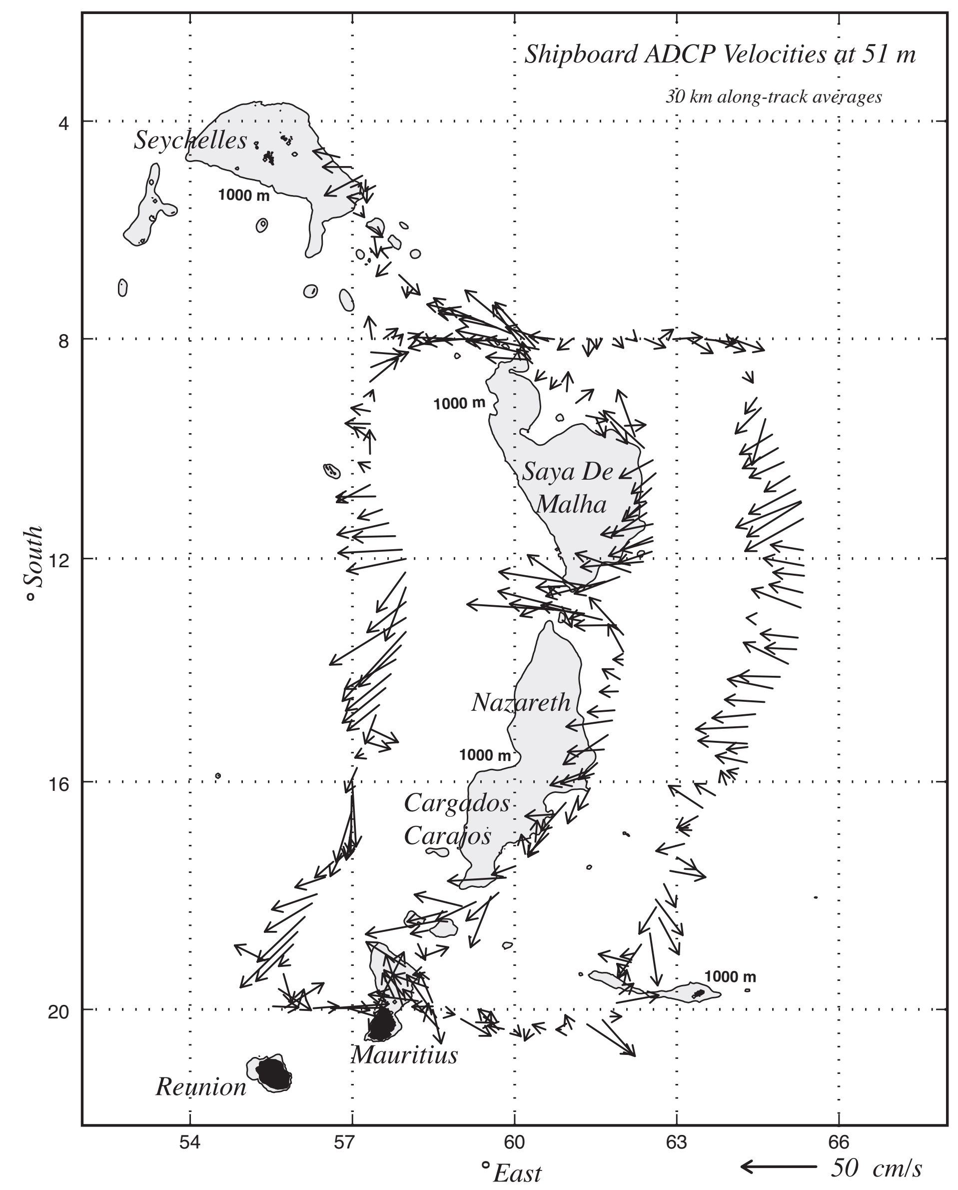


Figure 2: Currents at a water depth of 51m, recorded by Acoustic Doppler Current Profiler (ADCP) on board RRS *Charles Darwin*, 1 June – 11 July 2002. Velocity vectors represent averages over 8 m in the vertical and 30 km in the horizontal; note scale bar depicting vector arrow length for a average velocity of 50 cm s^{-1} (after New *et al.*, 2005).

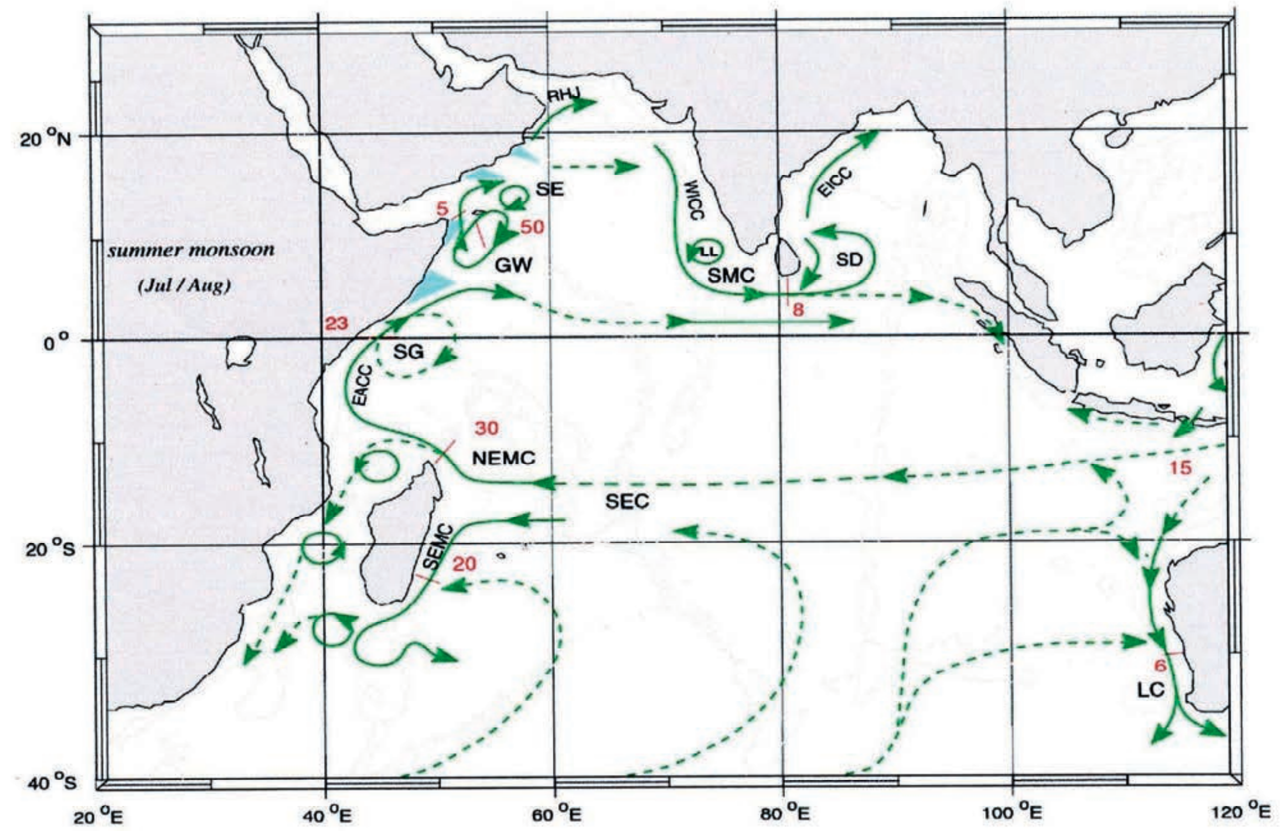


Figure 3: Schematic representation of current flows during the Southwest Monsoon (July / August). Currents identified are South Equatorial Current (SEC), Northeast and Southeast Madagascar Current (NEMC and SEMC), East African Coast Current (EACC), Southern Gyre (SG), Great Whirl (WG), Socotra Eddy (SE), Ras al Hadd Jet (RHJ), West Indian Coast Current (WICC), Laccadive Low (LL), Southwest Monsoon Current (SMC), Sri Lanka Dome (SD), East Indian Coast Current (EICC) and Leeuwin Current (LC). Areas in blue indicate upwelling regions and red numbers indicate transport rates (Sv, where 1 Sv = 10^6 m^3 s^{-1}) (after Schott and McCreary, 2001).

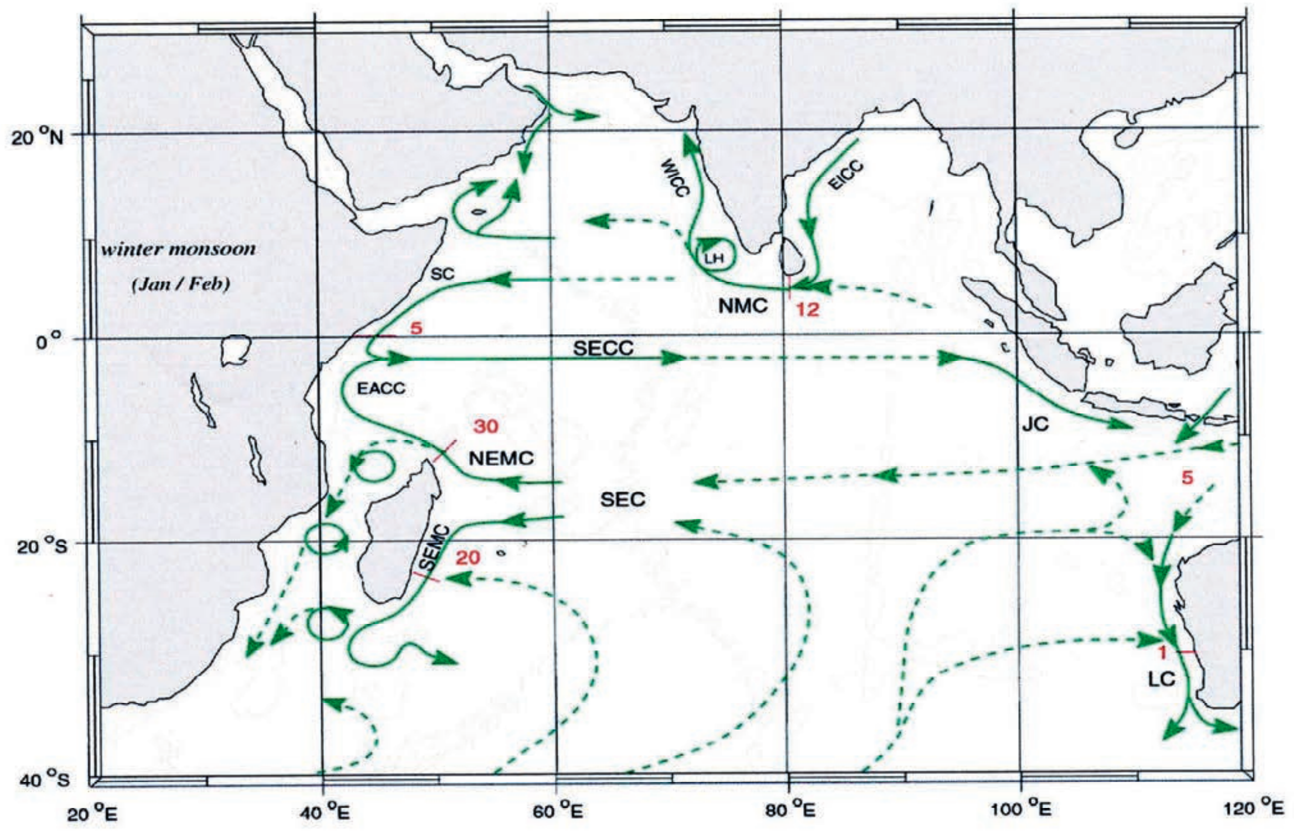


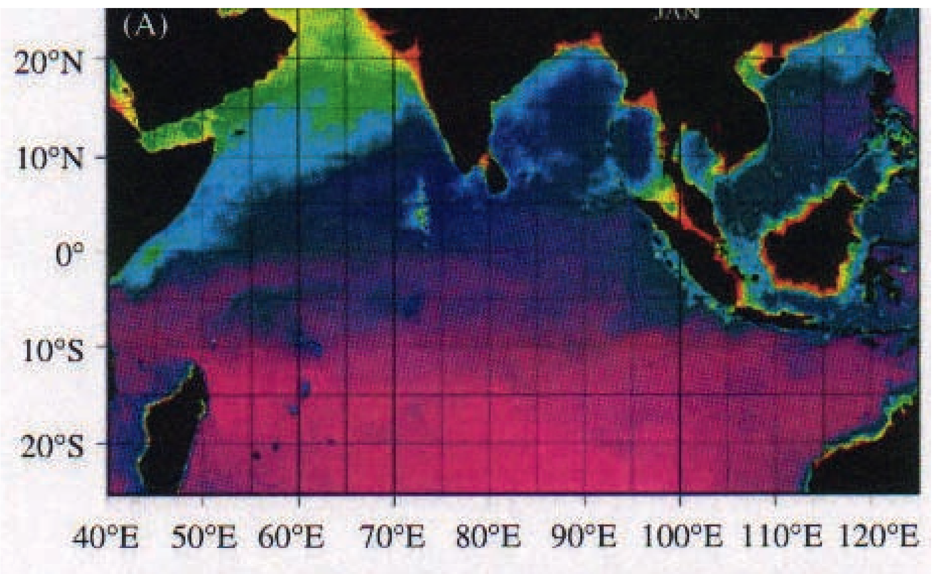
Figure 4: Schematic representation of current flows during the Northeast Monsoon (January / February). Currents identified as in Figure3 and additionally Somali Current (SC), South Equatorial Countercurrent (SECC), Laccadive High (LH), Northeast Monsoon Current (NMC) and Java Current (JC). East Indian Coast Current (EICC), and Leeuwin Current (LC). Red numbers indicate transport rates (Sv, where 1 Sv = 10^6 m^3 s^{-1}) (after Schott and McCreary, 2001).

flowing South Equatorial Countercurrent, best developed in the month of February.[10] Current flow south of Sri Lanka is now formed by the westward-flowing Northeast Monsoon Current.

In fact, actual circulation patterns are more complex than suggested by this semiannual model.[11] Thus, for example, surface currents in the equatorial Indian Ocean reverse direction four times per year; the eastward currents, known as 'Wyrtki jets', typical of the spring and autumn transitions between the monsoons, have characteristic durations of two months and current strengths of 0.1 m s^{-1}.

Marine biogeochemical processes

The reversing ocean circulation systems also cause substantial variations in marine biogeochemical processes and ecosystem response. An Indian Ocean seasonal climatology of surface chlorophyll *a* has been derived from the ocean colour satellite, SeaWiFS.[12] During the Northeast Monsoon, offshore winds result in winter phytoplankton blooms in the north and central Arabian Sea but not further south or east (Figure 5). During the Southwest Monsoon, phytoplankton blooms are associated with current patterns around Sri Lanka and, in particular, along the coasts of Somalia and Oman, extending up to 500 km offshore (Figure 6). In addition, this northern summer climatology also shows enhanced chlorophyll *a* in the region of the Seychelles Plateau / Mascarene Plateau. This pattern has, to some degree, been verified by variations in mesozooplankton biomass from direct sampling on either side of the Mascarene Plateau between the Seychelles and Mauritius[13]. This enhancement may be due to turbulent mixing by the South Equatorial Current as it passes through the passages in the Mascarene Plateau or it may be due to flow patterns along the northern edge of the South Equatorial Current. The latter dome the thermocline between 5–15°S, thus bringing relatively nutrient rich subsurface waters into the mixed layer.[3, 7, 13, 14]



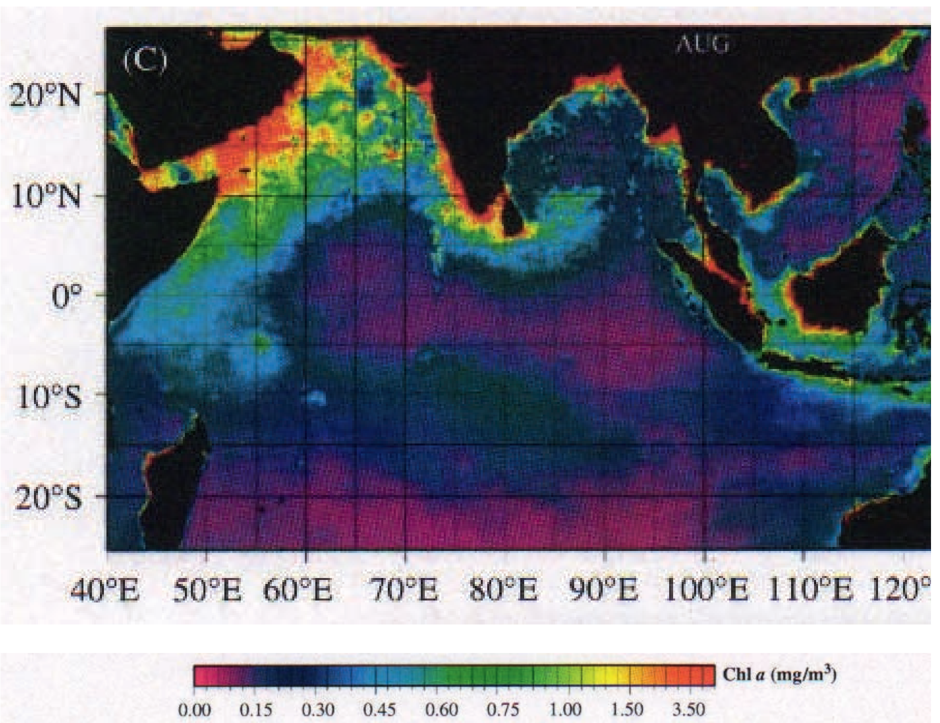


Figure 5 (top): SeaWiFS chlorophyll *a* climatology, month of January (after Wiggert *et al.*, 2006)

Figure 6 (bottom): SeaWiFS chlorophyll *a* climatology, month of August (after Wiggert *et al.*, 2006).

Ocean – atmosphere coupling, climate modes and coral bleaching in the Western Indian Ocean

Traditionally, the role of the Indian Ocean in the SE Asian Monsoon has been seen as being essentially passive, providing only specific heating differences and a supply of water vapour, through evaporation, to the climate system. Yet surface wind-driven ocean transports are comparable in magnitude, but opposite in sign, to atmospheric transports and thus in reality the Indian Ocean acts through negative feedback to modulate climate cycles. In this way, ocean processes can either enhance a weak monsoon or reduce the intensity of a strong one. These processes are considerably perturbed during major atmosphere-ocean re-organisations.

The SE Trades, and the SW Monsoon, typically weaken during a Pacific Ocean ocean-wide warming, or El Niño Southern Oscillation (ENSO) episode. Some recent studies of the inter-annual variability of Indian Ocean Sea Surface Temperatures (SSTs) have suggested a quasi-periodic ENSO signal, with the dominant mode of variability in phase with the peak El Niño warm phase off the west coast of South America or lagged some six to nine months behind it.[15] However, other research has argued that the oscillations in SSTs, precipitation and winds between the eastern and the western Indian Ocean - a tropical Dipole Mode - are the result of internal ocean - atmosphere dynamics and not a direct response to external ENSO forcing.[16, 17]

A 'dipole structure' has been identified, characterised at one extreme by positive SST anomalies, high sea levels and increased rainfall over the western Indian Ocean and East Africa and negative SST anomalies off Sumatra and drought over Indonesia and at the other extreme, by a reversal of these characteristics. Figure 7 shows the evolution of one such event in 1997 – 1998.[16] A 'Dipole Mode Index', constructed from differences in SST between the eastern and western Indian Ocean, can be compared with the record of ENSO warmings[17]. In some years the two indices coincide - as in 1972 and 1997 - but in many years do not, as in 1961, 1967 and notably in 1994 when a significant Dipole Mode event corresponded to a weak El Niño.

The growth and decay of areas of exceptional ocean heating and cooling (as seen in the areas in red and blue in Figure 7) can be tracked through large-scale, repeat imagery of Sea Surface Temperature from satellites. These anomalies can then be related to thermal tolerance thresholds for corals to identify potential loci for coral bleaching episodes.

'Coral bleaching' is the term used to describe the whitening of corals which results from the degeneration and/or loss of symbiotic algae from coral tissues. This process occurs when elevated temperatures, possibly in conjunction with high solar irradiance, cause coral photo-protective mechanisms to be overridden, the threshold typically being a water temperature in excess of +1°C above the maximum monthly temperature at any particular location. Coral bleaching is often patchy, and recovery good, from short-lived, small temperature excursions but prolonged and severe warmings may lead to mass bleaching of entire reef systems and high levels of post-bleaching coral mortality.

The most recent of these major warmings took place in the Indian Ocean in 1997–1998. Significant potential for coral bleaching began to be seen in the Indian Ocean in December 1997, as a relatively narrow NW–SE band of warm water. This then strengthened to become an ocean-wide Sea Surface Temperature anomaly south of the Equator between February and April 1998, before migrating north and east across the Indian Ocean and ultimately decaying by June 1998. Figure 8 shows the Sea Surface Temperature anomaly / coral bleaching hotspot map at the end of March 1998, near the peak of the event.[18]

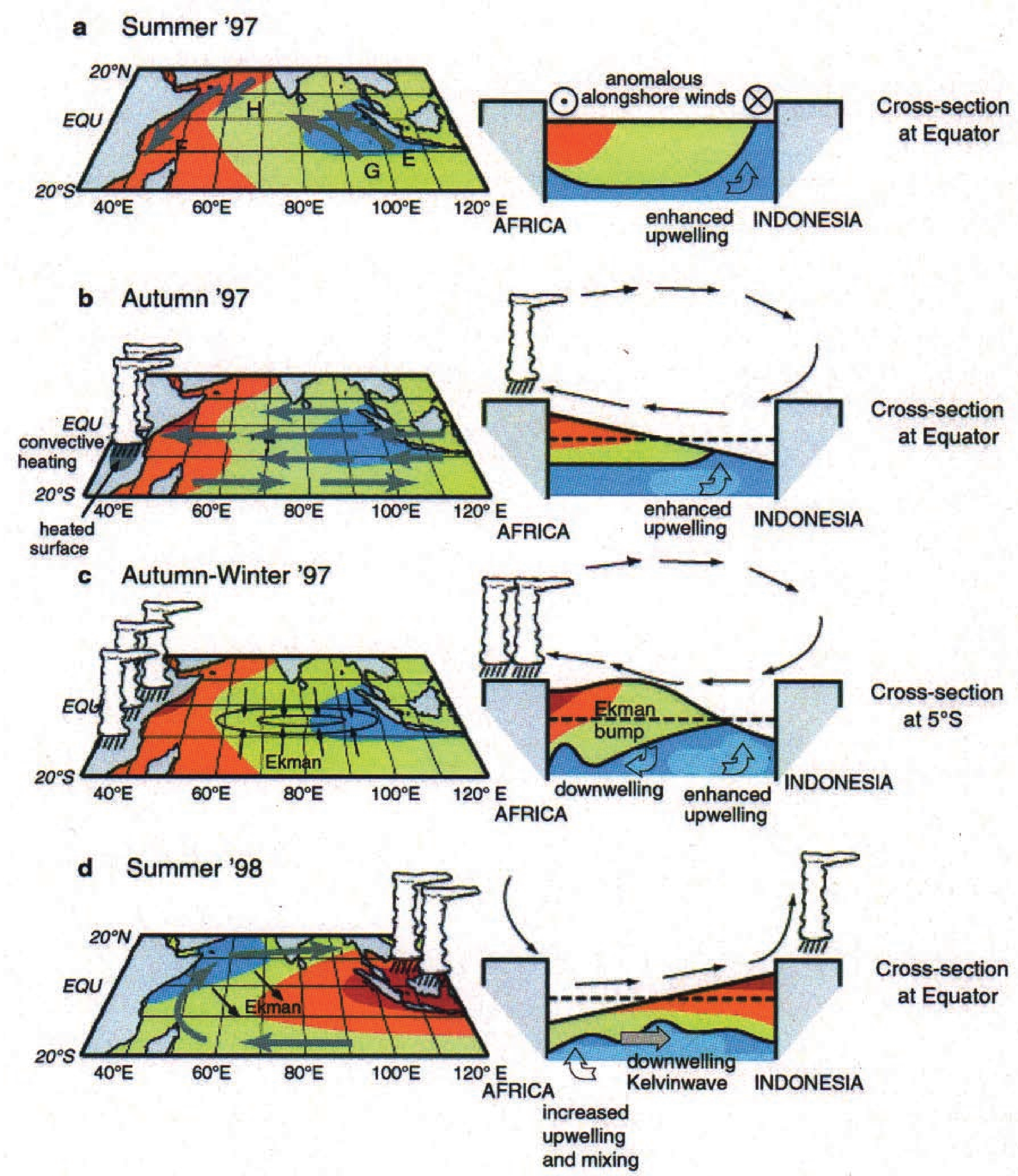


Figure 7: Development of the 'Indian Ocean Mode' (according to Webster *et al.* 1999)

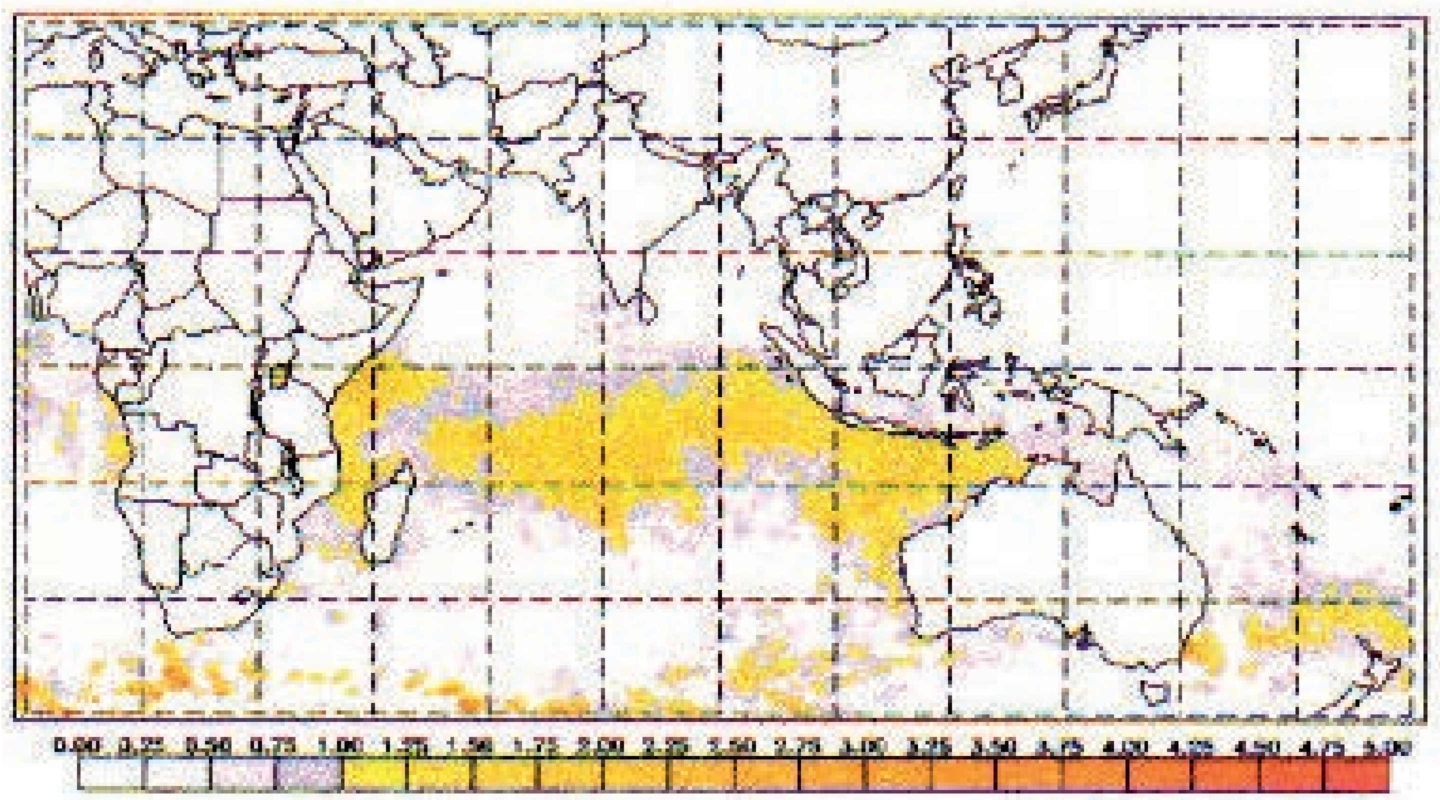


Figure 8: NOAA/NESDIS Sea Surface Temperature (SST) anomaly coral bleaching hotspot chart for 30 March 1998 (for more detailed discussion see Spencer *et al.*, 2000).

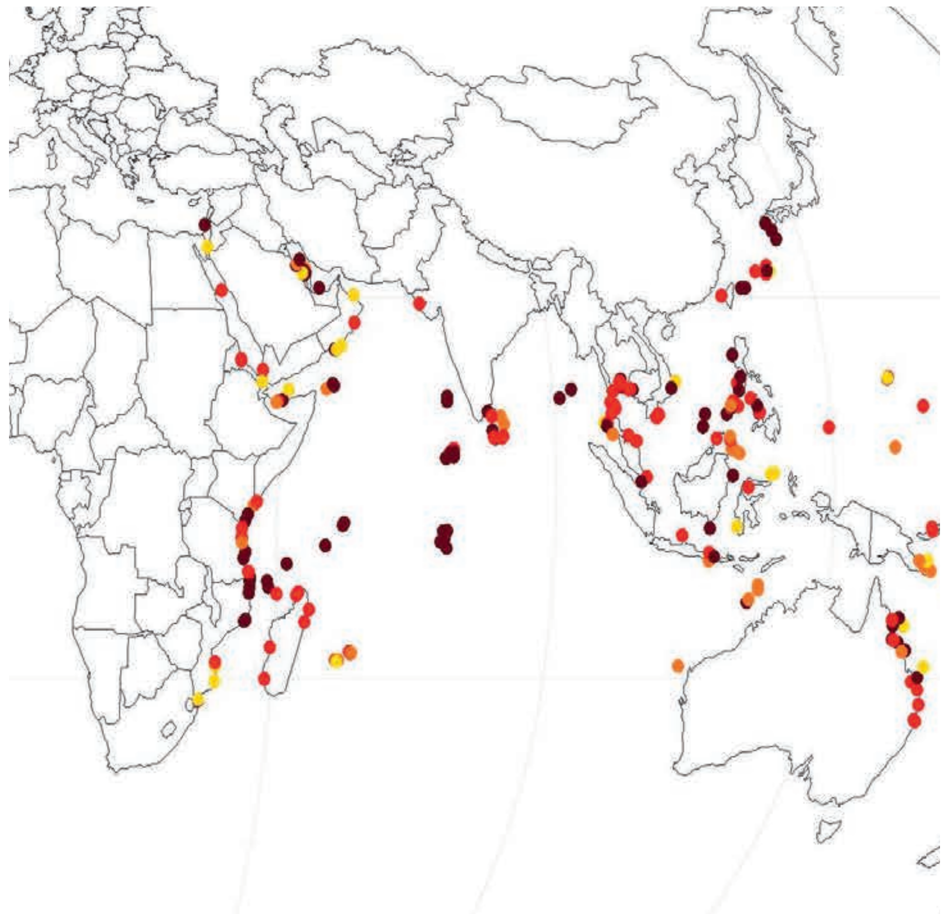


Figure 9: Coral bleaching in the Indian Ocean in 1997 – 1998 (after IUCN / WCMC)

The mass coral bleaching event of 1997–1998 has been described as the most severe on record. Bleaching was particularly severe in the Indian Ocean (Figure 9), with post-bleaching mortality reaching as much as 90% in parts of East Africa and the Maldives and 50–90% over extensive areas of shallow reefs in the granitic Seychelles, Comoros Archipelago and Chagos Archipelago. However, bleaching impacts were less severe in the southern Seychelles (at Aldabra), Mauritius, and Reunion.[19]

Regional climates of the Seychelles

Atmospheric processes

In the Seychelles region, mean monthly air temperatures always lie above 20° C and relative humidities (at 1000 hours) between 75 and 80 %. Mean annual sea level temperature at Port Victoria, Mahé (4°37'S, 5°27'E) is 26.6°C (mean monthly range: 25.7–27.8°C).[1]

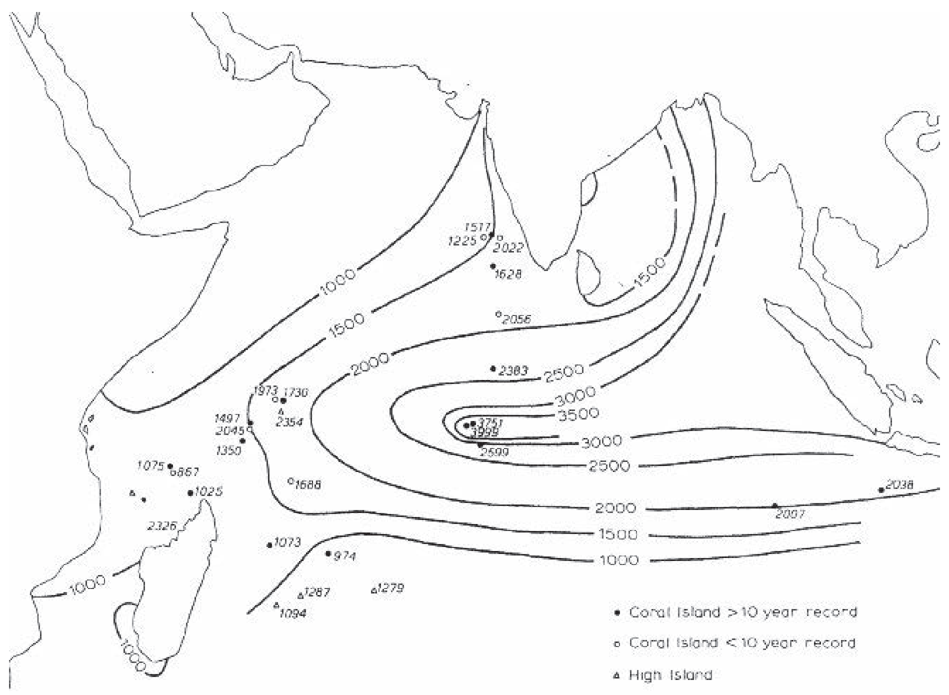


Figure 10: Mean annual rainfall at sea level over the western Indian Ocean (after Stoddart and Walsh 1979).

Regional mean annual rainfall at sea level shows a central Indian Ocean high in excess of 3,500 mm which then falls to the north, west and south (Figure 10).[20-22] In the Seychelles outside of the high granitic islands - where rainfall, strongly influenced by aspect and relief, reaches annual totals well in excess of 3,000 mm - there is a strong gradient from the northeastern to the southwestern atolls. Thus, for example, mean annual rainfall on the rim of the Seychelles Bank at Denis (1951–62: 1730 mm; Figure 10) is almost twice as high as at Aldabra (1949–1976: 966 mm; 1967–1976: 1075mm; Figure 10). In the Amirantes, records for broadly comparable periods at D'Arros (1950-1962: 1497 mm) and Alphonse (1949-1962: 1350 mm) are as predicted by this gradient. A short record from Poivre, however, records a higher than expected total (1961-1962: 2045 mm).

There are also strong differences in the length of the dry season, from one dry month (< 102 mm monthly total) at Denis to 8 months at Aldabra; in some years dry periods at the latter location can extend to 10-12 months. Again, the islands of the Amirantes show intermediate characteristics: there are typically 4 dry months at D'Arros, reaching 6 months at the southern end of the archipelago at Alphonse.[1]

In addition to these generalised differences, there have been marked temporal fluctuations over the period of historical records, tentatively related to changes in the position of the ITCZ and patterns of cyclone development on the poleward margin of the convergence. At Mahé, high rainfalls occurred in the periods 1891–1904, 1923-1937 and 1959-1970 with lower totals (by 500 mm, equivalent to -20 %) in the intervening periods 1905–1922 and 1938–1958. At Aldabra, the mean annual rainfall for the period 1949-1959 was 27 % less than that in the wetter period 1967–1976. A further period of low rainfall was experienced between 1980 and 1997.[23]

Figure 11 shows monsoon-influenced monthly variations in average wind direction at Mahé. The typical mean windspeed at the height of the SE Trades (month of August) at Mahé is 4.7 $m\ s^{-1}$; further south at Aldabra mean windspeeds peak in September at 5.4 $m\ s^{-1}$. By comparison, mean windspeeds associated with the NW Monsoon peak at 2.1 $m\ s^{-1}$ in January at Mahé and windspeeds in the calm transitional months of April and November are even lower, at 1.7 and 1.9 $m\ s^{-1}$ respectively. Maximum mean annual, mean monthly and maximum daily windspeeds of 5.6 $m\ s^{-1}$ (1972), 10.0 $m\ s^{-1}$ (March 1971) and 22.6 $m\ s^{-1}$ (21 September 1968) respectively have been recorded at Aldabra.[1]

These variations in wind direction and windspeed have implications for coastal morphology. At Mauritius, more than 70% of waves are driven by the SE Trades, with typical wave heights of 3 m and periods of 7-10 s, and this leads to strongly differentiated windward and leeward reef morphologies.[4] These differences are maintained throughout the region, although less so as far north as the granitic Seychelles.

Tropical cyclones are rare in the north of the region but more prevalent further south where they develop from small disturbances within the SE Trades. Analysis has shown mean frequencies of only 2.1 cyclones per decade in the area 0-10°S; 50-60°E compared to 25.4 per decade at 10-20°S; 50-60°E[24]. Cyclones typically occur between December and March and move westwards and polewards at 5-40 km h-1 before dissipating, typically after 5-10 days, over cooler waters in the southern Indian Ocean.

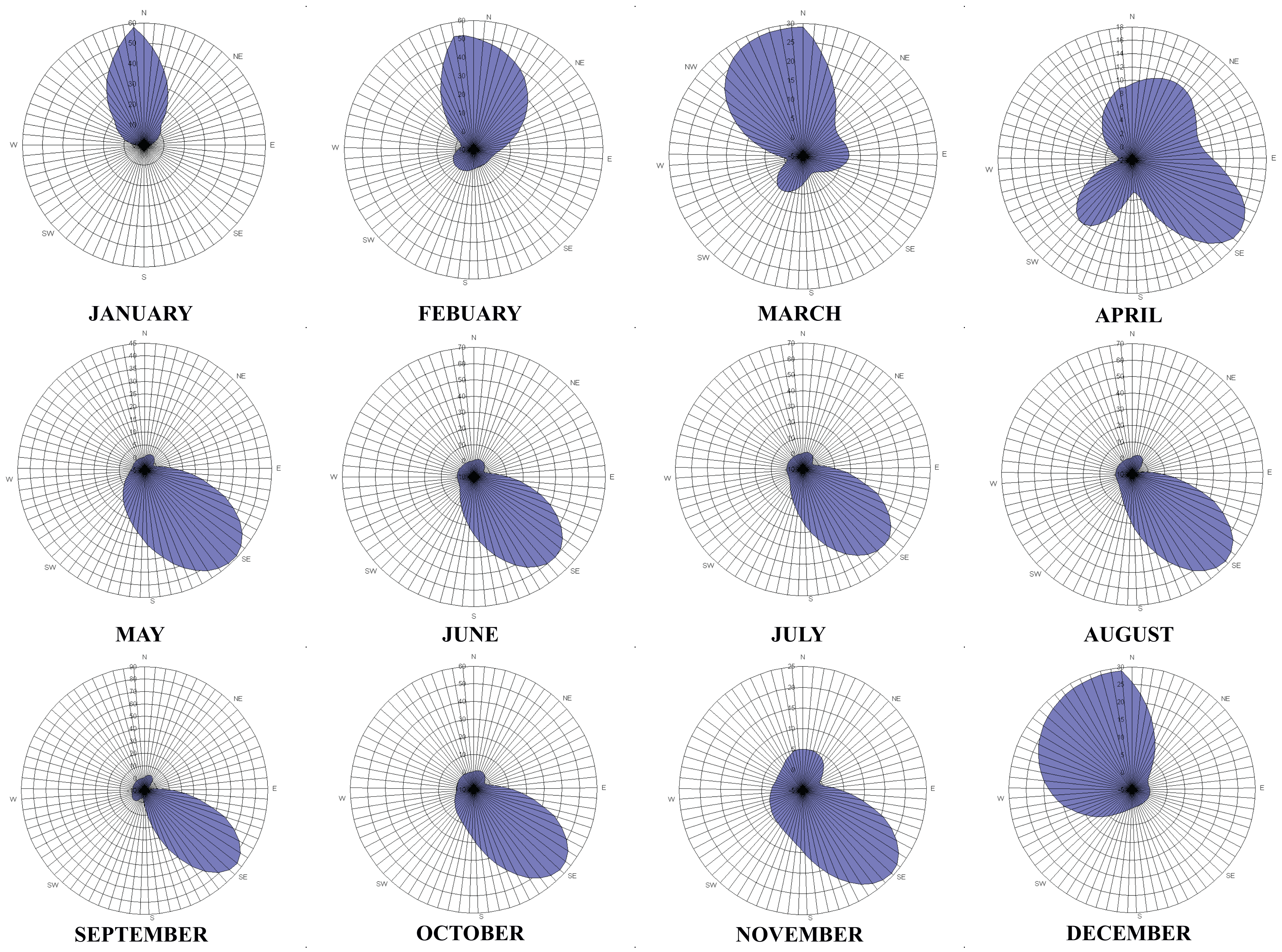


Figure 11. Annual total proportion of winds (≤ Beaufort force 5; 8-10.8 $m\ s^{-1}$) observed from each direction across the West Indian Ocean at Mahé (4°37'S, 5°27'E). Data averaged for the period July 1949-September 1954 and interpolated across 360°. Source: U. S. Navy Marine Climatic Atlas of the World. Volume III. Indian Ocean (1976).

Figure 12: Coral boulder debris field on northwest reef-flat, Alphonse Atoll, October 2007. Newly dead *Porites* colony (90 cm diameter) in foreground (photograph: A Hagan).

In December 2006, Cyclone Bondo formed southwest of Diego Garcia and moved west across the Indian Ocean. It was a small but intense system (radius of hurricane force winds < 20km) and category 2 strength (154–177 km h^{-1}) winds hit the Seychelles. In response to the potential danger from Bondo, 35 of the 43 residents of Farquhar (10°S; 51°E) were evacuated, with the remaining eight taking shelter in the island's concrete bunker[25]. Bondo passed 330 km south of Alphonse atoll, and although no terrestrial damage was observed, the associated wave energy generated a coral boulder debris field on the northwest reef-flat (Figure 12). Coral blocks and newly dead *Porites* colonies, some measuring over 1 m in diameter, were observed. During underwater surveys at Alphonse in October 2007, it was deduced that these coral blocks and *Porites* colonies originated from depths of 7-12 m from the fore-reef slope and had been transported approximately 500 m to reach the reef-flat.

Recent coral bleaching and tsunami impacts in the West Indian Ocean

The Mascarene Plateau is close to a tidal amphidrome and microtidal ranges (0.3-1.0 m) characterise Mauritius (tidal range = 0.5 m) and St. Brandon. The islands of the granitic Seychelles, and of the Amirantes, are classified as mesotidal (1.0-2.0 m) whilst the islands of the Aldabra group experience spring tide ranges of 2.0-3.0 m, greater than for any other oceanic reefs.[4]

In the region between 6–10°S; 45–54°E, mean monthly Sea Surface Temperatures reach their maximum (ca. 29°C) in March – April and their minimum (ca. 25°C) in August. However, during Indian Ocean warmings, this annual cycle can be considerably perturbed. Thus during the 1997 – 1998 warming, regional Sea Surface Temperature anomalies of greater than + 1°C (the commonly held threshold for coral bleaching) were exceeded from November 1997 to April 1998, with a maximum anomaly of +1.84°C (Figure 13). At Alphonse, the steep rise in sea surface temperature occurred in February 1998, to +1.8°C on the long-term monthly mean and there then followed a two and a half month long period when sea surface temperatures exceeded 30°C. Finally, the maximum local temperature anomalies, of +2.5°C were experienced on the Seychelles Bank, probably as a result of the heating of the relatively shallow bank waters.[18]

Amirantes reefs are recovering in terms of live coral cover following the 1997-98 ocean warming event[26], but on-going monitoring is required to gauge

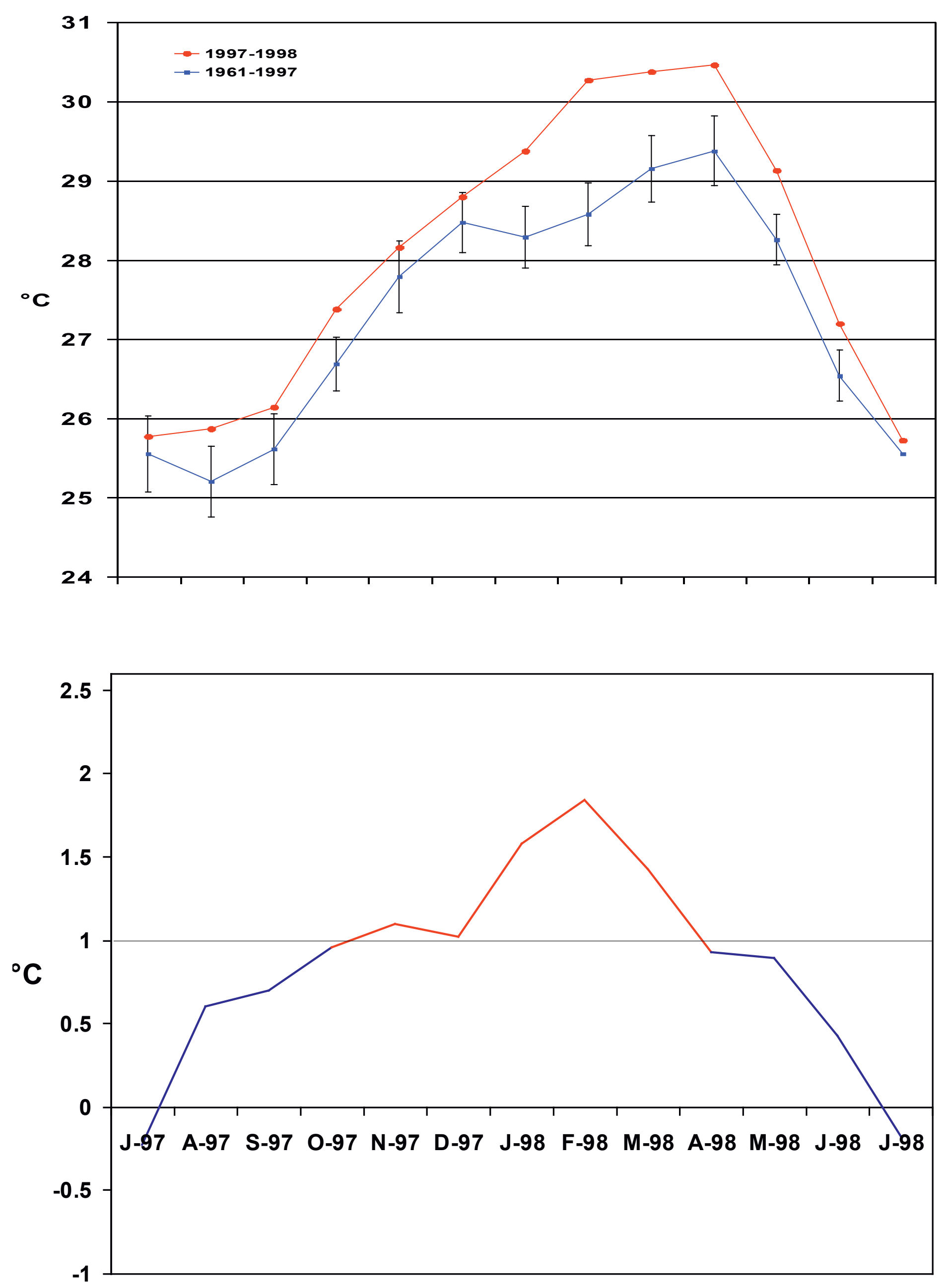


Figure 13: Sea surface temperatures for the area 6–10°S; 45–54°E, July 1997–July 1998:
(top) Long-term monthly mean (± 1S.D.) for 1961–1997; monthly means 1997–1998 (source: GISST2.3b);
(bottom) Monthly Sea Surface Temperature anomalies (source: MO-HSST6D).
(After Spencer *et al.*, 2000).

the timescales which may be required for these reefs to regain their former coral diversity.

Field observations reported in this Atlas were collected shortly after the 2004 Asian Tsunami which devastated islands and reefs throughout the Indian Ocean basin.[27] Tsunami waves reached Mahé at about the same time they impacted Mauritius and Salalah, Oman, approximately 7 hours after the earthquake. Water level residuals above and below predicted tidal levels continued for some 36 hours after the initial waves; it seems likely that the tsunami excited some form of seiche (what does this word mean?) on the Seychelles Bank that both amplified and prolonged the initial tsunami signal.[28]

In the granitic Seychelles, maximum water levels reached + 1.6–4.4 m and + 1.8–3.6 m above mean sea level on Mahé and Praslin respectively.[29] Some of the highest elevations were recorded on leeward shores, suggesting that the tsunami waves were refracted across the Seychelles Bank, converging on the western sides of the islands. No physical damage from this event was observed in either the terrestrial or marine environments at any of the islands visited elsewhere in the Amirantes or southern Seychelles.[29] The littoral hedge remained intact and there was no evidence of beach sediment movement or water inundation at island margins. Underwater there was no evidence found of tsunami-related mechanical damage on the reef; no physical damage to branching corals (principally *Pocillopora*) and no coral toppling was observed. On Alphonse, D'Arros, Desroches, Marie-Louise and Poivre, island personnel said that there had not been any impact caused by the tsunami and they hardly noticed the event.

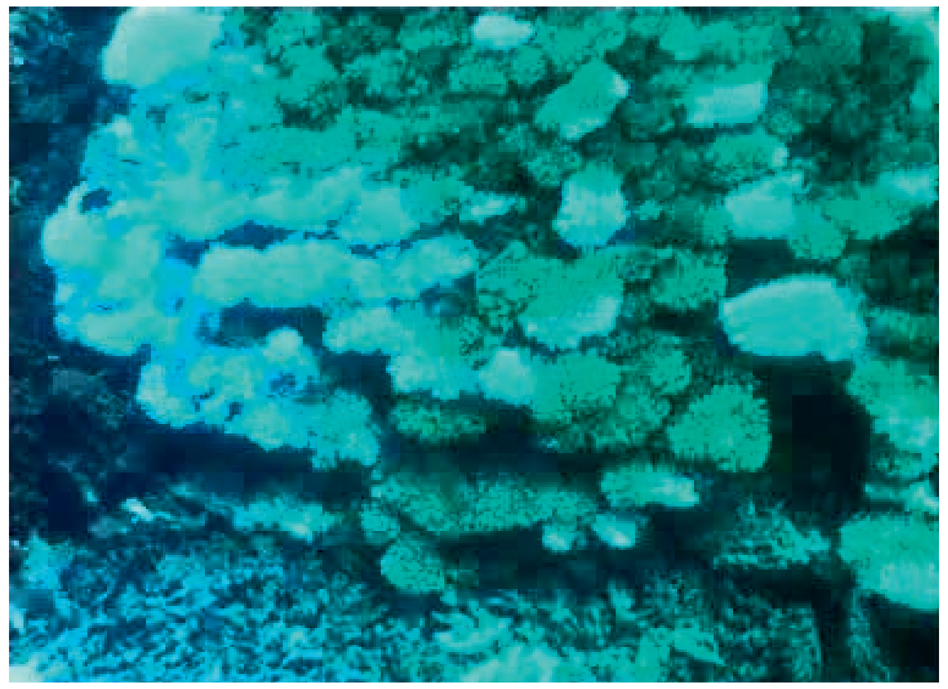


Figure 14: Partially bleached *Pocillopora* sp. coral, St Pierre, southern Seychelles, April 1998 (photograph: K. Teleki).

The lack of noticeable impacts within the southern islands compared to islands further north appears to be related to both reduced tsunami wave heights to the south (due to the ocean basin-scale refraction of the wave from the east – west axis of maximum impact at 0 - 5°N and to differences in regional bathymetry, the tsunami being accentuated by the shallow shelf seas of the Seychelles Bank in the north and not amplified around the southern islands which are surrounded by deep water.[29]

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Mapping the Amirantes

Introduction

Stoddart[1] defines the beginning of scientific studies in the Seychelles as the hydrographic survey by Fairfax Moresby in 1822; subsequent charting in the Amirantes was undertaken between 1882 and 1897 and between 1971 and 1976. However, the first extensive descriptions and collections in the Amirantes, come from two expeditions, that of HMS *Alert* in 1882 and that of HMS *Sealark* in 1905. RW Coppinger's island descriptions[2] provide useful information on changing island morphologies and, in particular, on the nature of these islands just before most were transformed by the great expansion of coconut plantations. In 1905, J. Stanley Gardiner made extensive collections during the Percy Sladen Trust Expedition and provided descriptions for some of the islands.[3-5] Apart from the seabird studies of Desmond Vesey-Fitzgerald in the 1930s, and Viscount Ridley and Lord Richard Percy in the 1950s, the most important subsequent studies were the comprehensive inventories of geology, mineral resources and soils by Baker[6] and Piggott[7-8], following field visits in 1960. For many of the locations mapped in this Atlas, these studies still provide the only detailed information on the nature of subaerial island surfaces.

The cruise of the M.F.R.V. *Manihine* in 1967 yielded collections of plants and birds[9] and in 1967, 1968 and 1976, parties from the Royal Society of London's research programme at Aldabra Atoll were able to visit several locations in the Amirantes.[10-14] Numerous bird surveys have been conducted since then; these are detailed under individual island descriptions. Wilson visited Marie-Louise and Desnoeufs in June 1979 and July 1980 and reported on the terrestrial flora and fauna.[15-16] Seagrass inventories were undertaken in 1989 by the joint USSR – USA expedition on the R.V. *Academician Nesmeyanov*[15] and significant benthic surveys were undertaken by The Netherlands Indian Ocean Programme[14] onboard the R.V. *Tyro* in 1992 – 1993.[17] Research on patterns of reef recovery and regeneration following coral bleaching has been undertaken over the last decade at Alphonse Atoll. Monitoring commenced at the peak (April 1998) of the 1997 – 98 ocean warming and has continued with repeat underwater videography surveys in the period 2001-2007.[19-21] At the present time, there are scientific / conservation research centres on D'Arros and Alphonse; a further station is planned for Desroches.

For most of the islands in this Atlas, the new maps generated by this project supersede earlier, lower resolution maps of terrestrial vegetation and, to a lesser extent, marine habitats. These earlier maps were produced for the Republic of Seychelles in the late 1970s by the UK Government's Ministry of Overseas Development (Directorate of Overseas Surveys) using aerial photographs from around 1960. In some cases, however, the maps provided here are the first detailed maps for a particular location.

Methods: habitat mapping from remote sensing imagery

Airborne remote sensing data were acquired in January 2005 over 13 islands in the Amirantes from the seaplane *Golden Eye*, flown at a height of 1000 m above sea level. An area of 270 km^2 was covered, across 133 pre-determined parallel survey lines. Full details of the methods used to transform the raw data into habitat map classes are given in Appendix 1 to this Atlas. For Desroches, a habitat map has been created from Landsat imagery (for methodology see Appendix 2). As well as the CASI data, a number of (unregistered) oblique aerial photographs were taken for the Cambridge Coastal Research Unit by Mr Herb Ripley from the *Golden Eye* during the surveys; a selection of these photographs are presented under the individual island descriptions.

A habitat classification, with a two-tier hierarchical structure (Table 1), was developed to accommodate user requirements, field data availability and the spatial and spectral resolution of the CASI sensor.

Table 1: Two-tier hierarchical classification scheme used for generating habitat maps of the Amirantes from CASI data. Plates 1 - 25 show example photographs for each of these classes. Note: 'density' of seagrass refers to the degree to which the substrate is obscured by seagrass, not to the number of stems m^{-2}. Seagrass density characteristics are, therefore, a reflection of both the morphological characteristics of different species of seagrass and the nature of the canopy associated with those species.

First tier	Second tier
1. Terrestrial vegetation: trees and shrubs	1.1 Coconut woodland
	1.2 Other trees and shrubs
2. Herbs and grasses	
3. Saline pond	
4. Cleared/ bare ground	
5. Buildings and other structures	
6. Littoral hedge	
7. Mangrove woodland	
8. Coarse beach material and rocks	8.1 Coral sandstone / raised reef
	8.2 Coral boulders
	8.3 Beachrock
9. Beach sand	
10. Rock pavement	
11. Reef-flat sand	
12. Seagrass	12.1 Low density seagrass / macroalgae
	12.2 Medium density seagrass
13. High density seagrass	
14. Lagoon patch reef	
15. Lagoon sand	
16. Fore-reef slope material or structure. Not sand.	16.1 Coral rubble with coralline algae
	16.2 Fore-reef slope coral spurs with coralline algae
	16.3 Rocky fore-reef slope
	16.4 Fore-reef slope rubble and sand
	16.5 Fore-reef slope with coral
17. Fore-reef slope sand	

In general, good quality image classifications were achieved that provided a clear and accurate representation of the heterogeneity apparent in the raw imagery. Overall habitat map accuracy ranged from 67 to 77% (see Appendix 1 for methods of accuracy assessment).

The following photographs show examples for each of the classes listed in Table 1.

Plate 1: Coconut woodland (class 1.1), Alphonse (photograph: Annelise Hagan, October 2007).

Plate 2: Other trees and shrubs (class 1.2), Marie-Louise (photograph: Martin Callow, January 2005).

Plate 3: Herbs and grasses (class 2), Alphonse (photograph: Annelise Hagan, October 2007).

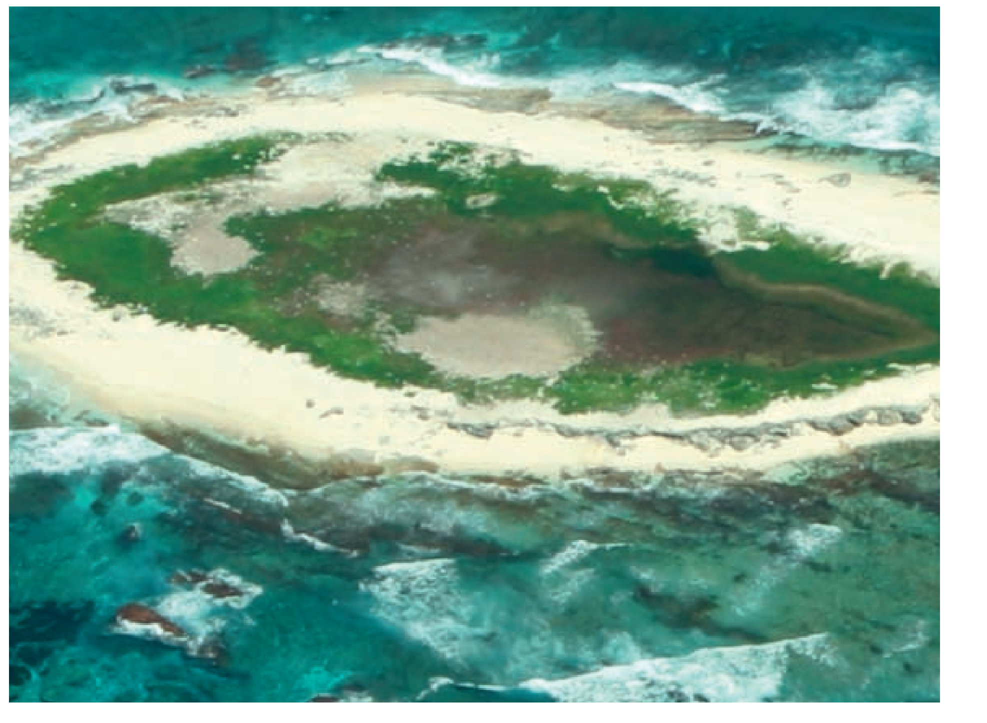

Plate 4: Saline pond (class 3), Boudeuse (photograph: Herb Ripley, January 2005).

Plate 5: Cleared / bare ground (class 4), Alphonse (photograph: Annelise Hagan, October 2007).

Plate 6: Buildings and other structures (class 5), Poivre (photograph: Martin Callow, January 2005).

Plate 7: Littoral hedge (class 6), Alphonse
(photograph: Annelise Hagan, October 2007).

Plate 8: Mangrove woodland (class 7), St. François
(photograph: Martin Callow, January 2005).

Plate 9: Coral sandstone / raised reef (class 8.1), Marie-Louise
(photograph: Martin Callow, January 2005).

Plate 10: Coral boulders (class 8.2), Desnoeufs
(photograph: Jen Ashworth, January 2005).

Plate 11: Beachrock (class 8.3), Marie-Louise
(photograph: Jen Ashworth, January 2005).

Plate 12: Beach sand (class 9), Alphonse
(photograph: Annelise Hagan, October 2007).

Plate 13: Rock pavement (class 10), Marie-Louise
(photograph: Martin Callow, January 2005).

Plate 14: Reef-flat sand (class 11), Alphonse
(photograph: Chris Banks, October 2007).

Plate 15: Low density seagrass/macroalgae (class 12.1), Alphonse
(photograph: Annelise Hagan, October 2007).

Plate 16: Medium density seagrass (class 12.2), Alphonse
(photograph: Annelise Hagan, October 2007).

Plate 17: High density seagrass (class 13), Alphonse
(photograph: Annelise Hagan, October 2007).

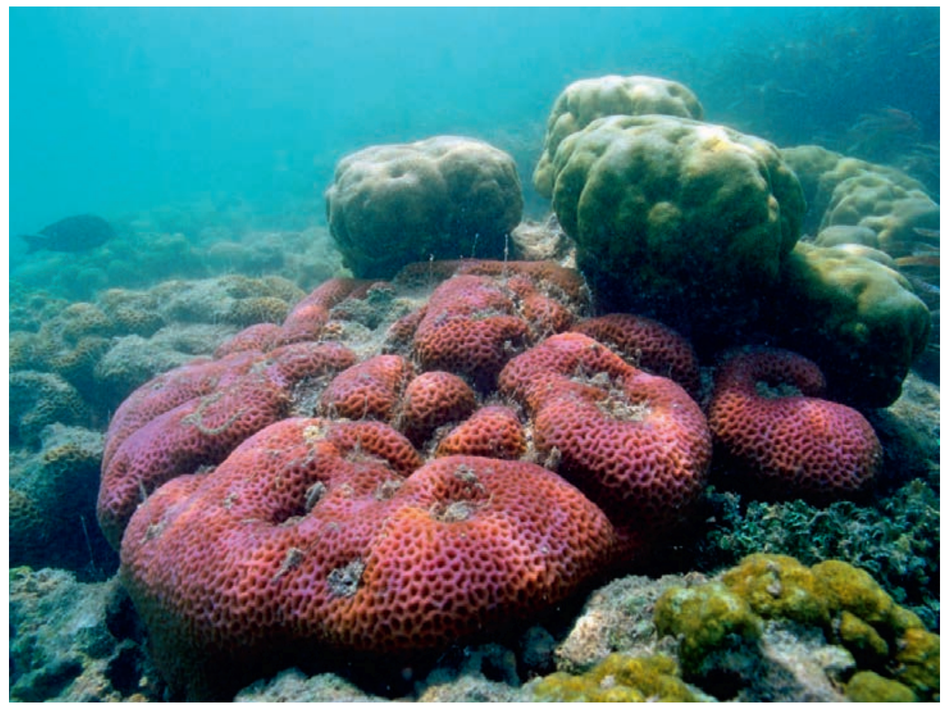

Plate 18: Lagoon patch reef (class 14), Alphonse
(photograph: Annelise Hagan, March 2003).

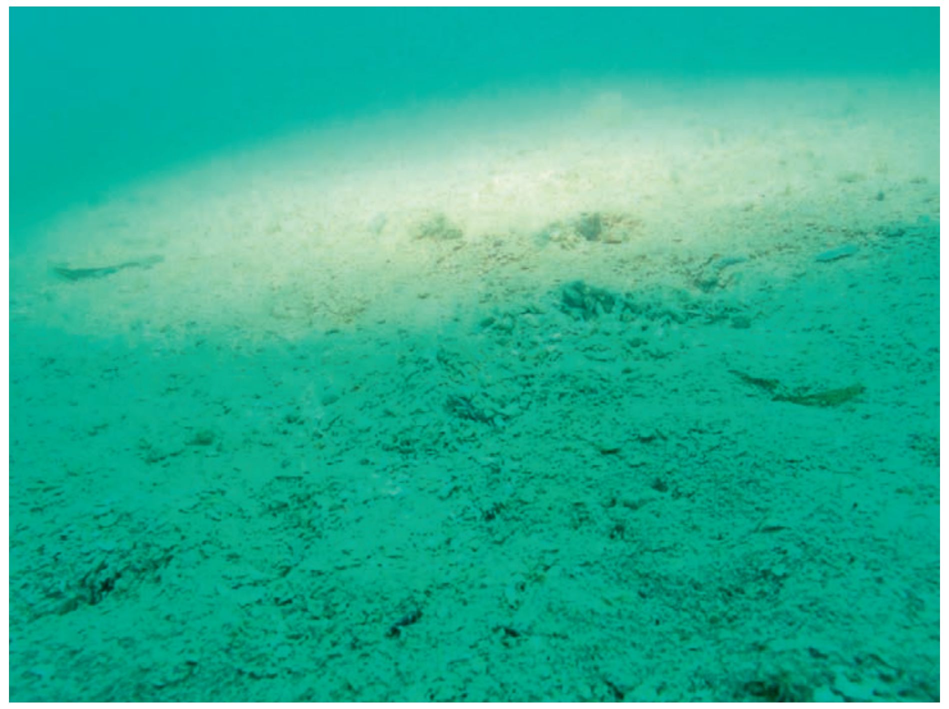

Plate 19: Lagoon sand (class 15), Alphonse (photograph: Annelise Hagan, March 2003).

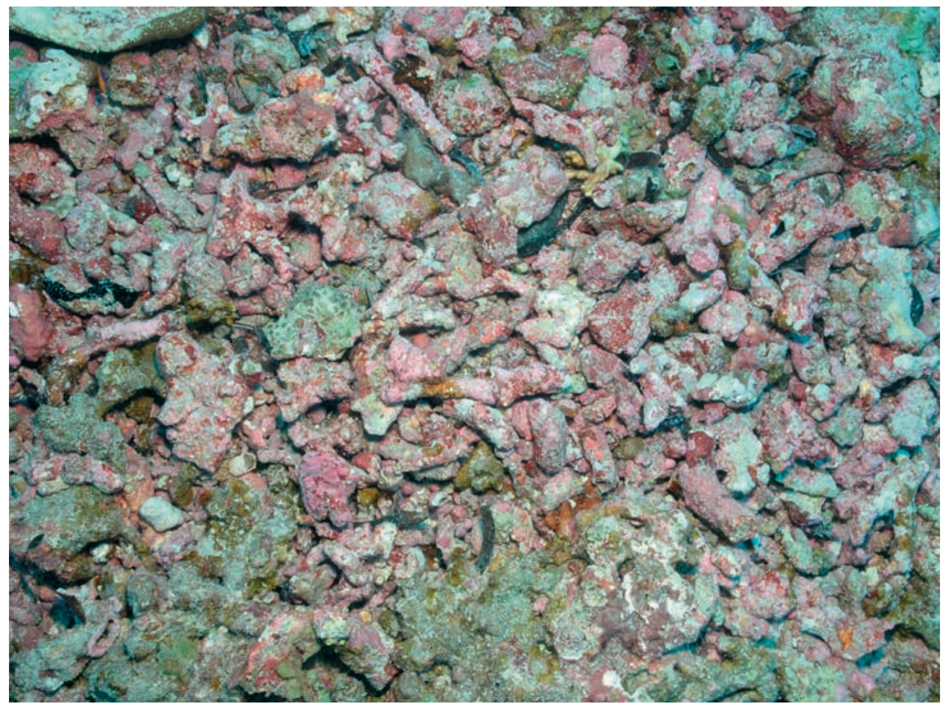

Plate 20: Coral rubble with coralline algae (class 16.1), Alphonse (photograph: Annelise Hagan, October 2007).

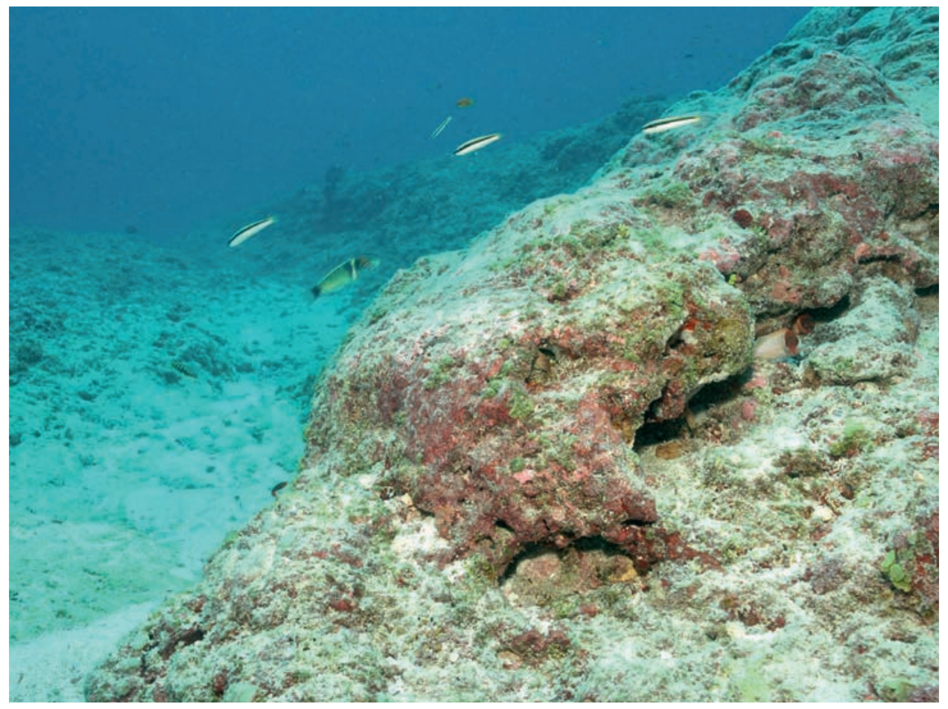

Plate 21: Fore-reef slope coral spurs with coralline algae (class 16.2), Alphonse (photograph: Annelise Hagan, October 2007).

Plate 22: Rocky fore-reef slope (class 16.3), Alphonse (photograph: Annelise Hagan, October 2007).

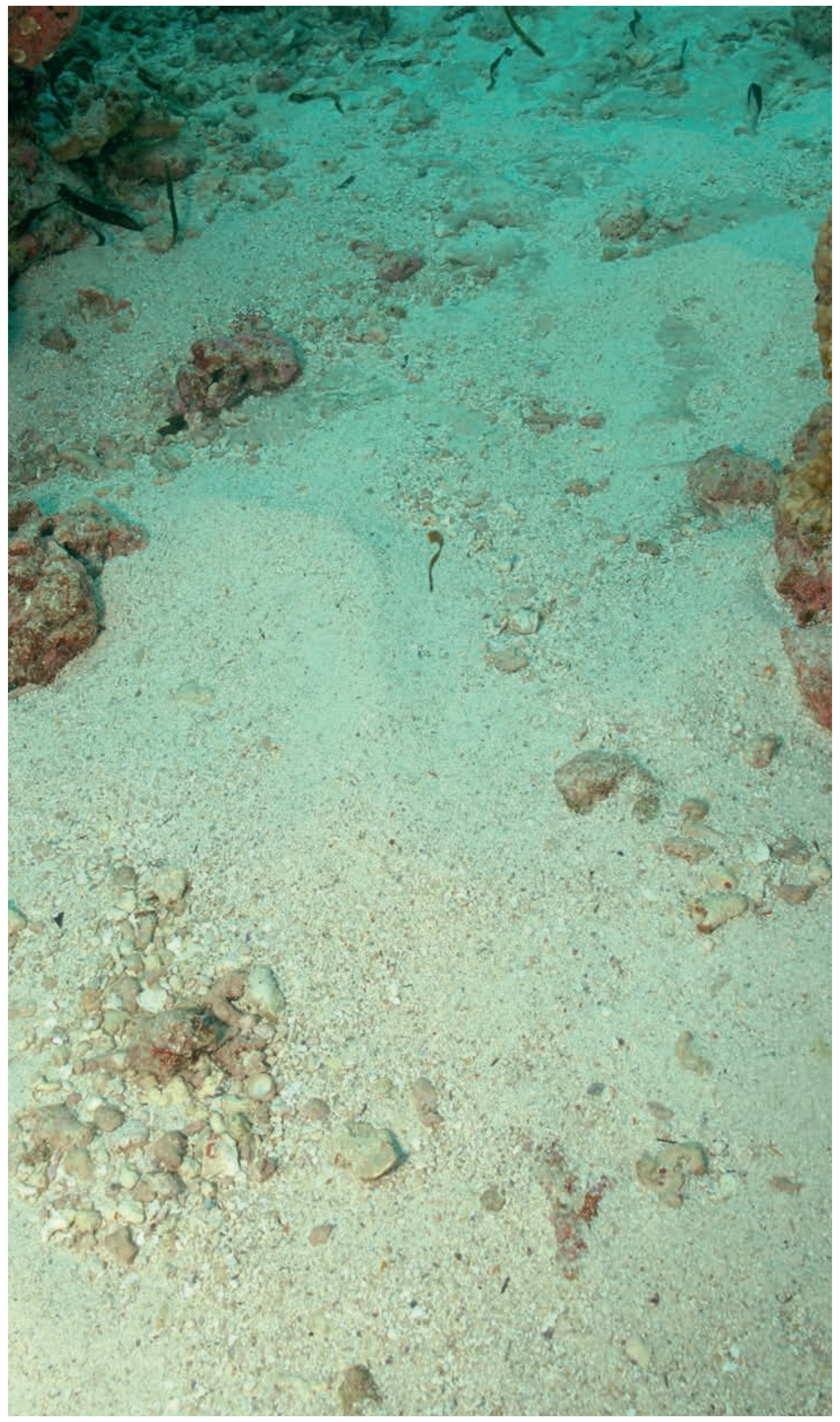

Plate 23: Fore-reef slope rubble and sand (class 16.4), Alphonse (photograph: Annelise Hagan, October 2007).

Plate 24: Fore-reef slope with coral (class 16.5), Alphonse (photograph: Annelise Hagan, October 2007).

Plate 25: Fore reef-slope sand, Alphonse (class 17) (photograph: Annelise Hagan, October 2007).

Methods: underwater surveys

Quantitative underwater surveys were conducted in January 2005 at selected islands using well-established video transect methods.[22] The video data recorded was a plan view of a rectangular section of the benthic reef community measuring 20 m x ~0.3 m; by recording both sides of the transect line, double this area was covered (i.e. 20 m x ~0.6 m). If time allowed, transects were placed at shallow (5 m), mid-depth (10 m and 15 m) and deep (20 m) water depths, depending on local bathymetry.

Video transect footage was analysed using the AIMS 5-dot analysis method.[23] Ten benthic categories were identified: sand; rubble; bare substrate; dead standing coral; pink calcareous algae on bare substrate; pink calcareous algae on dead standing coral; Scleractinia; non-Scleractinia; macroalgae; and others (e.g. zoanthids, molluscs, bivalves). Scleractinia, non-Scleractinia and macroalgae were identified to genus level and the relevant genera recorded. Percentage cover was calculated for each of the ten benthic categories.

Ground-referencing in shallow water was conducted from the surface using tenders from M.Y. *Golden Shadow*. Each tender was driven in a straight line from a start point where the water depth was approximately 20 m in towards the shore, perpendicular to the beach. The tender was stopped approximately every minute and the substrate (viewed using a glass-bottomed bucket or a diving mask) was recorded, along with a GPS position.

Methods: terrestrial surveys

The terrestrial surveys encompassed beach profiles, vegetation surveys, sediment samples, soil samples, collections of insects and observations of plant and bird life. Vegetation surveys were conducted using the Line Intercept Transect technique. Once an area of vegetation had been selected, a tape measure was laid out on top of the vegetation for a distance of 30 m and the intercept measurements of different vegetation types were recorded.

Shallow marine and terrestrial habitats in the Amirantes

Of the seven reef types identified in the Seychelles by Stoddart,[24] three are present in the Amirantes: platform reef, atoll and drowned atoll. The platform reefs are complex in form but can be grouped into three characteristic morphologies. On the Type 1 platform reefs, at African Banks and Remire Reef, the entire surface of the platform has been covered by intertidal reef-flat sands; there is no subaerial cay at Remire Reef and the land area at African Banks (North Island) is extremely small relative to the total area of the platform within the breaker zone (Table 2). In the southern Amirantes, the Type 2 platform reef islands of Marie-Louise and Desnoeufs, and to a lesser extent Boudeuse, clearly record complex histories with the presence of raised reefs, bedded calcareous sandstones (often phosphatised) and beachrock ridges. 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 2) 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 Bordeuse. At each of the two Type 3 platform reef islands, D'Arros and Poivre, the infilling of the platform surface has allowed the development of subaerial islands which exceed 2 km^2 in total area. The percentage coverage 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 than at the Type 2 sites. Thus the islands at D'Arros and Poivre account for a much greater proportion (38 – 13% respectively) of the total area classified at these two locations (Table 2). A similar distribution of platform reef morphologies to that seen at D'Arros characterizes Remire Island, not mapped in this project.

Table 2: Platform reefs of the Amirantes

Locality km^2	Total classified area[1] km^2	Total reef platform area[2] km^2	Peripheral reef area[3] km^2	Land area[4] km^2	Land area as proportion of total reef platform area %	Land area as proportion of total classified area
Type 1						
African Banks	20.66	8.05	7.99	0.06	0.75	0.29
Remire Reef	19.30	11.61	11.61	0.00	0.00	0.00
Type 2						
Boudeuse	9.00	0.11	0.08	0.03	24.10	0.29
Marie-Louise	7.89	0.94	0.20	0.74	78.59	9.36
Desnoeufs	5.93	0.72	0.24	0.48	67.06	8.14
Type 3						
D'Arros	5.48	3.26	1.16	2.10	64.42	38.32
Poivre	20.24	14.67	12.01	2.66	18.13	13.14

1. Total area classified from CASI imagery and shown on island habitat maps
2. Total area inside the breaker zone at each island, including area of any subaerial islands
3. Area between the breaker zone and island marginal sediments and rocks (habitat categories 7. and 8.)
4. Area in habitat categories 1. – 8. (see Table 1)

The atolls are small by global standards. They are characterised by wide reef-flats, typically occupying 50-60% of the reef platform inside the breaker zone (Table 3), shallow lagoons and poor lagoon-ocean exchange. At St. François, the largest of the atolls, extensive sand sheets on the windward coast are infilling 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 3) and has a maximum depth of 6.4 m. At St. François, the subaerial islands account for only around 2% of the area of the peripheral reefs (between the breaker zone and the lagoon or island margins) whereas at St. Joseph the islands are large by global atoll margin standards[25] and occupy 16.5% of the peripheral reef area. Alphonse is small and the land area, occupying 22% of the peripheral reef area, is relatively large (Table 3). The one drowned atoll is Desroches. The total area classified from Landsat imagery at Desroches was 189 km^2, making it more than twice as large as the largest sea level atoll, Bijoutier and 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 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%). The subaerial island, on the southeastern rim of the atoll, occupies less than 5% of the submerged reef platform and only 2% of the total classified area.

Finally, Sand Cay and Etoile are very small (0.3 km^2) and highly mobile sand cays, apparently positioned on very localised highs in the Amirantes Ridge surface and surrounded by extensive subtidal sand sheets and seagrass beds of varying density.

These different island morphologies are reflected in the varying presence/absence of shallow marine and terrestrial habitats, both by reef type (Figure 1) and when disaggregated to the level of individual islands (Figure 2).

Table 3: Atolls of the Amirantes

Locality km^2	Total classified area[1] km^2	Total reef platform area[2] km^2	Peripheral reef area[3] km^2	Lagoon area km^2	Land area[4] km^2	Peripheral reef area as proportion of total reef platform area %	Lagoon area as a proportion of total reef platform area %	Land area as a proportion of peripheral reef area
St. Joseph	31.54	17.62	10.43	5.48	1.72	59.19	31.10	16.5
Alphonse	23.44	13.61	7.42	4.55	1.63	54.52	33.43	22.0
Bijoutier and St. François	71.33	37.99	19.48	18.05	0.46	51.28	47.51	2.4

1. Total area classified from CASI imagery and shown on island habitat maps
2. Total area inside the breaker zone at each island, including area of any subaerial islands
3. Area between the breaker zone and island marginal sediments and rocks (habitat categories 7. and 8.)
4. Area in habitat categories 1. – 8. (see table 1).

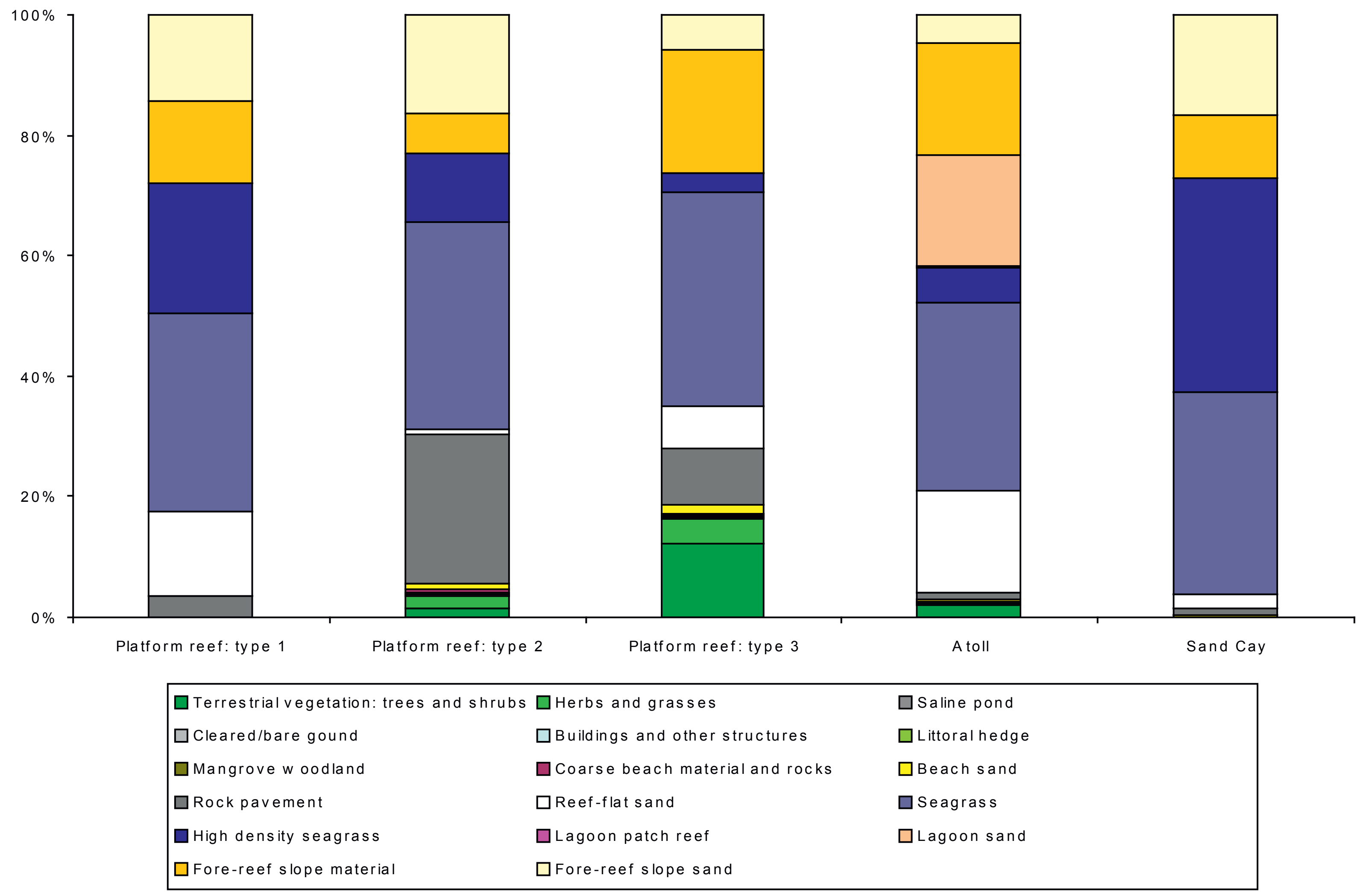

Figure 1: Tier 1 breakdown (see Table 1) of habitat coverages in the islands of the Amirantes, grouped by island type. Island groupings are: Platform Reef Type 1 (African Banks and Remire Reef); Platform Reef Type 2 (Desnoeufs, Marie-Louise, Bordeuse); and Platform Reef Type 3 (D'Arros and Poivre); Atoll: Bijoutier and St. François, St, Joseph, Alphonse; Sand Cay: Sand Cay, Etoile. (Note: Desroches was mapped from Landsat, not CASI, imagery. Its mapping was, therefore, not directly comparable with the mapping of the other islands and is not included here).

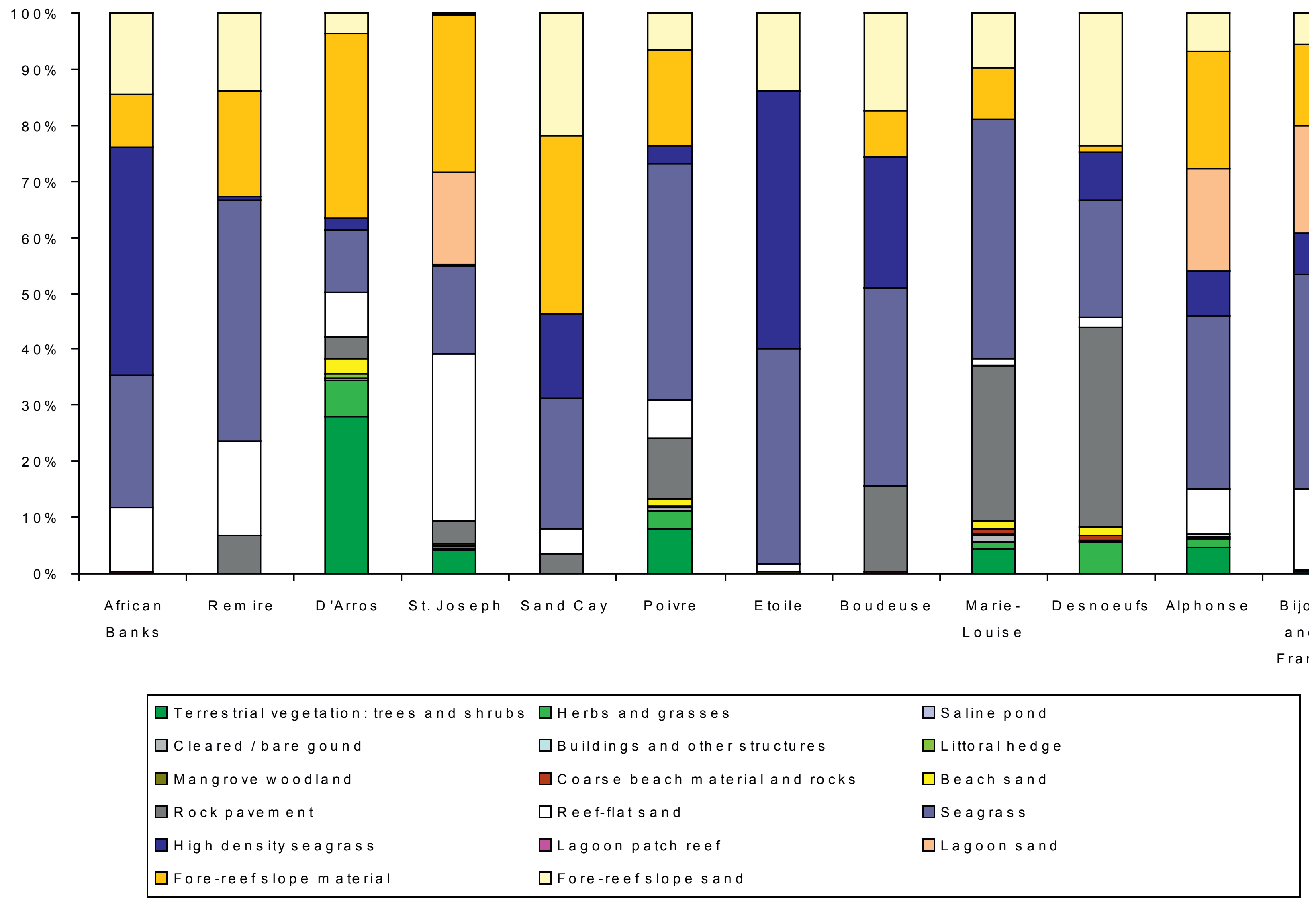

Figure 2: Tier 1 breakdown (see Table 1) of habitat coverages in the islands of the Amirantes and Alphonse Group, from north to south.

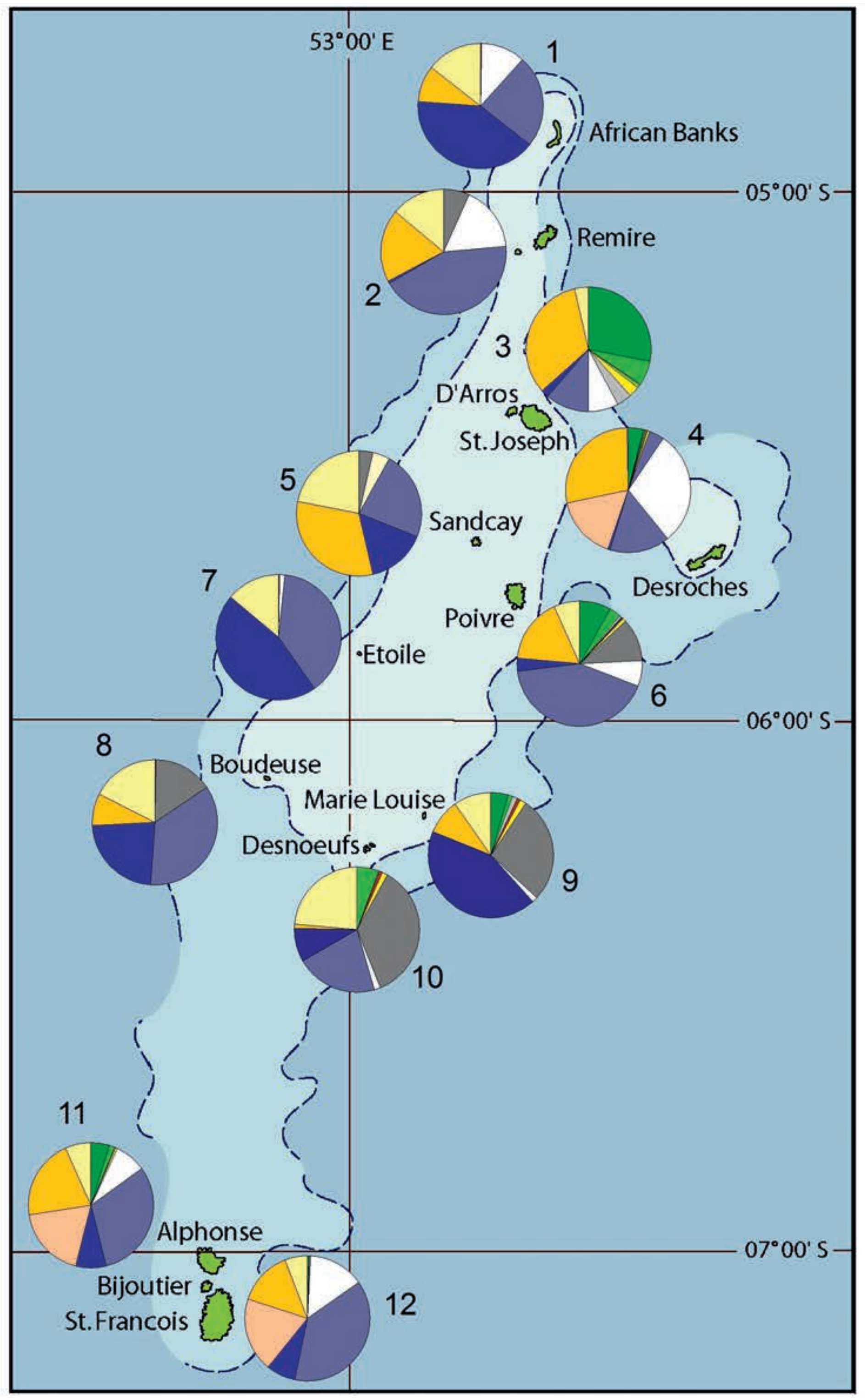

Figure 3: Spatial pattern of Tier 1 (see Table 1) breakdown of habitat coverage from CASI imagery of the Amirantes and Alphonse Group. (For pie chart key see Figure 2). Locations: 1. African Banks; 2. Remire Reef; 3. D'Arros; 4. St. Joseph; 5. Sand Cay; 6. Poivre; 7. Etoile; 8. Boudeuse; 9. Marie-Louise; 10. Desnoeufs; 11. Alphonse; 12. Bijoutier and St. François.

With regard to habitat richness, Alphonse has the highest number of habitat classes, with Bijoutier and St. François and D'Arros and St. Joseph also supporting a wide range of habitats. Conversely, Sand Cay, Remire and Etoile support a lower numbers of habitat classes, with a dominance of fore-reef slope material, seagrass and high density seagrass respectively (Figure 1). Islands with consistently high biodiversity metrics (i.e. those comprised of a wide range of evenly distributed habitat types) tend to be composed of both marine and terrestrial habitats. Some of the islands (e.g. Etoile, Remire and Sand Cay) are made up of a limited number of different habitat types, i.e. seagrass and sand of varying densities and grain composition, yet display even coverage of different habitat types; thus they yield comparable Shannon-Wiener diversities. The Shannon-Wiener Index, which incorporates an element of evenness into the metric, is highest for D'Arros and Poivre, which have moderate habitat richness but this richness is distributed comparatively evenly across classes.

Figures 1 – 3 utilise the first (Tier 1) level of classification to report general habitat characteristics in the Amirantes; the individual maps which follow for each island further disaggregate the habitats classified to the Tier 2 level (Table 1).

Source materials

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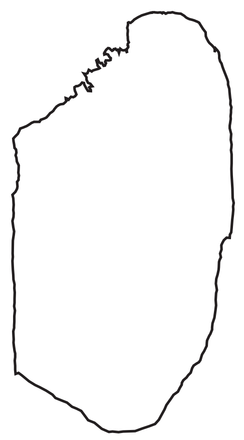
The Amirantes

African Banks

(04°53' S; 52°22' E)

Key to Habitat Classification: African Banks

- Coconut woodland
- Other trees and shrubs
- Herbs and grasses
- Saline pond
- Cleared / bare ground
- Buildings and other structures
- Littoral hedge
- Mangrove woodland
- Coral sandstone / raised reef
- Beach sand
- Coral boulders
- Beachrock
- Rock pavement
- Reef-flat sand
- Low density seagrass / macroalgae
- Medium density seagrass
- High density seagrass
- Lagoon patch reef
- Lagoon sand
- Coral rubble with coralline algae
- Fore-reef slope coral spurs with coralline algae
- Rocky fore-reef slope
- Fore-reef slope sand
- Fore-reef slope rubble and sand
- Fore-reef slope with coral

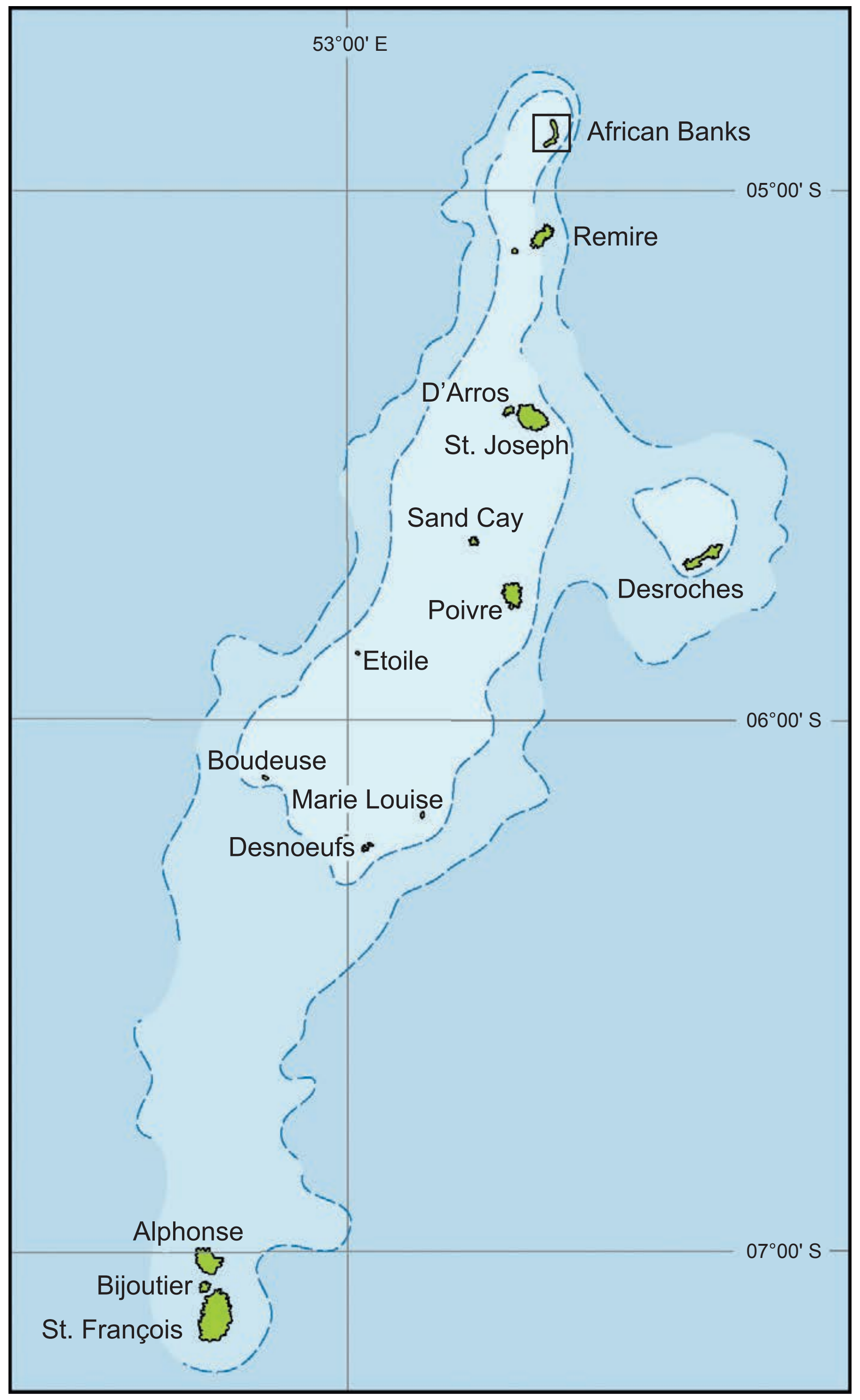


No Landsat data required

The map shows the key shallow water benthic habitats of African Banks, part of the Amirantes group, southern Seychelles, Western Indian Ocean. This was produced by performing a classification on 17 bands of CASI imagery acquired in January 2005. Where data are missing due to cloud cover, gaps have been filled by classifying georeferenced Landsat data (2000).

Projection and Sensor Information

Projection: UTM, Zone 40
Spheroid: GRS 1980
Datum: NAD83
Sensor: Compact Airborne Spectrographic Imager
Pixel Size: 1m
Electromagenetic spectrum region: 434-849nm
Acquisition Date: January 2005



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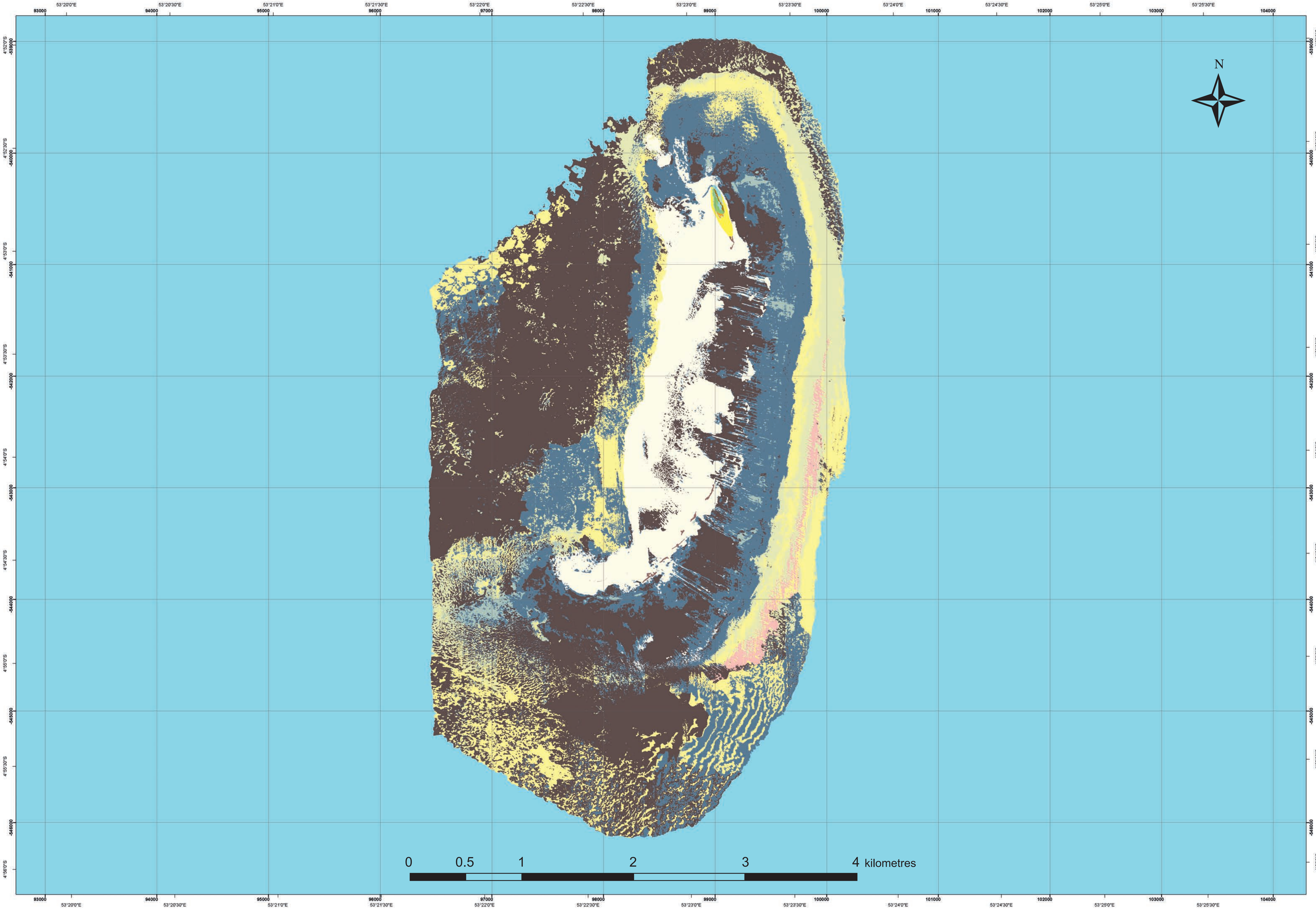

African Banks

Note: This site was not visited by the Expedition and therefore the habitat map presented here has not been ground referenced. Information from the map and from oblique aerial photography (from January 2005) has, however, been used below to supplement information from published sources, most notably the accounts of Baker[1], Stoddart and Poore[2] and Feare.[3]

Island history

The name African Banks, or Bancs Africains, describes an area of sand shoals supporting until recently (see geography and geology below) two small (total area 32 ha) islands, North Island and South Island, the most northerly in the Amirantes. Their discovery is attributed to the Chevalier de la Biollière[2], of the *L'Etoile du Matin*, in November 1771 and named[4] Ilots Africains by Admiral Willaumez, commander of the frigate *La Régénérée*, in 1797. HMS *Spitfire* was wrecked on South Island on 21 August 1801, North Island was visited in 1821 by HMS *Menai* and bird observations were made in 1882, 1937, 1955, 1966 and 1968[2], in 1974[3] and in 1997.[5] Coppinger's report[6] from the visit of HMS *Alert* provides the only general early observations of topography and vegetation before those of Stoddart and Poore. There is no evidence of there ever being any permanent settlement at African Banks, although previously a small hut on South Island was used by egg collectors and fishermen. Administration of the islands passed from Mauritius to the Seychelles in 1903. An automatic lighthouse was constructed on North Island in 1972 but this is now (2008) derelict.[3,7]

Geography and geology

The sand shoal area of African Banks is situated at the northeastern corner of the Amirantes Ridge, with water depths in excess of 100 m only 2.5 km to the north and 3.5 km to the east of North Island, but with the Ridge margin over 8 km to the west. Water depths over the Ridge vary from 10–16 m near its western margin but typically reach 20 m at more central locations, 5 km to the west of African Banks. The shoal area is aligned N–S and is approximately 4 km in length, recurving to the west at its southern extremity, and between 0.4 and 1 km in width (Plates 1 and 2).

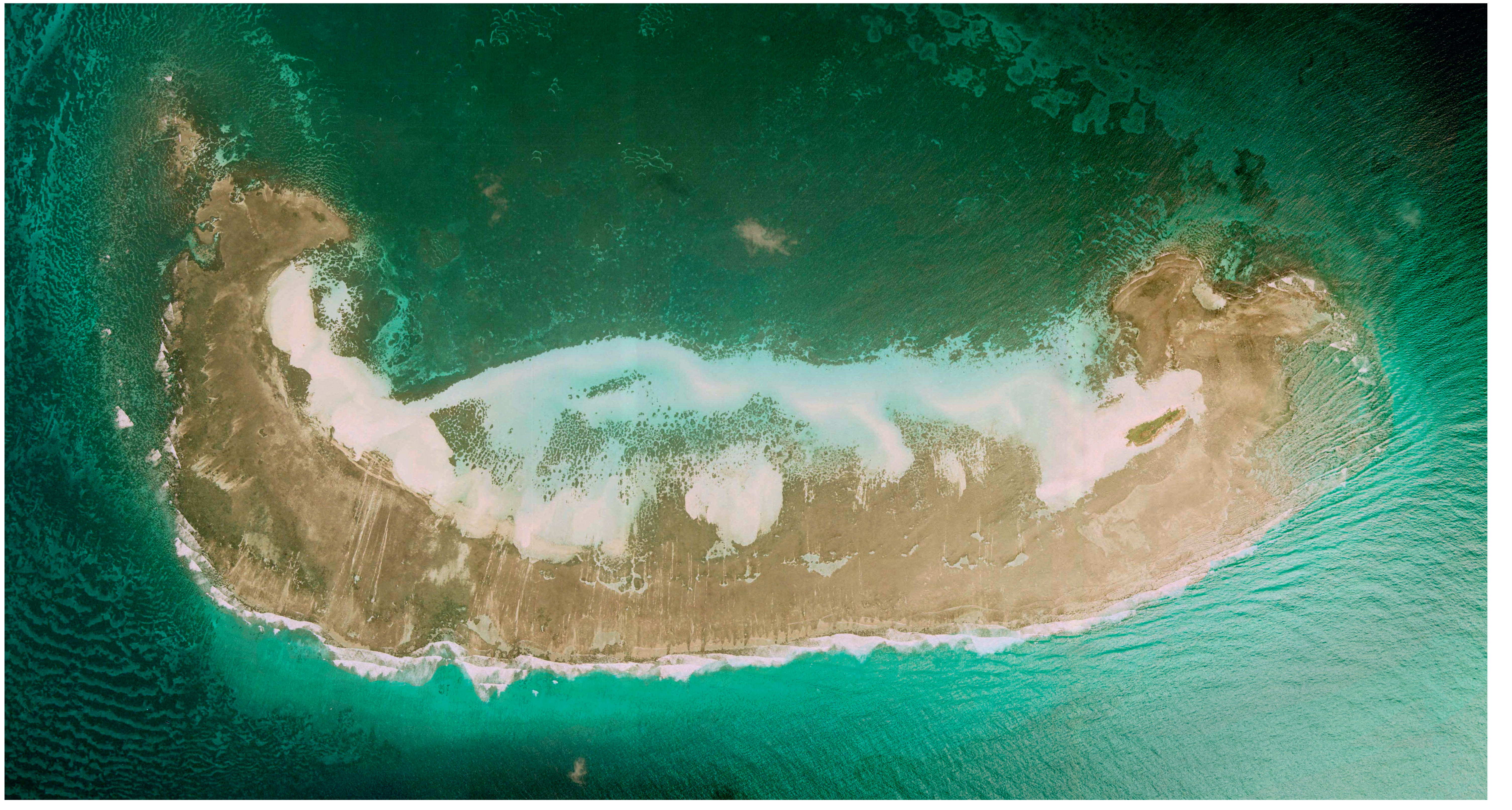

Plate 1: African Banks in 1999 (source: Maps Geosystems; reproduced with kind permission of the Government of the Seychelles).

Plate 2: Eastern margin of African Banks, January 2005

Previous descriptions identified two islands 2.9 km apart: North Island, the larger of the two (275 m long and 45 – 90 m wide) and South Island (230 m long and 70 m wide).[2] Baker[1] describes lines of relict beachrock extending up to 1.1 km north of South Island, indicating considerable island instability. The current habitat map clearly shows Baker's beachrock outcrops but no sign of South Island in its expected position (and see section to left, Plate 2m). Stoddart and Poore[2] recorded evidence for frequent wave overtopping at this location and no shrub vegetation appears to have been left on the island in July 1974.[3] It appears[7] that the island disappeared in 1976, leaving behind some additional beachrock ridges, to the south of the deposits identified by Baker. A visit in 1997 confirmed the presence of residual beachrock only.[5]

Coppinger[6] describes North Island as a low, flat elliptical cay, composed of foraminiferal sand with 'upraised coral sandstone' at its northern end, 'grooved and honeycombed into various fantastic shapes'. Feare[3] confirmed these observations but noted that in 1974 a 'honeycombed sandstone cliff', 1-2 m high, was exposed not only on the north coast but also on the south and east coasts. The habitat map shows these deposits at the northeastern corner of the island, with beachrock ridges at the northwestern and southern ends of the island (Plates 3). The centre of the island is a phosphatic sandstone plain, overlain by sand at the northeastern and southern margins of the island.[3]

Terrestrial flora and fauna

15 plant species were reported[8] from South Island in 1968; Stoddart and Poore described the vegetation communities as low bushes of *Tournefortia argentea*, *Suriana maritima* and *Scaevola taccada* with numerous herbs, grasses and creepers. For North Island, Coppinger[6] mentioned 'scrubby grass and low bushes of the same character as those at Bird Island i.e. *Tournefortia*' from his visit there in 1882 and Baker[1] reported 'low scrub of littoral type'. Feare[3] described the beachridge on the western coast as being dominated by *Scaevola taccada*, with scattered *Tournefortia argentea*, and *Cassytha filiformis* overgrowing both species. The seaward side of the ridge was colonized by *Suriana maritima* and *Cyperus pachyrhiza*. The central part of the phosphatic plain was bare but surrounded by a ground cover of *Portulaca oleracea*, *Tribulus cistoides* and *Boerhavia repens*. At the southern end of the island there was an area of *Achyranthes aspera* and *Stachytarpheta jamaicensis*. Four *Cocos nucifera* (coconut palm) trees were seen in 1974 at the southern end of the island and one at the north.[3]

Both Stoddart and Poore[2] and Feare[3] provide lists of birds sighted (and in some cases breeding) at African Banks. The key species have been identified[6] as *Sterna sumatrana* (Black-naped Tern), *Sterna fuscata* (Sooty Tern) and *Anous stolidus* (Brown or Common Noddy). The colony of *Sterna fuscata*, estimated at less than 5,000 pairs[5], was once much larger; in 1955 it was estimated at 40,300 pairs[9] and in 1974 at 20,300 pairs.[3] Poaching of eggs and adults is thought to be considerable.[3,5] The site holds one of only three colonies of *Sterna dougallii* (Roseate Tern) in the Seychelles. Current estimates are 82 pairs, compared to 250-300 pairs in June/July 1966.[10] Other species include *Sterna bergii* (Crested Tern) (six pairs in 1974, possibly no longer breeds[7]). Coppinger[6] reported unfledged 'gannets' in 1882, thought to be *Sula dactylara* (Masked Booby), and *Sula leucogaster* (Brown Booby) may also have bred here in historical times.[11] By 1955, the booby populations were said to be negligible[9], probably as a result of poaching.

Marine habitats

The western margin of the sand shoal, described by Baker as 'sandy and shelves gradually away', is characterized by a narrow band of fore-reef sand (with the red branching alga *Dasya mollis*, and green algae *Halimeda* spp. being present at a southern site[12]) and medium density seagrass, followed by an extensive area of high density seagrass at water depths of approximately 10 m. The eastern margin of the intertidal sands abut and overlie beds of high density seagrass, interrupted by sand-filled channels which show evidence of a WNW–ESE lineation (see centre of Plate 2). To seaward, in water depths of less than 2 m, is a continuous, 500 m wide band of medium density seagrass (comprising *Thalassia hemprichii* and *Thalassodendron ciliatum*, with the algae *Valonia fastigiata* and *Microdictyon* sp.[12]), replaced to the south by high density seagrass (*Thalassodendron ciliatum*[12]). The boundary of the seagrass marks the breaker zone which is characterized by fore-reef sand and coral rubble with coralline algae and then by a narrow zone of coral spur and groove (most probably the 'numerous deep surge channels' described by Baker[1]) with coralline algae, at water depths of 2 – 4 m. The reef widens to its maximum extent at the southeastern end of the platform, presumably where incident wave energy is greatest from the Southeast Trades. The area to the north of North Island shows a similar patterning but the area beyond the breaker zone is characterized by fore-reef slope sand and high density seagrass (*Thalassodendron ciliatum*[12]), with neither coral rubble nor reef being present. Outside the breaker zone to the south is a mosaic of fore-reef sand, medium density and high density seagrass; in the far southeast, medium density seagrass is organised into a series of SW–NE trending waveforms (most probably the 'current-aligned strips' described by Baker[1]).

Both Coppinger[6] and Feare[3] report evidence of turtle nests and excavations; Feare reports a sighting of a small *Chelonia mydas* (Green Turtle) in July 1974. Frazier[13] estimates 100 nesting females each year (and 10 nesting *Eretmochelys imbricata* (Hawksbill Turtle).

PPlate 3: North Island, looking southeast in January 2005. Note (foreground and to left) medium and high density seagrass beds on the reef platform, unvegetated sands extending the vegetated island to the south and reef-flat sand on the leeward margin of the seagrass beds.

Source materials

1. Baker BH 1963 Geology and mineral resources of the Seychelles archipelago. *Geological Survey of Kenya Memoir* 3: 1-140.
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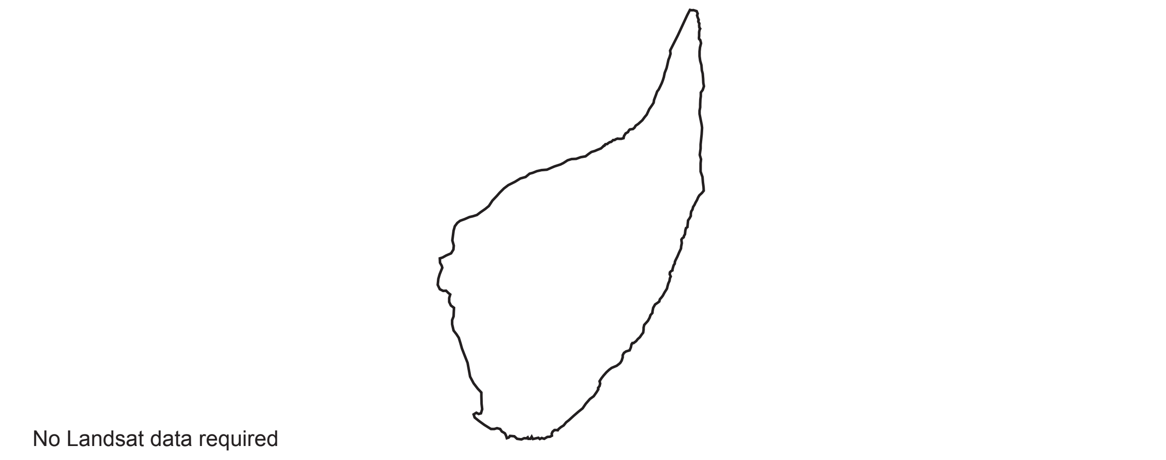
Remire Reef

(05°05' S; 53°21' E)

Key to Habitat Classification: Remire Reef

Coconut woodland	Reef-flat sand
Other trees and shrubs	Low density seagrass / macroalgae
Herbs and grasses	Medium density seagrass
Saline pond	High density seagrass
Cleared / bare ground	Lagoon patch reef
Buildings and other structures	Lagoon sand
Littoral hedge	Coral rubble with coralline algae
Mangrove woodland	Fore-reef slope coral spurs with coralline algae
Coral sandstone / raised reef	Rocky fore-reef slope
Beach sand	Fore-reef slope sand
Coral boulders	Fore-reef slope rubble and sand
Beachrock	Fore-reef slope with coral
Rock pavement	

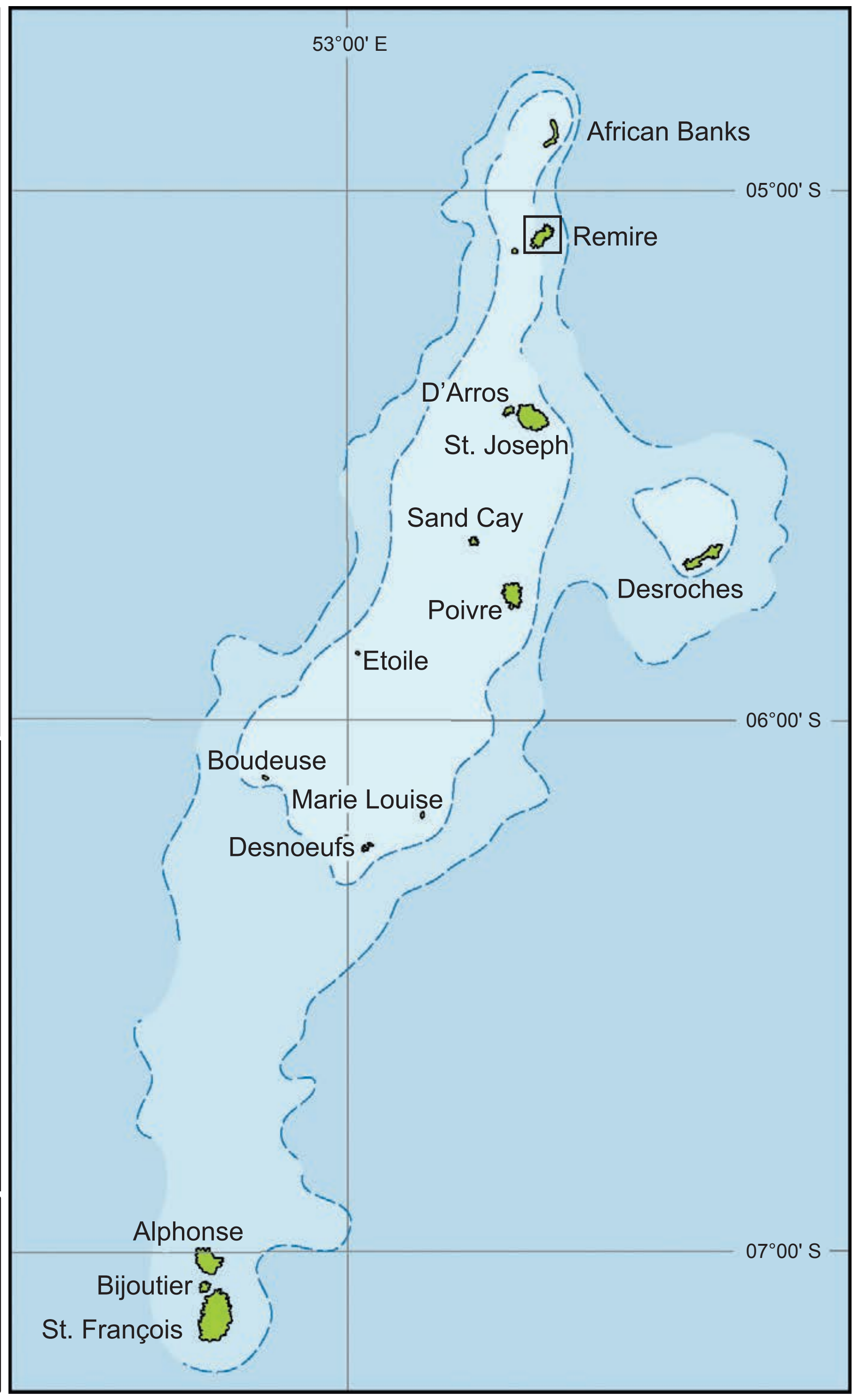


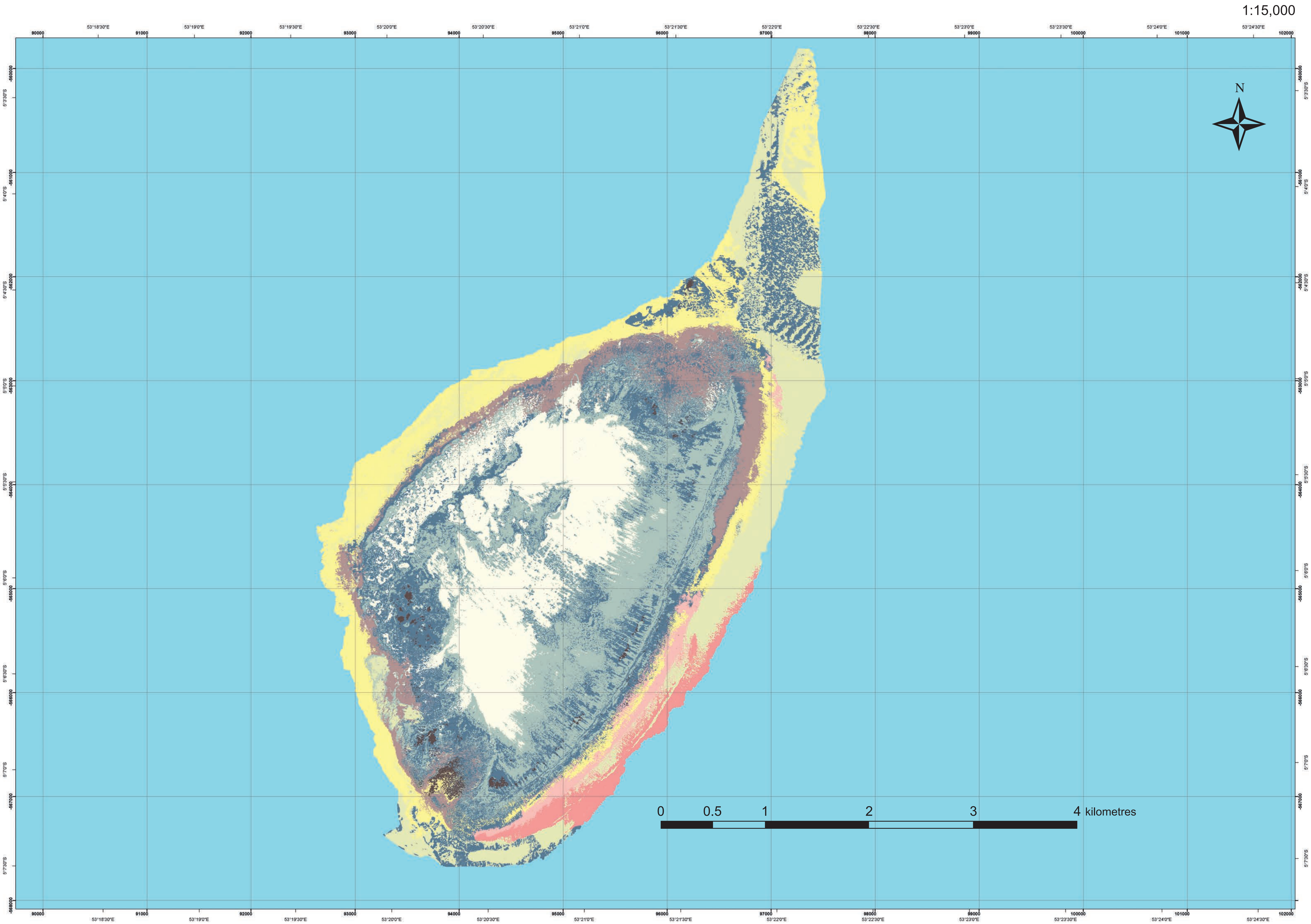
No Landsat data required

The map shows the key shallow water benthic habitats of Remire Reef, part of the Amirantes group, southern Seychelles, Western Indian Ocean. This was produced by performing a classification on 17 bands of CASI imagery acquired in January 2005. Where data are missing due to cloud cover, gaps have been filled by classifying georeferenced Landsat data (2000).

Projection and Sensor Information

Projection: UTM, Zone 40
Spheroid: GRS 1980
Datum: NAD83
Sensor: Compact Airborne Spectrographic Imager
Pixel Size: 1m
Electromagenetic spectrum region: 434-849nm
Acquisition Date: January 2005

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Remire

Note: The name Remire refers both to Remire Island and to Remire Reef. In January 1995, airborne surveys were restricted to Remire Reef and therefore the account below is largely restricted to this reef complex. Detailed descriptions of the topography, geology, soils and vegetation communities of Remire Island can be found elsewhere.[1-5] Remire Reef was not visited by the Expedition and thus the comments below are based on the analysis of the habitat map, assisted by oblique aerial photographs (from January 2005) collected at the same time.

Geography and geology

Remire Reef and Remire Island sit on the eastern margin of the Amirantes Ridge, approximately 25 km south of African Banks, at a point where the Ridge narrows to less than 20 km in width. Water depths along this eastern margin are typically less than 20 m (although very rapidly increasing eastwards to water depths in excess of 1,000 m), whereas depths of 22 to 35 m characterise the Ridge to the west of Remire Reef. Immediately to the south of Remire Island there is a 25 m deep passage through the eastern margin of the Ridge. Remire Reef lies 5-6 km to the northeast of Remire Island, being separated from the reef platform that supports the island by a channel at least 16 m deep (Plate 1).

Remire Island is 0.8 km in diameter and has an area of 80 ha. It sits at the northeastern corner of a small reef platform; the reef-flat is widest (370 m), towards the southeast (Plate 2). Relict beachrock ridges on the south coast indicate that the island at one time extended further south than at present.[2] Much of the interior of the island is composed of a plate of phosphate rock, at least 1.5 m thick[3], which outcrops along the SE coast in 3-4 m high cliffs. Soils of the Jemo Series[4] characterise the phosphate areas. In 1968, the island was covered with dense coconut woodland in areas of sandy substrate and more open woodland, areas of *Carica papaya* (papaya) and areas covered with herbs and creepers on the phosphate areas; all strikingly different from the shrub-covered island described in late eighteenth century reports (Coppinger 1883[6]). The island is uninhabited but has a paved airstrip 457 m in length.

Remire Reef is a broad oval-shaped reef system orientated SW-NE, measuring 5 km in length and 3 km in width.

Plate 3: General view of Remire Reef, looking across the reef system towards the southeast. Note reef edge-parallel linear ridges of high density seagrass at reef-flat margin, reef-flat sands and depressions on the reef-flat (right foreground).

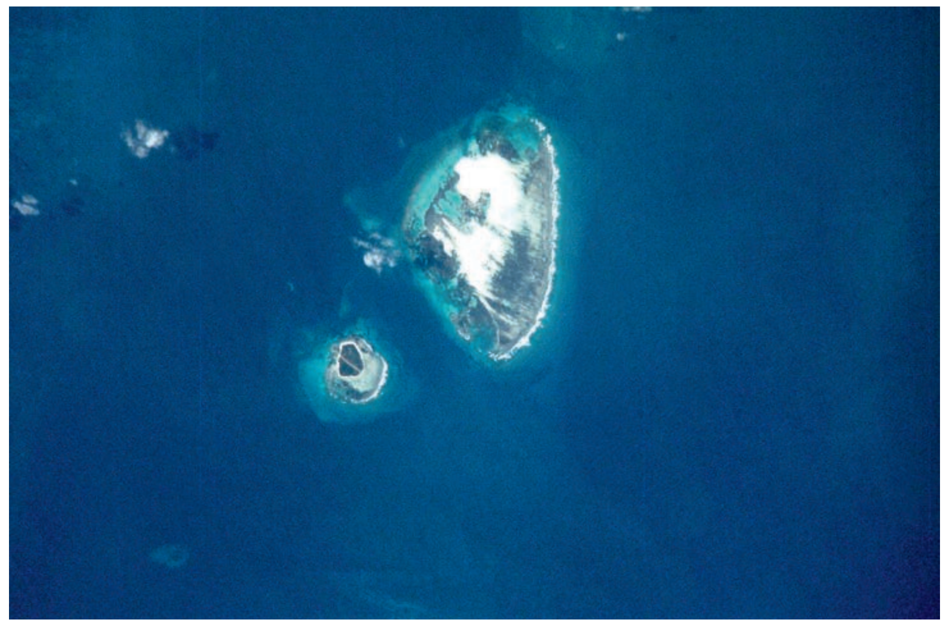
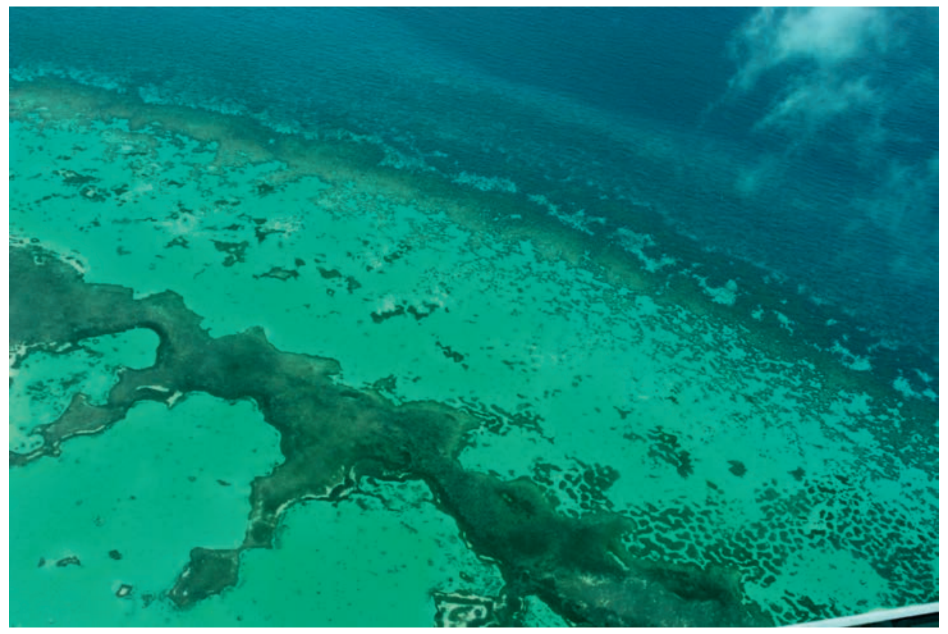


Plate 1: Remire Reef (to right) and Remire Island (source: Image Science and Analysis Laboratory, NASA-Johnson Space Center, The Gateway to Astronaut Photography of Earth, 2001)

Plate 2: Remire Island, looking southwest. Note the greatest extent of reef-flat towards the southeast. Phosphatic sandstones outcrop to either side of the southern end of the airstrip. Arcuate relict beachrock ridges on the reef-flat indicate the former increased extent of the island in this direction. Water depths beyond the breaker zone are reported[1]as being less than 35 m.



Plates 4 (left) and 5 (right): Northwestern margin of Remire Reef, showing reef-flat sand divided by a ridge of medium to high density seagrass.

The central parts of the reef are characterised by sand shoals which dry at low tide. There are no subaerial islands present. The centre of this reef-flat sand area is characterised by a series of interconnected depressions which support low density seagrass and macroalgae (Plate 3). Interestingly, in 1905 The Percy Sladen Trust Expedition[7] stated 'Remire has blue water in the centre, stated to be 3-4 fathoms [5.5-7.3 m] deep, and is … termed an atoll'. Along the northwestern margin, the reef-flat sands are separated by a 1.5 km long, SW-NE trending ridge of medium to high density seagrass (Plates 4 and 5).

On their southeastern side, the sand shoals meet an extensive belt of low density seagrass with macroalgae, 600 m to 900 m in width and showing narrow sand channels orientated WNW–ESE (Plate 6). Locally, these lineations extend to the northwest into the sand shoals; this is particularly marked in the central area of the shoals where lines of medium to high density seagrass extend into the centre of the reef system.

By contrast to these strongly lineated patterns, the reef-flat along its western and northern margins shows less organised mosaics of medium density seagrass, with occasional patches of reef-flat sand and high density seagrass. It is probable that both the bare and vegetated sands sit upon an underlying rock platform; this is exposed in places on the western side of the reef and, more extensively on the northern reef margins. The breaker zone is characterised by a narrow zone of fore-reef sands. Coral spurs with coralline algae are well-developed along a 3 km long section along the southeast margin, immediately to seaward of the breaker zone.

As water depth increases in this region, the fore-reef slope is characterised by areas of coral rubble and sand (at the southern point being colonised by medium density seagrass) and slopes with coral. Apart from some limited reef development at the northeastern point of the reef, the other fore-reef margins do not support well-developed reefs but are instead characterised by either sand (western and northwestern slopes) or rubble and sand (northeastern slopes). A tongue of fore-reef sand / rubble and sand extends northeast from the reef, supporting medium density seagrass beds. In places, these beds are clearly organised into SW–NE trending bands of alternating sand and vegetation.

Source materials

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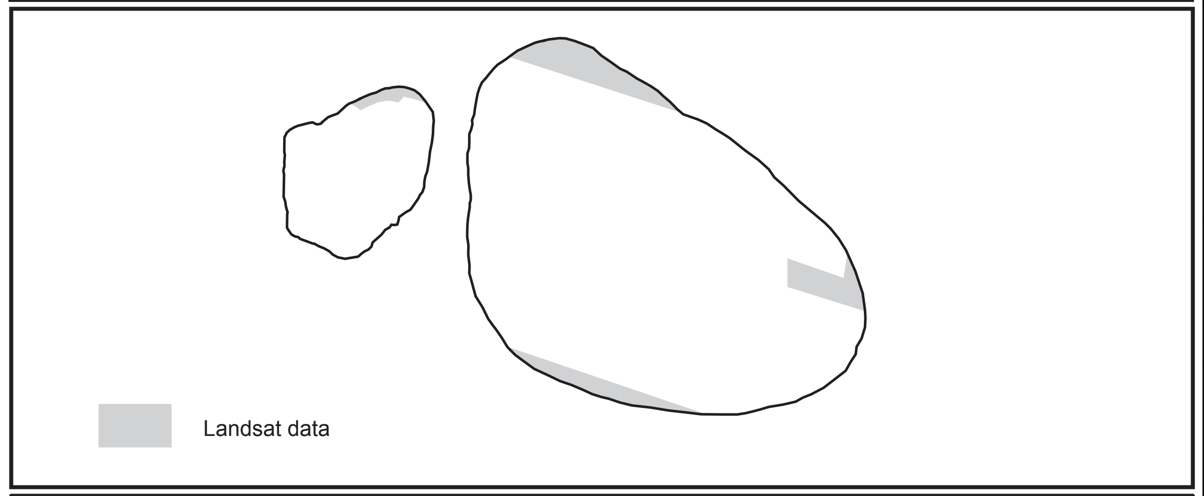
Plate 6: Central section of the southeastern side of the sand shoals, looking northeast. Note lines of medium to high density seagrass extending towards the centre of the reef complex.

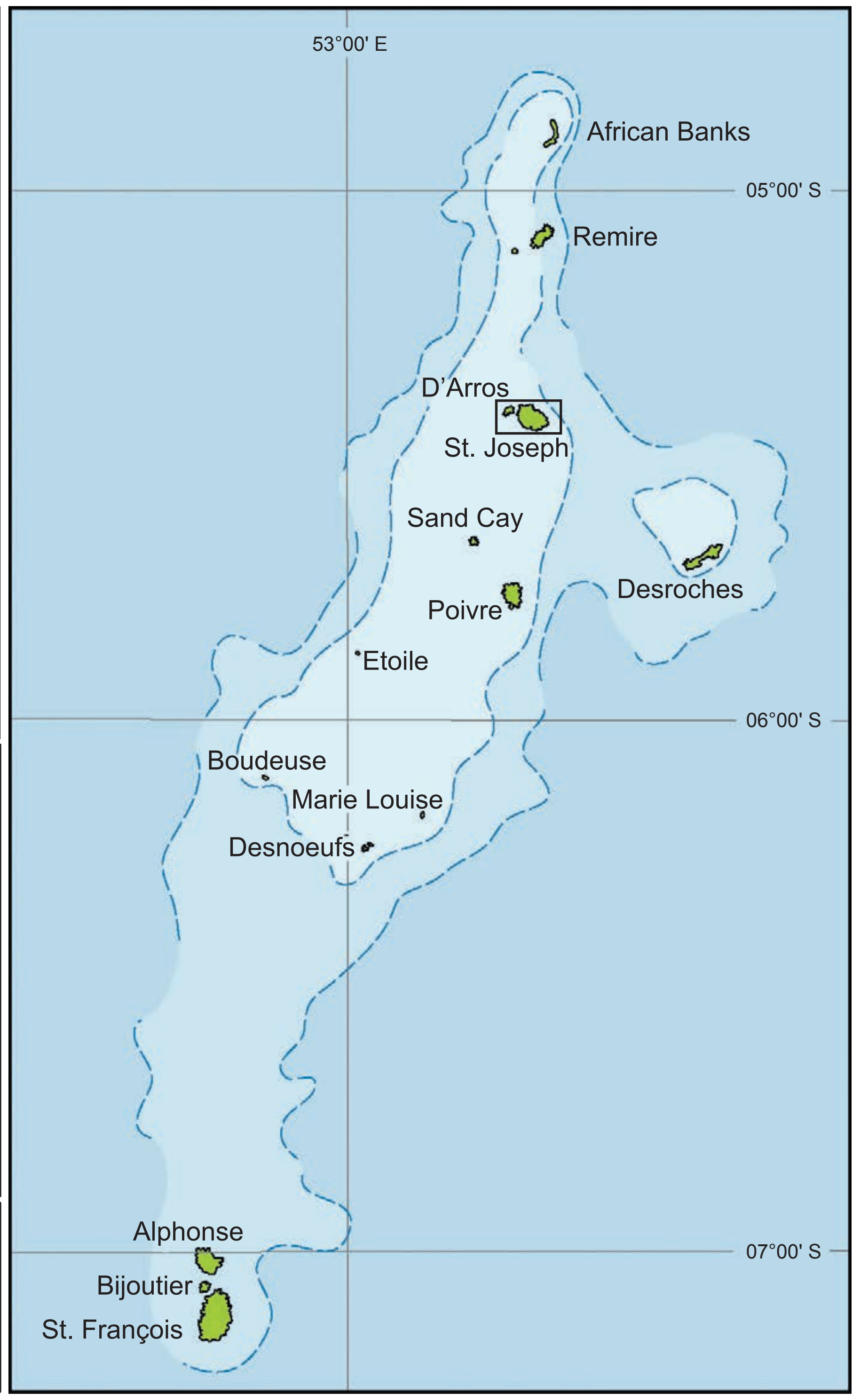
D’Arros and St. Joseph

(05°25' S; 53°17' E and 05°25′ S; 53°20′ E)

Key to Habitat Classification: D'Arros and St. Joseph

Coconut woodland	Reef-flat sand
Other trees and shrubs	Low density seagrass / macroalgae
Herbs and grasses	Medium density seagrass
Saline pond	High density seagrass
Cleared / bare ground	Lagoon patch reef
Buildings and other structures	Lagoon sand
Littoral hedge	Coral rubble with coralline algae
Mangrove woodland	Fore-reef slope coral spurs with coralline algae
Coral sandstone / raised reef	Rocky fore-reef slope
Beach sand	Fore-reef slope sand
Coral boulders	Fore-reef slope rubble and sand
Beachrock	Fore-reef slope with coral
Rock pavement	



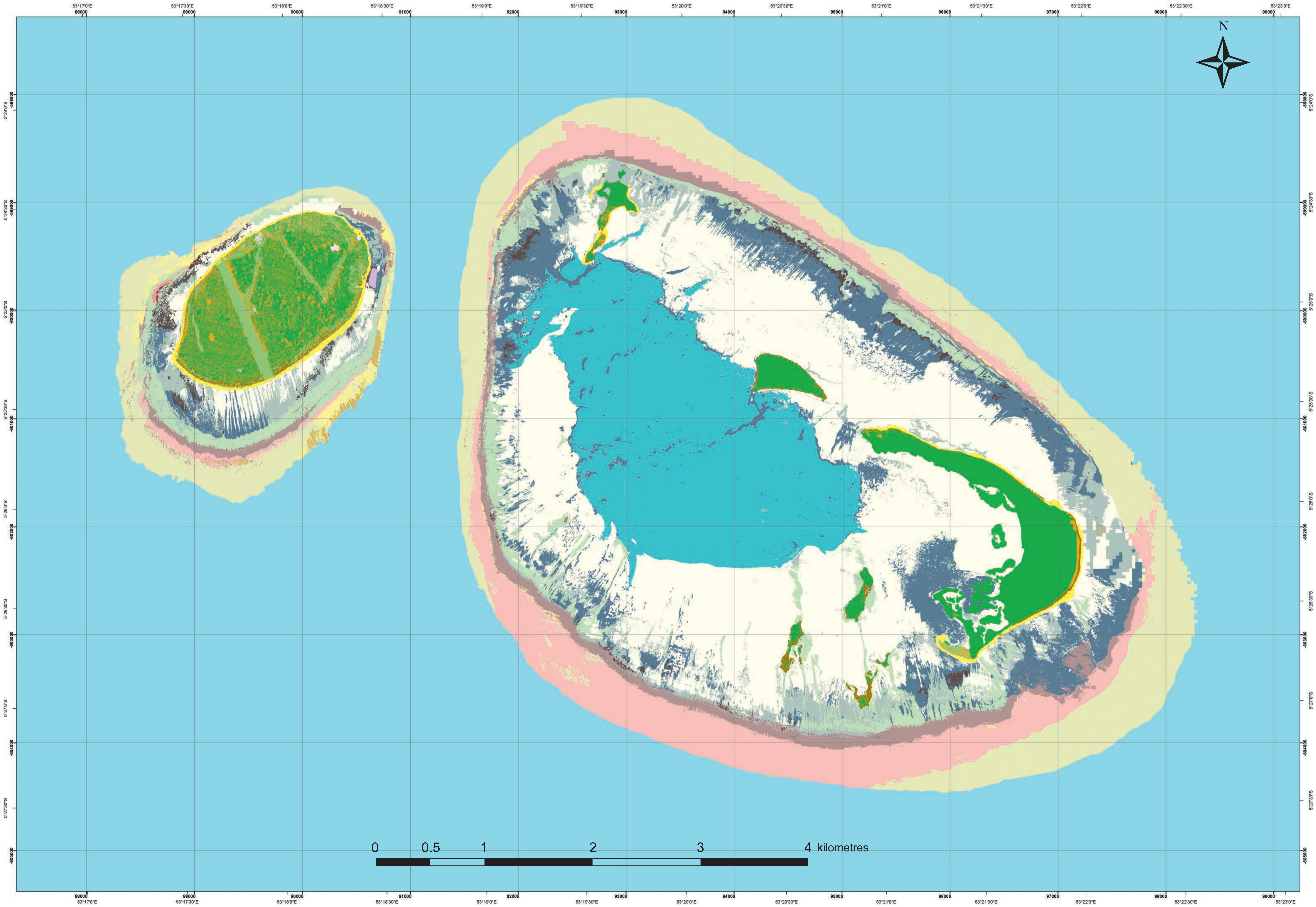


The map shows the key shallow water benthic habitats of D'Arros and St. Joseph, part of the Amirantes group, southern Seychelles, Western Indian Ocean. This was produced by performing a classification on 17 bands of CASI imagery acquired in January 2005. Where data are missing due to cloud cover, gaps have been filled by classifying georeferenced Landsat data (2000).

Projection and Sensor Information

Projection: UTM, Zone 40
Spheroid: GRS 1980
Datum: NAD83
Sensor: Compact Airborne Spectrographic Imager
Pixel Size: 1m
Electromagenetic spectrum region: 434-849nm
Acquisition Date: January 2005

1:14,500



D’Arros Island and St. Joseph Atoll

Note*:* The platform reef of D’Arros Island and the neighbouring atoll of St. Joseph were not visited by the Expedition in January 2005 and therefore the habitat map presented here has not been ground referenced. Information from the map and from oblique aerial photography (also from January 2005) has, however, been used below to supplement information from published sources, most notably the accounts of Baker[1], Piggott[2-3] and Stoddart, Coe and Fosberg.[4-5, 8-9] We are grateful for detailed comments, on both the draft and final versions, of the habitat maps by Dr U. Engelhardt, Scientific Director, D’Arros Research Centre.

D’Arros Island

Island history

D’Arros was discovered in 1771 by M. de la Biollière[4]. The island had a population of 11 in 1882 and census returns for 1905-6 variously report 24 to 42 individuals in residence. Census returns for 1931, 1947 and 1960, give population totals of 24, 35 and 105 respectively. There is an uncertain history of guano production[1,3] but commercial coconut planting began around 1880, leading to commercially viable yields in the early twentieth century.[4] The first scientific visit was undertaken during the visit of HMS *Alert* in 1882 and the Percy Sladen Trust expedition, on board HMS *Sealark*, made general observations and collections in 1905.[4] Geological[1] and soil[2-3] mapping were undertaken in the 1960s and, following further ornithological and botanical studies, the most recent comprehensive field studies were undertaken by Stoddart and Coe in 1976.[4] In 1975, the lease of the island was taken over by H.I.H. Prince Chahram Pahlavi and an airstrip constructed in 1976. The island currently has one large house for use of guests, who rent the island, and a collection of smaller, permanently occupied houses for the island’s staff. In 2005, the island’s owners and management established the D’Arros Research Centre, an environmental research facility focussing on both terrestrial and marine scientific research in the central Amirantes region.

Geography and geology

The platform reef at D’Arros Island sits on the western side of the confluence of two channels on the Amirantes Ridge, one trending SE-NW to the north of the platform and reaching a water depth of 48 m and the other, a narrower S-N trending channel which divides D’Arros from St. Joseph and which reaches water depths of 73 m (U. Engelhardt, personal communication, 2008). Slopes to the southeast are moderate and the 30 m isobath lies over 1 km from the reef margin. However, water depths rapidly increase to the north and particularly to the east, where the 30 m contour lies only 100 – 300 m from the reef edge. Stoddart and Coe[4] give the total reef area at low water as 270 ha, with the island occupying 170 ha (62%) of this area. The island is oval in shape, with a long axis 1.9 km long and orientated NE-SW. The reef-flat is 250 – 400 m wide on the southern side of the island but only 75 m wide in the north.

Terrestrial flora and fauna

The island surface is generally 2 – 3 m above sea level, reaching a maximum elevation of less than 7 m.[4] Most of the island is composed of carbonate sands, although the surface soils, of the Shioya Series[2], exhibit a 30 – 45 cm think organic layer. There are two small areas (< 4 ha in total) of phosphatic sandstone in the centre of the northern side of the island and a more extensive area (> 25 ha) in the western part of the island. The surface topography varies between being littered with blocks of angular sandstone (perhaps the product of guano extraction) and forming a rock plate at least 1 m thickness.[1,4] The areas of phosphatic sandstone are characterised by soils of the Jemo Series.[2] D’Arros is presently covered in coconut woodland, dating from 70 – 100 years ago, interspersed with occasional *Casuarina litorea* and with an understorey of

Plates 1 and 2: D’Arros Island (above) and St. Joseph Atoll (left) in 1999 (source: Maps Geosystems; reproduced with kind permission of the Government of the Seychelles).

young *Casuarina, Morinda citrifolia, Pipturus argenteus, Leucaena leucocephala* and, in the phosphate areas, *Carica papaya*. There is a diverse ground cover of herbs and grasses, many being introduced weedy species.[4] Stoddart and Coe also described groves of *Ochrosia oppositifolia, Calophyllum inophyllum* and small groups of other broadleaf trees, presumably indicative of the indigenous woodland of the island; these areas are now (2008) increasing under an active management regime (U. Engelhardt, personal communication, 2008). The south and west margins of the island are surrounded by a dense, 50 m wide littoral hedge of *Scaevola taccada*. Historical records and collections in 1976, including sight records, has resulted in a list of 70 plant species.[4-6]

Plate 3: Platform reef of D’Arros, looking towards the northeast.

Plate 4: Reef-flat and fore-reef habitats, south coast of D’Arros Island, looking NNE.

Stoddart and Coe[4] synthesised all previously published records of the avifauna, supplemented by their own observations in 1976. Five *Foudia sechellarum* (Seychelles Fody) from Cousin were introduced in 1965 by an expedition from Bristol University, UK. The birds have become established and now around one hundred pairs occur alongside the other landbirds present: introduced *Foudia madagascariensis* (Madagascar Fody), *Passer domesticus* (House Sparrow), *Geopelia striata* (Zebra Dove) and *Streptopelia picturata* (Madagascar Turtle-Dove).[7]

Marine habitats

The island is surrounded by sandy beaches; there is some beachrock on the northeast coast. On south-facing coasts, reef-flat sands are underlain by a rocky pavement and no living corals are present.[4] The reef-flat margin is characterised by low to medium density seagrass *Thalassia hemprichii and Thalassodendron ciliatum* which in places extends back to the island in narrow linear strips orientated NNW-SSE. The western and northwestern reef-flat, by comparison, has more extensive patches of medium and high density seagrass and the northeastern reef-flat displays large areas of low and medium density seagrass. To the south of the island, a series of concentric habitats are found in the vicinity of the breaker zone. The first of these bands comprises coral rubble with coralline algae, with mats of *Cladophoropsis sundanensis* and *Valonia fastigiata*.[11] This zone is at its widest (> 100 m) on the south coast but extends around the majority of the island’s periphery. This is followed, along a 2 km arc, by a rock pavement which in turn is replaced seawards by coral spurs with coralline algae. This latter unit extends further east than the rock pavement.

Coral rubble and sand is well developed on the outer fore-reef on the southern and western coasts but to the east is replaced by fore-reef sands and rocky slopes. The north coast is more irregular and broken by several small passes.[1] There is rock pavement at the northeast point and a small area on the northwestern coast.

St. Joseph Atoll

Island history

St. Joseph Atoll was discovered, and named, by M. de la Biollière in 1771. Its position was fixed in 1822 and charted by HMS *Alert* in 1882 and again by HMS *Hydra* in 1975. The first general scientific observations were by the Percy Sladen Trust expedition in 1905. Geological[1] and soil[2-3] mapping were undertaken in the 1960s, along with studies of the marine fauna, birds and plants. Prior to the establishment of the D’Arros Research Centre, the most recent comprehensive field studies were undertaken by Stoddart and Coe in 1976.[8]

Geography and geology

St. Joseph Atoll lies on the eastern edge of the Amirantes Ridge; water depths reach over 1,000 m at 2.5 km from the northeastern margin of the reef. The atoll is positioned immediately east of D’Arros Island but separated from its neighbour by a 1.1 km wide, S-N trending channel reaching a maximum recorded depth of 73 m (Plate 5). This channel extends north of St. Joseph, leaving a relatively shallow spur on its eastern margin, with water depths gradually increasing to 40 m at 1.5 km north of the northern point of the atoll.

To the southwest, water depths are characteristic of the general water depths on the Amirantes, ranging between 36 and 43 m. General statistics for St. Joseph are given by Stoddart and Coe.[8] The atoll is roughly oval in shape, 7 km in length and 4.4 km wide and covers a total area of 2,253 ha. The atoll is dominated by reef-flats that cover 1774 ha (79% of the total area) (Plate 6).

The windward reef-flat reaches a width of 2.8 km at the eastern point of the atoll and the northern, southern and western reef-flats are 1 – 1.5 km, 1 km

Plate 5: Deep water channel between St. Joseph Atoll (left) and D’Arros Island (top right), looking WSW. Note reef island of Ressource (bottom left), reef-flat sands and medium to high density seagrass beds on reef-flat.

Plate 6: Reef-flats of St. Joseph, looking W, January 2005. Note reef island of Ressource (to right), reef-flat sand bordered by seagrass on lagoon margin (foreground) and coral rubble with lagoonward reef-flat sand on western atoll rim.

Plate 7: The island of St. Joseph, looking SW, with (from left to right) islands of Benjamen, Chien and Pelican beyond.

Plate 8: The northern tip of St. Joseph, looking SW. Note extensive reef-flat sand, coral rubble on reef margin (with occasional shore-normal lines of high density seagrass) and areas of medium – high density seagrass (right).

and 600 – 800 m in width respectively. Baker[1] identifies shallow breaks in the reef-flat at the southeastern corner of the atoll, midway along the northeastern margin and to the west of the northern point. In hydrodynamic terms, the atoll is 'closed'; the main connection between the lagoon and the ocean is a shallow sill, the Passe Lerein Fin, on the western margin of the atoll, opposite D'Arros Island. The central lagoon, with a centroid towards the western end of the atoll, is similar in shape to the atoll as a whole, with a maximum length of 4 km and a typical width of 2 km. It accounts for 480 ha (21%) of the total area. Reef top islands and islets account for 8% of the area of the reef-flats. Stoddart and Coe[8] identify two types - longitudinal and transverse - although there are cases where hybrid island forms are present. The two largest islands, St. Joseph (Plates 7 and 8), which occupies the eastern end of the atoll, and Fouquet (Plate 9), which lies 500 m west of the northwestern end of St. Joseph, are of the longitudinal type and aligned parallel to the reef edge.

Fouquet is on the inner reef-flat margin and protrudes into the lagoon. The form of St. Joseph suggests that the island has grown by the longshore transport of sand to both the northwest and to the southwest. At the southwest point, sediment transport under wave refraction has led to sand spit development normal to the general direction of island extension. The longitudinal islands are composed of carbonate sands and have probable maximum elevations of 2.5 m above reef-flat level. Piggott[2-3] commented upon the apparent recency of the islands and, as a result, the dominance of immature sand and gravelly Shioya Series soils and the absence of Jemo Series soils associated with phosphatic deposits. Baker[1], however, noted the presence of an area of phosphatic sandstone in the southern part of

Plate 9: The island of Fouquet (right) and the northern tip of St. Joseph (left), looking SW. Beyond St. Joseph on the reef-flat lie Pelican (left) and Chien (right).

St. Joseph. The transverse islands are cored by transverse rubble bars. These are tongues of storm debris about 1 m above the reef-flat, often flaring seawards and, in some cases, extending across the whole width of the reef-flat. These rubble accumulations are particularly characteristic of the southern reef-flat. They are relatively wide and well developed to the west of St. Joseph where they appear to underpin a cluster of four islets which have shown considerable changes in shape and size over the last one hundred years.[8] It also seems possible that of the two spits at the western end of St. Joseph, the more easterly, inactive and vegetated sand spit is a transverse island that has become incorporated into St. Joseph as it has extended westwards. A tranverse rubble bar is present on the reef-flat to seaward of this spit and Stoddart and Coe[8] note that in 1882 it was a separate island to St. Joseph. Further west, the rubble bars are thinner, supporting small vegetated islets, sandbanks or remaining as bare rubble. The northern corner of the reef-flat is occupied by the islet of Ressource (Plates 10 and 11). This appears to be a hybrid form, showing both longitudinal and tranverse island morphologies.

Terrestrial flora and fauna

The larger islands (St. Joseph, Fouquet and Ressource; Plates 7-11) are covered with coconut plantations but the luxuriant herb and grass flora present in such plantations on neighbouring D'Arros is absent; Stoddart and Coe[8] speculate that this is may be due to the difficulty of human access to the reef-encircled lagoon and thus a more restricted flora of introduced weeds. Introduced trees and shrubs are, however, characteristic of the small settlement at the western end of St. Joseph. A littoral hedge of *Scaevola taccada*, with occasional *Tournefortia argentea*, is found on seaward beach margins on the larger islands and is particularly well developed on the eastern margin of St. Joseph. Trees of *Guettarda speciosa* and *Casuarina litorea* are also present on Ressource, Fouquet and the islets west of St. Joseph. The larger islands have beach-foot thickets of *Pemphis acidula* on lagoonal shores (where extensive these appear as 'other trees and shrubs' on the habitat map) and the transverse islands, in addition to *Pemphis acidula*, also support *Suriana maritima, Tournefortia argentea and Scaevola taccada* on generally bare sand and gravel surfaces. Stoddart and Coe[8] reported the presence of one individual of *Rhizophora mucronata* on the largest of the islands west of St. Joseph and commented on the lack of mangrove elsewhere. The recent habitat mapping, and interrogation of oblique aerial photographs, suggest that the presence of mangrove is much more extensive now (2005) than in 1976. Historical records, and collections and sight records from 1976, have established a plant list of 45 species.[8-9]

Stoddart and Coe[8] synthesised all previously published records of the avifauna, supplemented by their own observations in 1976. Of particular interest in the historical records is the presence of a breeding colony of pelicans in 1892 and 1905, now identified as the *Pelecanus rufescens* (Pink-backed Pelican) and becoming extinct between 1905 and the 1930s.[10] The atoll supports large numbers of both *Fregata minor* (Greater Frigatebird) and *Fregata ariel* (Lesser Frigatebird) and a large breeding population (> 23,000 pairs) of *Puffinus pacificus* (Wedge-tailed Shearwater), mostly on Fouquet. In 2002, a breeding population of 350 pairs) of *Sterna dougallii arideensis* (Roseate Tern) was reported from the atoll (A. Skerrett, personal communication, 2002). In 2007, this breeding population of roseate terns at St Joseph Atoll was estimated at over 500 pairs, making it the second largest colony of this species in Seychelles.[12]

Marine habitats

The seaward margins of St. Joseph, and the entire margin of Ressource, are characterised by sandy beaches but elsewhere island margins merge into reef-flat sands. The coverage of the extensive reef-flats by unvegetated sand is striking and it is clear that sand sheets are actively encroaching into the lagoon. The seaward margin of the reef-flat on windward coasts is characterised by a 250 m wide zone of medium density seagrass, with local high density *Thalassodendron ciliatum*[11] in a narrow reef edge-aligned strip. Medium density seagrass also characterises the relatively low atoll rim southeast of Ressource – where the species *Thalassodendron ciliatum* and *Thalassia hemprichii* have been reported (with *Microdictyon* spp.)[11] and *Syringodium isoetifolium* sighted[8] - and has colonised the sheltered mudflats and sandflats behind the western end of St. Joseph and the channel between St. Joseph and Fouquet. By contrast, seagrass coverage on the leeward reef-flat is restricted to small patches of medium and low density, with *Halimeda* spp. communities.[11] As at D'Arros, a series of concentric habitats are found in the vicinity of the breaker zone but these are spatially more extensive at St. Joseph, varying in width but generally encircling the entire atoll. The first of these bands comprises coral rubble with coralline algae; this is restricted to the northeastern and northern reef margin. This is followed by a rock pavement, best developed south of St. Joseph, which in turn is replaced seawards by coral spurs with coralline algae. Thereafter, the reef margin is characterised by a fore-reef slope with rubble and sand; unlike many other islands in the Amirantes sand sheets on the fore-reef are noticeably absent.

The lagoon at St. Joseph is shallow: the maximum depth sounded by HMS *Alert* in 1882 was 6.4 m, with other soundings ranging between 2.1 and 3.7 m. It is weakly divided into a series of basins by parallel, flat-topped reef ridges trending SW – NE. The ridges are emergent at low spring tides and do not support living corals; rather, they are covered with the seagrasses *Thalassodendron ciliatum* and*Thalassia hemprichii*, at medium densities. Stoddart and Coe[8] were of the view that the lagoon in 1976 was being subject to high rates of sedimentation, with high turbidity and low productivity, and that the massive faviid and poritid corals on the flanks of the lagoon ridges were experiencing low growth rates and high bioerosion. Coral surveys in the lagoon waters conducted by the D'Arros Research Centre (DRC) in 2005 have identified patchily distributed but healthy stands of mature colonies of the massive coral *Porites lutea* and the branching corals *Acropora palifera* (U. Engelhardt, personal communication, 2005). The estimated age of these coral communities suggests that they survived the 1998 mass coral bleaching event unharmed. This is particularly remarkable, as seawater temperatures inside the atoll may exceed 38° C.[13]

Source materials

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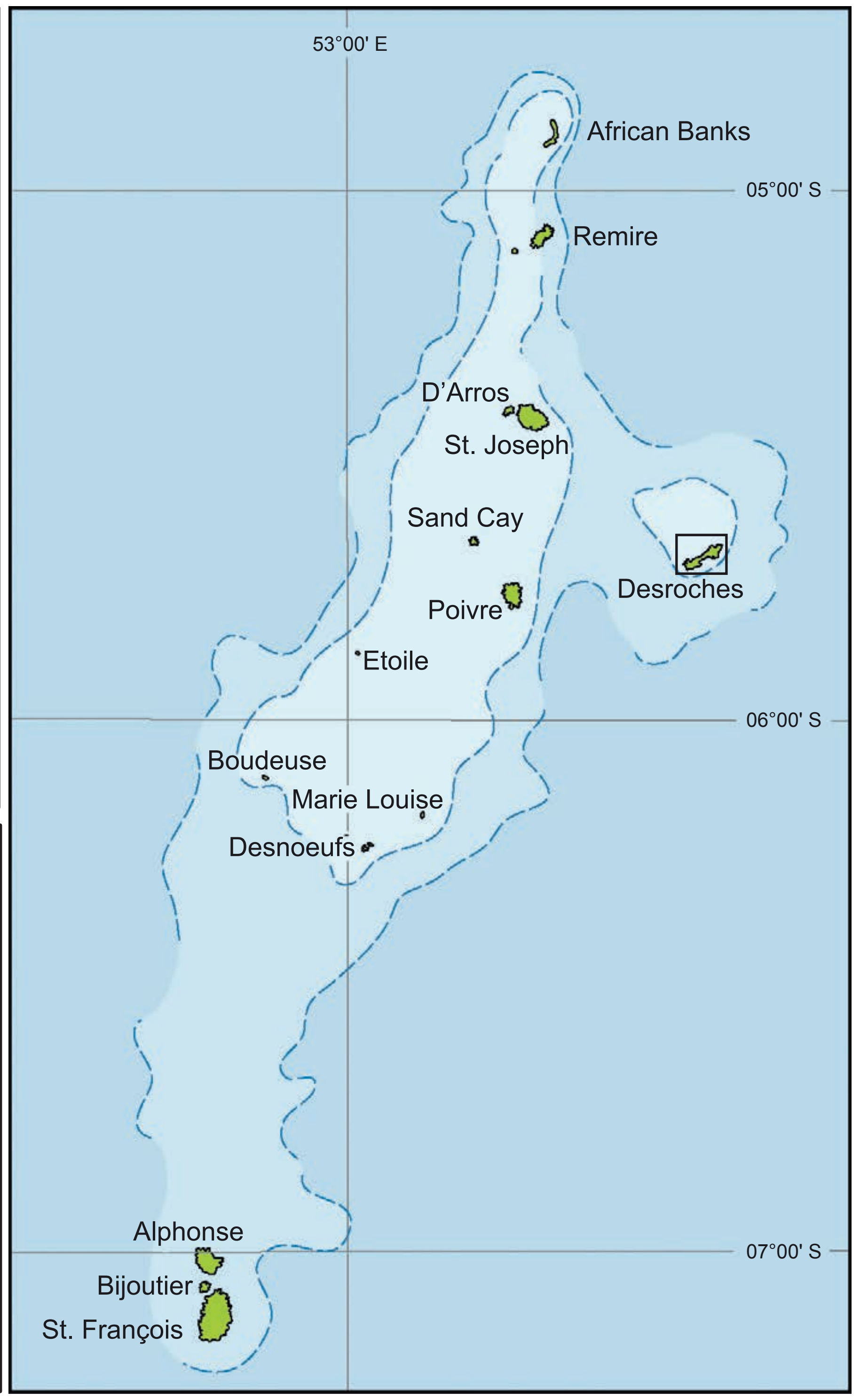
Plates 10 and 11: The reef island of Ressource, looking NE. Note medium to high density seagrass beds behind coral rubble and rock pavement on the atoll margin and medium density seagrass on reef ridges within the lagoon.

Desroches

(05°38' S; 53°38' E)

Key to Habitat Classification: Desroches

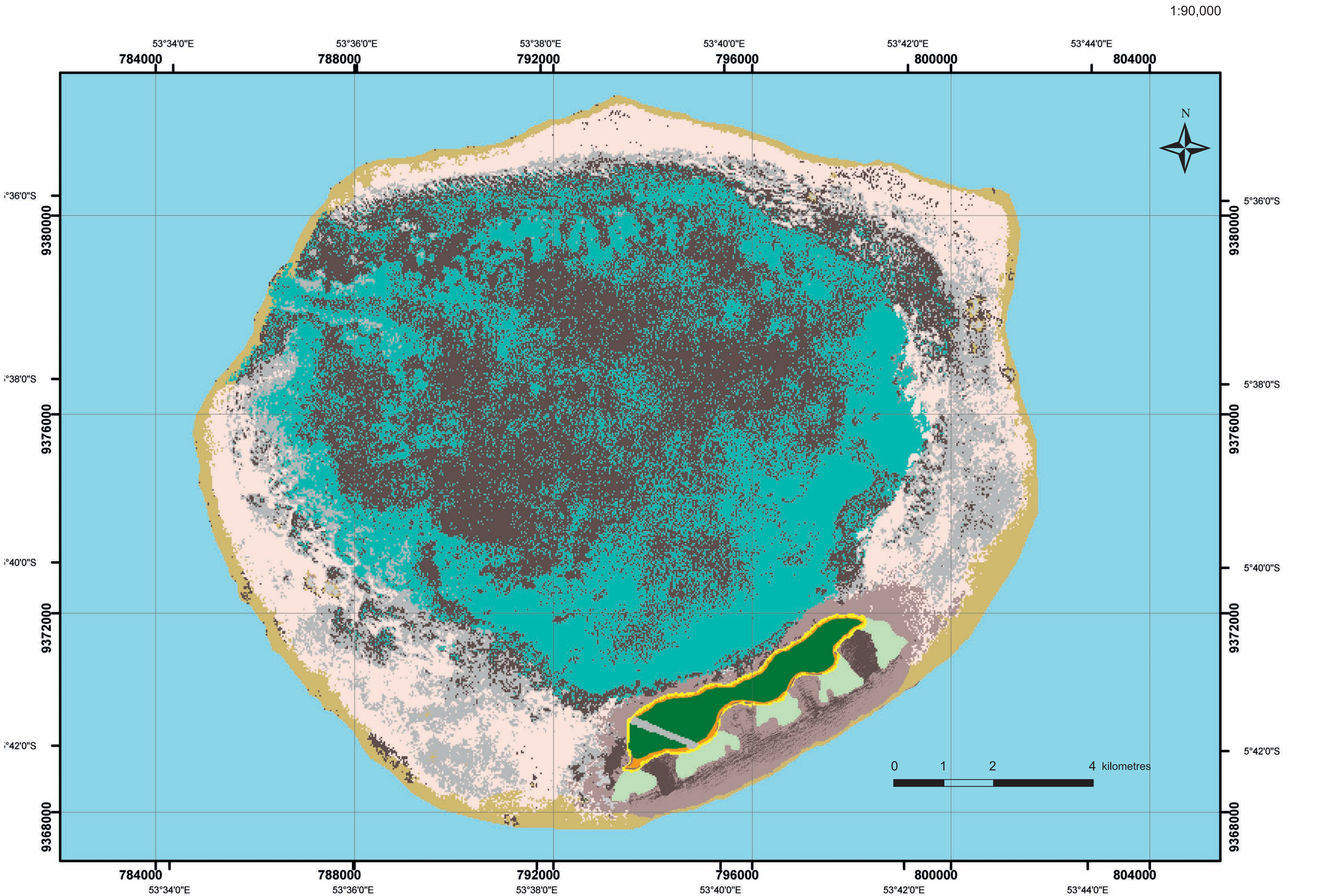
- Terrestrial vegetation: Trees and shrubs
- Cleared / bare ground
- Littoral hedge
- Beach sand
- Beachrock
- Rock pavement
- Reef-flat sand and rubble
- Low density seagrass / macroalgae
- Seagrass
- Submerged reef platform
- Lagoon sand
- Fore-reef slope material



The map shows the shallow water benthic habitats of Desroches, part of the Amirantes group, southern Seychelles, Western Indian Ocean. This was produced by performing a classification on imagery acquired by the Landsat Enhanced Thematic Mapper sensor in February 2000. The bands of this sensor span the visible section of the electromagnetic spectrum. It is possible to resolve features down to a depth range of 20-25 m, depending on water quality (see Appendix 2).

Projection and Sensor Information

Projection: UTM, Zone 39S
Datum: WGS 1984
Sensor: Landsat 7 ETM+
Pixel Size: 30m
Electromagenetic spectrum region: 450-12500nm
Acquisition Date: February 2000



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Desroches

Note: An airborne survey of the island of Desroches was undertaken in January 2005 but, unfortunately, the data was corrupted and could not be used to derive a habitat map. The remainder of the atoll was not surveyed at this time. However, in order to provide a comprehensive coverage of all the islands of the Amirantes for this Atlas, a habitat map has been constructed from Landsat imagery. It is important to note, therefore, that the basis for the habitat map presented here differs from that of the other islands; the legend to the habitat map gives further information on map production. The map has not been ground referenced but information from the map, from oblique aerial photography (from January 2005) and from published sources, most notably Stoddart and Poore[1], has been used to provide the description below, with valuable additions from Dr D. Rowat, Chairman, Marine Conservation Society, Seychelles.

Island history

Desroches was named after the Chevalier des Roches, the Governor of Mauritius (then Île de France) and Réunion (then Bourbon) from 1767 to 1772. It is not entirely clear that the atoll was discovered by Du Roslan in 1770[1]; Lionnet[2] states that it was explored by M. de la Biollière in 1771. *Casuarina* trees were planted during a brief settlement in 1835; continuous habitation began in 1875-1880 with the establishment of coconut plantations. The first scientific visit was undertaken during the visit of HMS *Alert* in 1882 and the Percy Sladen Trust expedition, on board HMS *Sealark*, made general observations and collections in 1905[1]. Geological[3] and soil[4] mapping and ornithological and botanical studies were undertaken between 1960 and 1967; the most recent comprehensive field studies were undertaken by Stoddart and Poore in 1968.[1] Desroches was administered as part of the Seychelles between 1909 and 1965 but then assigned by the UK to the British Indian Ocean Territory (BIOT). It was returned to Seychelles on independence in 1976. The atoll is now administered by the Islands Development Company, a government parastatal. Under this management it has been used for several agricultural projects, from the growing of coconuts for copra production to the raising of livestock, including hybrid goats and chickens.The island now (2008) supports a population of around 50, a paved airstrip and a small hotel.

Geography and geology

Desroches is the most easterly of the islands of the Amirantes, lying 48 km SE of St. Joseph and 40 km ENE from Poivre. The atoll is surrounded by deep water; a sounding of 1,740 m has been recorded between the island and the main Amirantes Ridge 16 km to the west and, in places, regional water depths exceed 2,000 m. Desroches is a submerged atoll, 19 – 21 km in diameter. The atoll rim takes the form of a 1 - 3 km wide submerged reef platform at depths of 4 - 7 m on its eastern and southern sides. In the north, the reef rim at Shark Rocks has water depths of less than 3 m. 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. These variations in the depth of the reef platform around the atoll suggest that the entire structure may have been tilted to the west, following a phase of sustained reef growth. In places the reef platform is characterised by karstic solution features such as sinkholes, tunnels, caves and overhangs. One example of such as sinkhole (~ 4 m in diameter) is at 'The Tunnel' dive site, to the west of the island, where a swim-through exists from the top of the rock platform (around 15 m depth) to the drop-off slope (over 25 m depth). Several submerged caves have stalagmite and stalactite deposits, as well as numerous blow holes to the reef crest (D. Rowat, pers. comm., 2008). The island of Desroches lies along the southeastern rim of the atoll and sits upon a rock pavement, rather than directly onto the submerged reef platform. It is 5.25 km long, 0.4 to 1.1 km wide and has an area of 324 ha.

Terrestrial flora and fauna

The island surface is a broad sandy plateau at 2 – 3 m above sea level, characterised by Shioya Series soils with scattered phosphatic nodules and patches of phosphatic Jemo Series soils.[3-4] Following the start of active management for copra at the end of the nineteenth century, it is clear that the indigenous vegetation is now largely limited to littoral locations. On the south coast in 1968, Stoddart and Poore[1] noted a littoral hedge of *Scaevola taccada* with occasional *Suriana maritima* and *Tournefortia argentea* and a landward fringe of *Guettarda speciosa*. On the north, lagoonal coast, *Scaevola* is again dominant but with trees of *Ochrosia oppositifolia*, *Guettarda speciosa*, *Pipturis argenteus* and *Cordia subcordata*. Elsewhere the island is dominated by *Casuarina equisetifolia* and planted coconuts, the latter with a diverse understory of grasses, herbs, sedges and the fern *Nephrolepis biserrata*.[1] In the centre of the island and near the settlement, specimens of *Guettarda speciosa*, *Morida citrifolia*, *Terminalia catappa*. *Ficus* sp., *Hernandia sonora* and *Calophyllum inophyllum* were recorded in 1968, along with several decorative and economic plants. It is not known if *Barringtonia asiatica*, described in 1905, is still present.[1] Records from earlier collections, and new collections and sight records observations in 1968, has resulted in a list of 60 plant species.[5-6]

Stoddart and Poore[1] synthesised all previously published records of the terrestrial fauna, supplemented by their own observations, in 1968.

Marine habitats

The most distinctive feature of the island of Desroches is the presence of four deep embayments into the sand and rubble-covered reef-flat on the south coast. The embayments are floored by a rock pavement which surrounds the island and which appears to sit upon the submerged reef platform. The landward margins of the embayments are backed by steep beaches of sand and gravel with beachrock, this being most extensive and massive at the southwestern end of the island. Sandy beaches of lower gradient continue along the lagoon shores of the island.

To varying degrees, each of the embayments support seagrass beds of *Thalassia hemprichii* (with *Udotea argentea*, *Dictyurus purpurascens* and *Turbinara ornata*) in shallow water, replaced by *Thalassodendron ciliatum* and *Halimeda* spp. (with *Caulerpa* spp., *Dasya mollis*, *Galaxaura* spp. and *Jania* spp.) at greater water depths[7]. The lagoon margin of the island supports three associations: *Thalassodendron ciliatum + Thalassia hemprechii + Halimeda micronesica*; *T. ciliatum + H. opuntia*; and *T. ciliatum* alone.[7]

The submerged reef platform is characterised by numerous small colonies of *Pocillopora* spp. and locally dense *Halimeda* spp. There are local patches of seagrass on the platform; on the northeastern rim of the atoll high density seagrass appears to have colonised a series of sand ridges which run sub-parallel to the atoll margin.

A channel on the western side of the atoll and 11 km northwest of the island of Desroches, leads into the lagoon. The Admiralty Chart shows that the channel is about 1.6 km wide with a minimum depth of 18.3 m. The lagoon shows little variation in depth with isolated soundings showing the lagoon floor at between 23 and 27 m. Early scientific observations drew attention to the absence of patch reefs within the lagoon[8], although in the southeast, three soundings of 10.7, 17.4 and 16.2 m indicate submerged reefs comprised of generally isolated coral bommies, mainly of *Porites* sp., surrounded by seagrass, at similar depths to the depth of the western submerged reef platform. The southeastern margin of the lagoon, adjacent to the eastern end of the island, formerly supported large banks of staghorn coral *Acropora formosa* but these have largely been turned into rubble banks following the impact of the 1998 bleaching event (D. Rowat, personal communication, 2008). The margins of the lagoon are characterised by bare sand but there are extensive areas of dense seagrass beds in the main body of the lagoon and on the northern margin of the entrance channel.

Plate 1: Island of Desroches in 1999 (source: Maps Geosystems; reproduced with kind permission of the Government of the Seychelles). *insert page 1, 1-Desroches here*

Plate 2: Island of Desroches, looking west. Note areas of reef-flat and intervening embayments, with seagrass beds, along the south coast. *insert page 2 1-DSCN0812 jpg here*

Plate 3 (top): SW point of island of Desroches, looking north

Plate 4 (middle): South west coast of island of Desroches, looking north

Plate 5 (above): South coast of island of Desroches, looking southwest

Plate 6: South west point of island of Desroches, looking northeast. Note beachrock at SW Point and seagrass beds of high density *Thalassodendron ciliatum*

Plate 7: Lagoon shore of island of Desroches, looking southwest. Note wide sandy beach, littoral hedge and tall *Casuarina*

Plate 9: Northern and eastern submerged reef platform (water depths 3 – 7 m), looking south towards island of Desroches

Plate 10: Detail of northern submerged reef platform (lagoon top right). Note high density seagrass, in association with sand ridges aligned sub-parallel to the atoll margin

Plate 8: Lagoon shore of island of Desroches, looking SSW. Seagrass beds of *Thalassodendron ciliatum + Thalassia hemprechii + Halimeda micronesica association in shallow water replaced by T. ciliatum + H. opuntia* and *T. ciliatum* associations further into the lagoon

The outer reef on the southeastern margin is generally devoid of large coral structures, the reef-crest being characterised by small colonies of *Pocillopora spp.* while the reef front is generally a sheer wall extending from the reef-crest to a lower wave cut platform at from 27-35m. This area faces into the prevailing south-easterly trade winds and swell pattern and as such is subject to the dominant direction of wave attack. The limestone base in this area is pock-marked with caves, sink-holes and shows evidence of collapse with large slabs of limestone having been split from the face. The reef face or 'Desroches Drop' as it is known, is colonised by cup corals *Tubastraea* spp., black coral bushes, *Antipathes* sp., and black coral whips, *Sticopathes* sp., all indicative of the high current flow experienced by the twice daily tidal flow into and out of the large lagoon. The outer reef areas to the west and northern margins are less well defined with considerable sand overburden and the presence of isolated coral bommies, largely of *Porites* sp. (D. Rowat, personal communication, 2008).

Source materials

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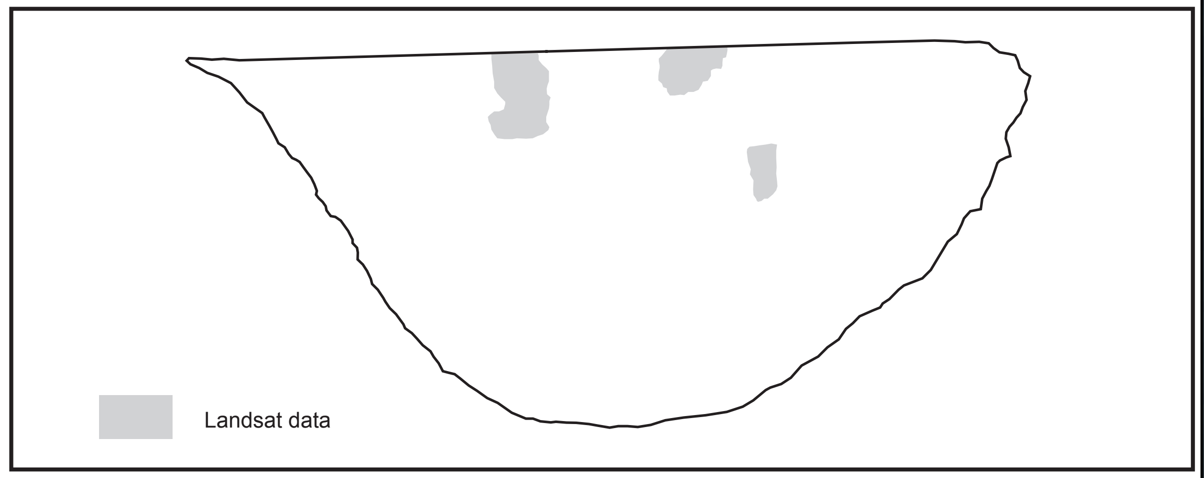
Sand Cay

(05°38' S; 53°14' E)

Key to Habitat Classification: Sand Cay

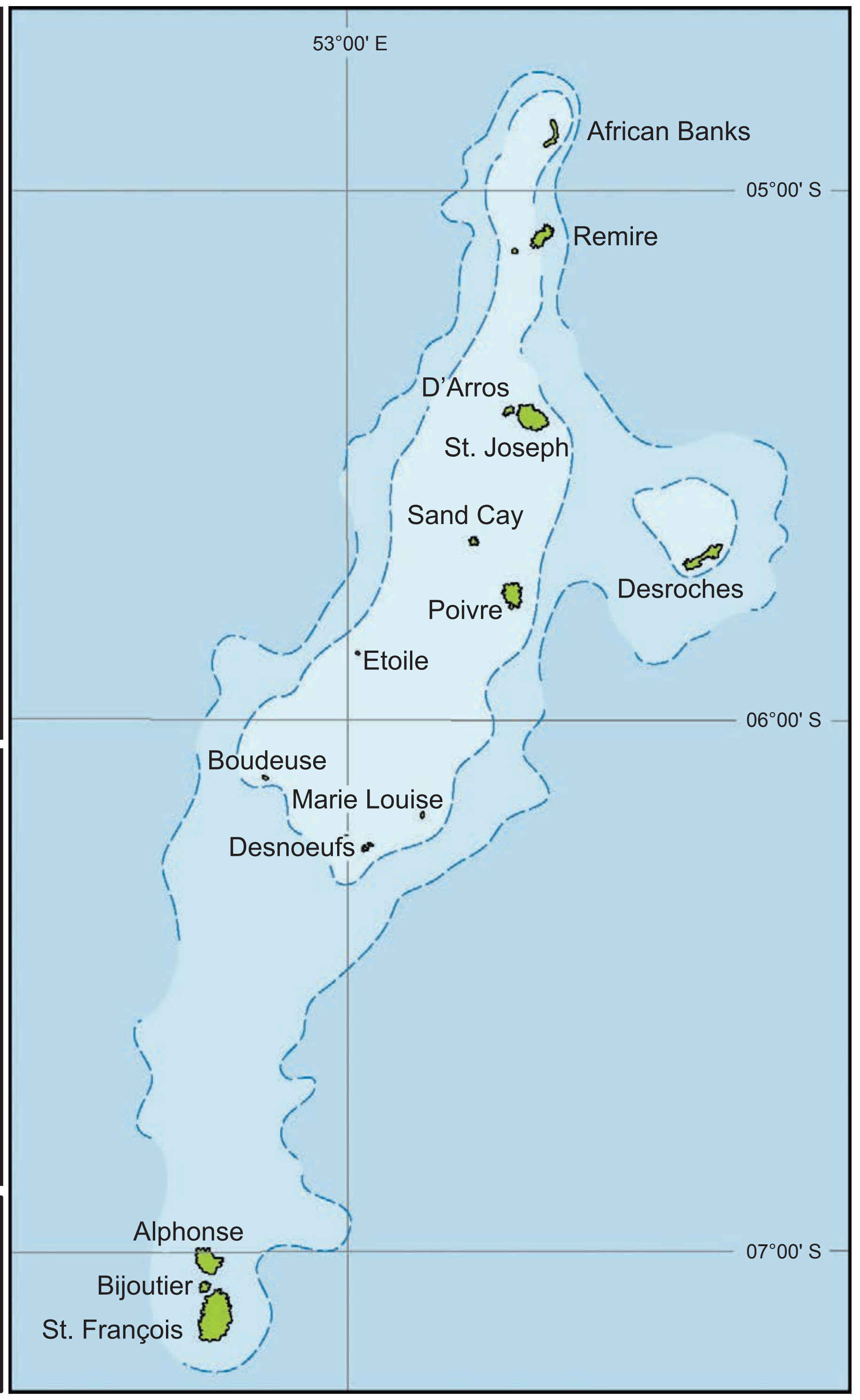
- Coconut woodland
- Other trees and shrubs
- Herbs and grasses
- Saline pond
- Cleared / bare ground
- Buildings and other structures
- Littoral hedge
- Mangrove woodland
- Coral sandstone / raised reef
- Beach sand
- Coral boulders
- Beachrock
- Rock pavement
- Reef-flat sand
- Low density seagrass / macroalgae
- Medium density seagrass
- High density seagrass
- Lagoon patch reef
- Lagoon sand
- Coral rubble with coralline algae
- Fore-reef slope coral spurs with coralline algae
- Rocky fore-reef slope
- Fore-reef slope sand
- Fore-reef slope rubble and sand
- Fore-reef slope with coral



The map shows the key shallow water benthic habitats of Sand Cay, part of the Amirantes group, southern Seychelles, Western Indian Ocean. This was produced by performing a classification on 17 bands of CASI imagery acquired in January 2005. Where data are missing due to cloud cover, gaps have been filled by classifying georeferenced Landsat data (2000).

Projection and Sensor Information

Projection: UTM, Zone 40
Spheroid: GRS 1980
Datum: NAD83
Sensor: Compact Airborne Spectrographic Imager
Pixel Size: 1m
Electromagenetic spectrum region: 434-849nm
Acquisition Date: January 2005



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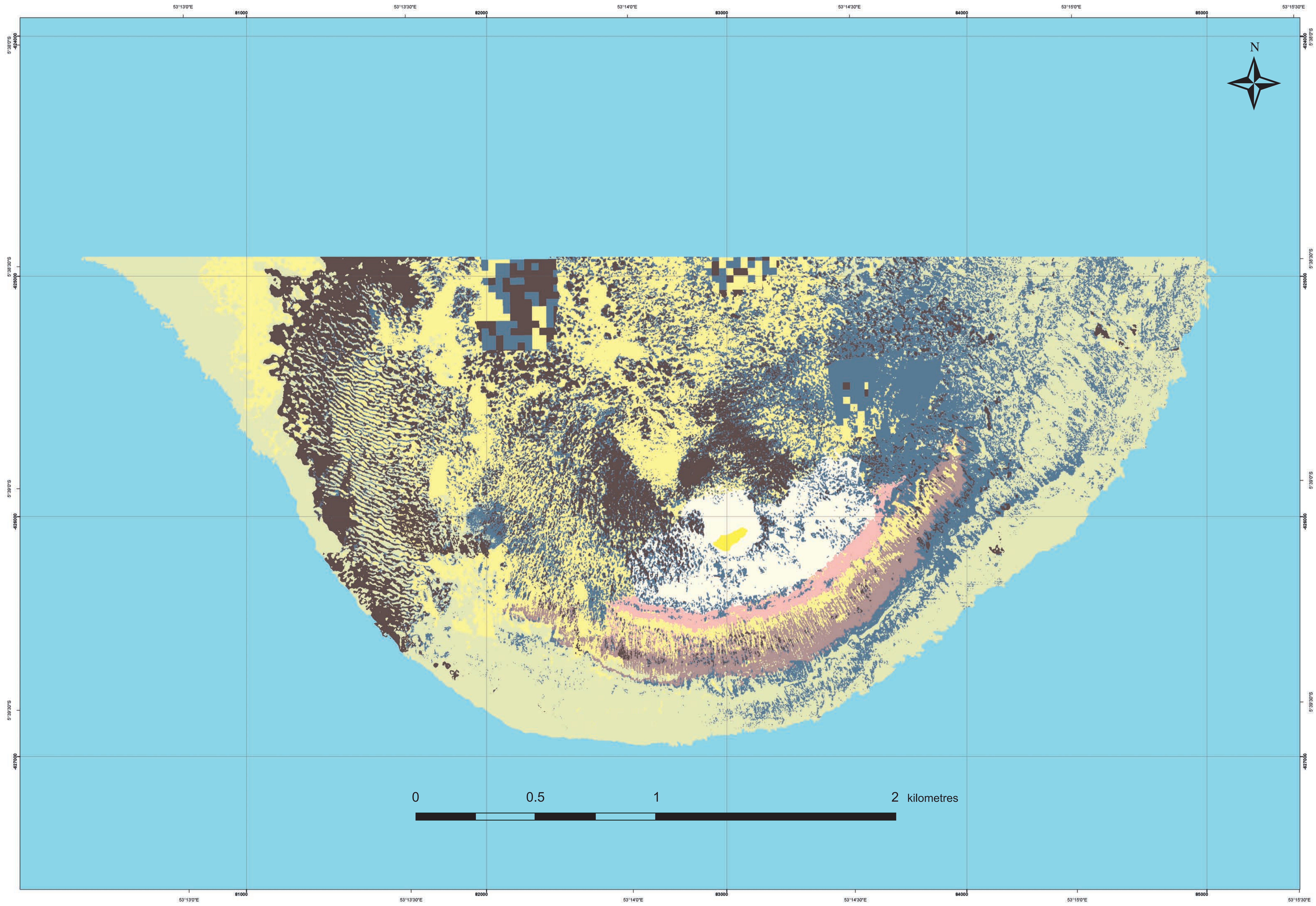
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Sand Cay

Note: Sand Cay, an extremely small and isolated island, was not visited by the Expedition in January 2005. The comments below are based on the analysis of the habitat map, assisted by earlier vertical aerial photography (1999) and an oblique aerial photograph collected in January 2005.

Geography and geology

Unlike all other islands in the main group of the Amirantes, which sit close to either the western or, more usually, the eastern margin of the Amirantes Ridge, Sand Cay is positioned in the centre of the Ridge. It lies 26 km southwest of St. Joseph and 15 km northwest of Poivre. The island occupies a position at the southwest corner of a small SE-NW trending shoal with water depths of between 7 and 10 m. General water depths in the centre of the Amirantes Ridge are 21- 39 m but they are flanked to both the north and the south by water depths in excess of 50 m.

The subaerial expression of Sand Cay is an unvegetated sandbank, 110 m long and 70 m wide, which sits on a circular sand sheet, approximately 200 m in diameter. It seems likely that this sandbank periodically shifts its precise position on the sand sheet in response to variations in the local wave climate. At times, the sandbank itself is not present, as appears to have been the case in 1999.

To the southeast of the present sandbank, a number of clearly delineated shallow water habitats are present across a broad arc 1.5 km in length. The first of these habitats is a 200 m wide reef-flat covered with reef-flat sand and occasional seagrass patches. This is followed by a narrow (< 60 m) reef, with coral spurs and coralline algae. The base of the reef is characterised by fore-reef sands which feed into numerous narrow, sand-filled channels in a rock pavement which extends to 300 m from the reef crest. The margin of the rock pavement is marked by a zone of medium density seagrass overlying rubble and sand. A second band of seagrass is apparent further offshore and the patterning of seagrass here suggests that some of the channel lineations seen on the rock pavement continue into this area.

The area to the northeast of the reef-flat sands is characterised by medium density seagrass over rubble and sand. Immediately north and northwest of the sandsheet and sandbank are two areas of high density seagrass. Further north and west, well developed sandsheets and broad sand channels divide areas of high density seagrass with, in places, thin ribbons of seagrass orientated WNW–ESE.

Plate 1: Sand Cay in 1999 (source: Maps Geosystems; reproduced with kind permission of the Government of the Seychelles). Note the absence of a subaerial sandbank or island at this time.

Plate 2: Sand Cay looking northeast, January 2005.

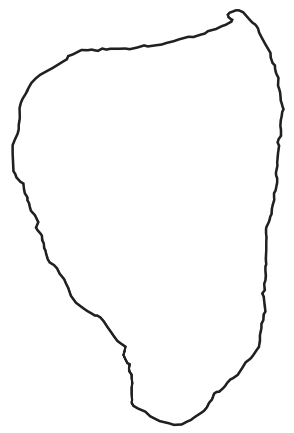
Note the numerous, well developed channels in the rock pavement to seaward of the reef crest

Poivre

(05°45' S; 53°18' E)

Key to Habitat Classification: Poivre

- Coconut woodland
- Other trees and shrubs
- Herbs and grasses
- Saline pond
- Cleared / bare ground
- Buildings and other structures
- Littoral hedge
- Mangrove woodland
- Coral sandstone / raised reef
- Beach sand
- Coral boulders
- Beachrock
- Rock pavement
- Reef-flat sand
- Low density seagrass / macroalgae
- Medium density seagrass
- High density seagrass
- Lagoon patch reef
- Lagoon sand
- Coral rubble with coralline algae
- Fore-reef slope coral spurs with coralline algae
- Rocky fore-reef slope
- Fore-reef slope sand
- Fore-reef slope rubble and sand
- Fore-reef slope with coral

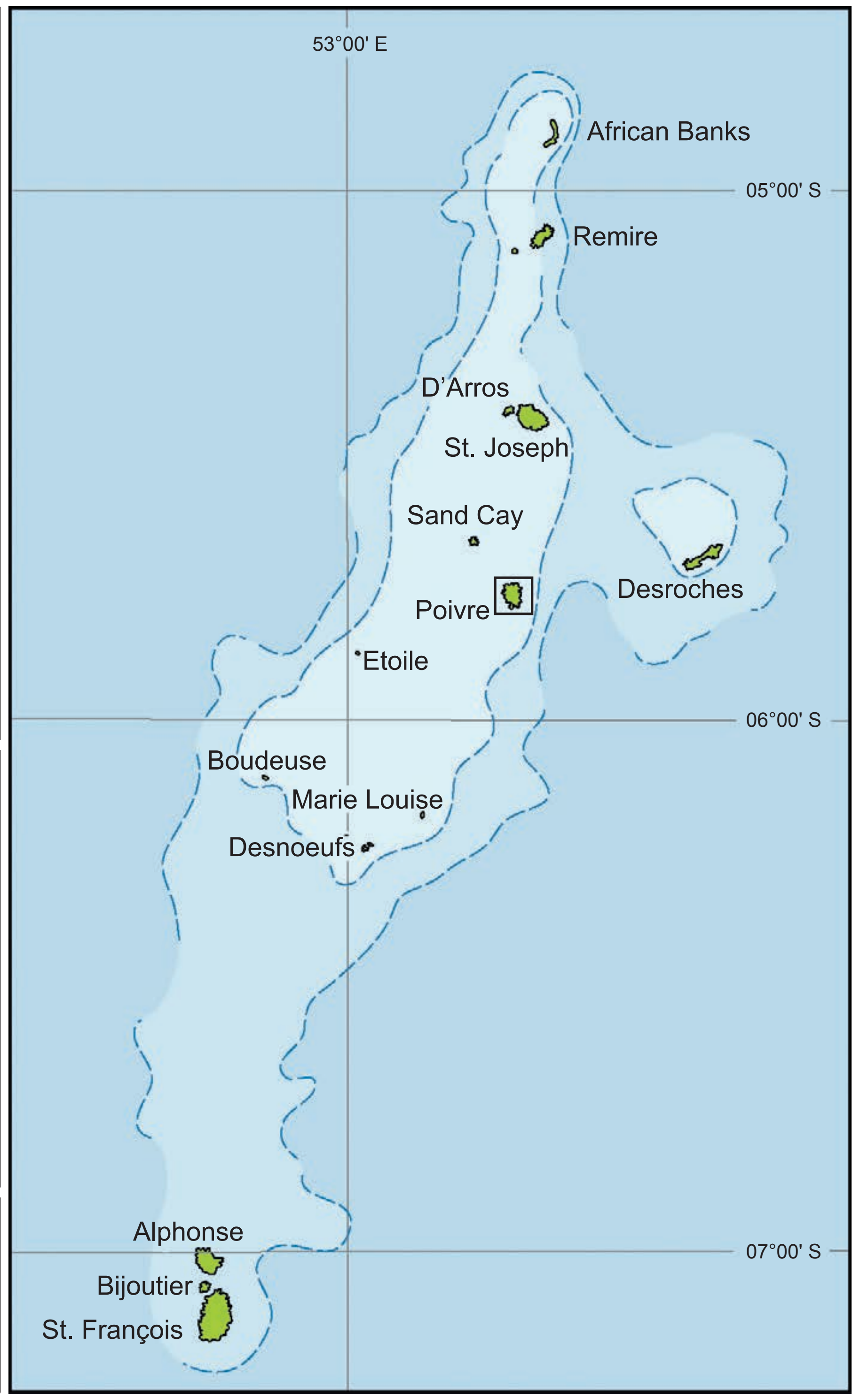


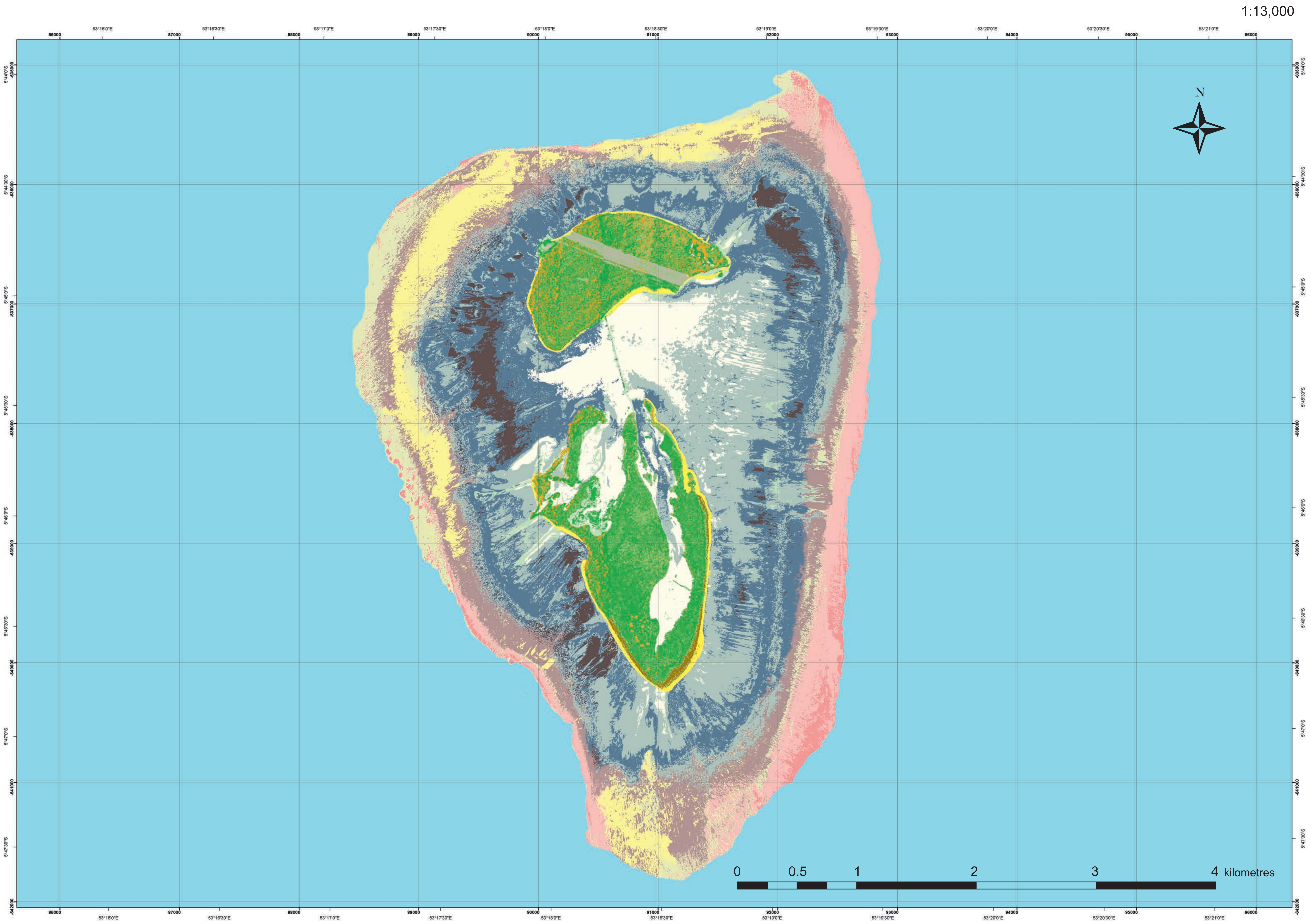
No Landsat data required

The map shows the key shallow water benthic habitats of Poivre, part of the Amirantes group, southern Seychelles, Western Indian Ocean. This was produced by performing a classification on 17 bands of CASI imagery acquired in January 2005. Where data are missing due to cloud cover, gaps have been filled by classifying georeferenced Landsat data (2000).

Projection and Sensor Information

Projection: UTM, Zone 40
Spheroid: GRS 1980
Datum: NAD83
Sensor: Compact Airborne Spectrographic Imager
Pixel Size: 1m
Electromagenetic spectrum region: 434-849nm
Acquisition Date: January 2005

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1
2
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4 kilometres

Poivre

Note: Poivre was visited by the Expedition in January 2005. SCUBA surveys were conducted at Poivre on 26 January between 1150 and 1730, shallow water surveys were conducted on 27 January between 0845 and 0940 and terrestrial surveys were conducted on 27 January between 1000 and 1330. The science team used kayaks to enter the boat channel and land ashore on the northern coast of the western tip of Poivre.

The timing of the terrestrial surveys was planned to be 2 hours either side of low water (predicted low water at 1240) to enable access on and off Poivre Island and to enable the survey team to use the man-made coral rock walkway that connects the islands of Poivre and Ile du Sud. Unfortunately, due to the weathered nature of the old coral rock walkway it was deemed unsafe to cross to Ile du Sud; the substrate between the islands is now sticky lagoon silt/clay and unsuitable for walking.

Island history

Poivre was visited by the Chevalier du Roslan and named in 1771 by M. de la Biollière. The naming was after Pierre Poivre, the famous 'Peter Pepper', Governor of Île de France (Mauritius) and Bourbon (La Réunion) from 1769 to 1772, an agronomist who was instrumental in setting up the spice industry in the Seychelles in the late 1770s. The first scientific visit was undertaken during the visit of HMS *Alert* in 1882; Coppinger[1] notes that Poivre Island had been colonized in 1820 and had a population of 27 persons. Coconuts 'covered every available spot of ground' and the introduced fauna included rabbits, poultry and pigs. The Percy Sladen Trust Expedition visited on 9 October 1905. Having crossed the sand-flat from Poivre to Ile du Sud, expedition members became trapped by the tide and thus had time to fully explore the southern island.[2] The third island, Florentin, lies within the western margin of Ile du Sud.

The morphology, soils, ecology and agriculture at Poivre Island were documented in the 1960s[3-4] and a plant list compiled by S.A. Robertson and F.R. Fosberg following a two day visit to the island by the first author on 26 and 27 October 1976. Robertson found the island in much the same condition as when described by Piggott (1969) but with greater agricultural activity and with cattle and pigs were being kept.[5]

When Poivre Island was visited in 2005, the only agriculture taking place on the island was for subsistence purposes, undertaken by a small number of workers from the Island Development Company, a government parastatal. A small settlement exists on the eastern tip of Poivre Island. In 2005, a hotel development was underway on the island, but progress has been slow. The centre of the island has been bisected by an 1100 m long airstrip and the existing boat channel is being enlarged to facilitate the entry of larger vessels.

Plate 1: Aerial view of Poivre Atoll in 1999, showing Poivre Island in the north, Ile du Sud in the south and the man-made causeway connecting the two islands (source: Maps Geosystems; reproduced with kind permission of the Government of the Seychelles).

Geography and geology

Poivre lies close to the eastern margin of the Amirantes Ridge, in the southern half of the main bank, 15 km southeast of Sand Cay (which is in the centre of the Ridge) and 40 km WSW of Desroches. The reef system probably sits on one of a number of topographic highs on the bank margin; local water depths of 15 – 17 m characterise these highs compared to 22 – 39 m on the general bank surface to the west of Poivre. To the east, water depths rapidly increase to in excess of 1,500 m. The reef platform is 5 km in length along a central N – S axis. The eastern margin runs S – N but the western margin is orientated SE – NW in its southerly two-thirds before trending SW – NE. As a result, the atoll is 3.5 km in width towards the north but tapers to less than 2 km in width towards its southern limits. The reef platform supports three reef islands, covering 17 % of the reef platform surface area (1,467 ha) (Plate 1). The most northerly island, Poivre Island (110 ha) (Plate 2), is connected to the large (135 ha) and topographically complex southern island, Ile du Sud (Plate 3), by a 750 m long causeway (Plates 4 and 5; wrongly positioned by Baker[3]). The very small (2.4 ha) third island, Florentin, lies behind and within the western margin of Ile du Sud.

Reef-flat widths, which are modest compared to other atolls in the Amirantes, are greatest on the northwest and northeast coasts, opposite the western and eastern points of Poivre Island respectively, where they reach 1 km. Around Ile du Sud reef-flat widths range between 500-750 m (west-facing coasts) and 750 m (east and south-facing coasts) (Plate 6). Thus, notwithstanding some differentiation between windward and leeward coasts, unlike the majority of islands in the Amirantes, reef-flats are not best developed on the highest energy coasts facing the southeast trades.

Baker[3] identified shallow breaks in the reef-flat at the southern point of the atoll and at several locations along the western margin but the only substantial channel, which gives access to Poivre Island, is on the northern reef. There is no central lagoon, the area between Poivre Island and Ile du Sud being characterised by reef-flat sands and muds which dry at low tide (Plate 7).

Terrestrial flora and fauna

Poivre Island is an arcuate island, with a strongly convex northern margin, measuring approximately 1.7 km from east to west and 750 m north to south. Baker[3] mapped a large area of phosphatic sandstone at its eastern end, with basins, pipes and crevasses filled with guano and mixed to varying degrees with sand and humus. This phosphate outcrops on the inner reef-flat immediately offshore from the settlement and along the eastern margin of the boat channel. Gravel sand bars and small spits characterise Pointe Baleine, the eastern point of the island, and Ile Corail, at the northeastern end of the airstrip, where the spits enclose a saline pond. A further discrete patch of phosphatic sandstone lies in the centre of the island with two small outliers further west. The largest land area at Ile du Sud contains a 9 ha area of phosphatic sandstone which presumably represents the old core to the island. This core tapers to the north, to La Pointe; a number of spit structures appear to have developed around it. Firstly, a 2.75 km long eastern arm has probably extended over time northwards, the result of longshore sediment transport driven by waves from the southeast. This arm thins significantly at 1.8 km from the southern tip of Ile Du Sud, suggesting a reduction in long-term sediment

Plate 2 (top left): Poivre Island looking west, January 2005. Note emergent reef-flat sands, extensive reef-flats (with dark areas of high density seagrass), channel to Poivre Island and range of fore-reef slope habitats.

Plate 3 (top right): Ile du Sud and Florentin, looking northwest, January 2005.

Plate 4 (middle left): Poivre Island looking northwest, showing causeway connecting Poivre Island to Ile du Sud. Note lineations in reef-flat low density seagrass and macroalgae.

Plate 5 (middle right): View of causeway from Poivre Island, looking south to Ile du Sud. Note presence of *Rhizophora mucronata* mangroves on the causeway (photograph: Martin Callow, January 2005).

Plate 6 (bottom left): Southwestern reef-flat and Ile du Sud, looking southeast. Note broad embayments in the reef-flat and the series of transverse rubble bars on the reef-flat which stretch from coral rubble at the reef-flat margin to underpinning the spit structures on northwestern Ile du Sud.

Plate 7 (bottom right): Emergent reef-flat sands and muds between Poivre Island and Ile du Sud with single *Rhizophora mucronata* mangrove (photograph: Jen Ashworth, January 2005).

supply. Recent (2008) satellite imagery suggests continued northward development, in a small arc of mobile sand between the tip of the vegetated island (Pointe Mozambique) and the causeway to Poivre Island. Secondly, a complex of islands – named 'Grande Terre' by Baker[3] - extends to the northwest from the central core of Ile du Sud, formed of a series of closely-spaced low storm-ridges. There are at least three fossil spit units which run SW – NE from the seaward reef-flat margin of this complex. It appears that these spits increase in age to the northwest as the most northwesterly of these units, which has a complex star-like structure with five radiating arms, is clearly currently active, with numerous sand washover deposits and gravel ridges recurving towards the island of Florentin which lies behind this area. This active extension is not shown on Baker's map[3] and has therefore developed within the last 40 years. It is likely that the island Florentin is now starved of new sediment and is a fixed, fossil feature. In each case, the positioning of the fossilized and vegetated spits represents the landward extension of features analogous to the 'transverse rubble bars' described from the western reef-flat at St. Joseph by Stoddart and Coe.[6] These are tongues of storm debris about 1 m above the reef-flat which flare seawards to join with extensive coral rubble banks immediately shoreward of the breaker zone and extend across the whole width of the reef-flat.

Poivre Island, is largely covered in coconut palms, and was once an important site of copra production[1] (Plate 8). A high canopy of *Cocos nucifera* (coconut palm) is found approximately 80 m west of the settlement. The most dominant vegetation here is the sedge *Cyperus dubius*, with the short grass *Stenotaphrum dimidiatum*, the creeper *Passiflora suberosa* and the small perennial shrub *Stachytarpheta jamaicensis* also exhibiting high levels of cover. Other plant species in this area include *Crotalaria sp.*, *Cyperus aromaticus*, *Turnera ulmifolia*, *Euphorbia hirta*, *Alocasia macrorrhiza* and the herb *Vernonia cinerea*, whose roots are often used in the Seychelles for treating abdominal pains.

About 200 m west of the settlement, the area is again shaded by a high canopy of *Cocos*, with a low growing (< 40 cm tall) ground cover. The dominant

Plate 8: One of the many tracks on Poivre Island showing high canopy of *Cocos nucifera* (photograph: Martin Callow, January 2005).

Plate 9: Littoral hedge showing *Scaevola taccada* and *Casuarina equisetifolia* (photograph: Martin Callow, January 2005).

species in this layer are the mat forming grass *Stenotaphrum dimidiatum* and the creepers *Passiflora foetida* and *Tridax procumbens*. Other plant species in this area include *Stachytarpheta jamaicensis*, *Nephrolepis biserrata*, *Passiflora suberosa*, *Vernonia cinerea*, *Synedrella nodiflora* and *Crotalaria* sp. Areas of other trees and shrubs are characteristic of the settlement, near the eastern point, immediately to the east of the northeastern end of the airstrip and along the north coast to the west of the airstrip. Ile du Sud and Florentin are also dominated by coconuts, although there are other trees and shrubs in pockets along the western margins of both islands, particularly on Grande Terre. A littoral hedge (Plate 9) characterises the eastern and southwestern coast of Ile du Sud, being particularly well developed on the southeastern coast.

Historical records, and collections and sight records from 1976, have established a plant list of 87 species.[5] 46 plant species were recorded at Poivre during 3.5 hours in January 2005, all previously recorded from the atoll.

Plate 10: Beach on southern margin of Poivre Island (photograph: Jen Ashworth, January 2005).

Plate 11: Medium density seagrass exposed at low tide on the reef-flat on the western side of Poivre Island (photograph: Martin Callow, January 2005).

Plate 12): *Rhizophora mucronata* mangroves on the southern side of Poivre Island (photograph: Jen Ashworth, January 2005).

Marine habitats

Narrow sandy beaches surround Poivre Island, widening on the central southern shore (Plate 10) and at the eastern point, where they are associated with coral rubble deposits.

Sandy beaches also characterise the seaward margin of Ile du Sud, being widest on the southeast coast. Frazier[7] estimates 5 nesting *Chelonia mydas* (Green Turtle) females each year in March – April (and 20 nesting *Eretmochelys imbricata* (*Hawksbill Turtle*)) at Poivre. Florentin has no sandy beaches. The reef-flat margin on windward coasts is characterised by medium density seagrass, with patches and lineations showing either a WNW – ESE orientation or, near the south point, a NW – SE alignment. High density seagrass is rare on the southeastern reef-flat but there is an extensive area at the northeastern corner of the atoll, away from the seaward margin, medium density seagrass is replaced by quasi-continuous area of low density seagrass with macroalgae. On leeward coasts west of Ile du Sud there is a mosaic of high, medium and low density seagrass with macroalgae. The reef-flat to the west of Poivre Island is characterised by more extensive coverage of medium density seagrass and a large band of high density seagrass (Plate 11).

The centre of the atoll, between Poivre Island and Ile du Sud, and the interior embayments of Ile du Sud and Florentin, are characterised by bare reef-flat sands and, in places, carbonate muds which dry at low tide. The mangrove *Rhizophora mucronata* is present between the islands of Poivre and Ile du Sud, forming a band along the southern coast of Poivre and near to, and on, the causeway (Plates 5 and 7) and infilling the southern embayments of Ile du Sud.

In the vicinity of the breaker zone, rock pavement encircles the atoll. Surveys in 2005 showed a rock platform in water depths of 2 – 7 m northwest of Poivre Island, with live coral representing around 2 – 10% of the benthic cover. On the eastern coast, the rock pavement is followed in deeper water by a fore-reef slope of coral spurs with coralline algae, with more extensive coral coverage on the southeastern fore-reef slope. East of Poivre, the substrate was observed as coral on rock platform, with sand patch and sand channels shallower than 15 m. The amount of live coral present was estimated to range between 2 and 15% and dominant genera were *Acropora* spp. and *Pocillopora* spp. East of Ile du Sud, between 12 m and 20 m, large amounts of rubble were observed, interspersed with branching corals (*Acropora* spp. and *Pocillopora* spp.) which accounted for approximately 5% of the benthos. At depths shallower than 12 m, coral on rock platform was observed, with live coral cover constituting between 5% and 10% cover. A similar general pattern is found on the southwestern fore-reef slope. At water depths of 3 - 10 m west of Ile du Sud the substrate was rock platform with branching corals, interspersed with *Halimeda* spp. and brown filamentous algae, with large patches of *Thalassodendron ciliatum* at depths greater than 10 m. Western, northwestern and northern coasts are characterised by large areas of fore-reef slope sand, followed in deeper water by coral rubble and sand (typically at 10 – 18 m water depth) and localised coral communities. SCUBA surveys (January 2005) were conducted at 20 m, 15 m, 10 m and 5 m depths on the western fore-reef slope (5°45.334′ S; 53°17.348′ E). Coral rubble accounted for 50% of the benthos at 10 m, and high levels of rubble were recorded at all depths except for 5 m. The amount of bare substrate was greatest at 5 m and 20 m. Live scleractinian cover was greatest at 15 m, followed by that at 20 m, where it constituted 25% and 22% cover respectively. Live scleractinian cover constituted only half this amount (approximately 10%) at the shallower sites. Macroalgal cover was recorded to be low throughout all depths, but displayed the highest cover (4%) at the shallowest site.

Live coral cover on the reefs of Poivre was seen to represent between 8% (at 5 m) and 25% (at 15 m) of the benthos. The two most dominant genera were typically *Porites* followed by *Pocillopora*, except at 10 m where *Heliopora coerulea* dominated. *Pocillopora damicornis* has been described as an opportunistic species, due to its rapid reproductive cycle, widespread larval dispersal and fast growth rate on settling, enabling it to quickly occupy any newly available space[8] such as that available following the 1997-98 coral bleaching event in the Amirantes group. However, the presence of *Porites* spp. as the most dominant genera at Poivre may suggest that these slow-growing, massive colonies survived the 1997-98 bleaching event.

Source materials

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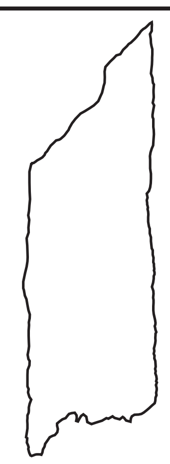
Etoile

(05°35' S; 53°01' E)

Key to Habitat Classification: Etoile

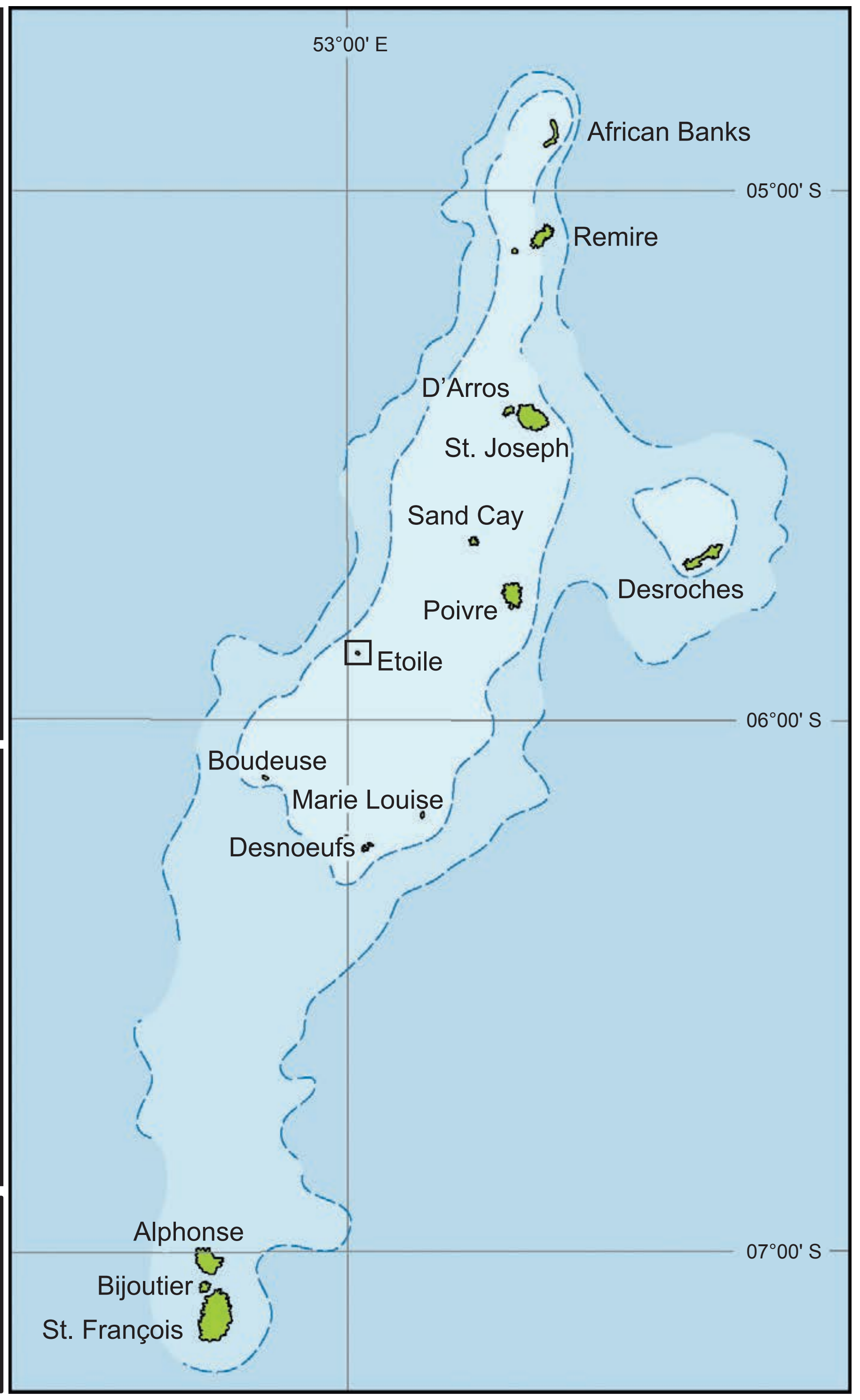
Coconut woodland	Reef-flat sand
Other trees and shrubs	Low density seagrass / macroalgae
Herbs and grasses	Medium density seagrass
Saline pond	High density seagrass
Cleared / bare ground	Lagoon patch reef
Buildings and other structures	Lagoon sand
Littoral hedge	Coral rubble with coralline algae
Mangrove woodland	Fore-reef slope coral spurs with coralline algae
Coral sandstone / raised reef	Rocky fore-reef slope
Beach sand	Fore-reef slope sand
Coral boulders	Fore-reef slope rubble and sand
Beachrock	Fore-reef slope with coral
Rock pavement	

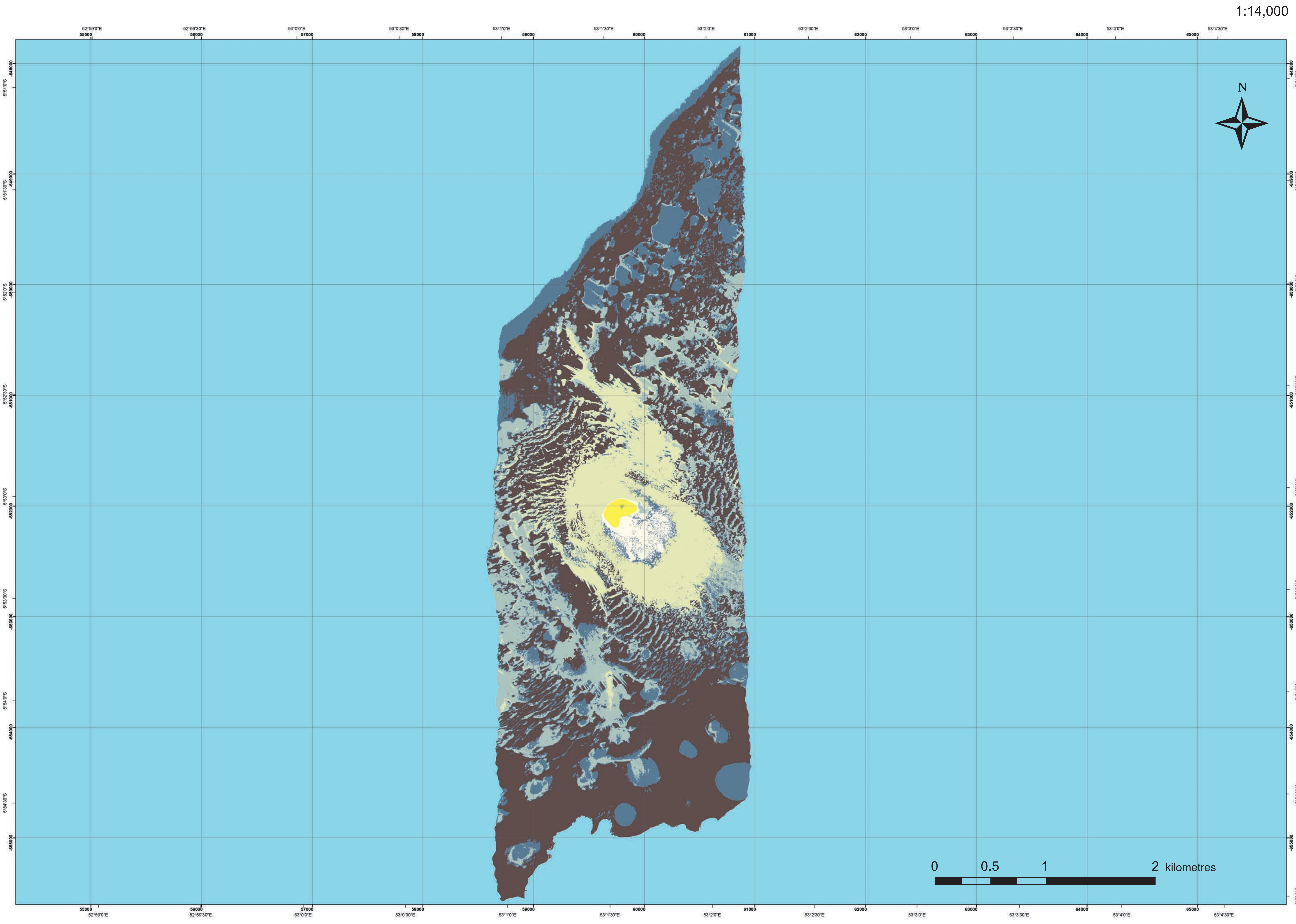


No Landsat data required

The map shows the key shallow water benthic habitats of Etoile, part of the Amirantes group, southern Seychelles, Western Indian Ocean. This was produced by performing a classification on 17 bands of CASI imagery acquired in January 2005. Where data are missing due to cloud cover, gaps have been filled by classifying georeferenced Landsat data (2000).

Projection and Sensor Information
Projection: UTM, Zone 40
Spheroid: GRS 1980
Datum: NAD83
Sensor: Compact Airborne Spectrographic Imager
Pixel Size: 1m
Electromagenetic spectrum region: 434-849nm
Acquisition Date: January 2005




1:14,000
N
0
0.5
1
2 kilometres

Etoile

Note: The island was visited by the Expedition on 25 January 2005. Kayaks were used to land ashore on the northwest coast and terrestrial surveys were conducted between 1550 and 1710 local time. Shallow-water surveys were conducted between 1600 and 1700 local time. These observations have been supplemented with oblique aerial photography, also from January 2005.

Island history

Etoile's name is believed to be derived from one of the two ships of Bougainville's round the world voyage from 1766 to 1769. Like many of the other islands of the Amirantes, Etoile was named by Chevalier du Roslan in 1771. Due to its size, and thus its probable lack of economically significant guano deposits, the island has never been inhabited.

Geography and geology

Etoile is a small (1 ha) isolated sand cay, unusually situated near the western margin of the Amirantes Ridge (most islands sit on the eastern margin of the Ridge). Water depths immediately to west of Etoile rapidly exceed 1,000 m but the western margin of the Amirantes Ridge reaches to within 11 to 17 m of sea level, compared to water depths in excess of 50 m in the centre of the Ridge to the east. Etoile is situated at a location where this marginal rim doubles in width; the island itself probably occupies a small topographic high as local water depths are 9 m or less. A steep sandy beach surrounds the small vegetated area and the cay has a maximum elevation of less than 5 m.

Plate 2: Unvegetated area of the sand cay at Etoile, showing a wide berm at the landward margin of the beach and sand washover deposits (photograph: Jen Ashworth, January 2005).

Plate 1: Aerial view of Etoile showing sand cay, vegetated area and surrounding marine habitats (source: Maps Geosystems; reproduced with kind permission of the Government of the Seychelles). (Note: photograph taken in 1999; shape of cay different from that shown on the 2005 habitat map).

Terrestrial flora and fauna

Etoile is treeless, but an herbaceous vegetation mat, including *Boerhavia repens*, occupies the centre of the sand cay (Plate 3).

It was reported[1] that there was a breeding colony of *Sula dactylatra* (Masked Booby) at Etoile in September-October 1941 but no such colony was observed in November 1976. It is thought that the extinction of this breeding colony has been largely due to significant island erosion.[2] The biggest threat to the breeding colony of *Sterna fuscata* (Sooty Tern) at Etoile is also considered to be island erosion and in 1976 the island was reported to have been 'largely eroded away, leaving a large sea-swept sand bank with a small, *c.* 0.3 ha, vegetated area'.[3]

During a visit to the island in January 2005, numerous nesting seabirds, with eggs and chicks, were observed in the herbaceous mat (Plate 4). On the southern side of the vegetated area, there were two separate colonies (n = 120 and n = 140) of *Anous tenuirostris* (Lesser Noddy) and on the northern side, there was one colony (n = 60) of *Sterna fuscata* (Sooty Tern) and a mixed colony of *Anous tenuirostris* (n = 80) and *Sterna fuscata* (n = 50). On the western side of the sand cay, nesting on the sand, was a colony of *Sterna hirundo* (Common Tern).

Marine habitats

The cay is small and sits on the leeward side of a larger oval shaped fore-reef sandsheet orientated NW-SE, approximately 1.5 km long and 1 km wide. A tongue of sand also extends to the north. It is known that there was considerable erosion of the subaerial island in 1976 (see above) and comparison of the 1999 photograph (Plate 1) and the habitat map (2005) shows that the present island has changed shape and orientation. To the south and east of the cay, reef-flat sand supports scattered patches of medium density seagrass.

Shallow water observations around Etoile Cay in January 2005 showed that there is no true coral reef present here. The benthos is dominated by *Thalassodendron ciliatum* seagrass beds of varying densities, which reach as shallow as 5 m water depth. No live coral was observed on the east, south and west sides of the island, only bare rock, with an occasional covering of macroalgae.

North of the island, at water depths of greater than 10 m, dense seagrass beds were observed, interspersed with coral rubble. The habitat map shows large patches of medium density seagrass within these dense seagrass beds. At shallower depths, the substrate was dominated by a mixture of sand, coral rock and rubble. A small amount (< 5% cover) of live coral was observed to the north of the cay.

Plate 3: Vegetated area of the sand cay at Etoile
(photograph: Jen Ashworth, January 2005).

Plate 4: *Sterna fuscata* (Sooty Tern) nesting on herbaceous vegetation mat at Etoile
(photograph: Jen Ashworth, January 2005)

On the eastern side of the island, observations were made between water depths of 3 m and 18 m. At depths greater than 16 m, and between 4 m and 10 m, *Thalassodendron ciliatum* seagrass was interspersed with sand and rubble. The habitat map shows seagrass beds here organised into linear structures, separated by sand channels. Between 10 m and 16 m depths, the substrate was comprised of coral rubble on sand. No live coral was observed to the east of the island.

On the south side of the island, the benthos was again dominated by dense *Thalassodendron ciliatum* seagrass at depths beyond 10 m, with circular areas of medium density seagrass. The shallower depths also exhibited rocky substrate. On the western side of the island, *Thalassodendron ciliatum* seagrass was present from the maximum depth up to 5 m depth; linear structures interspersed with sand were often observed.

Source materials

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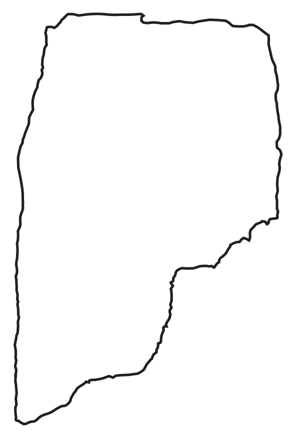
Boudeuse

(06°04' S; 52°50' E)

Key to Habitat Classification: Boudeuse

Coconut woodland	Reef-flat sand
Other trees and shrubs	Low density seagrass / macroalgae
Herbs and grasses	Medium density seagrass
Saline pond	High density seagrass
Cleared / bare ground	Lagoon patch reef
Buildings and other structures	Lagoon sand
Littoral hedge	Coral rubble with coralline algae
Mangrove woodland	Fore-reef slope coral spurs with coralline algae
Coral sandstone / raised reef	Rocky fore-reef slope
Beach sand	Fore-reef slope sand
Coral boulders	Fore-reef slope rubble and sand
Beachrock	Fore-reef slope with coral
Rock pavement	



No Landsat data required

The map shows the key shallow water benthic habitats of Boudeuse, part of the Amirantes group, southern Seychelles, Western Indian Ocean. This was produced by performing a classification on 17 bands of CASI imagery acquired in January 2005. Where data are missing due to cloud cover, gaps have been filled by classifying georeferenced Landsat data (2000).

Projection and Sensor Information
Projection: UTM, Zone 40
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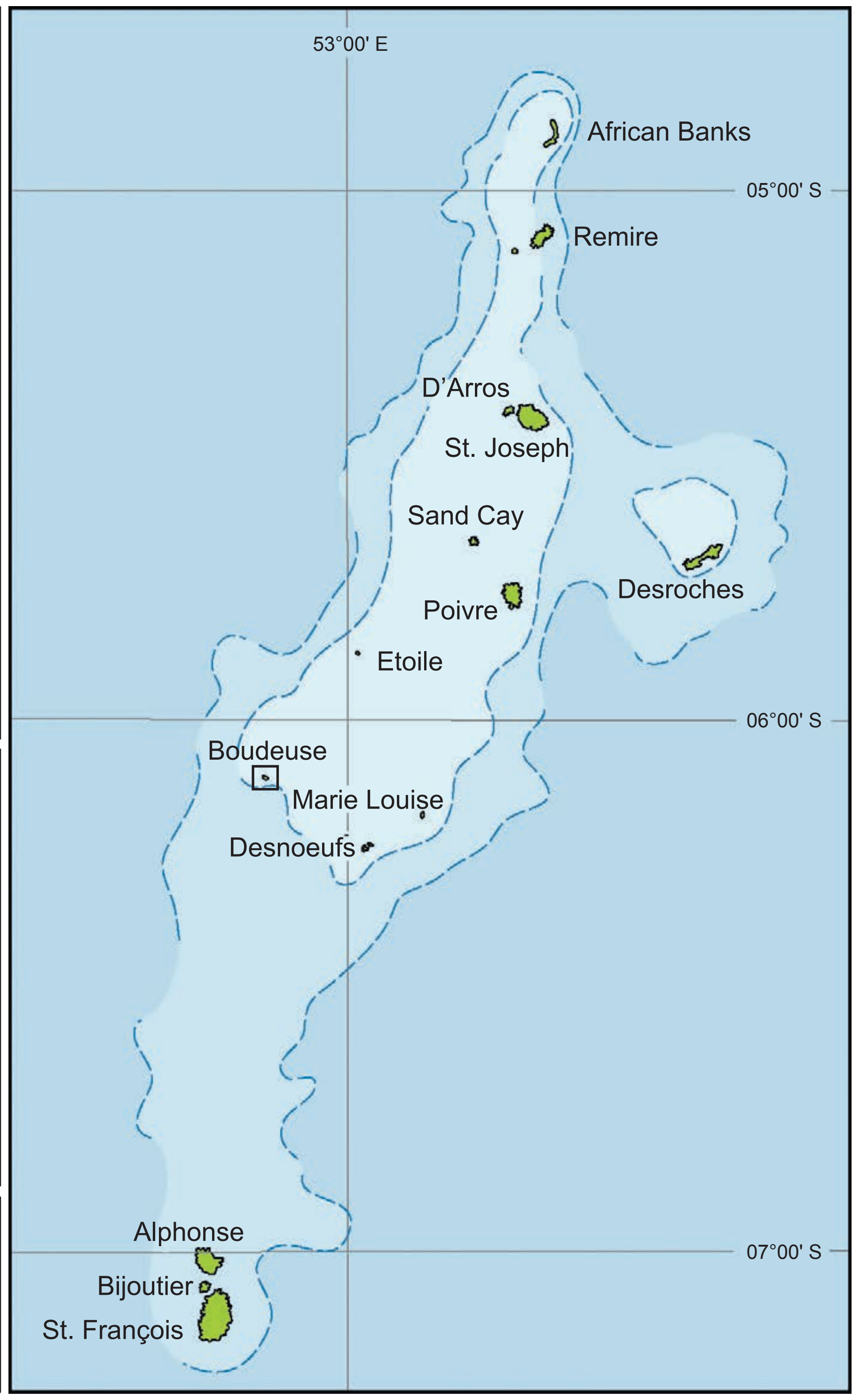
Datum: NAD83
Sensor: Compact Airborne Spectrographic Imager
Pixel Size: 1m
Electromagenetic spectrum region: 434-849nm
Acquisition Date: January 2005



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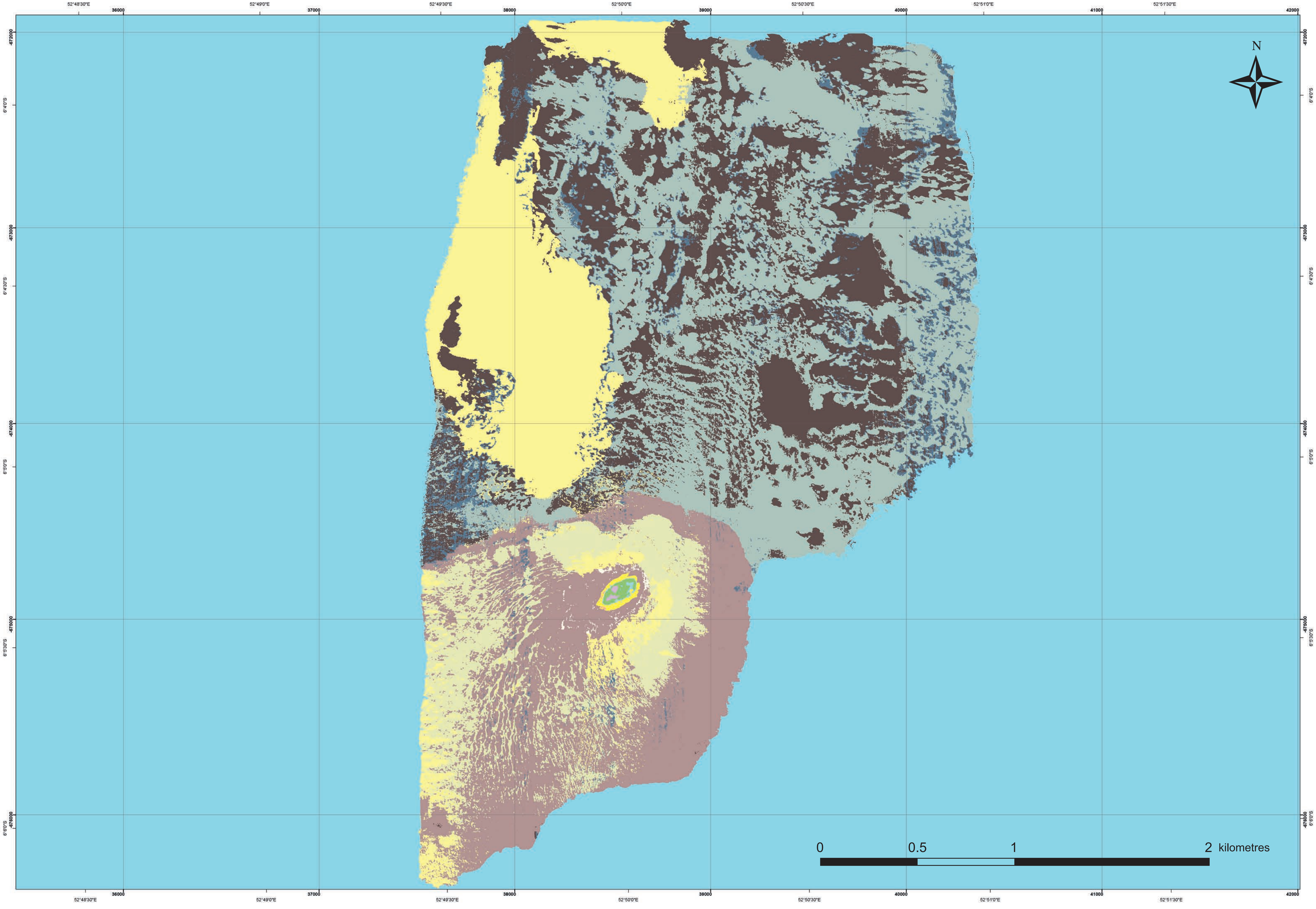
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Boudeuse

Note: The island was visited by small boat on 25 January 2005. Shallow water surveys were conducted between 1015 and 1115 and underwater surveys by SCUBA diving were conducted between 1150 and 1230. Sea conditions were too rough to allow a landing and therefore the terrestrial habitats presented here have not been ground referenced. Information from the map, from photographs taken from small craft and from oblique aerial photography (January 2005) have been used to supplement the very limited published material on this island.

Island history

Boudeuse is believed to have been named after one of the two ships of Bougainville's round the world voyage from 1766 to 1769. Like many of the other islands of the Amirantes, Boudeuse was named by Chevalier du Roslan in 1771. Due to its size (and thus the lack of commercially viable guano deposits) and the difficulty of landing even in calm weather, due to the surrounding heavy breakers, the island has never been inhabited although it is clearly visited on an intermittent basis by poachers.

Geography and geology

Boudeuse is a small (1 ha) isolated island situated at the south-westernmost point of the Amirantes Ridge, surrounded by water depths of 11 – 17 m but very close to water depths in excess of 1,000 m. It is approximately 200 m in length and 100 m in width, with a maximum vertical elevation of less than 5 m. Boudeuse sits upon a rocky platform and displays extensive beach sandstone.[1] Boudeuse is a seabird breeding area and thus is thought to have fresh guano deposits.[1]

Plate 1: View of Boudeuse looking towards the southeast. Note large sandsheet edged by seagrass in foreground, rocky platform upon which the island sits and rock pavement (breaking waves at margin) to the west of the island.

Plate 3: Boudeuse island (right) with exposed rock pavement (left). Note shallow submerged rock pavement in foreground (photograph: Martin Callow, January 2005).

Plate 4: Detail of exposed rock pavement to west of island (photograph: Martin Callow, January 2005).

Plate 2: Boudeuse island looking southeast showing vegetated island surface and steep beach with boulder deposits (photograph: Jen Ashworth, January 2005).

Terrestrial flora and fauna

Boudeuse is treeless. The habitat map and oblique aerial photos show that low growing vegetation is present around the outer edge and in the centre of the island. In the west, there are two small saline ponds. The terrestrial vegetation is interspersed with coral sandstone, which is more extensive in the east of the island. Coral boulders occur on the western beaches and at the southern point.

Although landing was not possible in 2005, it is reported that Boudeuse remains as one of the last two strongholds of *Sula dactylatra* (Masked booby) in the Seychelles, with 3,000-5,000 pairs breeding there annually.[2,3] The island is protected under the Wild Birds Protection (Nature Reserve) Regulations of 1966 but law enforcement is extremely difficult as the island has no human presence to report the activities of poachers.[3] In July 1955, it was estimated that there were around 5,000 birds present.[4] In 1976, 7,000 birds (representing ~3,000 pairs) were estimated on the island at all stages of breeding, but mostly with large chicks. However, Feare noted a pile of corpses left by fishermen and soon after his visit, many of the fledglings that he had ringed were killed.[5]

Marine habitats

There are three major geomorphological units at Boudeuse. The sand cay and raised rock platform sit in the northwestern quadrant of a more extensive circular reef platform. To the west and south of the sand cay this platform is characterised by a radiating pattern of anastomosing channels filled with sand and rubble (Plate 1). To the north and east of the island, an extensive area of fore-reef slope sand and rubble covers the rock platform and the habitat map shows scattered areas of seagrass growing on this platform. 0.5 km north of the island, a sharp convex, E-W trending boundary separates the rock platform from the other two geomorphological units. These are, to the north, an extensive area of bare fore-reef slope sand, 2 km in length and up to 1 km in width, and, to the northeast, extensive seagrass beds of varying densities.

Shallow water observations were made around Boudeuse Cay in January 2005. On the north side of the island, observations were made between 3 m and 21 m water depths over a distance of approximately 1 km. Deeper than 11 m, *Thalassodendron ciliatum* seagrass beds were observed, interspersed with small patches of bare sand at 21 m, 19 m and 14 m water depths. Between 11 m and 7 m depths, the substrate was a mixture of sand and coral rubble, although a small patch of *T. ciliatum* was recorded at 9 m depth. Shallower than 7 m, 'coral on rock pavement' was observed, interspersed with dense clumps of *Halimeda* spp.

The rock platform on the west side of the island was observed from 3 m to 19 m water depths over a distance of approximately 0.74 km. No seagrass was observed on the west side of the island. At depths greater than 6 m, the substrate was dominated by massive corals, including *Porites* spp., and encrusting corals, interspersed with sand. At depths shallower than 6 m, *Pocillopora* spp. became the dominant coral genus and there was extensive coverage by *Halimeda* spp. Coralline algal cover was observed on the rock platform at depths of approximately 3 m.

On the south side of the island, observations were made between water depths of 23 m and 3 m, over a distance of approximately 1 km. Seagrass was observed interspersed with corals (*Porites* spp. and *Pocillopora* spp.) at all depths between 5 m and 23 m. At less than 5 m water depth, coral rock encrusted with algal turf and/or coralline algae was present.

On the eastern side of island, the rock pavement was observed between depths of 4 m and 13 m, over a distance of 0.9 km. All observations noted the presence of live coral on the rock pavement, which was frequently interspersed with *Halimeda* spp. and occasionally interspersed with rubble. There was no seagrass observed east of the island.

A single SCUBA survey was conducted at 10 m depth on the northern side of the island. Bare coral rock was identified as the dominant benthic category (32% cover), followed by sand and rubble. *Halimeda* spp. accounted for 15% of the total benthic cover and represented twice as much of the benthos as live coral (7% cover). Over a third of the coral community was *Porites* spp., with *Favites* spp. accounting for 16%, and the branching corals *Pocillopora* spp. and *Acropora* spp. accounting for 9% and 7% cover respectively. The reefs of Boudeuse displayed a low percentage of live coral cover and were dominated by bare substrate, rubble, sand and macroalgae. The 1997-98 coral bleaching event as a result of increased sea surface temperature had a very severe impact on reefs of the Indian Ocean. The high level of macroalgal cover, bare rock and rubble at Boudeuse suggest that this recent bleaching event may have led to a benthic community with reduced coral cover and increased macroalgal cover, as has been hypothesised elsewhere.

Source materials

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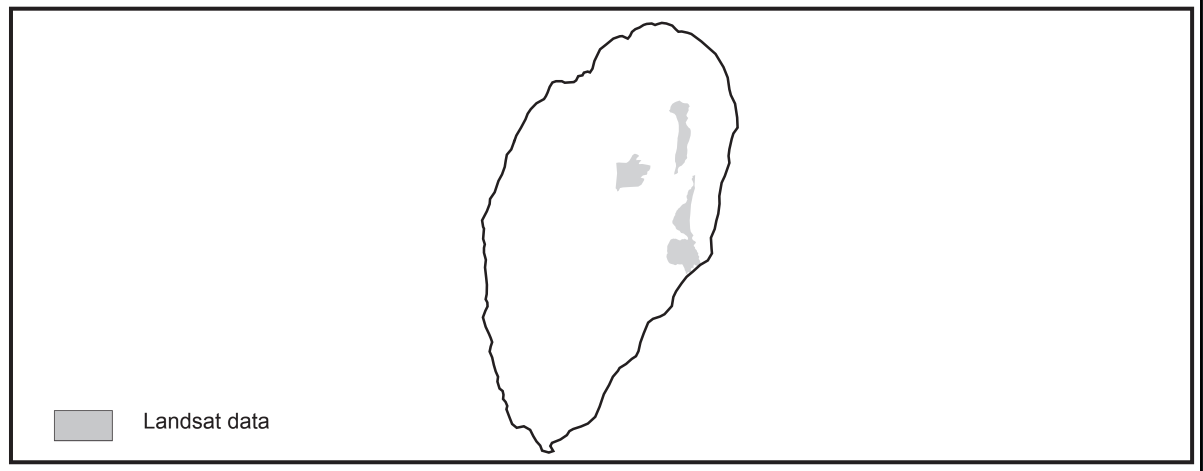
Marie-Louise

(06°11' S; 53°08' E)

Key to Habitat Classification: Marie-Louise

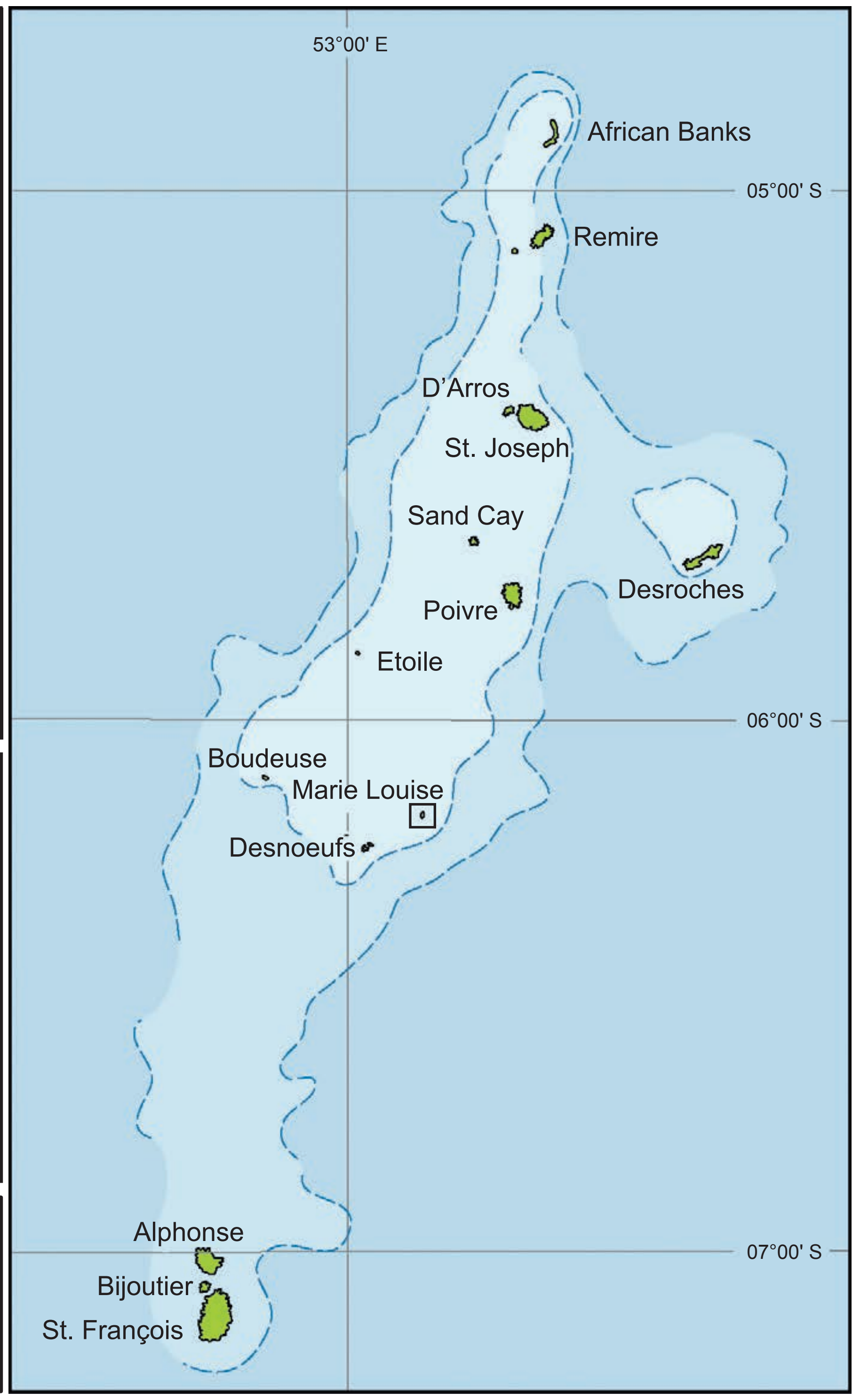
- Coconut woodland
- Other trees and shrubs
- Herbs and grasses
- Saline pond
- Cleared / bare ground
- Buildings and other structures
- Littoral hedge
- Mangrove woodland
- Coral sandstone / raised reef
- Beach sand
- Coral boulders
- Beachrock
- Rock pavement
- Reef-flat sand
- Low density seagrass / macroalgae
- Medium density seagrass
- High density seagrass
- Lagoon patch reef
- Lagoon sand
- Coral rubble with coralline algae
- Fore-reef slope coral spurs with coralline algae
- Rocky fore-reef slope
- Fore-reef slope sand
- Fore-reef slope rubble and sand
- Fore-reef slope with coral

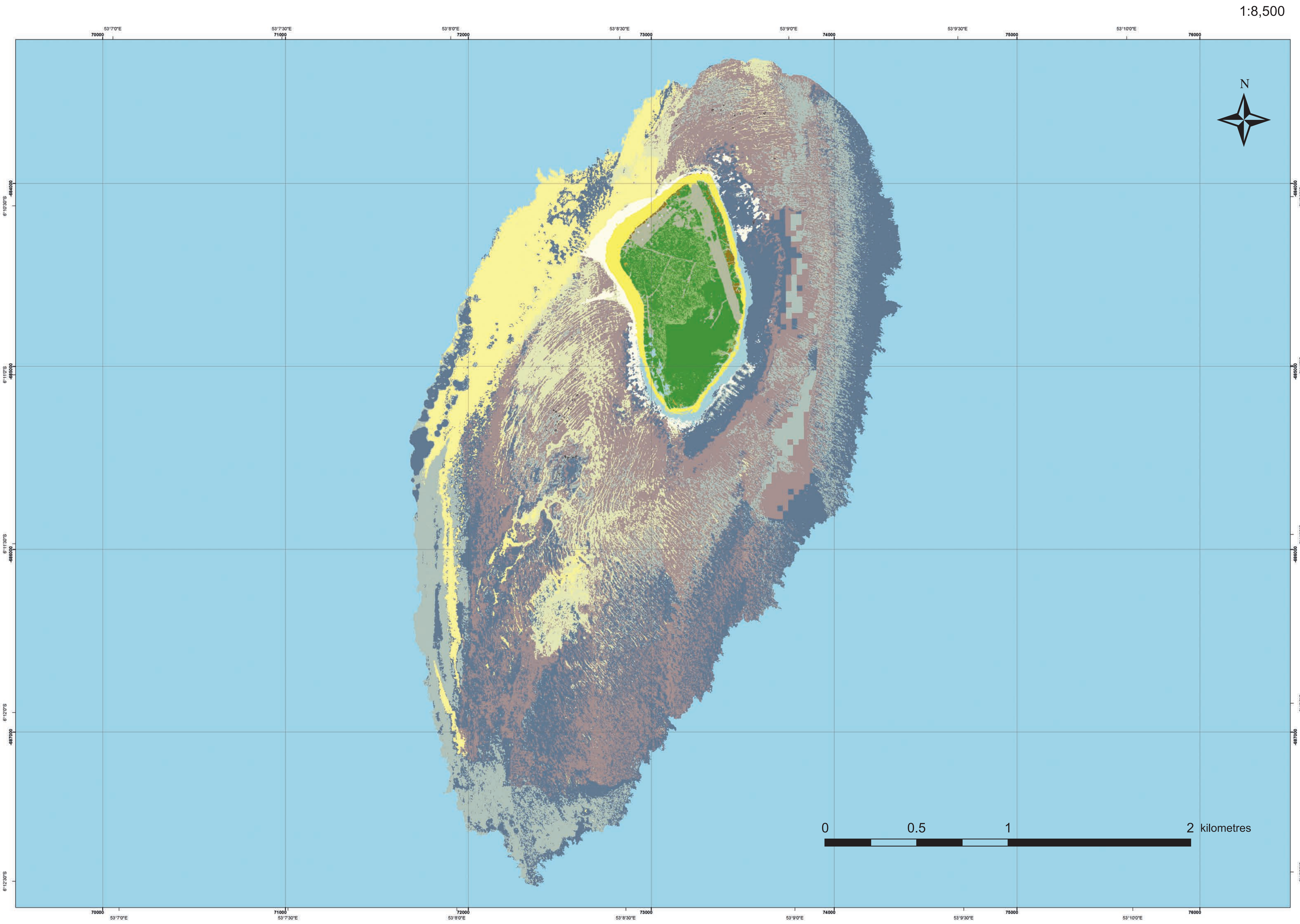


The map shows the key shallow water benthic habitats of Marie-Louise, part of the Amirantes group, southern Seychelles, Western Indian Ocean. This was produced by performing a classification on 17 bands of CASI imagery acquired in January 2005. Where data are missing due to cloud cover, gaps have been filled by classifying georeferenced Landsat data (2000).

Projection and Sensor Information

Projection: UTM, Zone 40
Spheroid: GRS 1980
Datum: NAD83
Sensor: Compact Airborne Spectrographic Imager
Pixel Size: 1m
Electromagenetic spectrum region: 434-849nm
Acquisition Date: January 2005

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Marie-Louise

Note: The island was visited by the Expedition on 24 January 2005. Island personnel collected members of the science team in a small boat and by surfing the waves, the boat was launched up the steep beach on the northwest coast. Terrestrial surveys were conducted between 0950 and 1145, shallow water surveys between 1300 and 1415 and SCUBA surveys between 1450 and 1540. These observations have been supplemented with oblique aerial photography, also from January 2005.

Island history

Marie-Louise was first sighted, and named, by the Du Roslan expedition in 1771 but remained uninhabited until the end of the nineteenth century.[1] In 1771 the island was reported to be densely wooded[2] but human settlement has greatly altered the natural vegetation. Marie-Louise is now government owned but was first leased in 1905, when the island had a population of 86 people.[3] In 1905, two co-lessees ran the island, one overseeing the production of guano and the other developing agriculture.[3] Over 3,500 tons of guano were exported from the island in late 1905[4] but by 1906 it was reported that the economically workable deposits had been exhausted.[3] In 1963 however, it was estimated that approximately 3,000 tons of guano remain on the island, of which half could be taken for local use without damaging agricultural potential.[5] In recent times, it has been reported that guano for agricultural purposes has been imported from Desnoeufs.[3]

The second lessee in 1905 was involved in establishing agriculture on the island. 800 coconut palms (*Cocos nucifera*) and numerous casuarina trees (*Casuarina equisetifolia*) had already been planted on the west coast, holes were dug through the sandstone to increase planting effort[3] and wells were sunk beneath the sandstone. Following the exhaustion of guano supplies, the island's main commodities turned to fishing and agriculture, supporting an island population of around 20 people. The island was neglected in 1969 and by 1979-1980 little change had occurred, although pigs, poultry, vegetables, maize, tortoiseshell and saltfish were produced for island use and to augment copra exports.[3] Space for an airstrip was cleared in the northeast in the mid-1960s although the work was never completed. Since 1981, the lease of Marie-Louise has been taken over by the Island Development Company, Government of the Seychelles. Today there are no commercial activities at Marie-Louise but a group of approximately 6 Island Development Company workers maintain the island.

Geography and geology

Marie-Louise is a small island which sits upon a much larger reef platform (Plate 1). The island is oval in shape, measuring approximately 1 km by 0.5 km, with its long axis lying north-south. The island area is 52.6 ha and elevation is typically 5-6 m, but reaches 9 m high at its maximum.[3] A gently sloping rock pavement, supporting rubble, sand and seagrass, surrounds the island, being at its narrowest (approximately 30 m) off the northern tip of the island and at its widest (over 1 km) off the south-west of the island.

Landing by boat is difficult due to the swell coming directly from the open seas surrounding the small island and waves permanently breaking on the surrounding shelf and steep beach (Plate 2). Perhaps due to this access difficulty, scientific studies at Marie-Louise have been limited.

It has been reported that the core of Marie-Louise is composed of calcareous sandstones dipping outwards from the centre, overlying and interbedded with gravels.[5,6,7] In the south of the island this substrate is less well developed and younger in origin.[3] Jemo Series soils, with a phosphatised layer of guano above the sandstones in turn overlain by a horizon of organic matter[8], have formed on the island but much of the unconsolidated material has been removed through human exploitation of guano. Bedrock is exposed on over three quarters of the island's surface.[3] Shioya Series soils, calcium carbonate sediments with a darker surface horizon of higher organic content[6] are present at the island's perimeter.[3] Observations of the coast of Marie-Louise in January 2005 confirmed Wilson's description. A wide beach exists in the north and northwest of the island, especially in front of the settlement (Plate 3).

The southern half of the island generally exhibits low cliffs (~1 m) in massive beach sandstone, fronted by rocky pavement, exposed beachrock and rubbly storm beaches (Plates 4, 5 and 6).

Plate 2: Steep beach on western side of Marie-Louise (photograph: Jen Ashworth, January 2005).

Plate 4 (top): Low cliffs (~1 m high) in blocky 'sandstone' on the southeast coast (photograph: Martin Callow, January 2005).

Plate 5 (middle): Bevelled rock pavement, boulder beach and island margin, southeast coast (photograph: Martin Callow, January 2005).

Plate 6 (bottom): Bevelled rock pavement, southeast coast (photograph: Martin Callow, January 2005).

Plate 1: The island and reef platform of Marie-Louise in January 2005, looking from the west.

Plate 3: View of Marie-Louise looking from the north, January 2005.
Note beach at its widest off the northwest point, feeding into a fore-reef sand sheet.

Terrestrial flora and fauna

Much of the original natural vegetation of Marie-Louise was altered during the heyday of the coconut industry in the twentieth century, with the planting of coconut palms on a commercial scale[3] and the accidental and deliberate introduction of non-native plant species. Today, at the southern end of the airstrip, the island is dominated by the white flowered *Catharanthus roseus* and the ground creeper *Boerhavia* sp. The creeper *Passiflora suberosa* and the herb *Acalypha indica* are also common. *Gossypium hirsutum* (cotton) is concentrated along the coast to the south-west of the airport with plants reaching several metres in height. On both sides of the airstrip, an area which is routinely cleared, *Dactyloctenium ctenoides* dominates. On the east coast *Scaevola taccada* is prevalent, forming a littoral hedge (Plate 7), as is the case with many of the low lying islands of the southern Seychelles.[8,9]

On the north-east side of the island, in an area which has previously been cleared but which appears to have been left untouched for a number of years, *Gossypium hirsutum* is the most dominant vegetation. *Stachytarpheta jamaicensis*, the grass *Dactyloctenium ctenoides*, *Scaevola taccada*, *Passiflora suberosa*, *Boerhavia* sp. and *Cyperus aromaticus* are also present. The northeastern side of Marie-Louise is more shaded and less exposed to the southeast trades as opposed to the south-east side which favours a higher diversity of terrestrial vegetation.

The centre of the island exhibits tall and dense vegetation with the top canopy comprising mainly *Cocos nucifera* (coconut palms) and *Carica papaya* (papaya) (Plates 8 and 9). Large *Ochrosia oppostifolia* trees grow near the settlement and are used by nesting *Gygis alba* (Fairy or White Terns). *Onychoprion fuscatus* or *Sterna fuscata* (Sooty Tern), *Anous tenuirostris* (Black or Lesser Noddy), *Anous stolidus* (Brown or Common Noddy), *Fregata minor* (Greater Frigatebird) and *Gallus gallus* (Feral chicken) are also found at Marie-Louise. Increased numbers of birds come to Marie-Louise during the breeding season of July and August.

Plate 7: *Scaevola taccada* forming a littoral hedge on the northwest coast of Marie-Louise (photograph: Jen Ashworth, January 2005).

Plate 8: *Cocos nucifera* near the settlement in the north of the island (photograph: Martin Callow, January 2005).

Plate 9: Dense vegetation in the centre of the island showing *Cocos nucifera* and *Carica papaya* (photograph: Martin Callow, January 2005).

Marine habitats

The outer reef platform is gently shelving and in all areas except for in the northwest, is composed of relatively flat, unbroken coral rock, scattered with small branching corals (*Pocillopora* spp., and to a lesser extend *Acropora* spp.) and macroalgae (Plate 10). Inside the breaker zone on the eastern side of the island is an area of dense seagrass. The western margin of the rock platform is characterised by medium density seagrass and, in deeper water, high density seagrass.

Within this rock platform, anastomosing sand channels run perpendicular to the shore-line (Plate 11); local currents in these channels cause the periodic re-suspension of sediment.

The edge of the rock platform is strongly delineated by a NNE-SSW trending boundary. To the west of the line is an extensive fore-reef sand sheet. Off the northwest point of the island this sand sheet is colonised by a large area of *Thalassodendron ciliatum* seagrass; there are also seagrass beds along its southwestern margin. The southwestern and southern margins of the platform is characterised by medium density seagrass.

SCUBA surveys (January 2005) at 15 m and 10 m depths on the southeast reefs, showed the dominant cover type to be macroalgae (~33% cover), with the most dominant genus being *Halimeda* (a single *Microdictyon* sp. and a single *Caulerpa* sp. were observed). Bare substrate was prevalent (~24% cover), closely followed by live coral cover (~19%). The 15 m site displayed higher macroalgal cover and lower scleractinian cover compared to the 10 m site. Although some non-scleractinian corals were observed, these contributed little to the overall benthic composition. The sand channels and sand patches contributed to approximately 10% of total substrate coverage.

The reefs of Marie-Louise are dominated by rock and macroalgae, and the scleractinian community is dominated by a small number of genera. The 1997-98 coral bleaching event as a result of increased sea surface temperature had a very severe impact on reefs of the Indian Ocean. A high level of macroalgal cover and bare rock at Marie-Louise suggest that this recent bleaching event may have led to a benthic community with reduced scleractinian cover and increased macroalgal cover, as has been hypothesised elsewhere.[10] However, although the granitic Seychelles islands in the north suffered over 90% coral mortality during the 1997-98 ocean warming[11], the southern islands were less severely affected, with average mortality of around 60%.[12] Furthermore, it is surprising that there was very little rubble present on these reefs, as coral rubble is a typical sign of recent coral mortality. The lack of rubble present suggests that even pre-1998, these reefs were most probably not dominated by a high coverage of branching corals.

The two most prevalent scleratinian genera at both depths surveyed were *Pocillopora* spp. and *Porites* spp. *Pocillopora damicornis* has been described as an opportunistic species, due to its rapid reproductive cycle, widespread larval dispersal and fast growth rate on settling, enabling it to quickly occupy any newly available space[13] such as that available following the 1997-98 coral bleaching event in the Amirantes group. *Pocillopora* spp. colonies at Marie-Louise typically measured 10-30 cm in diameter, sizes which could have been attained in the 7 years following the bleaching event. Conversely, the presence of *Porites* spp. as the second most dominant genera at Marie-Louise may suggest that these slow-growing, massive colonies survived the 1997-98 bleaching event.

Plate 10 (top): Coral rock platform in the southeast, with scattered *Pocillopora* spp. colonies and macroalgae (*Halimeda* spp.) (photograph: Jen Ashworth, January 2005).

Plate 11 (bottom): Anastomosing sand channels running through rock platform, January 2005.

Source materials

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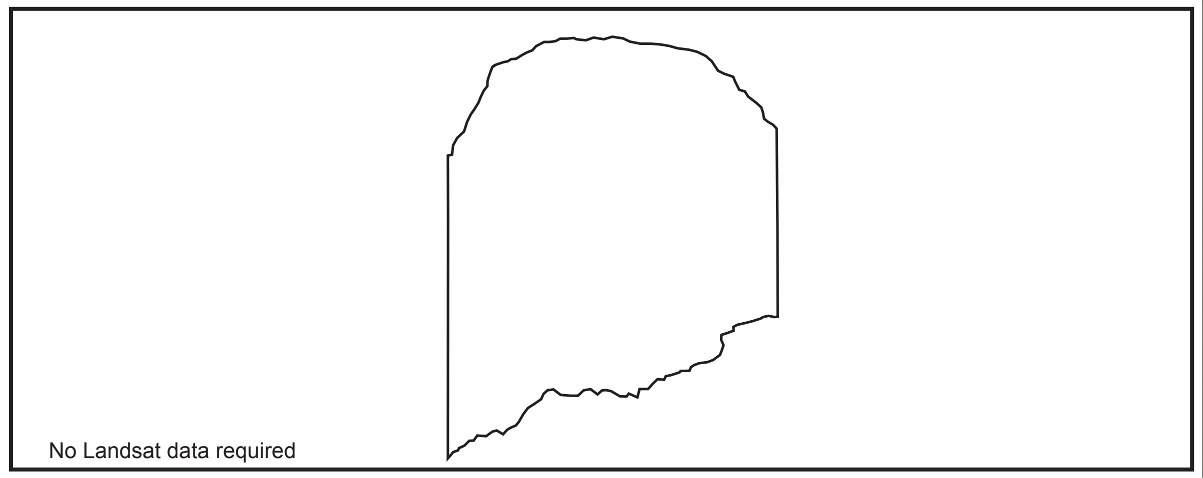
Desnoeufs

(06°13' S; 52°02' E)

Key to Habitat Classification: Desnoeufs

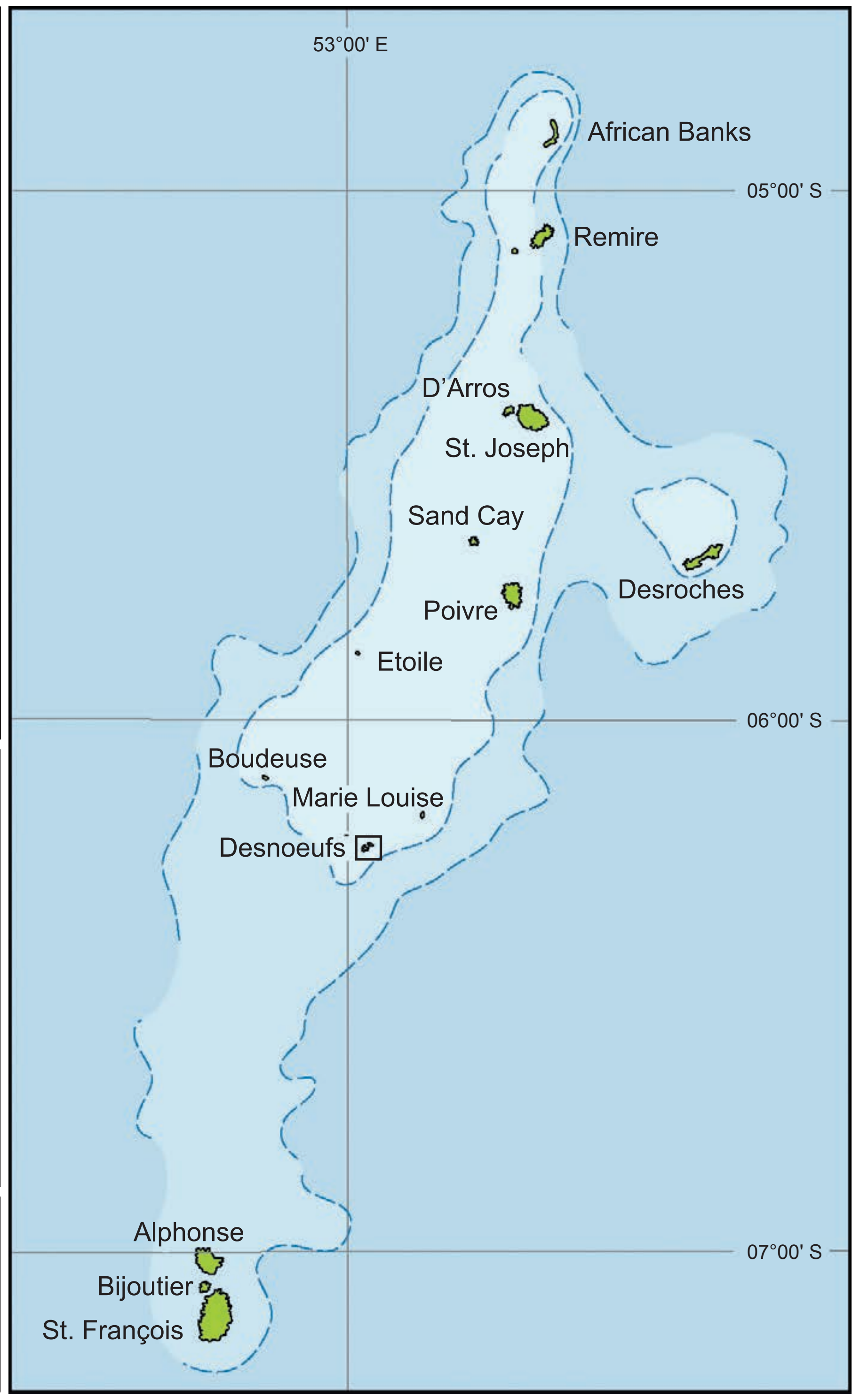
Coconut woodland	Reef-flat sand
Other trees and shrubs	Low density seagrass / macroalgae
Herbs and grasses	Medium density seagrass
Saline pond	High density seagrass
Cleared / bare ground	Lagoon patch reef
Buildings and other structures	Lagoon sand
Littoral hedge	Coral rubble with coralline algae
Mangrove woodland	Fore-reef slope coral spurs with coralline algae
Coral sandstone / raised reef	Rocky fore-reef slope
Beach sand	Fore-reef slope sand
Coral boulders	Fore-reef slope rubble and sand
Beachrock	Fore-reef slope with coral
Rock pavement	



The map shows the key shallow water benthic habitats of Desnoeufs, part of the Amirantes group, southern Seychelles, Western Indian Ocean. This was produced by performing a classification on 17 bands of CASI imagery acquired in January 2005. Where data are missing due to cloud cover, gaps have been filled by classifying georeferenced Landsat data (2000).

Projection and Sensor Information

Projection: UTM, Zone 40
Spheroid: GRS 1980
Datum: NAD83
Sensor: Compact Airborne Spectrographic Imager
Pixel Size: 1m
Electromagenetic spectrum region: 434-849nm
Acquisition Date: January 2005



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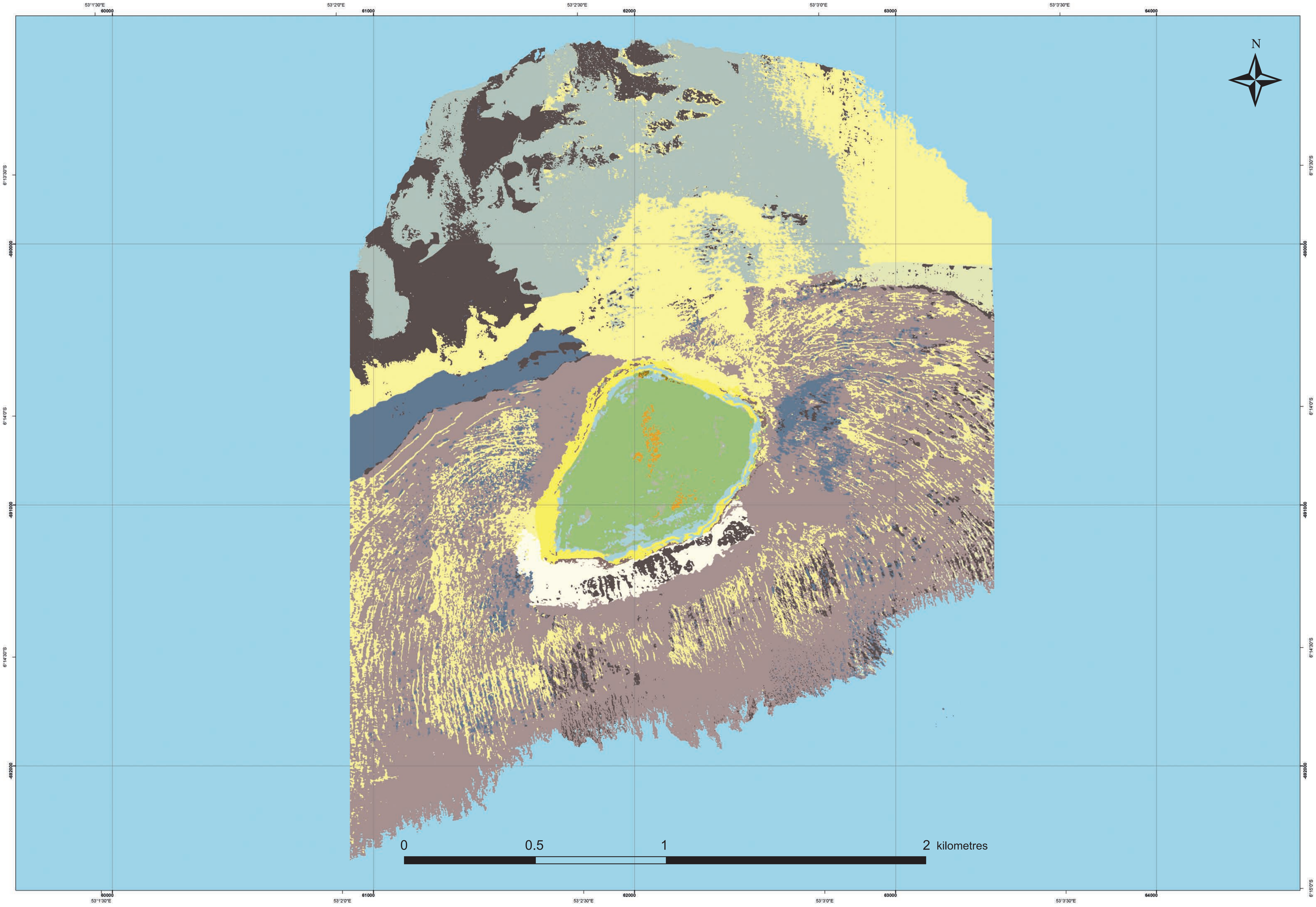

Desnoeufs

Note: The island was visited by the Expedition on 23 January 2005. Kayaks were used to land ashore on the northern coast. All terrestrial and marine surveys were conducted between 1300 and 1600 local time. These observations have been supplemented with oblique aerial photography, also from January 2005.

Island history

Desnoeufs is the most southerly of the main group of Amirante islands - its name means 'one of the nine' - lying 290 km southwest of the granitic island of Mahé.[1] It was the fifth island located by the Chevalier du Roslan in 1771 and he named it Ile des Neufs.[2] Desnoeufs lies approximately 13 km southwest from its nearest neighbour in the Amirantes, the island of Marie-Louise. In the mid-1900s, Marie-Louise developed both agriculture and guano production and it is thought that in these early days, Desnoeufs was run in a similar way, with the removal of 100 tonnes of guano, although agricultural production was much less successful than on the neighbouring island. Five coconut palms were planted on Desnoeufs in 1900[3] and rows of pits indicate that there were once plans to develop a coconut plantation on the island but these never came to fruition. Wilson[1] speculated that, under guano exploitation, the almost complete removal of the littoral hedge at the same time as the removal of the natural woodland cover exacerbated the difficulty of tree regeneration. This in turn allowed the expansion of ground-nesting seabird colonies and the development of vegetation communities which favoured seabird breeding, thus leading to the intensive egg harvesting which continues to this day.

There are a small number of huts near the landing point on the north of the island. This small settlement is utilised by workers of the Island Development Company (a government parastatal which took over ownership of the island in 1981) when they visit Desnoeufs between May and August to collect seabird eggs, mostly of *Sterna fuscata* (Sooty Tern), which are sent to Mahé for the local market. Desnoeufs is the only island in the Seychelles where egg collection still occurs in this official capacity. Stoddart[4] attempted to summarize the cropping of sooty tern eggs in the Seychelles between 1928 and 1974, showing Desnoeufs as the key supplier. During the period 1944-1965, 1.07 million eggs reached Mahé from the Outer Islands of which Desnoeufs supplied an annual average of 0.77 million. However, in 1943, 1.86 million eggs were taken from the Amirantes and in 1931, the peak year on record, 5.1 million eggs were taken from the Amirantes. A closed season for collecting was first established in 1933 and between 1956 and 1961 Desnoeufs was only cropped in alternate years. That system has now been replaced by annual cropping but with area controls. The western side of the island, an area of about 16.6 ha, is designated as a strict Nature Reserve from which no eggs can be collected. In addition, crate sizes have been reduced, so as to take 400 rather than 750 eggs, and Department of Agriculture staff monitor the collections. Nevertheless, cropping levels remain high. In 1979, 1,037,600 eggs and in 1980, 723,000 eggs were reported to have been taken from the island.[1] In 2005, 1 million eggs (including those sold, given free of charge and broken during collection) were removed from the island (Ministry of Environment, Seychelles, personal communication, 2005). The implications for vegetation community composition as a result of the interactions between birds, rabbits and egg collectors are described in more detail below.

Neither HMS *Alert* in 1882, nor the Percy Sladen Trust Expedition of 1905 landed at Desnoeufs, citing the difficulty of getting ashore through a heavy surf and the lack of a suitable anchorage respectively.[5-6] The island's natural history was first described in 1958 by Percy and Ridley[3]; since then there have been numerous re-surveys of the sooty tern colony.[1,7-9] The geology[10] and soils[11-12] were described in the 1960s and eight island vegetation communities described, and sight records of 30 species of vascular plants recorded, in 1979-1980.[1]

Geography and geology

Desnoeufs sits at the eastern margin of an oval-shaped area of shallow water depths of less than 20 m; water depths immediately to the west are 8-12 m. To the north, an extensive area with water depths of 24 – 27 m characterizes the southern end of the Amirantes Ridge whilst to the south, water depths rapidly exceed 1,000m. The island at Desnoeufs is roughly circular, with a land area of 39.7 ha (Plate 1).

The island is characterized by a core of sandstone which spreads out in concentric rings from a centre approximately 100 m in diameter[10-12] (Plate 2). The surface of the island is a basin, being approximately 2 m above sea level at its centre, but with marginal rims at around + 4.5 - 5 m.

Plate 1: Desnoeufs looking northeast. Note edge of rock platform and seagrass and sandsheets to the north, and reef-flat and breaker zone to the south, of the island.

Plate 2: Aerial view of Desnoeufs in 1999 showing the cliffed margin of the island, especially on the southern and eastern coasts. Note high density seagrass beds on southern reef-flat (source: Maps Geosystems; reproduced with kind permission of the Government of the Seychelles).

Plate 3: Littoral rock pavement of phosphatic sandstone on east coast (photograph: Jen Ashworth, January 2005).

Plate 4: Dark brown phosphatic sandstones and overlying carbonate sand and boulder beach on east coast. The island of Marie-Louise can be seen in the distance (photograph: Jen Ashworth, January 2005).

Plate 5: Steep upper beach of carbonate sands, lower boulder beach and beachrock ledges at water level on north coast, near the landing site. Note beach crest community of low herbs[1] (photograph: Jen Ashworth, January 2005).

Plate 6: Slabs of coastal phosphatic rock on southwest coast (photograph: Jen Ashworth, January 2005).

Sandstones inland have become phospatised to varying degrees and unconsolidated calcareous gravels and sands have been reported to underlie this rock. Parts of the island margin are formed of phosphatic sandstone and cliffed on its seaward side, especially on the east coast where large swell waves are present, confirming observations by Wilson.[1] The island has extensive guano deposits and the soils are formed from guano and wind-blown sand. Baker[10] estimated that the guano was 20 cm deep, but this is not evenly spread across the island. The Desnoeufs Series soil is typically a phosphate-rich, dark brown humus, derived from material imported by seabirds, rather than a weathering product from the underlying partially phosphatised sandstone.[11-12]

Windblown sand forms low dunes on the least exposed northeastern and southwestern coasts; on the more exposed northwestern and particularly southeastern coasts, windblown sand forms thin sand sheets, extending inland and characterized by shallow organic soils of the Farquhar Series.[1,11-12] Beaches are poorly developed on the eastern side of the island but are much better developed in the north and west (Plates 3 - 6) and at the time of mapping (January 2005), reached a maximum extent in the southwest. A small, sandy reef-flat surrounds the south and southwest of the island (~200 m at its widest), with the central section being colonised by high density seagrass beds (Plate 2).

Terrestrial flora and fauna

The island was described as being well-wooded by the Du Roslan Expedition in 1771.[1] Today (2005) it is not wooded but it is well vegetated, a contrast to Baker's observations[10] in 1960 when he reported an island surface 'bare of vegetation except for a small clump of littoral scrub on the sand by the landing place'. Vegetation surveys conducted in January 2005 showed that in the north of the island, close to the settlement, the vegetation is dominated by a dense canopy of the low growing shrub *Stachytarpheta jamaicensis*, often found inter-mixed with *Portulaca oleracea*. *S. jamaicensis* is an extremely common introduced plant on many of the arid islands of the southern Seychelles.[13] On Desnoeufs it was introduced sometime between 1900 and 1955; and it had not developed the dense coverage seen today (2005) in parts of the island by 1955.[3] It is now strongly associated with the areas in which egg collecting takes place.[8]

The southern side of the island is more exposed to the southeast trades, and the thin sand sheets are dominated by low lying vegetation. In 1979 and 1980, Wilson[1] described an island margin community dominated by *Stenotaphrum micranthum*. In 2005, *Portulaca oleracea* was recorded, with the erect grass *Dactyloctenium ctenoides* and *S. jamaicensis* also being present. The creeper *Passiflora suberosa* was observed but exhibited very low coverage. Large areas of a sheltered mixed herb community,[1] including the white flowered *Catharanthus*

Clockwise from top

Plate 7: *Scaevola taccada* littoral hedge on less exposed section of north coast (photograph: Jen Ashworth, January 2005).

Plate 8: *Cyperus ligularis* in the centre of the island, with large *Hibiscus tiliaceus* back left and coconut palms back right (photograph: Jen Ashworth, January 2005).

Plate 9: Typical protected area vegetation community of low, open mosaic of mixed herbs with large *Hibiscus tiliaceus* in the centre of the island (photograph: Jen Ashworth, January 2005).

Plate 10: Sheltered mixed herb community,[1] with *Catharanthus roseus* (Madagascar Periwinkle), behind the littoral hedge in the north of the island, close to the settlement (photograph: Jen Ashworth, January 2005).

roseus (Plate 10) and *Acalypha indica* were found in 2005 in the vicinity of the settlement, mixed with *S. jamaicensis* and *Ipomoea* sp. The northern fringe of the island supports a littoral hedge of *Scaevola taccada* (Plate 7) which is interrupted by the settlement buildings. Large areas of the sedge *Cyperus ligularis* (around 1 m tall) were found in the centre of the island. Other plants observed included *Cocos nucifera* (coconut palm), *Gossypium hirsutum* (cotton), *Morinda citrifolia* (Indian mulberry), *Desmanthus virgatus, Colubrina asiatica, Hibiscus tiliaceus* (Plates 8 and 9) and tobacco, most probably introduced by island workers.

Several bird species were observed nesting in the large, central *Hibiscus tiliaceus* bush and birds observed at Desnoeufs included: *Sterna fuscata* (Sooty Tern), *Sterna anaethetus* (Bridled Tern), *Anous tenuirostris* (Lesser Noddy), *Bubulcus ibis* (Cattle Egret), *Gygis alba* (Fairy or White Tern), *Anous stolidus* (Brown or Common Noddy), *Fregata minor* (Greater Frigatebird) and cardinals.

The Sooty Tern colony on Desnoeufs is remarkable; on the basis of observations from mid-June to mid July in 1979 and 1980, Wilson[1] estimated the maximum number of pairs on the island at any one time as lying between 844,800 and 1,195,00 pairs. Strong, but non-linear, relationships have been found between percentage vegetation cover and Sterna *fuscata* nest density; in late June – early July 1995, egg densities peaked at over 4 eggs per square metre at around 40 % vegetation cover.[8] In 1995, vegetation communities of *Portulaca oleracea* in association with bare ground and / or sparse *Stachytarpheta jamaicensis* typically supported over five nests per square metre and communities composed of *Boerhavia sp.* associated with varying combinations of bare ground, *P. oleracea* and sparse *S. jamaicensis* supported over three nests per square metre. By contrast, monospecific stands of *Cyperus ligularis* supported less than one nest per square metre and where there was dense *S. jamaicensis* there were almost no nests at all (0.05 ± 0.05 m^{-2}).[8] Sooty Terns modify vegetation by trampling around nest sites, and by seawater and faecal deposition; in undisturbed communities these processes can be active for a period of five months. However, as disturbance of breeding colonies by repeated egg collecting causes the colony to be abandoned after approximately two months, the influence of the birds on the vegetation is diminished and it is able to regenerate. The growth of tall vegetation inhibits nest-site recognition and increases injury risk to chicks returning to nest sites; fledgling success rates can, therefore, be tied to vegetation type, with the highest success rates in areas dominated by *Portulaca oleracea*. In addition, rabbits (*Oryctolagus cuniculus*) have co-existed with nesting seabirds at Desnoeufs for at least 60 years and it is thought that rabbits help retain herb vegetation in a condition attractive to the birds between breeding seasons.[9] In 1979-80 they were common, ranging over the whole island and rabbits were also observed in 2005.[1]

Harvesting of Sooty Tern eggs at Desnoeufs is likely to have led to the harvesting and disturbance of other seabird species. In the past, *Sula dactylatra* (Masked Booby) have been observed at Desnoeufs, with a population of 100-450 pairs being noted in the 1950s and 1960s.[3,14] However, in October 1976 there were only 17 occupied nests[15], with 18 nests in June 1979 and only 8 nests in July 1980.[1] Despite these birds being protected by law and the colony being within the designated nature reserve, egg collectors have often been noted to take masked boobies for their own consumption.[15] Similarly, around 20 pairs of *Sula leucogaster* (Brown Booby) were observed in July/August 1955.[3] However, in October 1976 and July 1979 only three occupied nests were observed.[1,10] No Boobies were seen at Desnoeufs in January 2005. By contrast, several thousand pairs of *Puffinus pacificus* (Wedge-tailed Shearwater) were found in burrows around the entire island perimeter in June 1979 and July 1980. Shearwater chicks are cropped annually between February and March, with around 2,000 shipped to the granitic Seychelles each year. [1]

Marine habitats

The island of Desnoeufs sits on the northern margin of an extensive rock platform characterized by a radiating pattern of numerous, narrow, sand-filled lineations. There is a well-defined, E-W trending boundary to the rock platform which lies just north of the island (Plate 1). The area to the north of this boundary is characterized in equal measures by fore-reef slope sand, low density seagrass, and, to the northwest, areas of high density seagrass. The northwestern boundary of the rock platform is also characterized by a strip of medium density seagrass.

Shallow water surveys were conducted in January 2005. The rock platform north of the island was observed from a depth of 6 m to 16 m, over a horizontal distance of 0.24 km. At 16 m, the substrate was bare fore-reef slope sand, but this gave way to a dense *Thalassodendron ciliatum* seagrass bed at water depths of between 14 m and 16 m. At 14 m water depth, bare sand was observed and at 12 m, *T. ciliatum* seagrass. At 10 m water depth the substrate was composed of rubble on sand and only at the shallowest observation (6 m water depth) was any live coral observed. Here small colonies of *Acropora* spp. and *Pocillopora* spp., interspersed with rubble were characteristic.

West of the island, observations were made between 18 m and 2 m depths, across a horizontal distance of approximately 1 km. Between 8 m and 7 m, the substrate comprised rubble on sand, interspersed with small live branching corals, typically *Pocillopora* spp. Between 7 m and 6 m water depth, live coral was found on a rock pavement. A sand channel at 5 m separated the reef from a large bed of *Thalassodendron ciliatum* seagrass at 4 m water depth. Shallower than 4 m, rock pavement was the dominant habitat, interspersed with live branching corals.

All observations on the south side of the island were recorded as 'coral on rock pavement' between water depths of 18 m and 6 m, over a distance of 0.29 km. On the eastern side of the island, observations were made between 17 m and 6 m water depth over a distance of approximately 0.46 km. All observations at depths greater than 10 m recorded 'coral on rock pavement', with the coral at these depths being typically small branching colonies. A small patch of coral rubble was observed at 16 m depth. Shallower than 10 m, bare coral rock was recorded.

On the north and west sides of Desnoeufs, *Thalassodendron ciliatum* seagrass beds were more prevalent than rock pavement but no seagrass beds were observed on the south or east side of the island, which were typified by rock pavement and small branching corals. The large expanse of rock pavement and dominance by the branching coral *Pocillopora* spp. on the south and east sides of the island may indicate that the coral bleaching event of 1997-98 which devastated the reefs of the Seychelles[16,17] may have had an effect on the reefs here. *Pocillopora damicornis* has been described as an opportunistic species, due to its rapid reproductive cycle, widespread larval dispersal and fast growth rate on settling, enabling it to quickly occupy any newly available space[18] such as that available following the 1997-98 coral bleaching event in the Amirantes group. *Pocillopora* spp. colonies at Desnoeufs typically measured 10-30 cm in diameter, sizes which could have been attained in the 7 years following the bleaching event. However, during previous surveys at Desnoeufs in 1993, coral constituted only 9% of the total benthic cover at one site on the northern reef-slope.[19] These previous surveys suggest that the reefs of Desnoeufs may not have been well developed prior to 1998 and that these reefs have only ever exhibited a small amount of live coral cover. However, these surveys were only to the north of the island, which the habitat map indicates as being dominated by sand and seagrass.

Crabs (*Grapsus* spp.), hermit crabs and lobster shells were observed on the beaches. Frazier[20] estimates 50 nesting *Chelonia mydas* (Green Turtle) females each year in March – April or, more likely, September – October. It is likely that the number of breeding animals varies greatly from year to year; Wilson[1] estimated a breeding population of 26 females from evidence gathered in 1979. Turtle nests seen in 2005 were tentatively identified as those of *Eretmochelys imbricata* (Hawksbill Turtle) and Wilson[1] reports a probable sighting of an individual *E. imbricata* offshore in 1979. Frazier[20] estimates 5 nesting *E. imbricata* each year at Desnoeufs.

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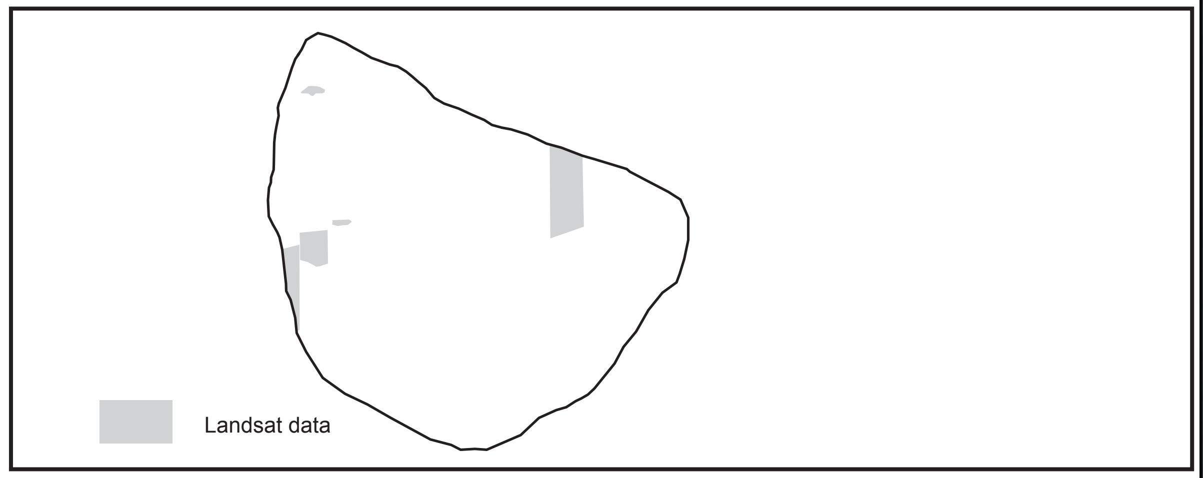
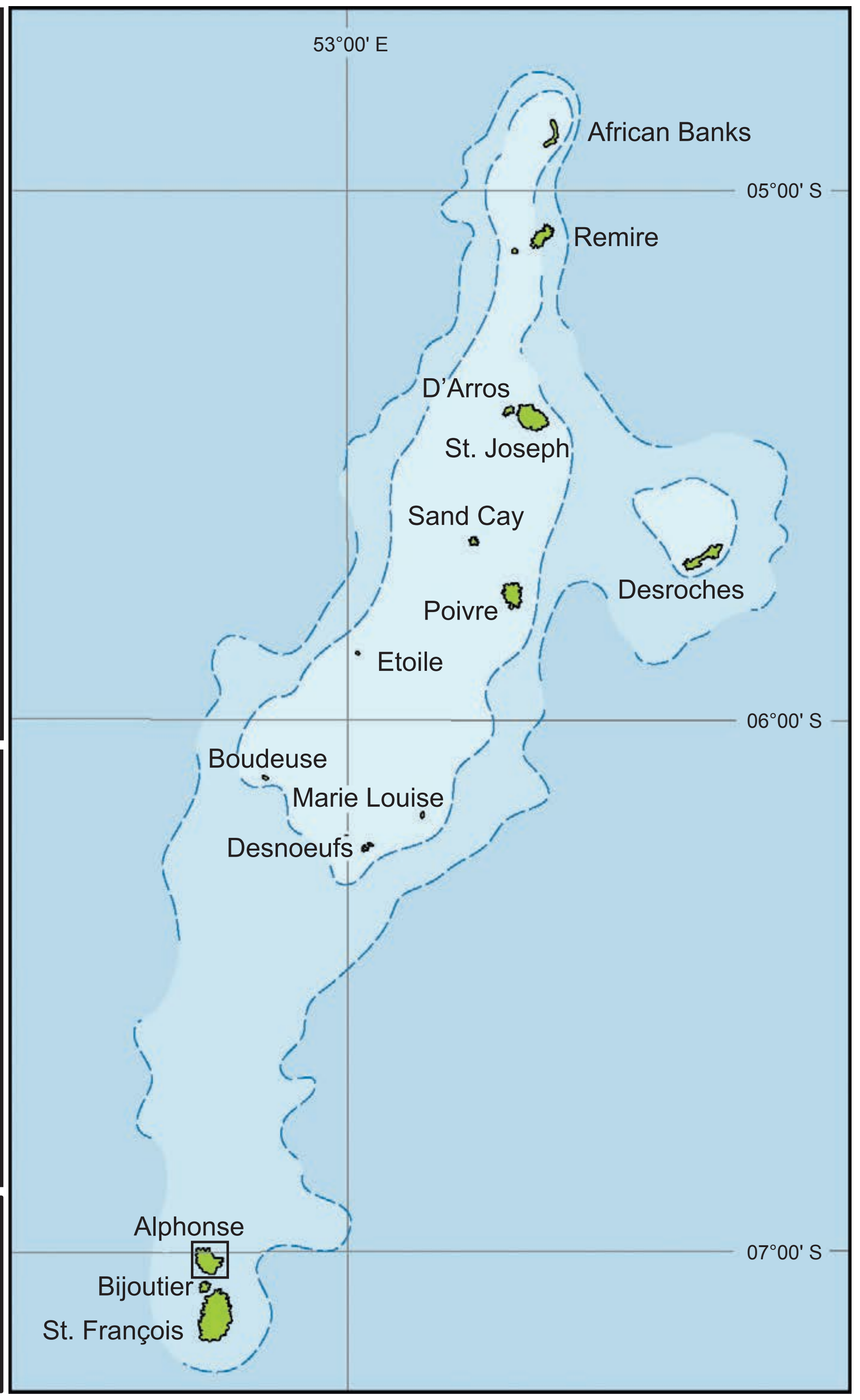
Alphonse

(07°01' S; 52°44' E)

Key to Habitat Classification: Alphonse

- Coconut woodland
- Other trees and shrubs
- Herbs and grasses
- Saline pond
- Cleared / bare ground
- Buildings and other structures
- Littoral hedge
- Mangrove woodland
- Coral sandstone / raised reef
- Beach sand
- Coral boulders
- Beachrock
- Rock pavement
- Reef-flat sand
- Low density seagrass / macroalgae
- Medium density seagrass
- High density seagrass
- Lagoon patch reef
- Lagoon sand
- Coral rubble with coralline algae
- Fore-reef slope coral spurs with coralline algae
- Rocky fore-reef slope
- Fore-reef slope sand
- Fore-reef slope rubble and sand
- Fore-reef slope with coral



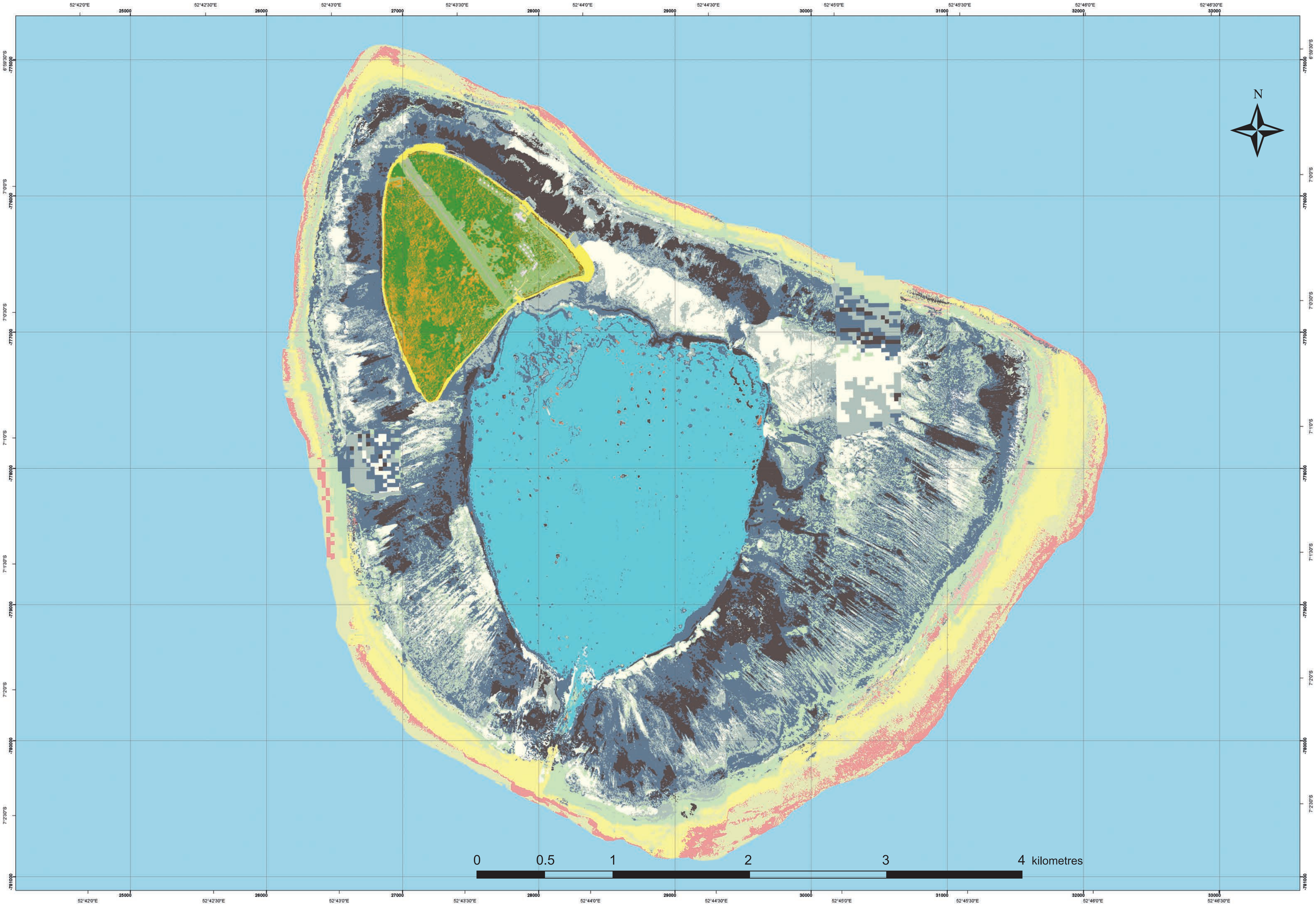


The map shows the key shallow water benthic habitats of Alphonse, part of the Amirantes group, southern Seychelles, Western Indian Ocean. This was produced by performing a classification on 17 bands of CASI imagery acquired in January 2005. Where data are missing due to cloud cover, gaps have been filled by classifying georeferenced Landsat data (2000).

Projection and Sensor Information

Projection: UTM, Zone 40
Spheroid: GRS 1980
Datum: NAD83
Sensor: Compact Airborne Spectrographic Imager
Pixel Size: 1m
Electromagenetic spectrum region: 434-849nm
Acquisition Date: January 2005

1:11,500



52°42'0"E
25000
52°42'30"E
26000
52°43'0"E
27000
52°43'30"E
28000
52°44'0"E
29000
52°44'30"E
30000
52°45'0"E
31000
52°45'30"E
32000
52°46'0"E
33000
52°46'30"E
N
0
0.5
1
2
3
4 kilometres

Alphonse Atoll

Note: Quantitative measurements of changing benthic cover at Alphonse Atoll have been made by the authors of this Atlas for almost a decade. Monitoring commenced at the peak (April 1998) of the 1997 – 98 ocean warming and has continued with underwater videography surveys of fixed transect lines on 5 occasions in the period 2001-2007. The Expedition visited Alphonse 19–22 January 2005. SCUBA surveys were conducted during this time period to re-survey selected sites within the established monitoring programme.[1] Terrestrial ground-referencing was conducted on 19 January 2005 and these observations were supplemented with oblique aerial photography (January 2005). An accuracy assessment of the Alphonse habitat map was conducted *in situ* on 14 October 2007.

Island history

The three islands of Alphonse, Bijoutier and St. François make up the Alphonse Group. All the islands were discovered on 28 January 1730 by the Chevalier Alphonse de Pontevez, commanding the French frigate *Le Lys*. The first scientific visit was by HMS *Alert* in 1882; Coppinger[2] reported a population of 28 individuals. The island was covered with recently-planted coconut palms; only a few trees were old enough to bear nuts. However, by the 1930s, a monthly harvest of 100,000 coconuts was typical (J. Skerrett, personal communication, 2002). The original settlement was situated on the lagoon side of the island, near the southern end of the runway. Several of the buildings from the island's time as a plantation still exist, including the manager's house and the island jail, with its two cells.

The Alphonse Group now falls under the jurisdiction of the Island Conservation Society (ICS), a Seychelles based conservation non-governmental organisation. The ICS, in partnership with the Island Development Company, is in charge of conservation in the outer islands. A small hotel was opened at Alphonse in December 1999 and there are regular flights from Mahé. From December 2006 the hotel has been operated by Great Plains, a partner of ICS. Reef rehabilitation, research and monitoring programmes are now being undertaken by the resident ICS staff.

Geography and geology

Alphonse is the northernmost island in the Alphonse Group which can be seen as the southern extension of the Amirantes Ridge. Alphonse Atoll is situated 87 km south of the main bank and 3 km north of St. François Atoll, separated by the 2.4 km wide Canal du Mort which has a sounding depth of 126 m and is renowned for strong currents.[3]

Alphonse is a small symmetrical, triangular atoll (6 x 4 km; total area 1,128 ha) (Plate 1). The single island (174 ha; 15% of the total area) sits at the northwestern margin of the atoll and is bisected by a concrete airstrip. The peripheral reef-flats cover an area of 402 ha and vary in width from 640 m, at the northwest tip of the atoll, to 1,900 m, on the east-facing atoll margin.[4] The atoll has a 540 ha (48% of the total area) lagoon with a simple dish-shaped morphology[5], reaching a maximum depth in its centre of 10 m. In the southwest of the atoll there is a single channel (Plate 2), 180 m in width and 4-10 m deep, connecting the lagoon to the outer fore-reef slope.

The interior of the island is largely phosphatic sandstone covered by much disturbed and impure guano[3], which can be characterized by two circular sub-areas. The outer zone (55 ha) is characterized by surface sand mixed with guano (up to 45 cm deep) and loose blocks of phosphatic sandstone near the base.[3] The inner, solid sandstone area (26 ha), exhibits pockets of guano of variable purity, although this zone has now been much disturbed by digging and construction.[3] The phosphatic areas are characterized by Jemo Series soils; these are encircled by soils of the Shioya Series.[5]

Plate 1: Alphonse Atoll in 1999 (source: Maps Geosystems; reproduced with kind permission of the Government of the Seychelles).

Plate 2: Southeastern reef-flat of Alphonse Atoll, looking southwest, January 2005. Note lineations in reef-flat sands and channel connecting lagoon to outer fore-reef slope.

Terrestrial flora and fauna

After two centuries of human occupation, little of the original vegetation still exists at Alphonse. Following the island's operation as a plantation, much of the island, especially the western half, is covered in *Cocos nucifera* (coconut palm). However, there are areas of other trees and shrubs to the west of the airstrip, particularly towards the southwest coast. These include remnants of plantation life in the form of crop plants that were used to feed the island staff, such as *Carica papaya* (papaya) trees that now grow wild down the margins of the airstrip, *Artocarpus altilis* (breadfruit) and other fruit trees. *Agave sisalana* (sisal) was grown to provide the islanders with the ability to make their own ropes and *Gossypium hirsutum* (cotton) was also grown, albeit on a small scale (A. Skerrett, personal communication, 2002).

During hotel development in the late 1990s, the eastern tip of the island and much of the northeast coast were cleared of vegetation and many ornamental plants, including *Plumeria alba* (frangipani), *Hibiscus* spp. (hibiscus) and *Bougainvillea spectabilis* (bougainvillea), were imported. *Casuarina equisetifolia* and *Scaevola taccada* (Plate 3) form a littoral hedge around the edge of the island, even in the vicinity of the hotel buildings. Other notable trees are *Calophyllum inophyllum* and *Barringtonia asiatica*, of which a large specimen grows close to the lagoon, east of the southern end of the runway.

Plate 3: *Scaevola taccada* littoral hedge, with *Cocos nucifera*, along the southern side of the island, adjoining the lagoon (photograph: Annelise Hagan, October 2007).

The island supports numerous bird species. Two introduced birds are common at Alphonse; *Passer domesticus* (House Sparrow), which is frequently observed around the hotel buildings and along the grassy verges of the airstrip, and *Esrilda astrild* (Common Waxbill). On the western side of the island there is a large frigatebird roost; both *Fregata minor* (Greater Frigatebird) and *Fregata ariel* (Lesser Frigatebird) occur here, but the closest breeding site is Aldabra, 700 km to the southwest (A. Skerrett, personal communication, 2002). A colony of *Puffinus pacificus* (Wedge-tailed Shearwater) breeds on the western tip of the island and numerous birds were observed nesting in burrows in October 2007.

Anous stolidus (Brown or Common Noddy), *Gygis alba* (Fairy or White Tern), *Thalasseus bergii* (Greater Crested or Swift Tern) and *Sterna sumatrana* (Black-naped Tern) are found at Alphonse, along with two species of heron *Ardea cinerea* (Grey Heron) and *Butorides striatus* (Green-backed Heron), which both breed on the neighbouring islands of Bijoutier and St. François. *Ardea cinerea* are often seen patrolling the reef-flats when the tide recedes and on the south coast of the island where it joins the lagoon. The first *Phylloscopus collybita* (Chiffchaff) recorded in Seychelles was observed in the grounds of Alphonse Island Resort and the first *Vanellus gregarius* (Sociable Lapwing) for the entire Southern Hemisphere spent several months feeding in the grassy margins of Alphonse airstrip in 2001 to 2002 (A. Skerrett, personal communication, 2002).

Marine habitats

The island at Alphonse is encircled by generally narrow sandy beaches which reach their greatest development at the southeast point. Although unvegetated reef-flat sand occurs in a wide band along the northwest-facing reef-flat to the southeast of the island (Plate 5), the coverage of reef-flat by medium and high density seagrass beds is noteworthy, being much greater than on many of the islands in the Amirantes.

The seagrass beds are composed of *Thalassodendron ciliatum* and *Cymodocea serrulata* (average dry weight of biomass in 2005 = 457 $g\ m^{-2}$). Extensive areas of high density seagrass are particularly characteristic of the northwest-facing reef flat between the island and the reef margin. *Eretmochelys imbricata* (Hawksbill Turtle) and *Chelonia mydas* (Green Turtle) breed at Alphonse and these, along with rays and juvenile lemon sharks, are frequently observed swimming in the shallow water of the reef-flats.

Plate 4: Beach along the southern side of the island, adjoining the lagoon (photograph: Annelise Hagan, October 2007).

Plate 5: Alphonse Island, looking northwest, January 2005. Note extensive sand sheet on northeastern reef-flat, medium to high density seagrass towards reef margin and at the boundary of the lagoon and patch reefs within the lagoon.

Plate 6: Western reef-flat at Alphonse, looking northeast, January 2005. Note sand lobes on reef-flat ((left margin) and areas of medium and high density seagrass adjacent to lagoon.

In 1882, Coppinger[2] noted the export of both Hawksbill and Green Turtle from Alphonse but particularly pearl shell; he was told that two thousand shells had been exported in the period 1880 – 1882 and that there were 900 shells in storage awaiting shipment. From his description of the 'black internal margin' of these shells, and his description of their collection from 'still water pools, inside the barrier reef', it seems likely that the species was *Pinctada margaritifera* (Black-lip pearl oyster) which is a characteristic species of the 'radial zone' between the algal ridge and seagrass beds on the Mahé reef flat.[7]

Thalassodendron ciliatum is found around the rim of the lagoon and sinuous patches of varying density *T. ciliatum* are found at depths of ~5-7 m, typically in the northern part, and especially in the northeastern sector, of the lagoon. Numerous patch reefs also occur in the northern lagoon. Live coral cover to the south of the island was ~50% in March 2003. The coral community comprised the massive and sub-massive corals *Porites* (58% of total coral community), *Favia* (22% cover) and *Lobophyllia*, *Goniastrea* and *Pavona* (all 6% cover).[1]

The topography of the outer reefs at Alphonse can be separated into 3 distinct sections.[5] Immediately seaward of the reef-flats, in less than 5 m water depth, is a shallow rocky pavement characterized in places by distinct spur and groove formations. Spur and groove topography is particularly well developed on the northwest, leeward side of the atoll, where the U-shaped grooves are approximately 2 m deep. In water depths of 5 to 15 m, a 50-150 m wide, gently sloping rock surface extends down to a drop-off[5], at a water depth of 17 m to 20 m. The drop-off may either be a sheer vertical reef wall, as observed on both sides of the northeastern tip of the atoll, or it may be a steep slope, as in the southwest.

Plate 7: Eastern tip of atoll, looking southeast, January 2005. Note coral rubble and sand sheets at reef margin, high density seagrass in central area of reef-flat and narrow bands of high density seagrass along the reef crest.

Plate 8: Detail of reef-flat to south of eastern tip of atoll looking south, showing overlapping sand lobes, in places overriding medium to high density seagrass beds.

The habitat map shows a concentric zonation of the outer reefs. The reef crest is dominated by coral rubble with coralline algae and moving seaward, bands of fore-reef slope sand, then rubble and sand dominate. The outer reef is at its greatest extent in the southeast and the outermost zone is dominated by fore-reef slope with coral interspersed with a mixture of rubble and sand.

The 1997-98 bleaching event had a considerable impact on the community composition of the fore-reef slope of Alphonse Atoll. In 1998, at the height of the bleaching event, live scleractinian cover was reduced to an average of 14.8%, and this value had further decreased one year after the bleaching event.[8] However, repeat surveys at Alphonse between 1999 and 2003 showed a good level of recovery following the 1997-98 bleaching event, with average live coral cover increasing from 10% of total benthic coverage in 1999, to 12-17% in 2001/02, and to 23% in 2003.[8] In 2005, SCUBA surveys on the fore-reef slope recorded an average of 22% live coral cover at sites with water depths of 5 to 17 m, with *Porites* being the dominant genus, in terms of percentage cover, at all survey sites, except for one 5 m depth site on the southwest fore-reef slope where the dominant genus was *Montipora* (50% of live coral cover). Due to the size of many of the *Porites* colonies observed, some measuring over 2 m across, it is clear that these massive, slow-growing colonies must have survived the 1998 thermal stress. In addition, lagoon corals and many shallow water corals also survived, presumably by being acclimatised to warmer water conditions. The survival of these pockets of corals is likely to have improved reef recovery on the fore-reef slope at Alphonse, with these colonies acting as larval sources to re-seed degraded areas.

The second most dominant genus in 2005 was *Pocillopora*, which was widespread on the fore-reef slope at Alphonse (Plates 9 and 10). *Pocillopora damicornis* has been described as an opportunistic species, due to its rapid reproductive cycle and fast growth rate, enabling it to quickly occupy any newly available space.[9]

Sharks, such as *Negaprion brevirostris* (lemon shark) and the fourth largest predatory shark *Galeocerdo cuvier* (tiger shark) are found at Alphonse, although only juvenile lemon sharks are observed regularly. Marine mammals frequent the waters of Alphonse, and a humpback whale (*Megaptera novaeangliae*), a pod of around 40 spinner dolphins (*Stenella longirostris*), and a dead short-finned pilot whale (*Globicephala macrorhynchus*) with a large bite out of its back, were observed over a 5 day period in October 2007.

Plate 9: *Pocillopora* spp. recolonising dead *Porites* colony on southwest fore-reef slope at a depth of 10 m. Note small patches of live *Porites* (photograph: Annelise Hagan, October 2007).

Plate 10: *Pocillopora* spp., *Acropora* sp. and *Stylophora pistillata* on northeast fore-reef slope at a depth of 12 m (photograph: Annelise Hagan, October 2007).

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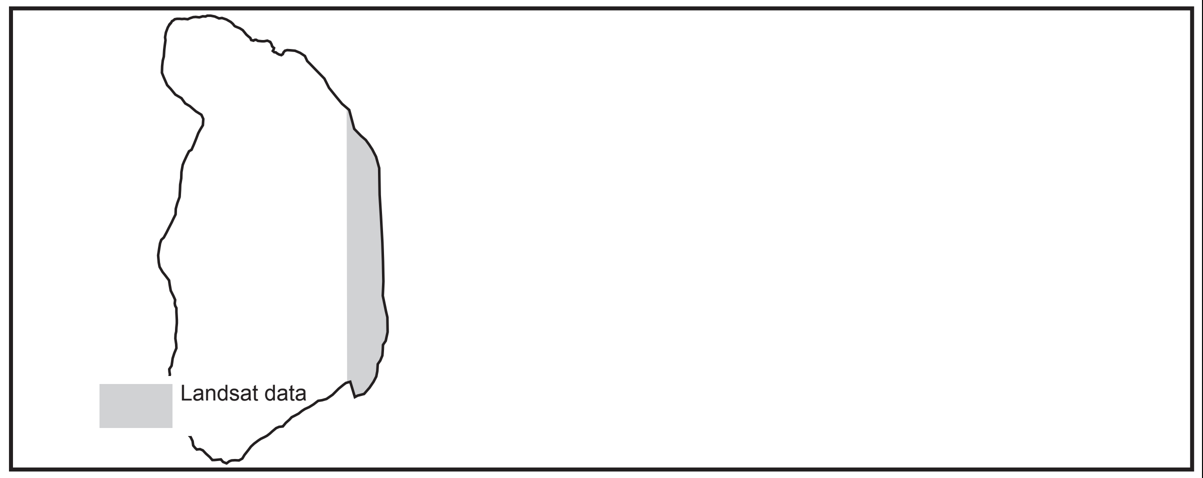
Bijoutier and St Francois

(07°04' S; 52°44' E and 07°09′ S; 52°44′ E)

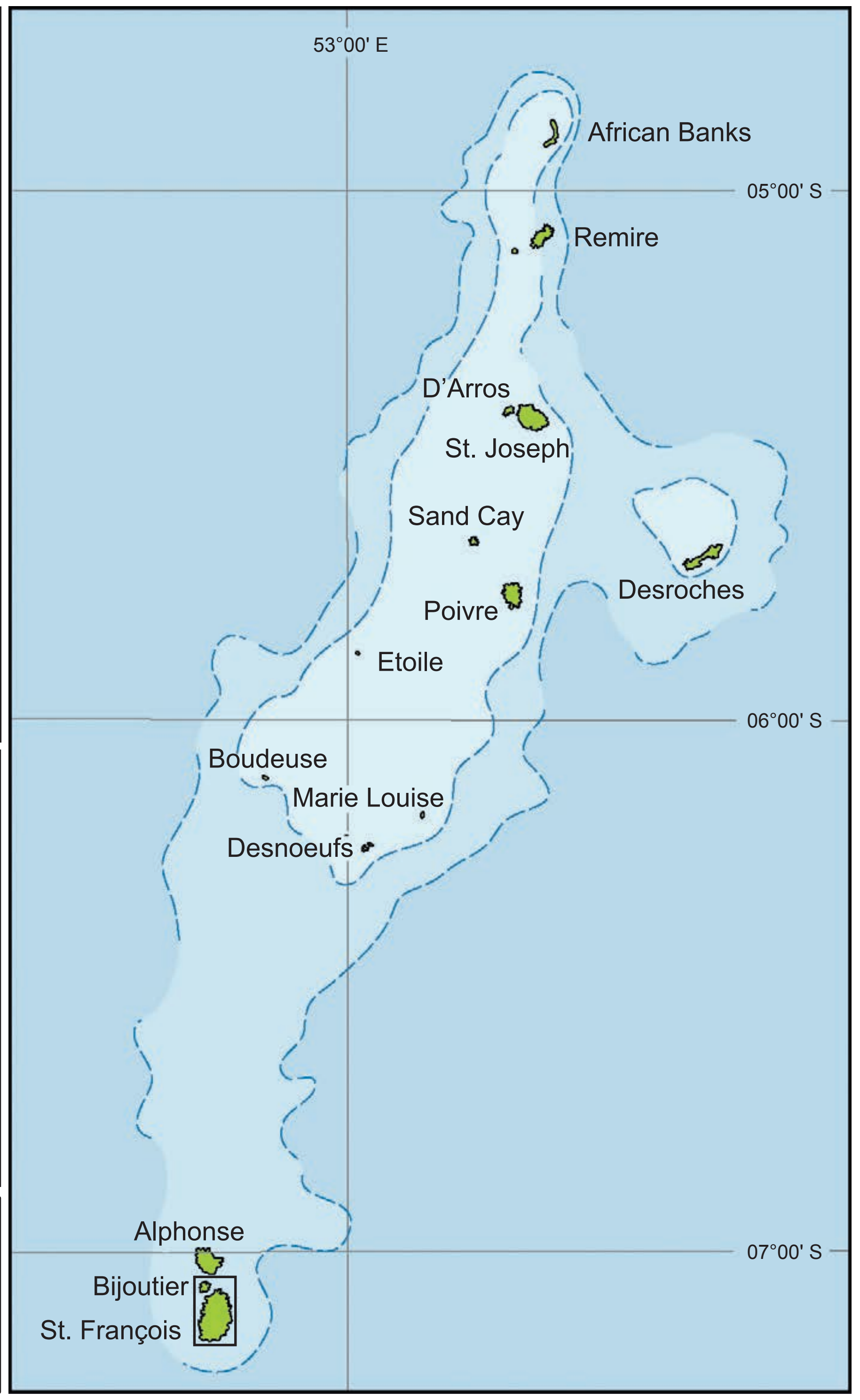
Key to Habitat Classification: Bijoutier and St. François

- Coconut woodland
- Other trees and shrubs
- Herbs and grasses
- Saline pond
- Cleared / bare ground
- Buildings and other structures
- Littoral hedge
- Mangrove woodland
- Coral sandstone / raised reef
- Beach sand
- Coral boulders
- Beachrock
- Rock pavement
- Reef-flat sand
- Low density seagrass / macroalgae
- Medium density seagrass
- High density seagrass
- Lagoon patch reef
- Lagoon sand
- Coral rubble with coralline algae
- Fore-reef slope coral spurs with coralline algae
- Rocky fore-reef slope
- Fore-reef slope sand
- Fore-reef slope rubble and sand
- Fore-reef slope with coral

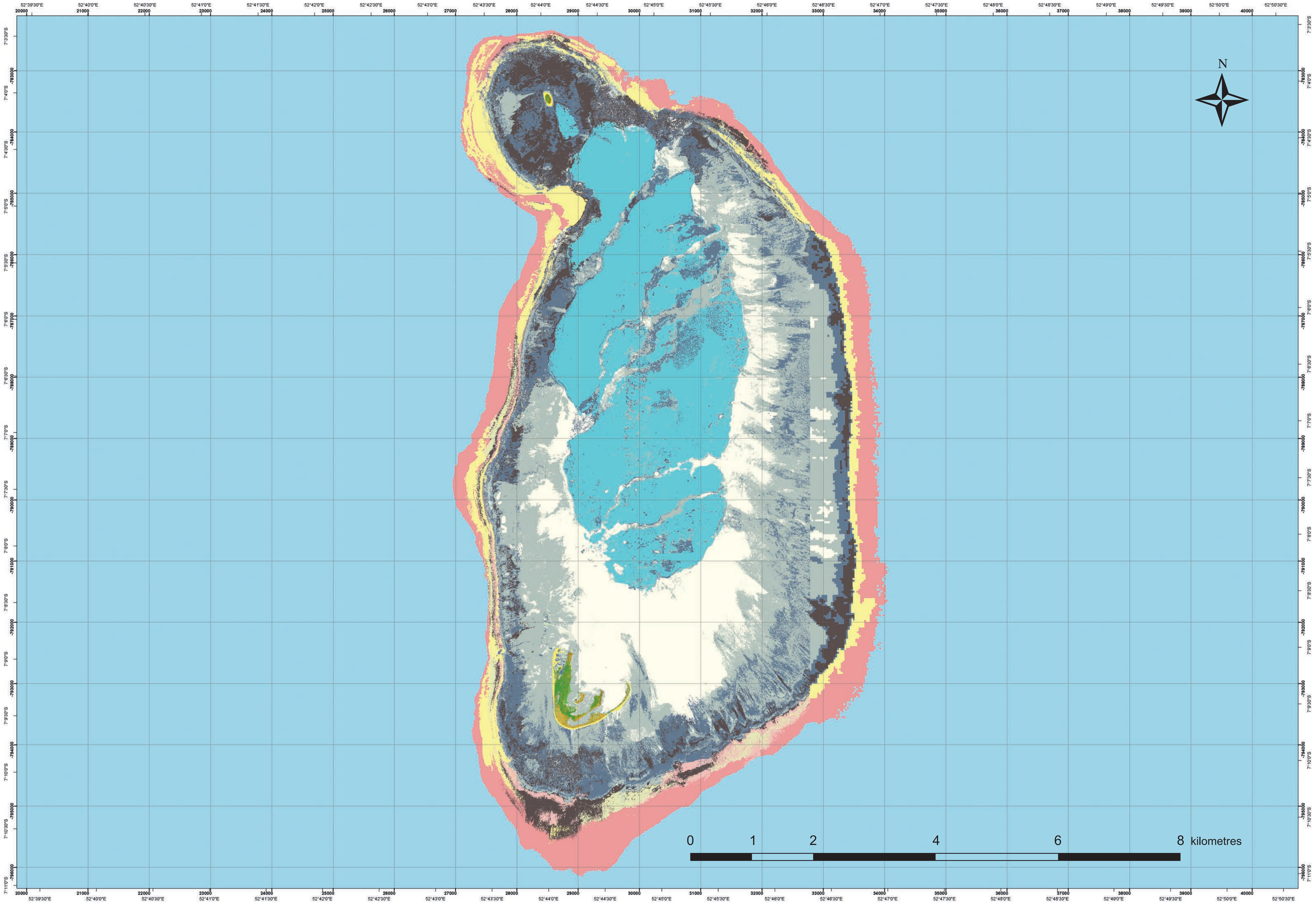


The map shows the key shallow water benthic habitats of Bijoutier and St.Fran« ois, part of the Amirantes group, southern Seychelles, Western Indian Ocean. This was produced by performing a classification on 17 bands of CASI imagery acquired in January 2005. Where data are missing due to cloud cover, gaps have been filled by classifying georeferenced Landsat data (2000).

Projection and Sensor Information
Projection: UTM, Zone 40
Spheroid: GRS 1980
Datum: NAD83
Sensor: Compact Airborne Spectrographic Imager
Pixel Size: 1m
Electromagenetic spectrum region: 434-849nm
Acquisition Date: January 2005



1:25,500



Bijoutier and St. François Atoll

Note: Bijoutier was visited by the Expedition on 19 January 2005 and the atoll of St. François was visited, for one hour, on the afternoon of 22 January 2005. The complete reef system covers a very large area (> 5,000 ha) and field observations at St. François were restricted to the southwestern reef flat and the western side of the active, outer islands at the southern end of the atoll. Ground referencing of the habitat map presented here is, therefore, partial and there is virtually no published information on either of these two islands. The account below is, therefore, largely derived from information derived from the habitat map and from oblique aerial photography taken at the same time (January 2005) as the other airborne imagery was acquired and limited ground referencing undertaken.

Plates 1 and 2: Aerial view of St. François atoll showing extensive reef-flats, enclosed lagoon and the islands of Bijoutier in the north (left) and St. François in the south (right) (source: Maps Geosystems; reproduced with kind permission of the Government of the Seychelles).

Island history

The three islands of Alphonse, Bijoutier and St. François make up the Alphonse Group. Bijoutier and St. François were discovered on the same occasion as Alphonse, on 28 January 1730 by the Chevalier Alphonse de Pontevez, commanding the French frigate *Le Lys*. Details of the naming of Bijoutier are not known, although the name means 'jeweller'. St. François is named after the religious feast day of 29 January, which is that of St. François de Sales.[1] Although neither Bijoutier nor St. François are inhabited, the reef-flats of St. François are frequented by salt-water fly fishermen who make the journey by boat from Alphonse. The Alphonse Group falls under the jurisdiction of the Island Conservation Society (ICS), a Seychelles based conservation NGO. The ICS, in partnership with the Island Development Company, is in charge of conservation in the outer islands. Strict restrictions are in place limiting the number of fly-fishermen at St. François at any one time, only barbless hooks are used, and all fishing is 'catch and release'.

Geography and geology

Bijoutier and St. François are located at the southernmost extension of the Amirantes Ridge. Regional bathymetry is poorly known but there are soundings of over 3,000 m at 7 km to the west of the islands and the 2,000 m isobath lies approximately 10 km to the east. There is a broad plateau with water depths of 137 – 155 m to the southeast and south of St. François with the 1,000 m isobath 9 km to the south. Bijoutier, at the northern end of the reef system, lies 3 km south of Alphonse Atoll, across the Canal du Mort which has a sounding depth of 126 m. The total area of Bijoutier and St. François is 5,382 ha, with peripheral reef-flats occupying 3,732 ha and the lagoon 1,650 ha (Plates 1 and 2).[2] The eastern reef-flats are 2,560 to 3,250 m wide, compared to 480 – 1,120 m on the west. At the southern point, reef-flat width exceeds 4,000 m. The lagoon is enclosed; there are no navigable channels in the reef margin. The total area of emergent islands is very small (35 ha) and are restricted to the northern and southern extremities of the reef system.

Terrestrial flora and fauna

Bijoutier is a small (2 ha), oval sand cay, orientated SSE-NNW, which can only be reached by boat at high tide. The terrestrial vegetation is a dense mix of *Cocos nucifera* (coconut palm) and *Casuarina equisetifolia*, with *Scaevola taccada* forming a littoral hedge around the circumference of the island (Plates 5 and 6). A large, presumably planted *Hernandia nymphaeifolia* (= *sonora*) tree stands in the centre of the island (B. Jumeau, personal communication, 2008).

The islands of St. François (33 ha) lie on the broad southern reef-flat, the apex of the main island lying approximately 1 km from the reef margin. The positioning and general planform is very similar to that of Ile du Sud at Poivre Atoll and, to a lesser extent, St. Joseph Island at St. Joseph Atoll. There is, however, no phosphatic sandstone present.[3] It is clear that there have been at least two phases of island growth, with the currently active island system – termed 'Ile Sêche' by Baker[3] - on the seaward side of an older, and now fixed and vegetated, island complex. In the centre of this older group is a small sand cay, Ile Fouquet. Both active and fossil systems show the same general planform and both contain multiple low (~ 1 m) ridges of gravelly sand. On the outer eastern arm of the island complex, a comparison of Baker's[3] map with the current (2005) configuration, suggests that island development has resulted from the lagoonward migration and then collision of two small barrier islands, with some subsequent counterclockwise rotation of the free end of the more northerly of these two barrier system with continued island migration to the west. The most active part of the complex at the present time is the outer western arm. This is extending northwards as a spit, with a series of lagoonward recurves off the main spine indicating periods of statis followed by renewed northerly extension. Vegetation colonisation is taking place on the stabilized areas of this system (P-A. Adam, personal communication, 2008).

Plates 3 and 4: Aerial views of Bijoutier, January 2005, showing remnant lagoon south of the island, large reef-flat sand sheet to northwest and extensive, high to medium density seagrass beds. Water depth outside the reef, in the vicinity of moored vessel, in Plate 3 is 16 m.

Plates 5 and 6: Bijoutier Island showing terrestrial vegetation dominated by *Cocos nucifera* and *Casuarina equisetifolia*, with *Scaevola taccada* forming a littoral hedge. Note *Eretmochelys imbricata* turtle track on beach (photographs: Martin Callow, January 2005).

Plate 7: Aerial view of St. François looking northwest, January 2005.

Plate 8: Unvegetated reef-flat sand north of St. François Island with Alphonse Island in the background (photograph: Martin Callow, January 2005).

Plate 9: St. François Island showing terrestrial vegetation of *Cocos nucifera* and littoral hedge of *Casuarina equisetifolia* and *Scaevola taccada* (photograph: Martin Callow, January 2005).

Plate 10: *Rhizophora mucronata* mangroves in the central embayment of St. François (photograph: Martin Callow, January 2005).

The terrestrial vegetation is dominated by *Cocos nucifera* (coconut palm) in the centre and western arm and a littoral hedge is formed by *Casuarina equisetifolia* and *Scaevola taccada* (Plates 9 and 10). The multiple low gravel ridges of the back-barrier environments are characterized by other trees and shrubs. *Rhizophora mucronata* mangroves are found in the central embayment, west and southwest of Ile Fouquet.

Numerous birds have been observed at Bijoutier and St. François including *Gygis alba* (Fairy or White Tern), *Anous stolidus* (Brown or Common Noddy) and *Fregata minor* (Greater Frigatebird). In February 2008, 11 breeding pairs of *Sterna sumatrana* (Black-naped Tern) were recorded at St. François (P-A. Adam, personal communication, 2008). *Ardea cinerea* (Grey Heron) frequently patrol the reef-flats in search of fish when the tide recedes. *Dromas ardeola* (Crab Plover), a wader with a bill specially adapted for eating crabs, is also found and St. François may be a site of global importance as a wintering ground. Up to 1,500 birds (3% of the known world population) have been recorded at St. François, and nowhere else in the world can such a high proportion of a migratory species' population be found wintering so far from a continental landmass (A. Skerrett, personal communication, 2002). St. François hosts a large number and diversity of crabs, including *Callinectes sapidus* (Blue Crab) and the world's largest crab, *Birgus latro* (Coconut (or Robber) Crab).

Marine habitats

Bijoutier is encircled by a wide sandy beach. The surrounding reef platform, probably an infilled lagoon as one small area of lagoon is still present to the southeast of the island, is almost completely covered with low to high density seagrass (*Thalassodendron ciliatum* and *Thalassia hemprichii*), with the macroalgae *Halimeda* sp. and *Microdictyon* sp. also being present.[4] There is no well-developed reef crest; rather, the fore-reef is characterised by extensive areas of fore-reef sand, particularly on the western margin, and concentric bands of reef, with localised strips of high density seagrass, merging into more continuous coral coverage in deeper water. Goreau described a rocky slope at the southeastern reef margin which, prior to bleaching in 1998, was dominated to water depths of 20 m by acroporid corals with some colonies of *Heliopora coerulea*, *Pocillopora verrucosa* and other species.[4] In deeper water, at least half the rocky substrate was encrusted with coralline algae. At 16 m to 25 m depth on the western fore-reef slope of Bijoutier, large reef buttresses support gorgonian sea fans and *Tubastrea micrantha*, indicating high current flow which attracts large schools of fish and megafauna. Surveys in March 2003 showed there to be 27% live coral cover at a depth of 17 m on this western fore-reef slope, with *Porites* and *Pocillopora* cover combined accounting for half the coral community present.[5]

There is a clear patterning to reef-flat habitats on St. François. The seaward reef-flat margin is characterised by a narrow band of high density seagrass which parallels the reef edge and in places extends as short, shore-normal SE–NW aligned lineations towards the lagoon. These areas are typically surrounded by medium density seagrass which show more extensive development around the southern point of the atoll. The eastern reef-flats are characterised by low density seagrass and macroalgae which extend on sediment tongues towards the lagoon, with localised medium density seagrass on higher surfaces. There are extensive areas of bare, mobile sand on the southeastern reef-flat. Medium and high density seagrass is well developed on the northeast reef margin between Bijoutier and St. François and on the northern half of the western margin of St. François; these may be areas of tidal exchange between the lagoon and the open sea over relatively low sections of the atoll margin. Near the breaker zone on the southeast coast, and in shallow embayments on the west coast, fore-reef coral spurs with coralline algae are present. On the southeastern and southern margin, these spurs also support high density seagrass and are surrounded by areas of coral rubble and sand. Both the eastern and western fore-reef has a narrow zone of fore-reef sand, followed by coral communities on deeper fore-reef slopes (although it should be noted that it was only possible to map eastern fore-reef habitats at 30 m resolution, using Landsat imagery).

Plate 11: Eastern reef-flat margin of St. François, showing coral rubble on reef margin with localised high density (see top left) and medium density seagrass. A series of sand lobes, with mobile sand on their lagoon margins, are migrating over reef-flat sand colonised by medium to low density seagrass and macroalgae.

Plates 12 and 13: Northern (left) and central (right) reef ridges extending across the St. François lagoon, looking west, January 2005. Note seagrass on northern ridge and complex structure of central ridge, with internal basins between ridges. Water depth in large basin in right distance of Plate 13 is 7 m.

Plate 14: Two southern reef ridges extending across St. François lagoon, looking west, January 2005. Note high density seagrass patches and extensive reef-flat sands on lagoon margins.

The lagoon at St. François is thought to be shallow.[2] A distinctive feature is the presence of a series of four reef ridges which extend across the lagoon and thus divide it into a series of separate basins (Plates 12-14). The two most northern ridges are best developed and trend SW–NE; the more southerly of the two is a complex, anastomosing structure, enclosing three internal lagoonal basins; lagoon water depths of 7 m have been recorded at the southwestern end of this complex (P-A. Adam, personal communication, 2008). Both northern ridge systems are colonised on their upper surfaces by low density seagrass with macroalgae and / or medium density seagrass, with occasional high density seagrass. The two smaller ridges to the south are simpler and narrow in structure, trend WSW–ENE and are either sand-covered or support low density seagrass/macroalgae.

A SCUBA survey in January 1993 revealed 28% live coral cover at the entrance of St. François lagoon, with 80% of the community being comprised of massive *Porites* (with 6% pocilloporids, 6% *Pavona varians* and 3% acroporids).[6] The St. François lagoon and reef-flats support numerous fish species, including *Albula vulpes* (Bonefish) and *Chanos chanos* (Milkfish), which are targeted by the fly-fishermen. Sharks, such as *Negaprion brevirostris* (Lemon Shark) and the fourth largest predatory shark *Galeocerdo cuvier* (Tiger Shark) are also common within the turbid lagoon and on the fore-reef slope. *Eretmochelys imbricata* (Hawksbill Turtle) and *Chelonia mydas* (Green Turtle), rays and juvenile lemon sharks are frequently observed swimming in the shallow water of the reef-flats. Turtle nests are often seen on the beaches of Bijoutier. Frazier[7] estimates 50 nesting *Chelonia mydas* females each year (and 20 nesting *Eretmochelys imbricata*) at St. François.

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Appendix
Developing Habitat Maps from Airborne Remote Sensing Imagery

Remote sensing of coral reef environments

Remote sensing instruments provide a synoptic portrait of the earth's surface by recording numerical information on the radiance measured from a series of picture elements (pixels) across a number of spectral bands, i.e. within discrete wavelength portions of the electromagnetic spectrum[1]. Passive instruments focus sunlight reflected off the earth's surface onto a CCD detector to create an electronic response, which is digitally recorded in a gridded pixel array (Figure 1c).

Broad scale coral reef habitat mapping is usually conducted by attaching a sensor to a satellite or airborne platform. Since the launch of the first earth observation satellites in the 1970s, sensor capability for mapping in shallow tropical environments has become well established.

The ability to accurately discriminate reef communities depends on the spatial and spectral resolution of the sensor used. Spatial resolution refers to the dimension of one pixel on the ground, specifically the length of one side of the pixel square. Spectral resolution refers to the number and width of waveband windows sampled within the electromagnetic spectrum (Figure 1b). Images acquired from airborne platforms typically have high spatial and spectral resolutions, enabling fine detail mapping, both in terms of the size of features detected and the thematic detail contained in the map.

Several well-placed, narrow (10 nm) spectral bands can detect subtle differences in reflectance between reef communities, e.g. seagrass vs. algal beds, coral vs. algae, brown algae vs. green algae[2] Mapping benthic assemblages on coral reefs therefore requires a band combination that emphasises distinct spectral characteristics apparent in the visible section of the electromagnetic spectrum, i.e. between 400 and 700 nm (Figure 2a).

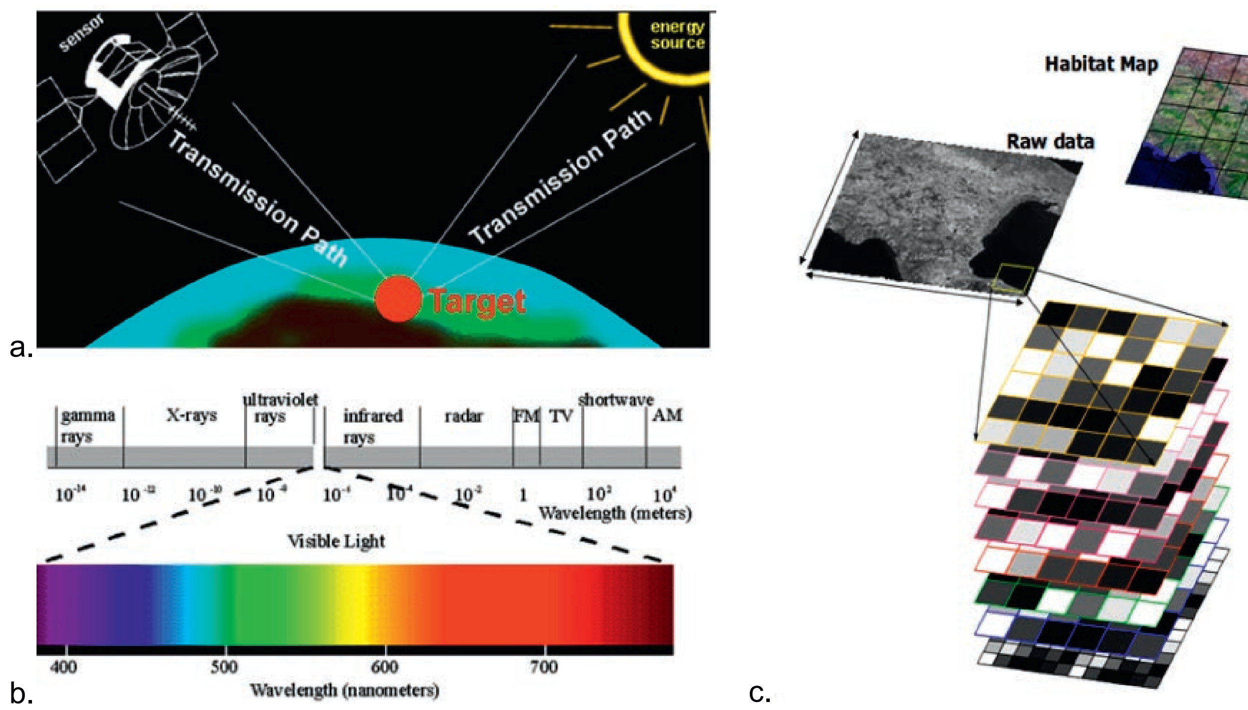


Figure A.1 The general principles of remote sensing

a. A satellite-mounted passive sensor detecting sunlight,

b. The visible section of the electromagnetic spectrum,

c. The components of a remotely sensed image.

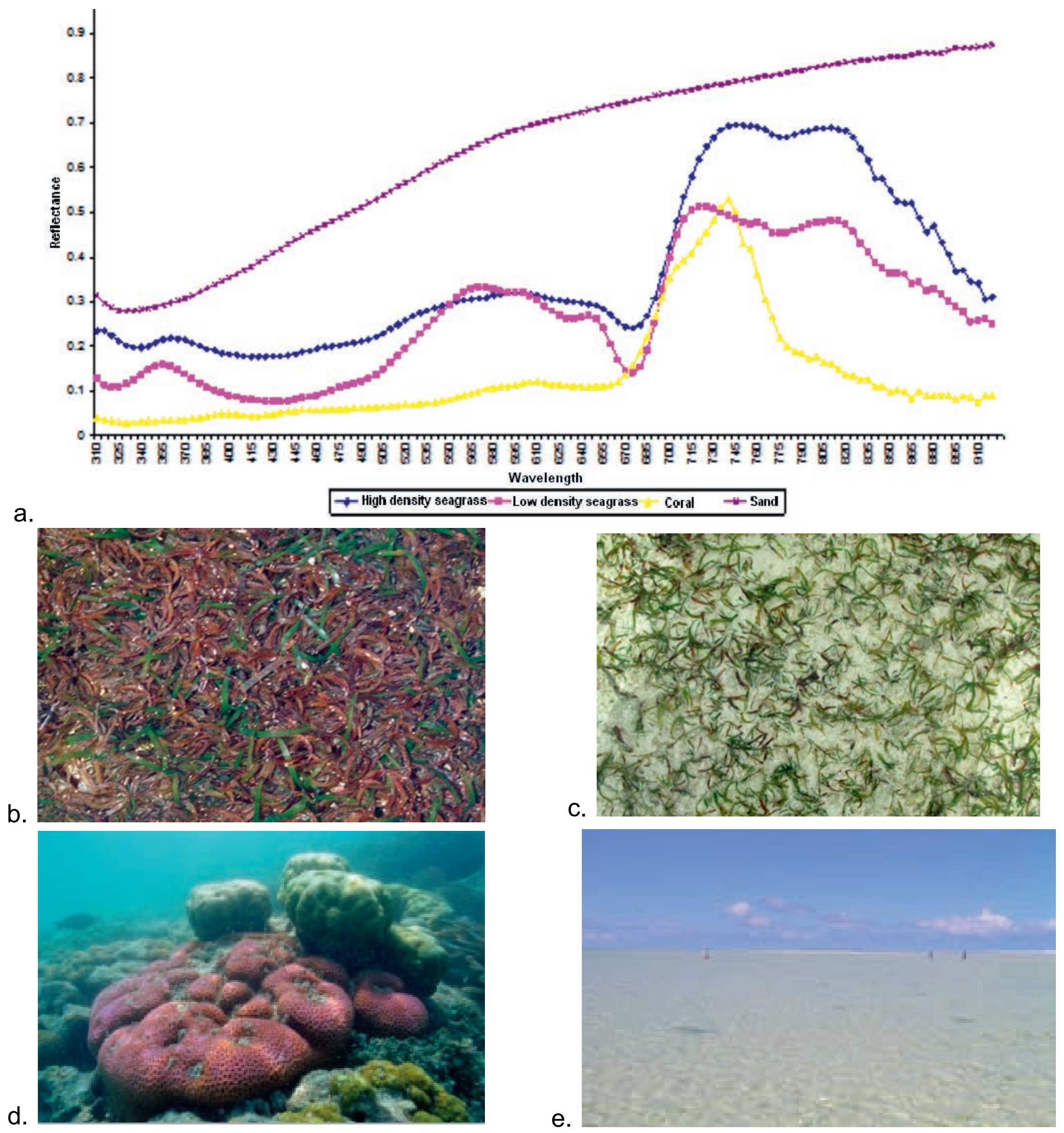


Figure A.2 a. Spectral reflectance curves for high density seagrass, l ow density seagrass, coral and sand b. High-density seagrass, c. Low density seagrass, d. Coral and e. Sand. (Photographs: A.Hagan).

Airborne data collection

Data for this project were collected using the passive Compact Airborne Spectrographic Imager (CASI) sensor mounted on the *Golden Eye* seaplane, flown at 1000 m. The CASI instrument was owned and operated by Hyperspectral Data International (HDI), Canada. Each island site comprised airborne data based on a series of parallel, overlapping flight-lines. The overlap between strips was variable, with a maximum overlap of 25% of the strip width. HDI carried out some radiometric and geometric corrections (see below), prior to delivery of the data to the University of Cambridge.

In full spatial resolution mode, CASI can record in up to 19 wavelengths in a pre-programmed bandset. It does so by focusing light that has been dispersed through a diffraction grating into a spectrum onto a CCD detector at the desired instantaneous field of view. This creates an electronic response, which can be digitally recorded on a pixel array (Figure 3). Data are then acquired in a series of flight lines covering the feature of interest.

Airborne surveys were conducted at 13 islands in the Amirantes (Table A.1). Reflectance data were collected over the 430-850 nm region of the electromagnetic spectrum.

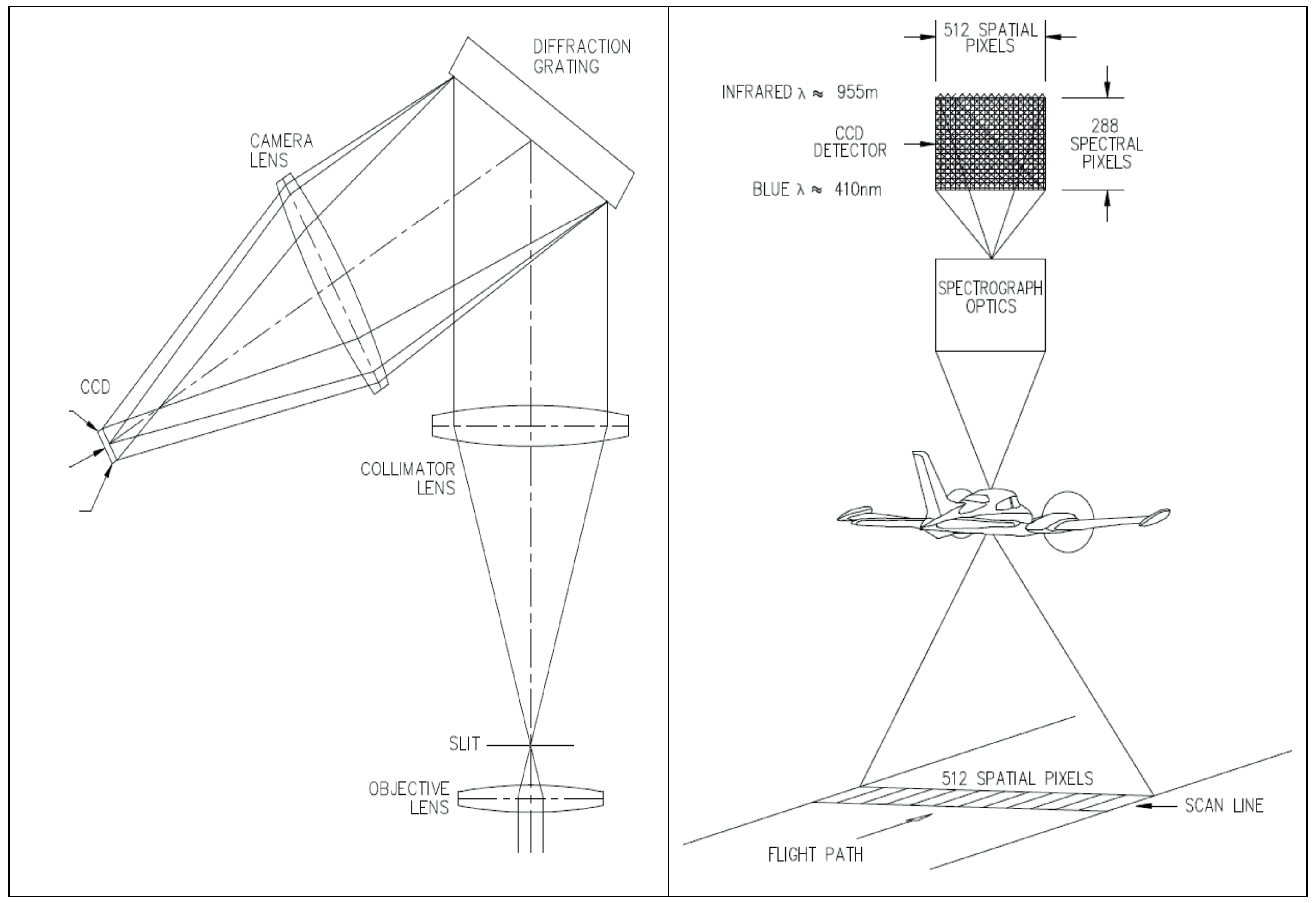


Figure A.3 CASI pushbroom scanner and its sensor head optical system.

Source: ITRES CASI user manual[3]

Table A.1 Aerial coverage of CASI data, southern Seychelles, January 2005.

Islands Flown	13
Area Flown	268 sq kms
Flight lines Flown	110 lines
Data Volume (Raw)	65 Gbytes
Data Volume Processed	150 Gbytes

Field data collection

Ground-reference data were collected in concert with airborne surveys. Coordinates were recorded using hand-held GPS units for target positions to enable subsequent geo-referencing of the CASI data. On land and underwater, positions were measured with a GPS unit and the island habitat represented at that position was recorded. In addition, detailed terrestrial and marine habitat surveys were conducted at the southern Amirante Islands. Terrestrial surveys encompassed beach profiles, vegetation surveys, sediment samples, soil samples, collections of insects and observations of plant life and bird life. Quantitative underwater surveys were conducted using well-established video transect methods[4].

Image processing and habitat map construction

A number of image processing steps were applied to the raw data to generate the final habitat map. These can be broadly divided into pre-processing of the imagery to remove the influence of external variables, classification of corrected response functions into 'habitat' labels and validation of the output thematic layer (Figure 4).

Data pre-processing

As sunlight travels through the atmosphere, and possibly through seawater, before hitting the earth's surface and being returned to the sensor, it undergoes several interactions that modify its value from 'pure' radiance. Spectral radiance is the amount of reflected light detected at a given wavelength for a given solid angle. Furthermore, locational inaccuracies can arise from various sources, such as GPS error, or pitch, roll and yaw of the plane. It was therefore necessary to apply a number of procedures to the raw data prior to the production of the habitat maps (Figure 5).

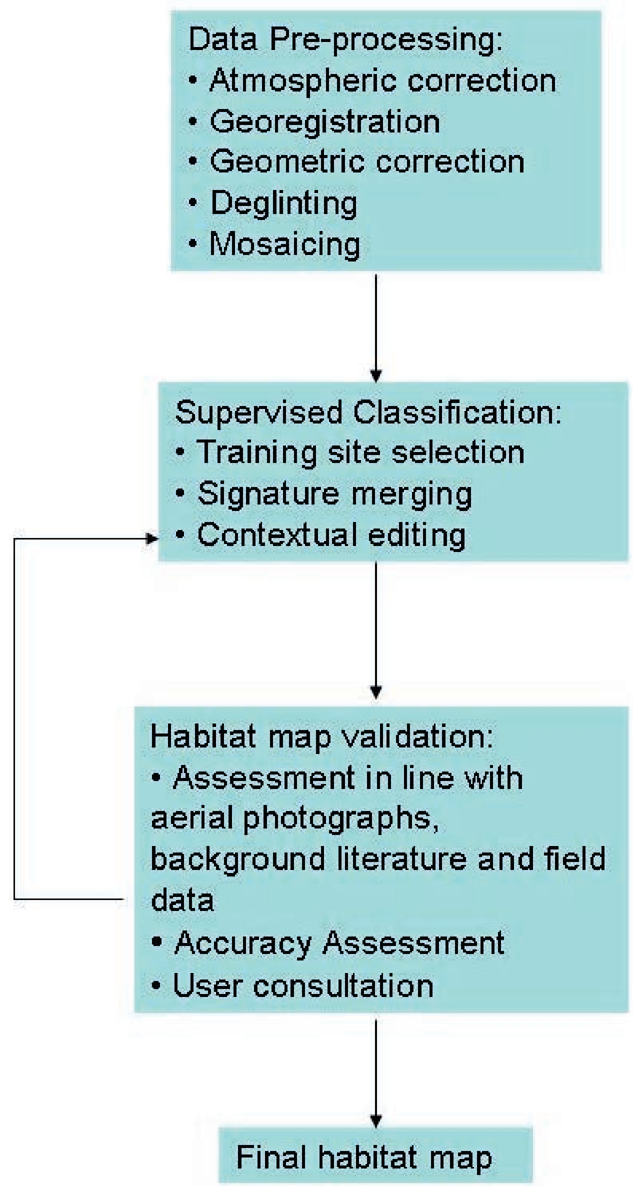


Figure A.4 A schematic representation of the image processing steps applied to the CASI imagery to produce the benthic habitat maps.

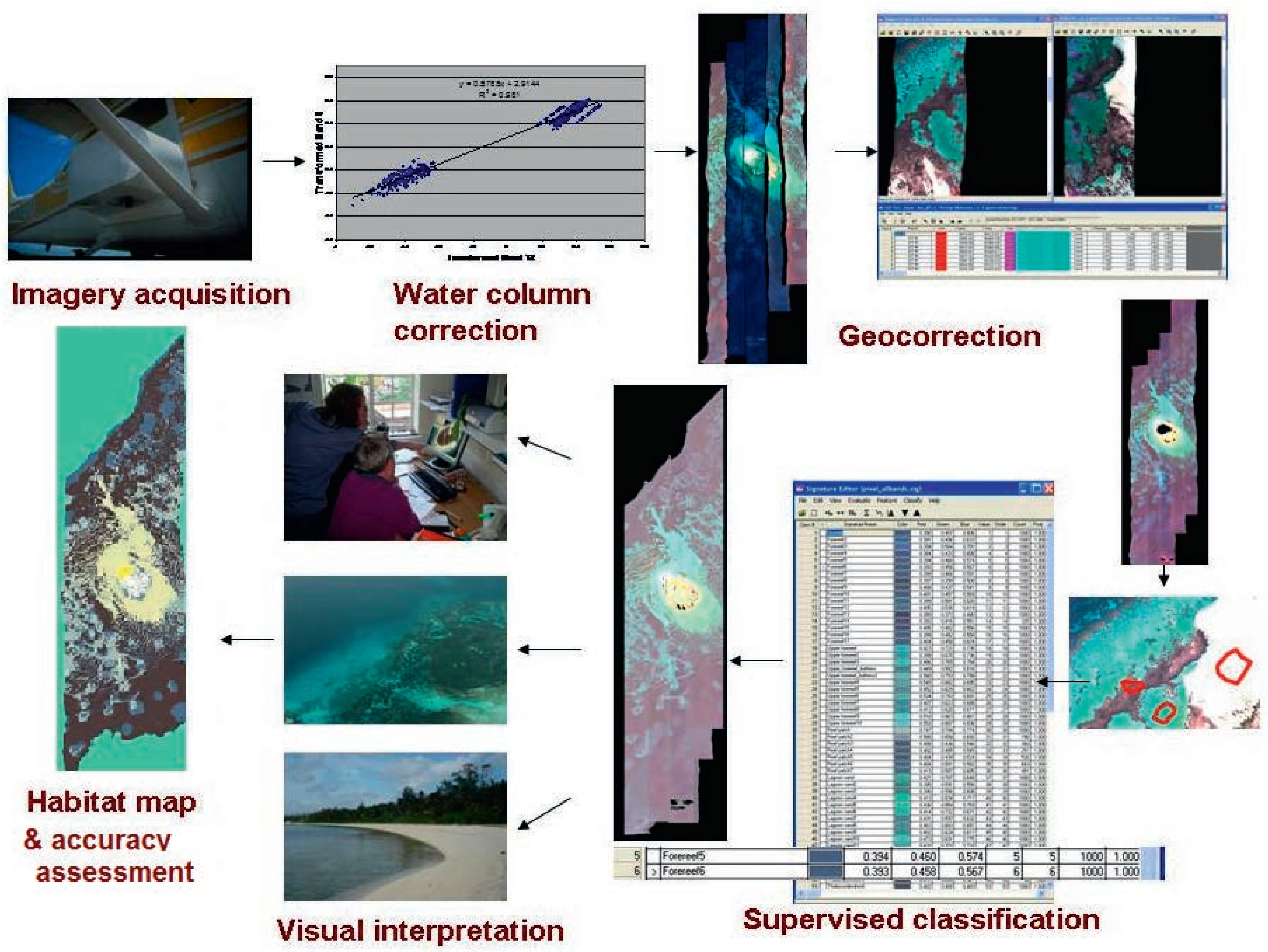


Figure A.5 Image processing steps applied to the CASI imagery to produce the benthic habitat maps

Atmospheric correction

Interactions between the sun's energy and the constituents of the Earth's atmosphere result in a number of confounding influences on the signal reaching the sensor. These include additional incoming electromagnetic energy entering the sensor field of view that has been redirected by scattering; electromagnetic energy entering the sensor field of view that has been reflected by features on the ground not located beneath the sensor; absorption of light as it passes through the atmosphere; variation in surface reflectance with the angle of view and solar illumination angle[5]

At-sensor radiance is therefore a function of the reflectance, transmittance, and path radiance of light. To provide an estimate of the true ground-leaving pixel radiance, it is necessary to correct for these influences. The ACORN atmospheric correction routine[6] was applied to the imagery prior to delivery. This provided a physics-based derivation of atmospheric properties such as surface pressure, water vapour column, aerosol and cloud influences, for incorporation into a correction algorithm. This algorithm was used to invert "radiance at detector" measurements into "radiance at surface" values.

Water column correction

Features of interest on coral reefs typically occur in geomorphological zones that span a wide water depth range. Differential attenuation of light within this range results in both a decreased ability to discriminate between different habitats with increasing depth and different spectra being recorded for the same habitat at different depths[1].

This influence on bottom reflectance hinders interpretation of sub-surface benthic features from remotely sensed imagery and it is necessary to characterise and correct for the effects of the water column on benthic reflection when producing habitat maps. Band pairs were selected to avoid saturation and correlation[7] and the method devised by Lyzenga[8] was used for band-wise correction of the effects of absorption and scattering in the water column. This assumes that the vertical radiative transfer through the water column can be approximated to a logarithmic decrease in radiation with increasing depth.

Deglinting

When the benthic signal received gets mixed with reflected light from wave slopes and crests, remote sensing imagery acquired above seawater surfaces can often be contaminated by glint[9]. This appears as areas of white densely speckled imagery, which can dominate a classification output and reduce accuracy.

The glint component of the signal can be estimated using infrared wavebands, which have limited reflectance over water. The minimum reflectance in the infrared can be used to approximate glint. Where necessary, a relationship was established between the infrared signal and the signal in other bands, using linear regression on image data where a range of sun glint was apparent[10]. From this, the waveband-specific magnitude of glint was estimated and subtracted from the imagery.

Geometric correction

Geometric correction is the transformation of a remotely sensed image so that it has the scale and projection properties of a given map, to enable use with maps and coordinate data in the same frame of reference. This process involves correction of the position and orientation of an image to a "corrected" data source. Ground Control Points (GCPs), common features on both uncorrected and reference information sources, are identified and input into a model to align the origin and scale of one image with another.

It was necessary to correct individual flight line image strips to each other. This was done by collecting ground control points on areas of strip overlap and applying a first order polynomial model to correct for the linear offset, with nearest neighbour resampling. Coordinates collected in the field were then used as the basis of an absolute geocorrection, with respect to the geoid.

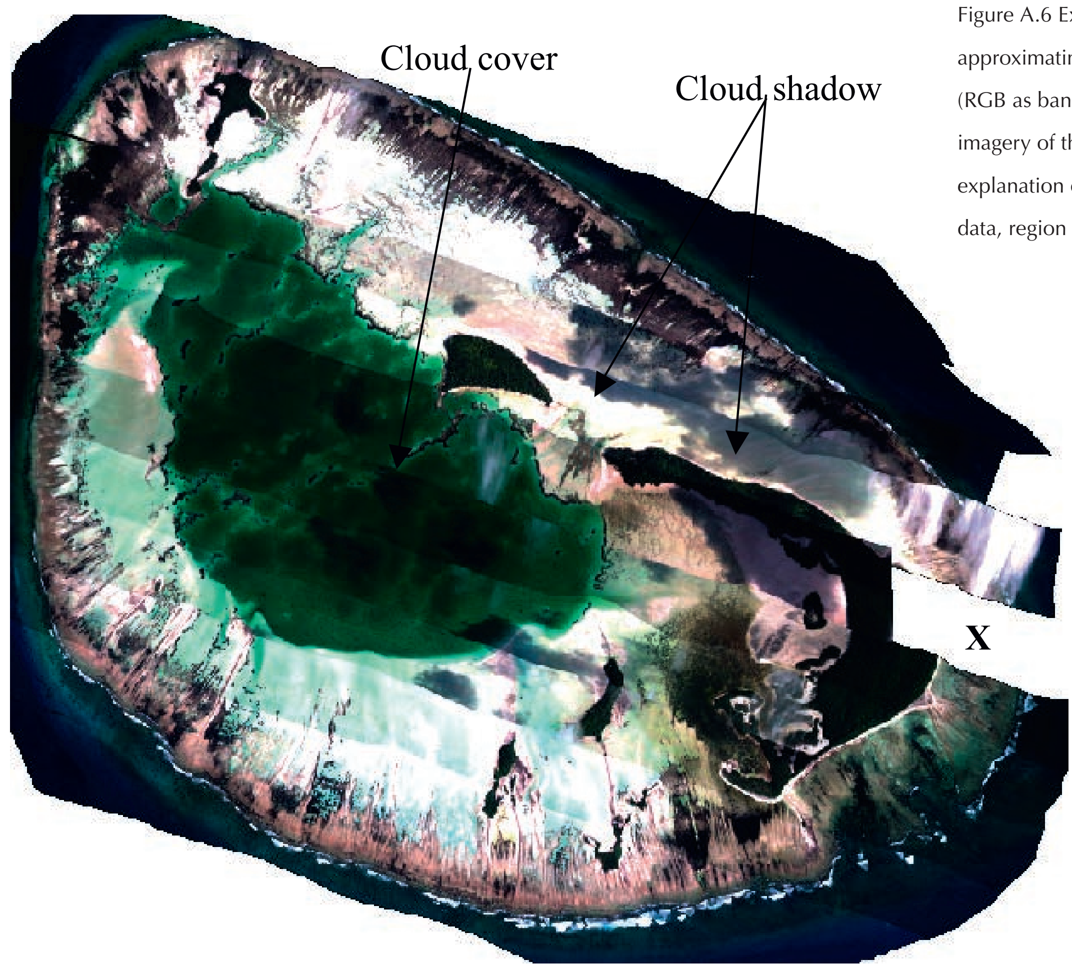


Figure A.6 Example of mosaiced imagery approximating true colour composite (RGB as bands 14, 7 and 1) showing imagery of the atoll of St Joseph. See text for explanation of mapping of area of missing data, region X.

Mosaicing

Strips were mosaiced to form a single image covering the features of interest. An example of a mosaiced image is shown in Figure A.6. During the mosaicing process, it is necessary to ensure that the overall brightness of adjacent flight strips is balanced. A band-wise linear colour balancing model was applied to minimise across-track variance, with histogram matching to adjust for radiance offsets.

Supervised classification

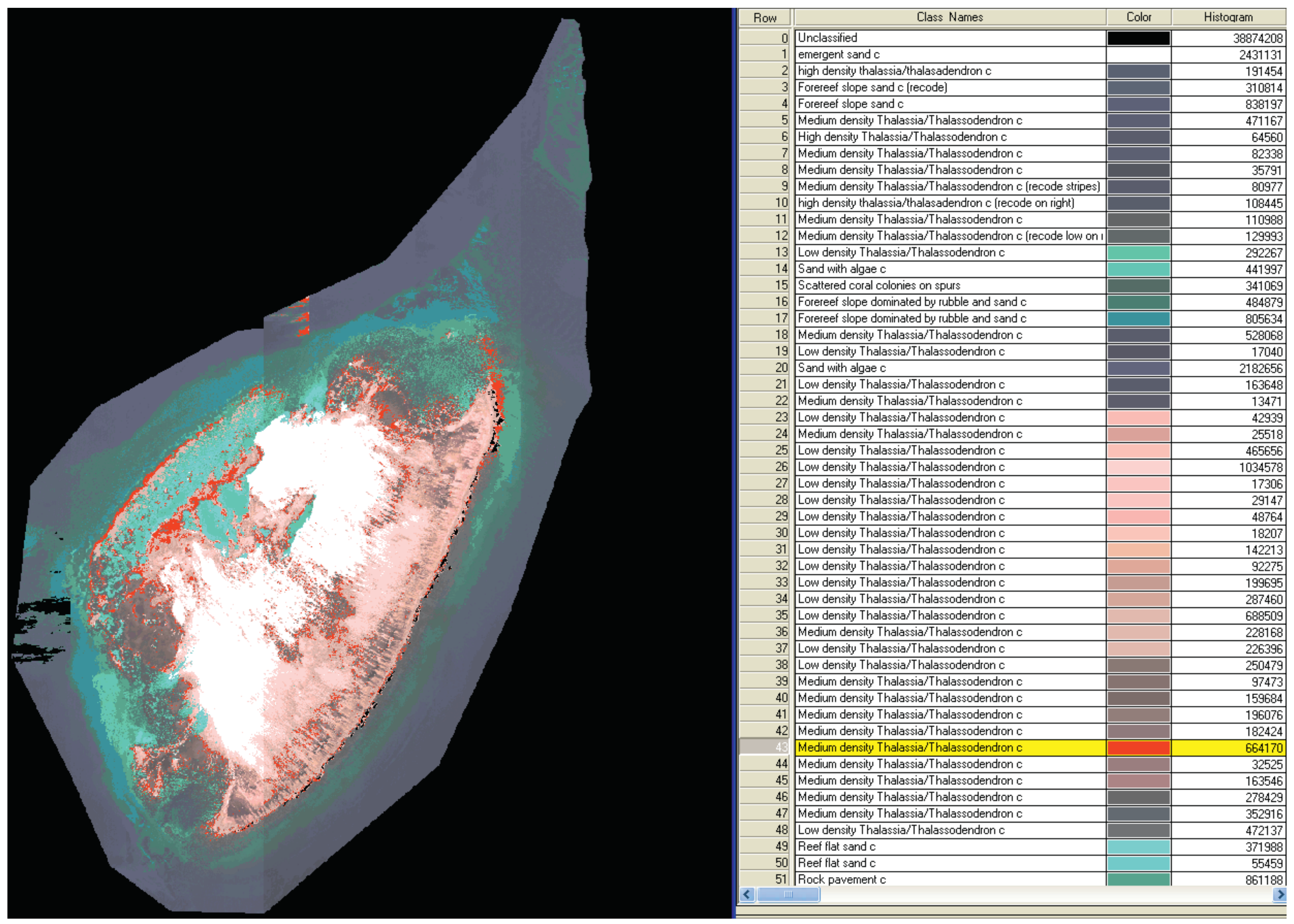
Classification in remote sensing involves the categorisation of response functions (i.e. detected light) as representations of real-world objects and the subsequent placing of pixels into user-defined groups[11]. In order to classify the remote sensing data, *in situ* ground-referencing data are required. Habitat types noted in the field are used as "training sites", to provide a link between pixel reflectance signatures and benthic habitats. Across the image, habitats of interest are related to measurable spectral characteristics and empirically extrapolated by a computer using clustering algorithms. Results of field survey can be extended in this manner to large areas of observation.

Training areas were collected from the mosaiced images to build up a statistical population of each reef habitat class reflectance in feature space; a total of 2108 signatures were evaluated for the dataset as a whole, before being merged into 24 habitat class populations. A maximum likelihood classification assigned each pixel of the image to the most likely class on the basis of statistical probabilities[5].

Classification meeting and contextual editing

The aim of this phase of the methodology was to derive an interpretation of the environment for each of the classified images. This was achieved using a combination of data sources in addition to the classified CASI images including photographs and ground-truth data discussed above. A team of experts was established and they held a minimum of one meeting per site. During these meetings, for each class the pixels were marked as a distinct colour (e.g. red) and their distribution was compared with aerial photographs, ground-truth data and existing maps and publications. Based on all the evidence each class was assigned a label relevant to the particular site. An example of the processing methodology applied is shown in Figure A.7 with a class ("*Medium density Thalassia/Thalassodendron*") highlighted in red.

In addition, pixels that were clearly located in the wrong position based on their contextual surroundings were recoded. For example, a class identified as 'seagrass' could not have pixels in a terrestrial area and a 'coconut' class would not have pixels in a lagoon.



Row	Class Names	Color	Histogram
0	Unclassified		38874208
1	emergent sand c		2431131
2	high density thalassia/thalasadendron c		191454
3	Forereef slope sand c (recode)		310814
4	Forereef slope sand c		838197
5	Medium density Thalassia/Thalassodendron c		471167
6	High density Thalassia/Thalassodendron c		64560
7	Medium density Thalassia/Thalassodendron c		82338
8	Medium density Thalassia/Thalassodendron c		35791
9	Medium density Thalassia/Thalassodendron c (recode stripes)		80977
10	high density thalassia/thalasadendron c (recode on right)		108445
11	Medium density Thalassia/Thalassodendron c		110988
12	Medium density Thalassia/Thalassodendron c (recode low on r		129993
13	Low density Thalassia/Thalassodendron c		292267
14	Sand with algae c		441997
15	Scattered coral colonies on spurs		341069
16	Forereef slope dominated by rubble and sand c		484879
17	Forereef slope dominated by rubble and sand c		805634
18	Medium density Thalassia/Thalassodendron c		528068
19	Low density Thalassia/Thalassodendron c		17040
20	Sand with algae c		2182656
21	Low density Thalassia/Thalassodendron c		163648
22	Medium density Thalassia/Thalassodendron c		13471
23	Low density Thalassia/Thalassodendron c		42939
24	Medium density Thalassia/Thalassodendron c		25518
25	Low density Thalassia/Thalassodendron c		465656
26	Low density Thalassia/Thalassodendron c		1034578
27	Low density Thalassia/Thalassodendron c		17306
28	Low density Thalassia/Thalassodendron c		29147
29	Low density Thalassia/Thalassodendron c		48764
30	Low density Thalassia/Thalassodendron c		18207
31	Low density Thalassia/Thalassodendron c		142213
32	Low density Thalassia/Thalassodendron c		92275
33	Low density Thalassia/Thalassodendron c		199695
34	Low density Thalassia/Thalassodendron c		287460
35	Low density Thalassia/Thalassodendron c		688509
36	Medium density Thalassia/Thalassodendron c		228168
37	Low density Thalassia/Thalassodendron c		226396
38	Low density Thalassia/Thalassodendron c		250479
39	Medium density Thalassia/Thalassodendron c		97473
40	Medium density Thalassia/Thalassodendron c		159684
41	Medium density Thalassia/Thalassodendron c		196076
42	Medium density Thalassia/Thalassodendron c		182424
43	Medium density Thalassia/Thalassodendron c		664170
44	Medium density Thalassia/Thalassodendron c		32525
45	Medium density Thalassia/Thalassodendron c		163546
46	Medium density Thalassia/Thalassodendron c		278429
47	Medium density Thalassia/Thalassodendron c		352916
48	Low density Thalassia/Thalassodendron c		472137
49	Reef flat sand c		371988
50	Reef flat sand c		55459
51	Rock pavement c		861188

Figure A.7 Example of initial classified image (for Remire Reef) with single class highlighted in red (taken as screen-dump from Erdas Imagine showing true colour approximation and the Raster Attribute Editor).

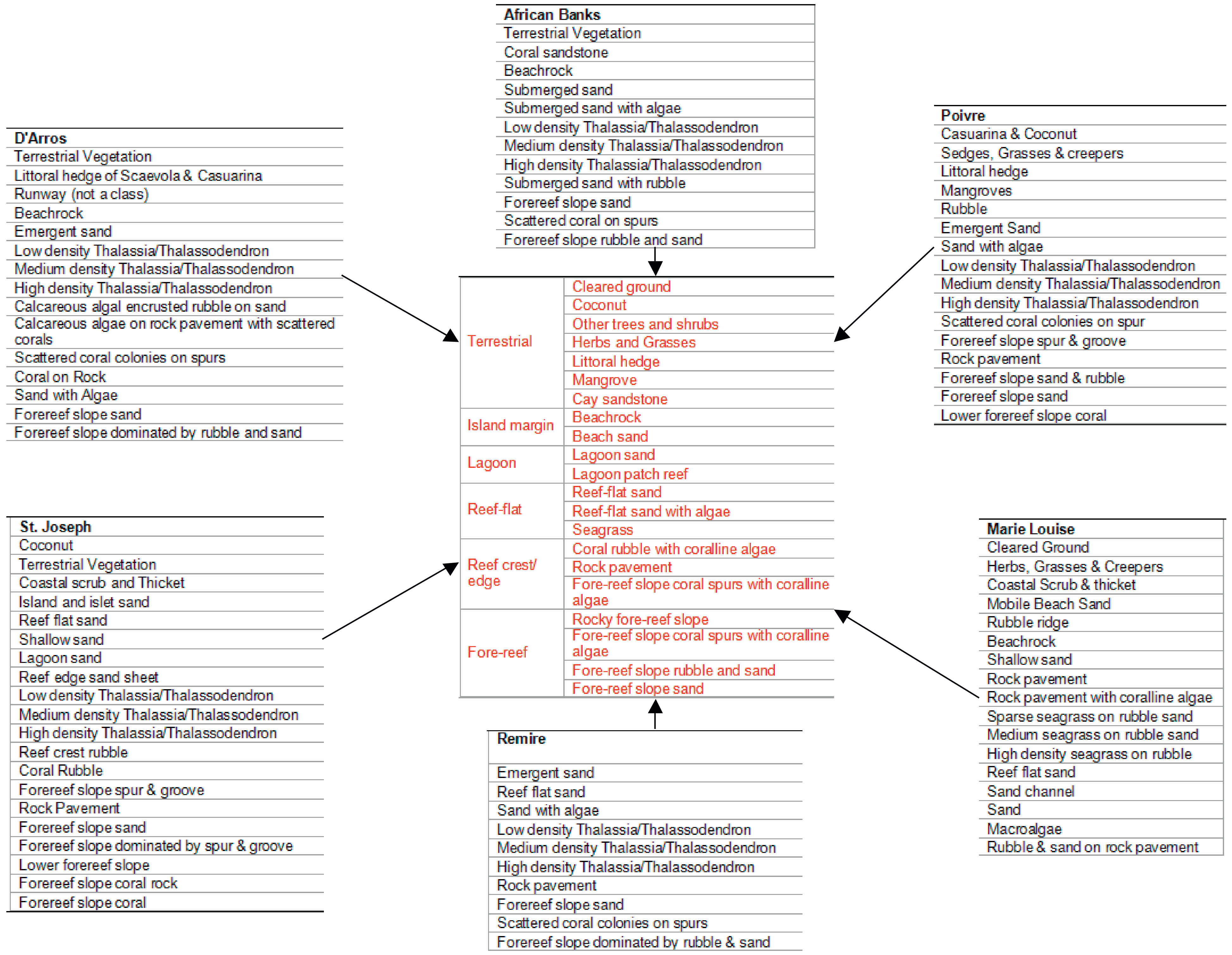


Figure A.8 Schematic of process to obtain overall habitat classification system.

Derivation of a single classification scheme

As a result of the classification meetings for the individual sites, a number of overlapping classification schemes were produced. These schemes were merged into a single comprehensive scheme, the scope of which covered the whole of the Amirante Islands. This part of the process is illustrated for a subset of the sites in Figure A.8. The finalised scheme enabled comparisons between all sites. However, it should be noted that not all sites necessarily contained all available classes.

The final classification scheme and example photographs of each of the classes can be found at the beginning of the Atlas.

Of the 13 islands mapped, six had areas of missing data due to cloud cover or survey procedure. Shape files were created for these islands using the geo-corrected imagery to identify specific regions of missing data. These shapefiles were then overlaid onto Landsat imagery that had been geo-corrected to the CASI data and subsets were extracted from the appropriate regions. A separate classification was carried out on individual subsets of the Landsat tiles in order to fill in the gaps of missing data. Classified tiles were then mosaiced to the rest of the island classification to produce a habitat map of complete coverage.

Habitat map validation

For the islands that were visited, classification accuracy was assessed with field data collected *in situ*. Patches from the GIS habitat map were randomly selected and their centroid coordinates were exported and loaded into a hand-held GPS. These were then visited in the field and the habitat type at each location with respect to the overall classification scheme was recorded. Field validation sheets were compared against the habitat class assigned by the map and labelled either correct if they were found to be the same, or incorrect if different. Overall accuracy was then expressed as the proportion of patches assessed that were found to be correct[12]. Such an approach encompassed both locational and thematic aspects of accuracy.

Where islands could not be visited, a similar approach was taken, but patches were compared against aerial photographs of the islands, as interpreted by independent validators.

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