Marine Habitats of Príncipe, Eastern Tropical Atlantic – Description and Map – Benjamin Cowburn

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1. Introduction

The island of Príncipe is located in the Gulf of Guinea in the Eastern Tropical Atlantic approximately 300km south of Nigeria and 200km west of Equatorial Guinea and Gabon (N 1.60°, E 7.40°). It is located on the Cameroon Volcanic Line, which includes 3 other balsalt islands São Tomé, Bioko and Annobón, and is thought to be the oldest of the islands with rocks dating from geological activity between 30-15MYA. Along with São Tomé and Annobón, Príncipe is an oceanic island surrounded by waters exceeding 2000m in depth and was never connected to the mainland, having an important influence on its terrestrial flora and fauna. Oceanographically the Gulf of Guinea is a warm body of water (25-28°C) where the Atlantic Equatorial Current originates, pushing westwards towards Brazil and the Caribbean. Along much of the rest of the West African coastline cold currents impact the shallow water environments, with the Benguela current from South Africa reaching as far as Angola and the Canary current from the North Atlantic reaching Cape Verde. This means extent of tropical marine habitats in the Eastern Atlantic is limited to this narrow band of warm water along the equator from Gabon to Sénégal. This region also happens to be the wettest in Africa receiving 2000-5000mm of rain per year. The mainland coastline is punctuated by large rivers, including the Niger and Komo, which produce shallow sediment and nutrient rich deltas and coastal waters. The Gulf of Guinea islands, along with a few other remote islands in the tropical Eastern Atlantic including St. Helena and Ascension, are unique in this region for their clear warm oceanic waters with solid substrate for different marine habitats to form.

The objective of this project was to categorise and map the distribution of the shallow marine habitats found around Príncipe. The island has a coastline of 93km and a shallow marine area (0-25m below sea level) of 86km^2 (Fig. 1). The island receives relatively low wind intensity (12-16km h^{-1}), usually directly from the south. Coastlines facing the south are more exposed to waves and have a relatively short distance (500-1000m) between the shore and deeper (>25m) water, whereas the northern coast has a more extensive shallow shelf (2-4km) and less wave exposure. Freshwater enters the sea all around the island from small streams and rivers, which forms small estuarine habitats in a few areas, but otherwise the coast faces the open ocean. The most enclosed area of sea is Bahia de Santo António, where the largest river Rio Papagaio and numerous other smaller streams flow into the shallow sheltered sediment rich bay. The main habitats types mapped were rocky reefs, boulder beds, rhodolith (gla-gla) beds and sand. The distribution of these habitats was mapped between the shoreline and 25m below sea level using transects spaced every 1km around the island (see Section 4 for full methods). The shoreline was characterised as being sandy beach, rubble, solid substrate or estuary. In the following sections maps are presented with analysis of habitat distributions and their relationship to wave exposure and depth.

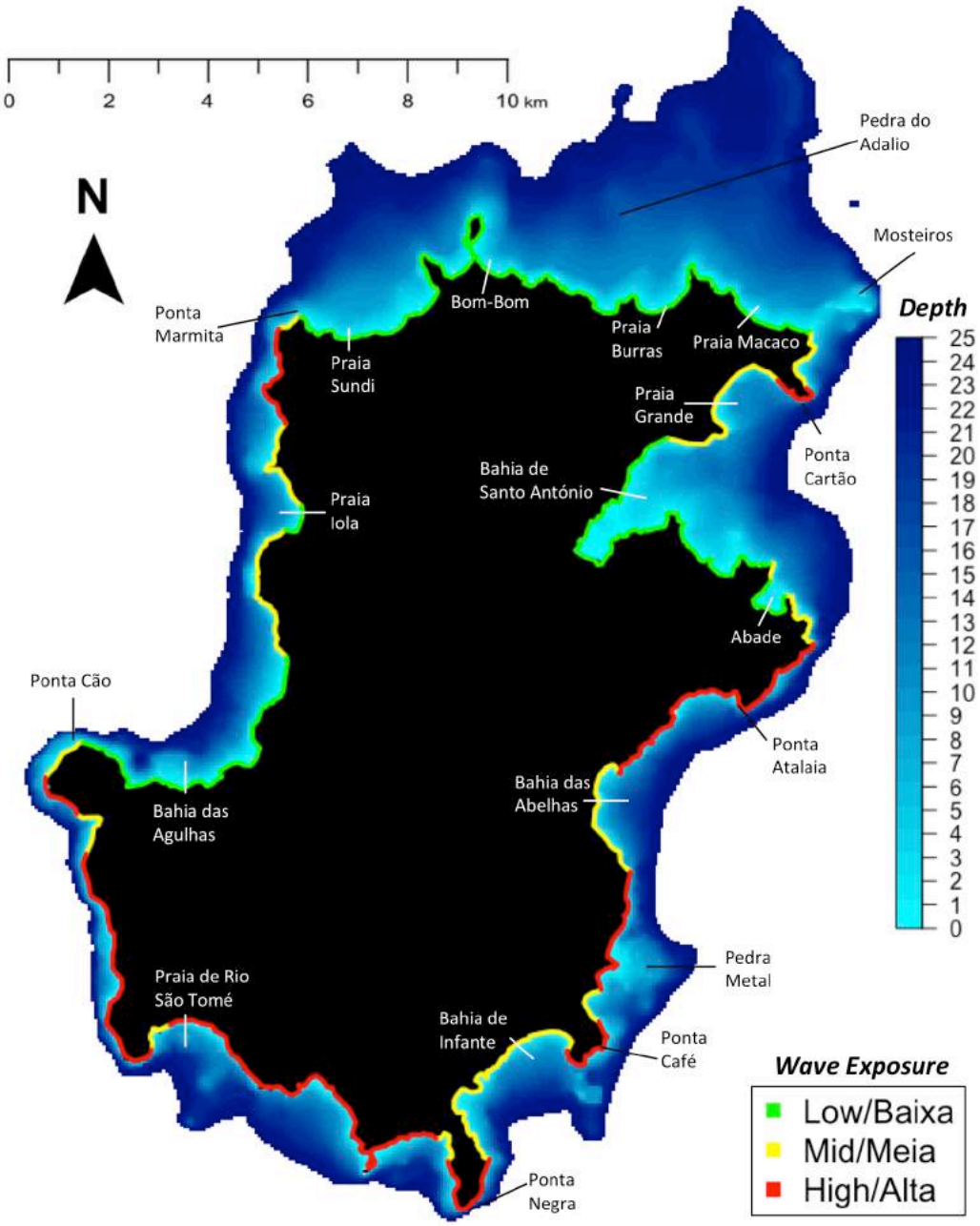

Figure 1. Depth and wave exposure in Príncipe's shallow water (<25m) environment. Depth is shown using a blue colour scale and sections of the coast defined as high, mid and low wave exposure are indicated. Place names of major bays (white text) and headlands (black text) are marked.

2. Habitat descriptions

Príncipe's marine habitats are notable in that they lack many of the components one would expect of an oceanic shallow tropical environment. Hard-bottom substrates lack macroalgae, soft corals (Alcyonacea) and have a very depauperate hard coral (Scleractinia) community consisting of just five species that produce no true carbonate reef structures. Steep coastlines and a narrow tidal range of ~1m mean that there are few places for coastal habitats to form, such as mudflats, mangroves or tidepools. While isolated pieces of the seagrass species *Halodule wrightii* have been found at Abade, no seagrass beds exist around the island. Geographic isolation from similar environments, freshwater inundations during rainy season and seasonal upwelling of cooler nutrient rich waters are potential reasons for this unusual marine community. The high level of endemism in the fish community, with 12% of species being only found in the Gulf of Guinea, may also be a result of these unique conditions.

In this project four subtidal habitats and four coastal habitats were mapped (Fig. 2). While variation in biodiversity and physical conditions are likely to exist within these habitat types, currently no research exists on the species distributions of marine life for Príncipe, hence these broad descriptions based on physical characteristics are used;

- **Rocky Reefs & Solid Shores:** These habitats occur where the volcanic basalt bedrock is exposed and life clings to the substrate. In places, such as Bahia das Abelhas and north of Praia Iola, a flat shelf extends out to sea with relatively low rugosity, while in others areas vertical rock faces plunge to great depths. In some rocky reefs, such as Ponta Café and Mosteiros, geology and erosion have produced complex reef structures with overhangs and caves. The substrate is colonised by a mixture of turf algae (<1cm in height), coralline algae, sponges, zooanthids and some hard corals depending on depth and wave exposure. A large number of fish species can be seen around rocky reefs, representing most of the major families of tropical reef fish, but with a notably lower species diversity compared to locations such as the Indian Ocean or the Caribbean. Solid rocky shoreline was usually very narrow as a result of low tidal range and steep coasts where it was usually found. Nearer the low water mark zooanthids and crabs are the most obvious biota, but otherwise little appears to live in this habitat.
- **Boulder Beds and Rubble Shores:** In many places the underlying bedrock has been eroded into rounded head-sized boulders. These boulders are stable and allow solid substrate communities similar to the rocky reefs to form. The 3D space created by boulders is quite different to the rocky reefs, with small crevices and holes for various fish (e.g. Morays) and invertebrates (e.g. Octopus) to live in, which is why this habitat is described separately. Some boulder beds also possess high levels of hard coral cover up to of 30-40% in patches, mostly of *Montastrea cavernosa* and some *Sidastrea radians* in shallower areas. In some locations e.g. Ponta Banana, boulder beds form a transition habitats between rocky reefs closer to the shore and sandy beds further out to sea. Rubble shorelines tended to be wider than solid shores and their structure provides more shade and allows tide pools to form. As a result

of this rubble shores have more intertidal marine life, including algae, anemones, sea cucumbers and molluscs.

- **Sandy Beds and Beaches:** Any loose substrate was considered as sand, although around the island the texture ranged from course highly mobile sands, such as those near Praia Macacu, to fine muddy settled sand in areas such as Bahia das Agulhas. The biodiversity of this habitat is unclear. To a causal observed the area appears empty, with no obvious benthic biota or fish community, however many of the species living here will be infaunal species (living under the sand) and will require specific research to understand this community. Occasionally large predatory fish, such as barracuda (*Syphraena barracuda*), wahoo (*Acanthocybium solandri*) or trevally (Carangidae) can be seen swimming in these areas, but how they are utilising this habitat is not yet fully understood. Sandy beaches were found in sheltered bays and tended to be quite short and narrow. They are an important habitat for turtle nesting and are visited by wading birds.
- **Rhodolith Beds:** Rhodolith describes numerous species of hard coralline algae that forms small (~5cm diameter) globular structures over mobile substrates. They are found all around the world and form semi-solid beds onto which other organisms can attach. While their ecology and biodiversity is well known in some areas, such as Europe, the species algae forming the beds and their associated species are poorly known. Rhodolith nodules are mobile and can move like tumble-weed on the sea floor, however comparing satellite images of rhodolith beds between different years indicates that the positions of these habitats are relatively stable.
- **Estuaries:** Some of the larger rivers flowing from the island form brackish lagoons, usually bounded at the seaward edge by sand banks that only submerge during the highest tides. These lagoons appear to be the main habitat for fish such as mullet (Mugilidae) and Atlantic mudskipper (*Periophthalmus barbarus*) and an important nursery ground for reef species such as the African red snapper (*Lutjanus agennes*) and crevalle jack (*Caranx hippos*). Some mangrove trees (*Rhizophora mangle*) are found in larger estuaries, but they are isolated and do not form thickets.

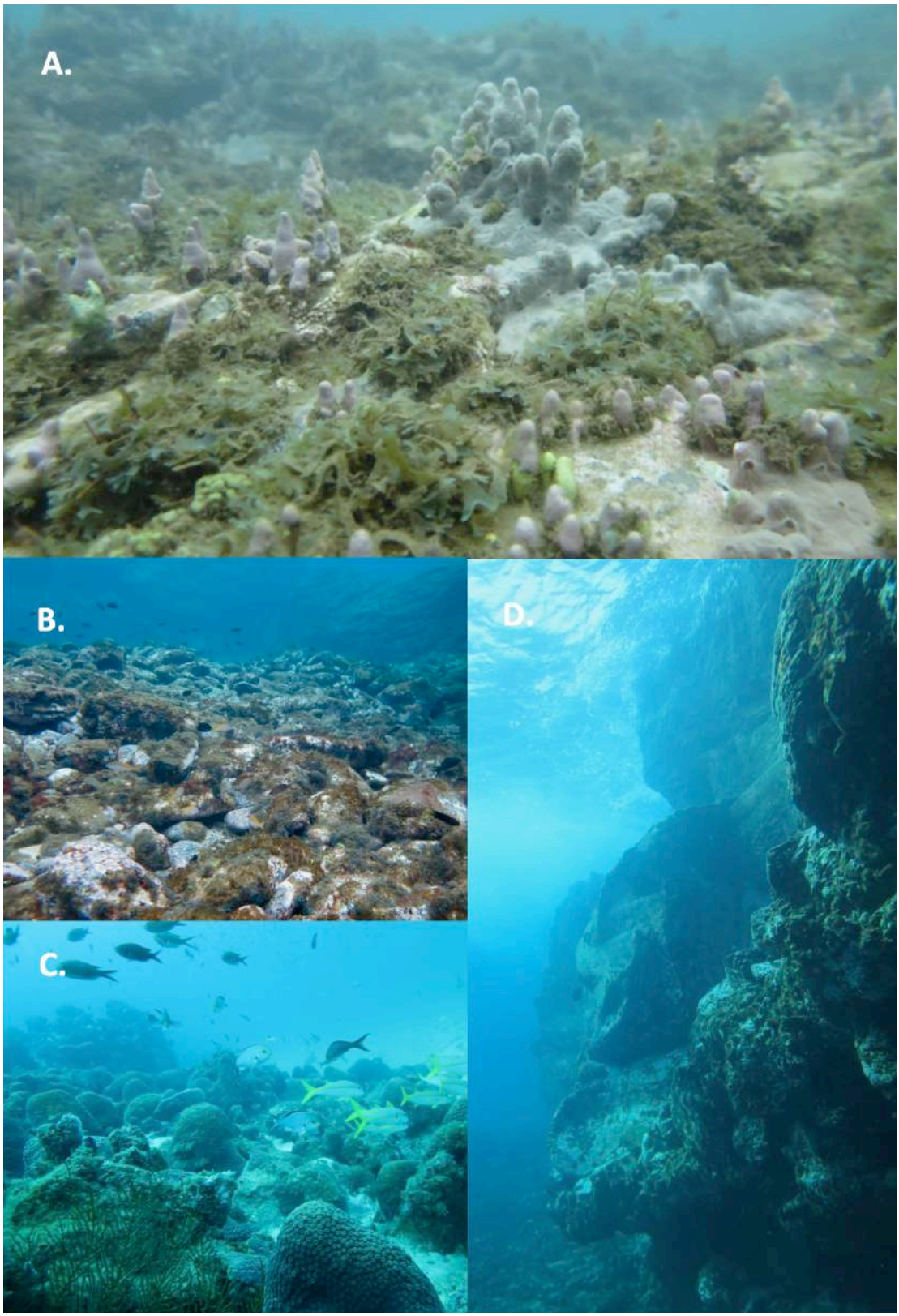

Figure 2. Marine habitats and biodiversity of Príncipe. A) Typical subtidal hard substrate benthic community with sponge, coralline algae and turf algae, B) Shallow water (0-5m) boulder community dominated by turf and coralline algae, C) Deeper (10-15m) boulder community with high coral cover of *Montastrea cavernosa*, D) Medium wave exposure rocky reef demonstrating the complex 3D structures created by the island's basalt geology, *continued next page*

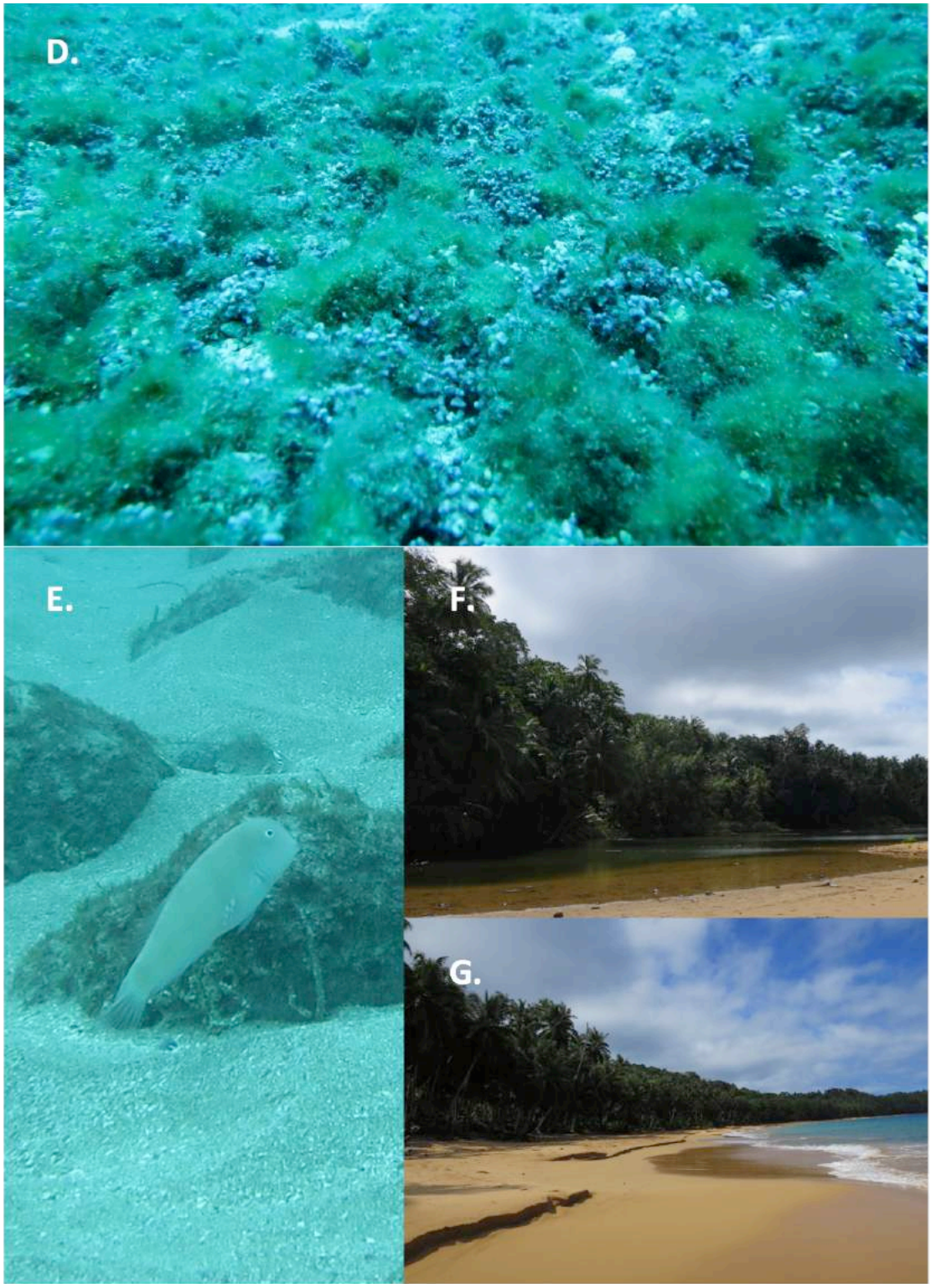

Figure 2. D) Rhodolith bed at 20m deep off the north coast, showing the 5-10cm nodules of unattached coralline algae that characterise this habitat, E) Many inhabitants of the subtidal sand beds are cryptic, such as this Pearly Razorfish (*Xyrichthys novacula*), which is excellently camouflaged and also can bury itself in the sand to be undetected by vagrant predators which move through this habitat, F) Brackish estuarine pools are found along sheltered flat shorelines where rivers outflow, but are generally small, G) Praia Grande, the largest sandy beach on Príncipe, *continued next page*

Figure 2. Marine habitats and biodiversity of Príncipe. H) Anemones (Actinaria) in a moist crevice of boulder habitat on a coast with high wave exposure, I) Tide pools amongst the boulder habitat at Ponta Banana contain a range of marine life including fish, echinoderms, molluscs and coral, J) Rocky coastlines are often steep meaning the area available to intertidal solid shoreline communities is very narrow, K) Dominant wind and waves from the south can produce very rough seas at headlands, as seen here at Ponta Negra.

3. Habitat Distributions

The largest subtidal habitat was sand covering 64.5km^2 (75.3%) of the 86km^2 mapped area, interspersed with rhodolith beds covering 11.4km^2 (13.3%) (Fig. 4). Rocky reefs covered just 6.6km^2 (7.7%) and boulder beds only 3.2km^2 (3.7%), meaning that only ~11% of the shallow water environment had a solid benthos, much of which was located close to the coast. Rhodolith was located all around the island and formed large aggregations offshore from Belo Monte, Bahia de Santo António and the southern coast. Rhodolith was most common below 15m (Fig. 3) and was significantly predicted by depth (z=6.439, p>0.001) (Table 1), but showed no relationship with wave exposure. Rocky reefs were usually located near to rocky coastlines around the island, with larger reefs extending offshore at Mosteiros, Pedra Metal and north of Praia Iola. They were significantly more prevalent in shallow (<10m) areas (z=-6.926, p>0.001), with an average rock cover of 42.3% at between 0-5m and 29.5% between 6-10m. Rocky reef was also found significantly more on exposed shores, with an average of cover of 17.8% on highly exposed coasts compared to 12.3% in mid-exposure (z=-2.075, p=0.038) and 10.1% in low wave exposure (z=-3.912, p>0.001). Deep offshore rocky reefs were rare, but were found at Pedra Adalio, Pedra de Galé and in small spots on the south coast. Boulder beds were significantly more prevalent in shallow depths (z=-6.438, p>0.001) with this entire habitat located in <15m deep (Fig. 4). There was significantly higher boulder cover in higher exposed coasts (9.9%) versus sheltered coasts (7.0%) (z=-2.636, p=0.008), but the difference in average cover is not very large. Hard coral cover was not extensive enough or in high enough density to be mapped as an independent habitat, but the cover was recorded in ground-truthing points allowing analysis of their distribution. Corals were found growing predominately boulder beds and some rocky reefs, especially in Bahia das Agulhas and Praia Santa Rita, where coral cover could reach ~30%. An unexpectedly rich boulder/coral bed was also found in centre of Bahia de Santo António. Coral presence was not significantly predicted by wave exposure, but had a significant relationship with depth (z=-4.870, p>0.001) with highest average cover (4.7%) between 6-10m.

Contrary to subtidal habitats, the shoreline of Príncipe is mostly solid with rocky shores making up 63.8km (68.6%) of the 93km coastline (Fig. 4). There were 43 sandy beaches mapped stretching along 15.8km (17.0%) of the coastline mostly found in sheltered bays and often associated with freshwater run-off. The largest beach was Praia Grande (1.4km) followed by Praia Burras (1.1km), which were the only beaches >1km long. Rubble coastline was the least extensive habitat type stretching just 11.9km (12.8%) and was found mostly along Bahia das Agulhas and Bahia de Santo António. Estuarine habitats were found in several locations around the island, but all are very small, amounting to a total area of just 0.1km^2. The largest four were >10,000m^2 and found in the north of the island at Rio Papagaio, Praia Grande, Praia Burras and Praia Caixão. In the south rivers often empty into the sea as small waterfalls or cascades, but in a few places, small estuary lagoons have formed at the mouth of Rio São Tomé, Rio Porco and Rio Bibi.

Table 1. Results of General Linear Models (GLMs) investigating habitat presence versus depth and exposure. Significant results are shown in bold and indicated as *significant, **highly significant or ***very highly significant

Habitat	Depth		Exposure Low		Exposure Mid	
	z	*p*	*z*	*p*	*z*	*p*
Gla-Gla	**6.439**	**<0.001*** **	-0.489	0.625	1.622	0.105
Rock	**-6.926**	**<0.001*** **	**-3.912**	**<0.001*** **	**-2.075**	**0.038***
Boulder	**-6.438**	**<0.001*** **	**-2.636**	**0.008** **	-0.659	0.510
Coral	**-4.870**	**<0.001*** **	-0.937	0.349	-0.469	0.639

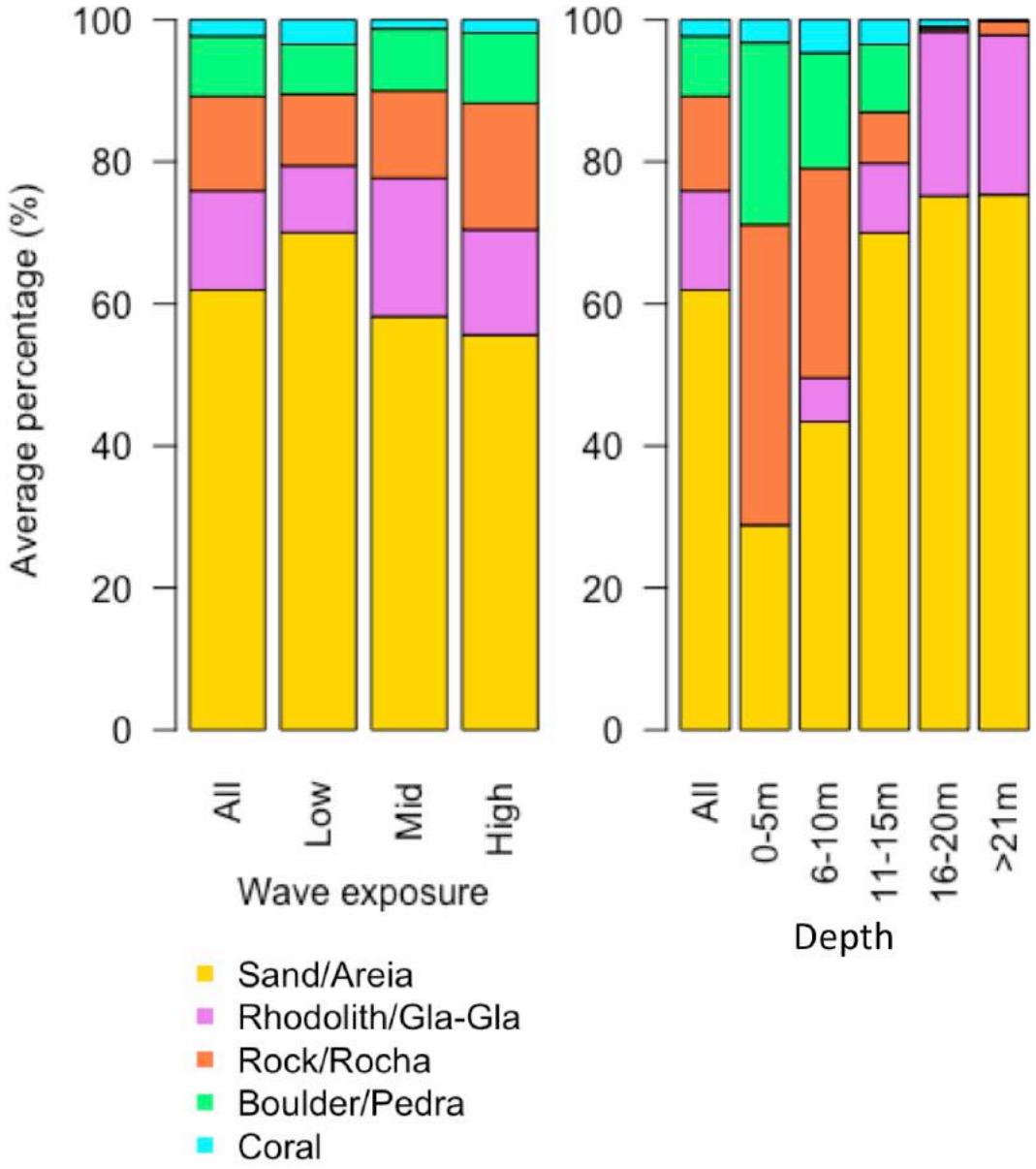

Figure 3. Barplots of the mean benthic cover at different wave exposures and depth categories for the mapped habitat types and hard coral (Scleractinia). Data are derived from ground-truthing points.

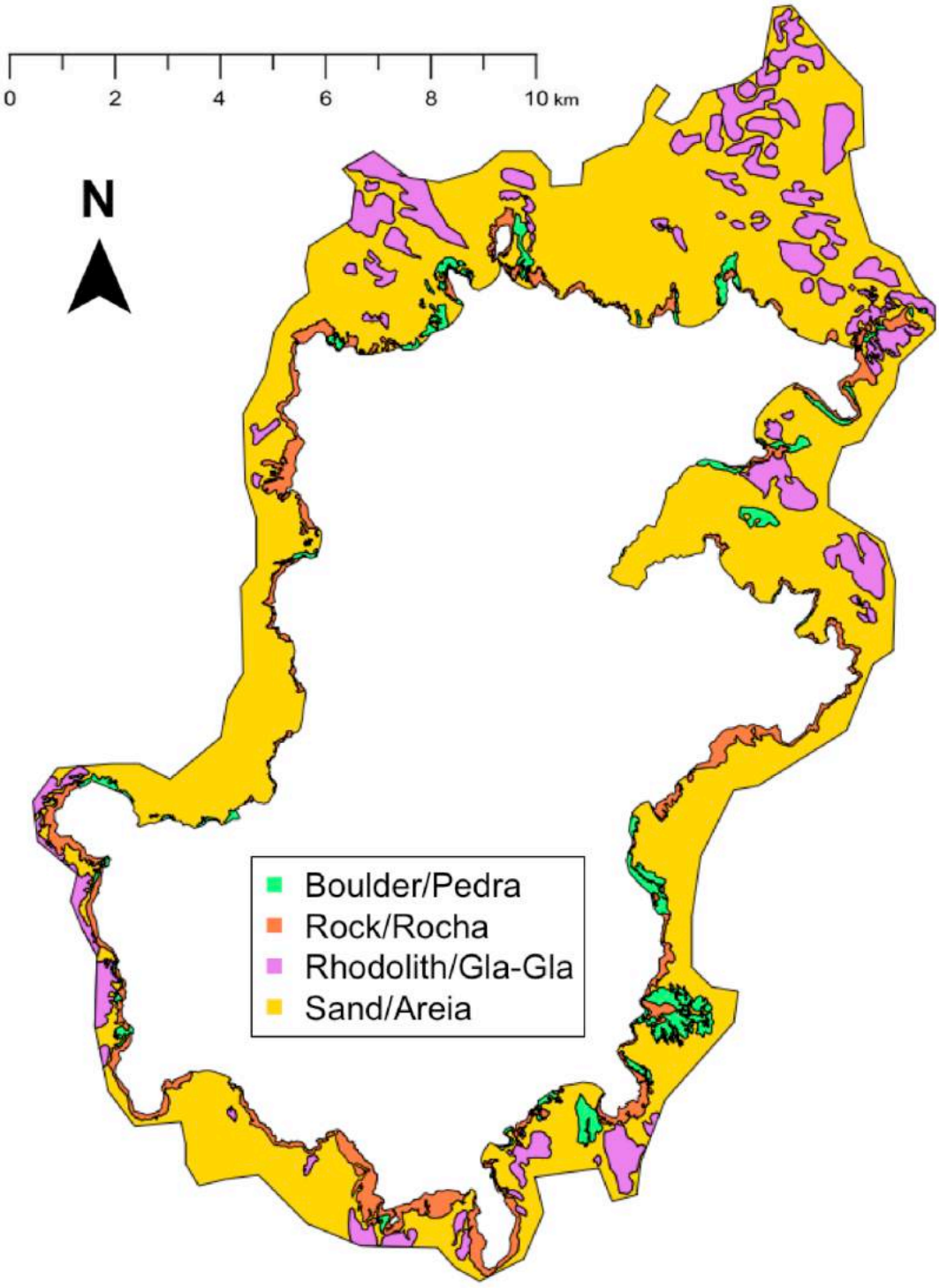

Figure 4. Habitat map of the shallow marine area (0-25m deep) around Príncipe showing the distribution of boulders, rocky reefs, rhodolith beds and sandy bottoms.

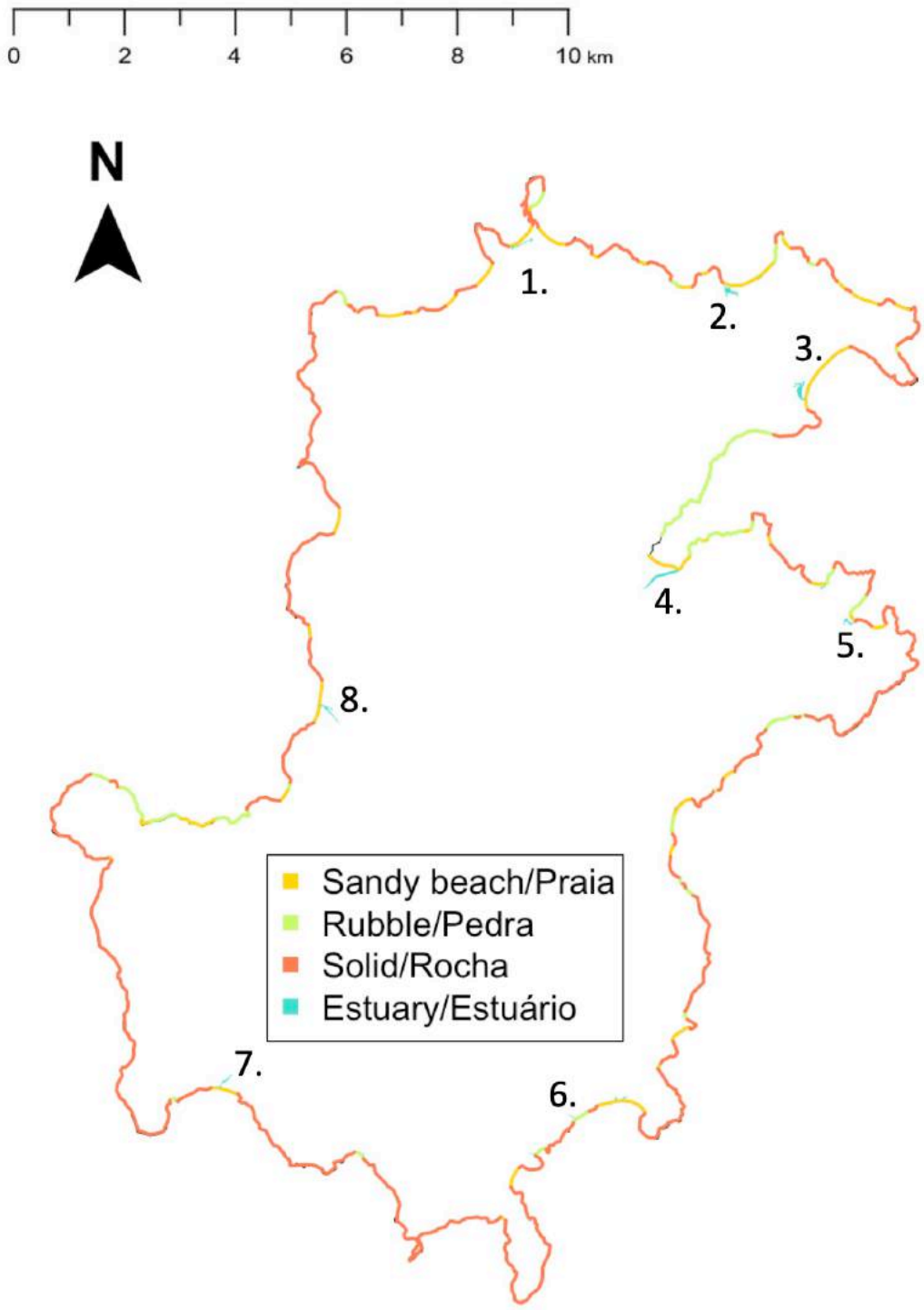

Figure 5. Habitat map of the shoreline of Príncipe showing solid rocky shore, boulders, sandy beaches and estuaries. Significant beach and estuary complexes are numbered; 1. Praia Bom Bom, 2. Praia Burras, 3. Praia Grande, 4. Rio Papagaio, 5. Abade, 6. Praia Infante, 7. Rio de São Tomé, 8. Praia Caixão.

4. Conclusions, Conservation importance and Future Research

The marine habitats of Príncipe have conservation value because of their unique ecology and endemic species, their importance for supporting artisanal fishing and food security on the island and their attraction to tourism. The island's small size, remoteness and low capacity to manage environmental threats makes it vulnerable to degradation, but as of yet most of the coastline remains unaltered by human development or deforestation. Pollution is poorly controlled and is probably a significant threat to marine life in the estuary of Rio Papagaio and Bahia de Santo António near the island's capital, but the small population size and low economic development level mean that pollution is not evident in most near-shore environments. Fishing is a diverse and important sector of the island's economy, using a range of gears and techniques including free-diving spear-gunners hunting for reef fish and octopus, known locally as *submarinos,* purse-seining with motorised boats offshore for mackerel, flying fish and other small pelagics and the use of simple hand-lines while sitting on rocks or from small canoes. All areas of the shallow-water environment are available to fishermen, with boats being seen regularly around the island, including the relatively uninhabited southern coast. It is assumed fishing will be having an impact on marine life, and, although the magnitude of this is currently unknown, may threaten biodiversity and future fish stocks.

The marine life of Príncipe and the Eastern Tropical Atlantic are poorly understood. During a short research expedition of less than a month Wirtz et al. (2007) documented 59 fish species as new records for São Tomé and Príncipe and ten that were new to science, demonstrating how little marine science has been conducted in the area. The work of Peter Wirtz, Bob Drewes, An Bollen and an expedition made by La Palma university (e.g. Tuya et al. 2018) represent the majority of the marine biodiversity and ecology research that has taken place in recent years (Bollen 2017). Their work provided this habitat map with a foundation of information on the species and habitat types that exist around Príncipe. This project adds to previous work by providing spatial information and analysis on habitat extents, which it is hoped will be a crucial cornerstone for this small base of knowledge. The habitat distributions presented demonstrate overarching ecological themes for Príncipe's marine ecology e.g. lack of seagrass and mangroves, large sandy beds in deeper offshore locations, more rocky reefs and solid substrate nearer to the shore.

Looking to the future, a comprehensive ecological assessment of Príncipe's marine life is greatly needed to understand human impacts (e.g. fishing and pollution) and identify conservation priority zones based on ecological uniqueness, important species (IUCN red-listed, endemic, keystone) and human use value (fisheries and tourism). Omali Vida Non are recording fish landings, monitoring fishing boat movements in the near-shore area and also deploying Baited Remote Underwater Videos (BRUVs) to understand the ecology of fish species relevant to the local fishery. Fundação Príncipe Trust carry out regular ReefCheck monitoring at three sites around the island for benthic cover and fish abundance and size, the first and only regular monitoring programme of Príncipe's coral dominated sites. Tuya et al. (2018) published their findings about the fish community of rocky reefs in Príncipe, but did not link this information with benthic or environmental variables known to impact species distributions. Maia (2018) used a method combining various elements of tropical

marine ecology on sites around São Tomé, allowing him to analyse patterns in habitat, environment and conservation/fisheries important species. A replication of Maia's methods in Príncipe would greatly benefit existing research efforts and help build a more comprehensive picture of its marine habitats.

5. Methods

Habitat distribution was mapped in the field using rapid habitat surveys of major benthic types conducted around the island. The marine zone <25m deep was divided into 54 transects approximately 1km apart running perpendicular to the coast. Transects were pre-loaded onto a GPS device before heading to the field and reached using a small boat. Depth measures were taken using a Plastimo Echotest II echo-sounder while driving slowly along the transect. A rapid habitat survey was conducted in points at 5m, 10m, 15m, 20m and 25m deep, giving a total of 270 surveys (Fig. 5). At each point a circular area 10m diameter area (78.6m^2) was assessed and the benthic cover of rock, boulder, sand, rhodolith and coral was estimated visually to the nearest 10% (see Beeden et al. 2014 for a similar method).

Satellite imagery of Príncipe was accessed from the LandSat-8 Level 2 repository on United States Geological Survey (https://landsat.usgs.gov/landsat-8) on several relatively cloudless days in 2018. Level 2 processing comes with atmospheric corrections applied, but required further processing to remove clouds, sun-glint (Lyzenga 1981), and correct water column depth (Hedley et al. 2005). These image processing steps were applied successfully, but an unsupervised classification of habitat types based on radiance values from the satellite pixels failed. Some areas near the coast appeared unusually low radiance, perhaps because of shadows from cliffs, which prevented accurate habitat classification using this method. Instead the processed satellite images and were used manually to digitise (draw) habitat areas, which were clearly visible on the satellite images (Fig. 6) and corroborated with rapid habitat assessment data. The accuracy of these manually produced layers is probably good (10-20m) in the shallow inshore regions, where the satellite image is clearest and the author had best personal knowledge of habitat distributions. In deeper offshore areas, particularly for gla-gla beds, the boundaries of habitats may have lower resolution and accuracy (50-100m).

Benthic data from rapid habitat assessments were used to statistically test the distribution patterns of subtidal rock, boulder, rhodolith and coral. The presence or absence of a benthic type was compared with depth and wave exposure to determine if these factors significantly predict the distribution of these habitat types. Estimated percentages were converted to presence/absence data (0% = 0 / >0% = 1) to reflect the numerous replicates where the benthic categories were recorded as zero. Depth was measured as a numeric variable, collected using an echo-sounder in the field. Wave exposure was categorised post-fieldwork by overlaying a compass on a map of the coastline and measuring the degrees facing open ocean from the south (i.e. betweeen 90-270° on the compass). Over 90° facing open waters to the south was classified as high exposure, 45-90° as mid and <45° as low. General Linear Models (GLMs) were conducted for each benthic component, excluding sand. The maximal model including the interaction between depth and exposure was initially tested, but found no significant results, hence GLM results are presented for the model in the equation: $Presence\ of\ Benthic\ Type = Depth + Exposure$. The GLMs used the binomial distribution, appropriate for presence/absence data. All satellite and data analysis were carried out using R.

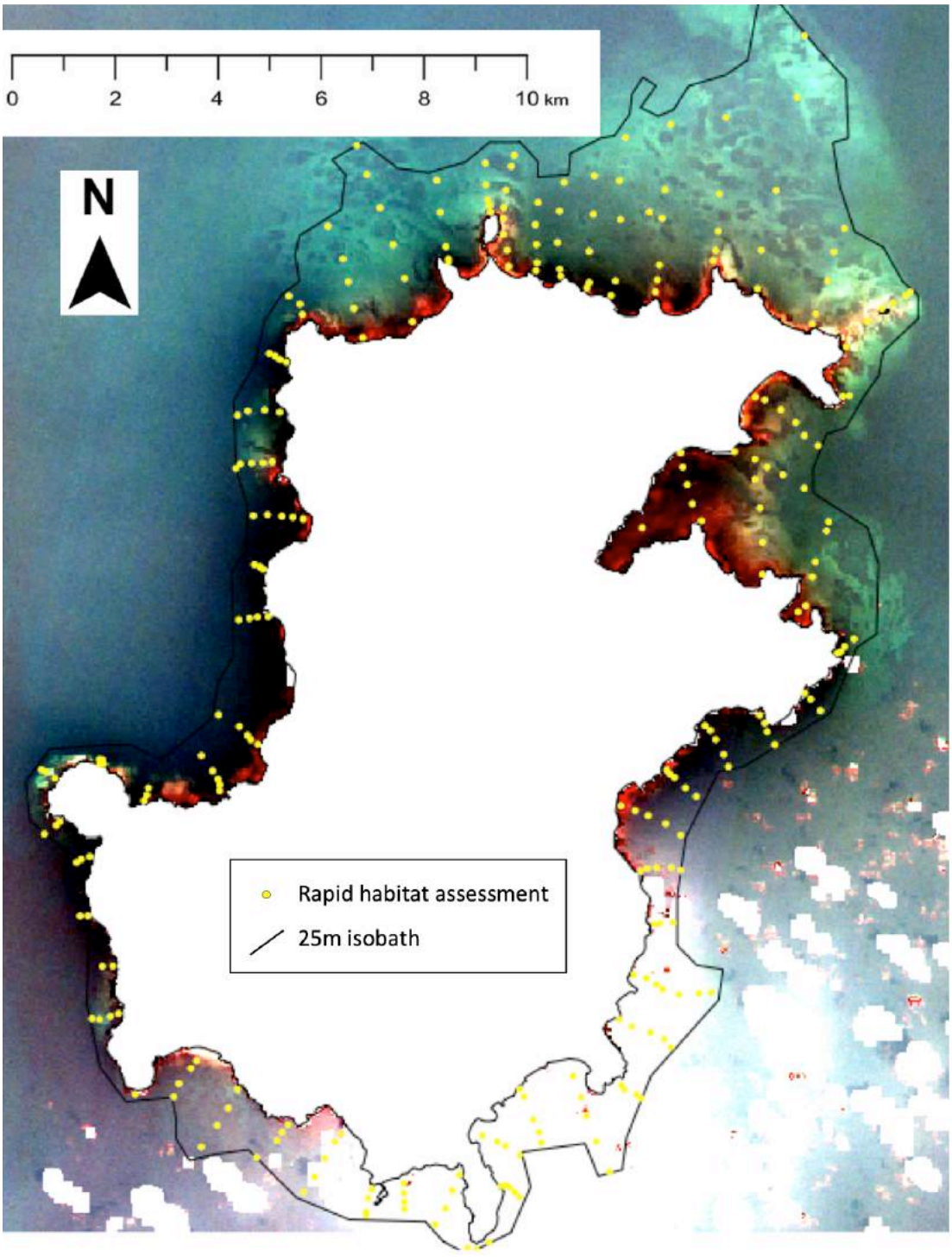

Figure 6. Landsat-8 Level-2 satellite image of Principe taken on 20th March 2018. Image was pre-processed for atmospheric corrections and underwent additional processing to remove clouds, land, sun-glint and water column depth effects. The locations where Rapid Habitat Assessments were conducted are indicated along with the 25m isobath, which was used to delimit the area mapped for habitats.

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