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## **Mapping Velondriake:** the application of bathymetric and marine habitat mapping to support conservation planning, southwest Madagascar



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## Abstract

There is a critical need for accurate data on coral reef habitat status and biodiversity in southwest Madagascar on which to base systematic MPA planning methods. However, the acquisition of reliable data documenting the location, distribution and status of marine habitats using conventional ecological monitoring techniques is logistically difficult, limited in geographical scope, and can become prohibitively expensive when working on a broad scale.

Working with the United States National Coral Reef Institute (NCRI) and local communities in the Velondriake protected area network, a detailed map of local marine and coastal ecosystems has been created, based on 2.4 metre resolution QuickBird imagery. This comprises a high-resolution spectral bathymetry and coastal habitat map. The accuracy of the outputs is estimated to be higher than 70%, at a cost of approximately \$2/hectare. The data are combined in a geographical information system (GIS) allowing for further analysis, vulnerability mapping and a range of cartographic outputs which provide the basis for encouraging and fostering community dialogue about local resource use.

This novel approach has enabled the production of the highest resolution habitat and bathymetric maps available for the region. These outputs have proven to be instrumental in developing a coherent protected area zoning plan and set of measurable management objectives for Velondriake, and this technique serves as a cost effective solution for surveying large swathes of shallow marine and coastal habitat.

**This technique is essential for the adoption of a holistic, ecosystem-scale approach to conservation planning in the region and a fundamental prerequisite to the development of a resilient network of marine and coastal protected areas across Madagascar's southwestern reef system.**

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This report is available at <http://gis.blueventures.org>, where further online resources and live datasets are available.

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**Front page:** spectral bathymetry of the Velondriake network, southwest Madagascar, derived from DigitalGlobe QuickBird imagery. Shallow marine areas are red and yellow, and deeper marine areas are black and green.

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## Introduction

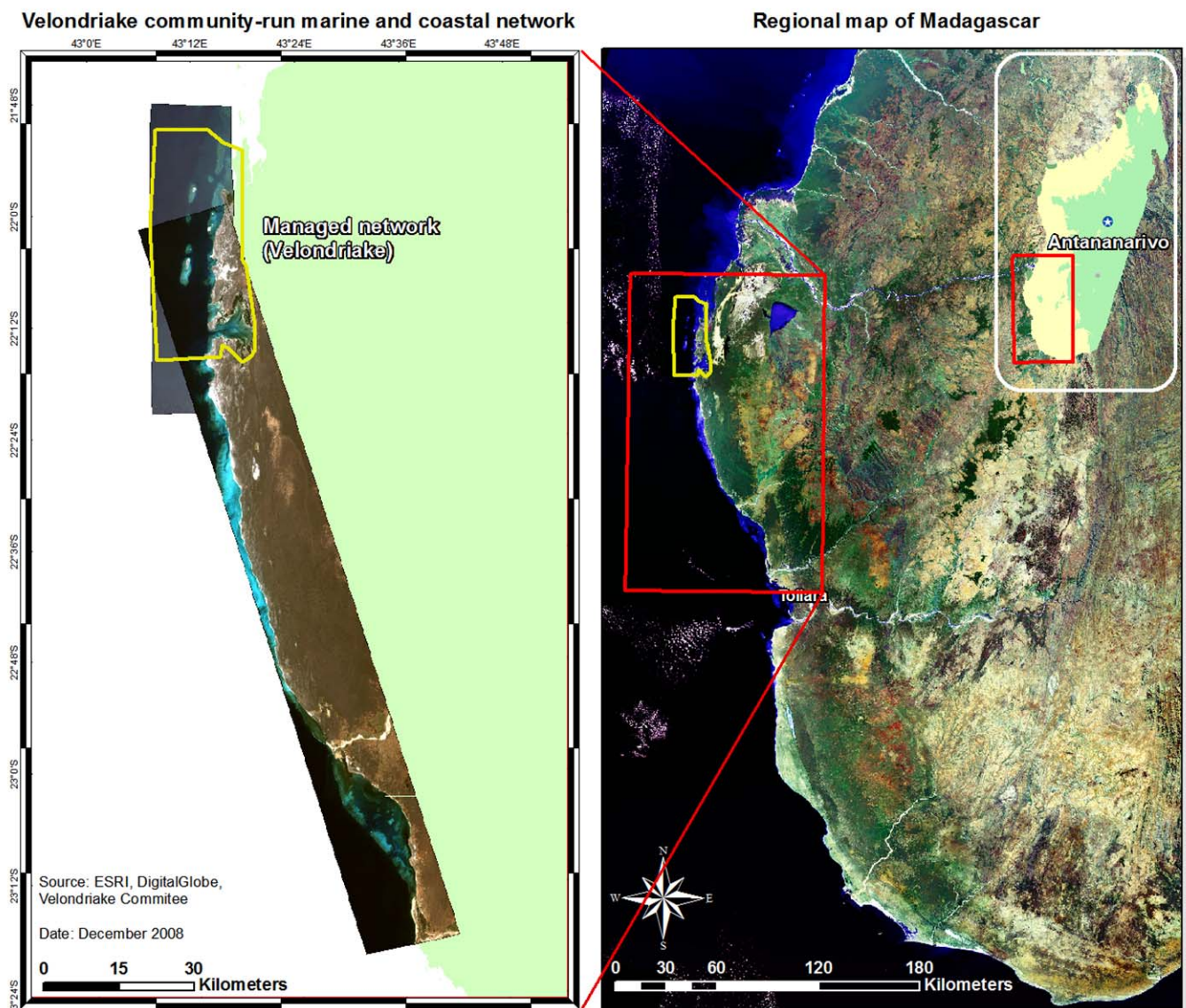
The remote Toliara region of southwest Madagascar contains some of the largest and most biodiverse coral reef systems in the Indian Ocean. This region is home to the third largest barrier reef in the world which is not only critical for thousands of marine species, but is essential to the survival of the indigenous semi-nomadic, tribal Vezo people.

All of the country's accessible reefs are exploited by traditional artisanal fisheries. Fishing effort on reefs has increased considerably over the past decade as a

result of rapidly expanding market demand. The growth of fishing effort has coincided with a diversification in the range of species targeted by fishers and collectors.

Marine protected areas (MPAs), particularly those incorporating fishery no-take zones (NTZs), have rapidly emerged as an important tool for improving the sustainability of tropical fisheries.

Figure 1. Location of the Velondriake network, southwest Madagascar, and QuickBird imagery swatches.



Blue Ventures, in collaboration with the National Coral Reef Institute (NCRI), part of the Nova Southeastern University in Florida, have developed a geographical information system (GIS) for the Velondriake network.

Blue Ventures is an award-winning, London-based not-for-profit organisation dedicated to working with local coastal communities. The results from our work help the local populations we work with to develop sustainable and alternative livelihoods, and propose new ideas to benefit coastal communities everywhere.

The Velondriake protected area is an 800km<sup>2</sup> network of marine and terrestrial reserves, which have been chosen by the community in response to their concern about the sustainability of coastal and marine resources. The villages in Velondriake are grouped into three regions, and have established a central Velondriake Committee, with members from each village, providing input and insight into all stages of planning, research, and implementation.

Throughout the MPA planning process, conservation practitioners have required data on coral reef habitat status and biodiversity on which to base systematic MPA zoning methods. Such data are essential for the adoption of a holistic, ecosystem-scale approach to conservation planning in the region and a fundamental prerequisite to the development of a

resilient network of marine and coastal protected areas.

However, the acquisition of reliable data documenting the location, distribution and status of marine habitats using conventional ecological monitoring techniques is logistically difficult, limited in geographical scope, and can become prohibitively expensive when working on a broad scale.

Working with the local communities, we have created a detailed map of regional marine and coastal ecosystems. This is comprised of a high-resolution spectral bathymetry and coastal habitat map, over which additional data layers, derived from ongoing MPA development programmes, have been incorporated.

The results from this mapping project have been presented to the community management committees responsible for zoning Velondriake, and have formed the basis for delineating protected area boundaries.

This report summarises the methodology used for production of the baseline habitat maps used to support the MPA zoning process, including results of the technique, and implications for MPA planning elsewhere in Madagascar and the broader Indian Ocean region.

## Methodology

### Overview

#### Study location

The Velondriake network (figure 1) is situated in southwest Madagascar, is 823km<sup>2</sup> in size and comprises over 40km of coastline. A boundary box of the network stretches from 21.83°S, 43.13°E (north-west corner) to 22.26°S, 43.30°E (south-east corner). The project base for this study was the Blue Ventures research site, located 0.5km from the village of Andavadoaka, approximately at the centre of the Velondriake network. The reefs in Velondriake occur at the northern extent of a reef system that stretches for 350km. Most of the reefs in this area are located between 3km and 5km offshore, and are composed of shoreline fringing communities, patch reefs, a series of inner lagoon reefs and a barrier reef. Until this study, the most detailed bathymetric mapping charts available for the region were those created by the French *Service Hydrographique de la Marine* in the 1960s.

#### Fieldwork and groundtruthing

We surveyed representative habitats from the entire Velondriake network. Over the duration of 2 weeks, we carried out several hundred kilometres of transects within Velondriake by boat, recorded 275 underwater videos of the seafloor substrate for further analysis and groundtruthing, and recorded 100,000 bathymetric (depth) readings. The on-board monitoring setup combines readily available components, which are multiplexed into a laptop. The equipment consists of an accurate differential GPS (dGPS), an underwater camera and GPS, field laptop, acoustic sounder and truck battery. The data are later processed using MatLab, ArcMap and ENVI.

All marine groundtruthing was completed using a 7m fibreglass-hulled boat, upon which surveying

equipment was assembled, mounted and dismantled daily.



An L-shaped wooden frame was constructed to fit the side of the boat, with an acoustic transducer attached to the bottom. The transducer constantly recorded the bathymetry, but only when the boat speed was below 14km/h; at higher speeds increased water drag distorted readings. An underwater camera with a 45m cable was multiplexed with a standard handheld GPS (eTrex Legend) to provide georeferenced videos of the benthic substrate, which were later analysed with the satellite imagery to reference and groundtruth habitat type.

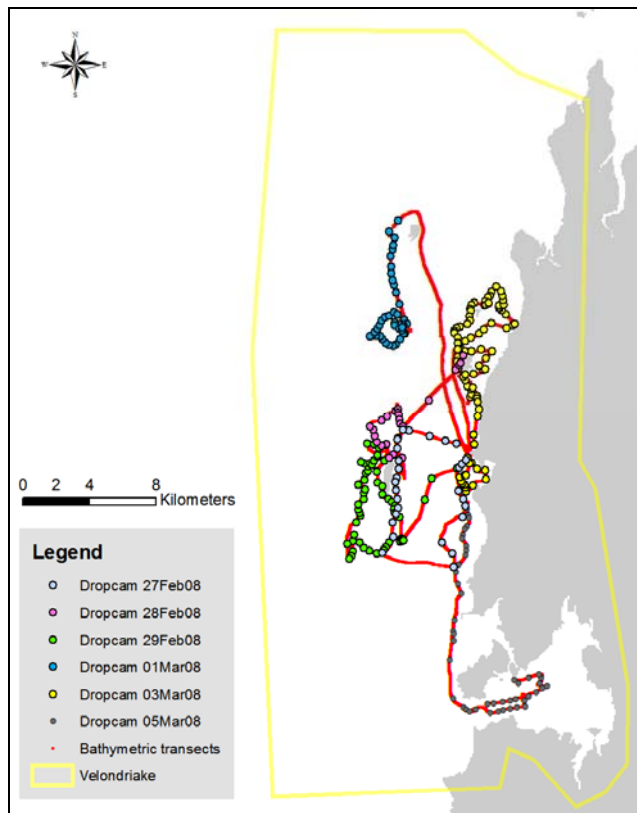
A highly accurate differential GPS (dGPS) recorded the precise location of the boat, and all equipment was attached to a field laptop, which recorded each datastream whilst overlaying the current position of the boat on a satellite map.



This allowed us to investigate relevant areas on the satellite map by positioning the boat over points of benthic interest, such as the perimeter of a reef, or on areas of rapid colour change. Upon arrival at such sites the underwater camera would be lowered and between 10 and 60 seconds of footage were recorded, depending on the homogeneity and complexity of the substrate ('Dropcam' points, figure 2).

After each day's surveying, the data were run through custom routines using MatLab v7 software. This process filters the data to enable selection only of bathymetric data with a corresponding high positional accuracy, to account for hourly variations in the accuracy of the dGPS.

**Figure 2. Bathymetric survey transects (red line) and underwater camera surveys (Dropcam points)**



## Creation of the habitat map and bathymetric digital elevation model (DEM)

### Post processing

As of 2008, the QuickBird satellite collects the second highest resolution imagery of Earth, behind WorldView-1, also owned by DigitalGlobe. The 4-band (R, G, B, NIR) QuickBird imagery used in the analysis of benthic substrate discrimination and bathymetric mapping provided an 8bit, 2.4m pixel

resolution, and was acquired on 11 September 2005 at 07:41 GMT (Scene ID 1010010004834D00, cloud cover 0%, average off-nadir angle 23°, average target azimuth 143°, with very high water clarity). We acquired a second QuickBird image (Scene ID 10100100014C3100) to cover the northern extent of the Velondriake region, but sun glint was very high, providing us with terrestrial data, but little marine data. A 2.5m resolution SPOT satellite image (acquired on 30 March 2006) was also used to improve distinction on the classification of the red algal ramparts class.

Due to the effects of the atmosphere and water column, marine substrates are much less easily identifiable than remotely sensed terrestrial habitats. To account for this, the image was radiometrically calibrated and corrected for atmospheric radiance, and the RGB bands were processed to remove the spectral effects of the water column (procedures detailed in Purkis & Pasterkamp, 2004).

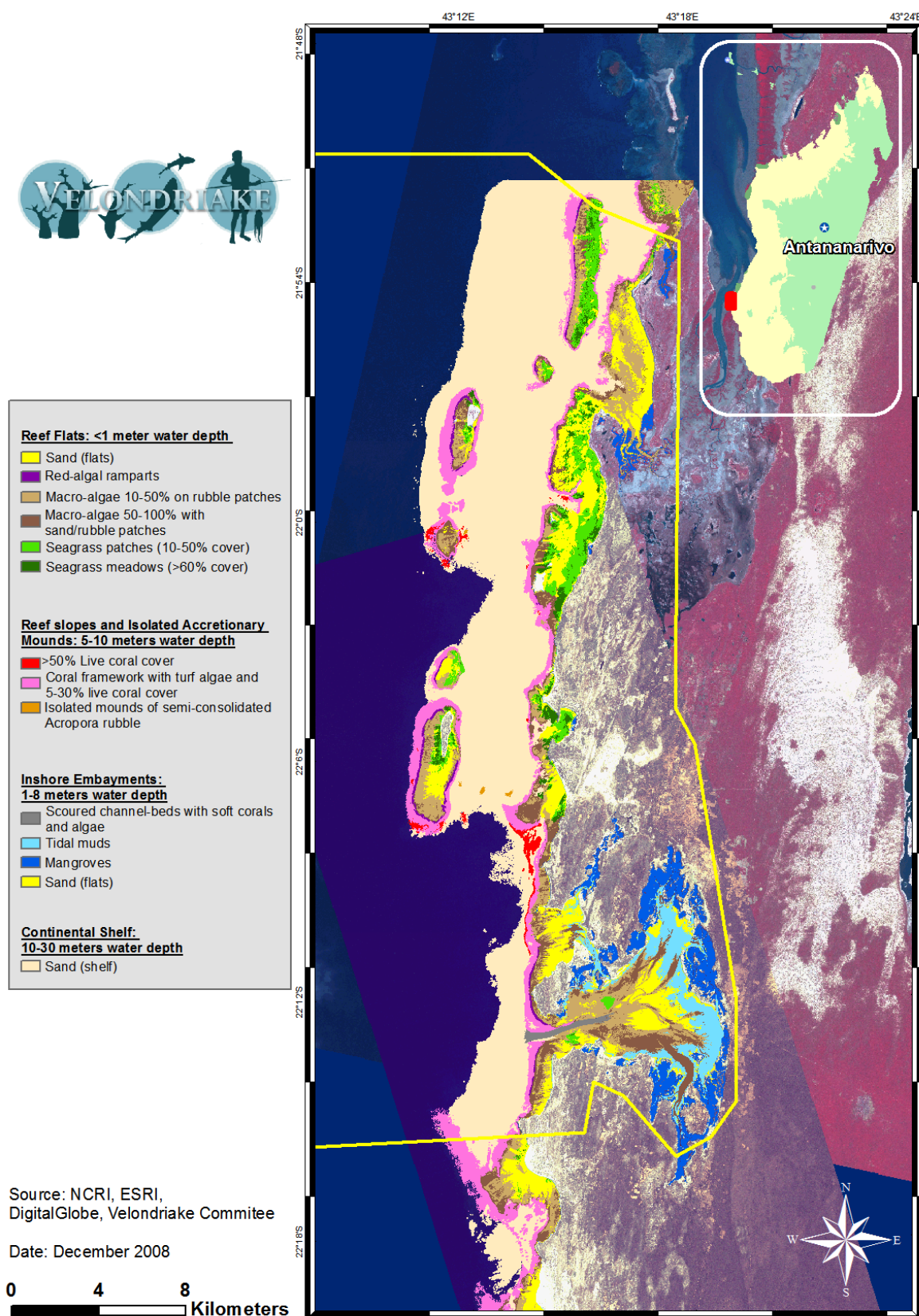
The bathymetric data can be extrapolated to a much wider area covered by the satellite imagery, rather than just the study region. Each bathymetric recording was cross-referenced to the associated georeferenced pixel on the satellite imagery. The correlation between the log-ratio of the green and blue bands and the depth can then be extrapolated to other areas of the satellite image, to produce an estimated bathymetry in regions that were not covered by boat transects. Distance travelled by boat might only be 20 to 30 km in one day, but since the transducer fires at a rate of three times per second, thousands of data points are captured.

Once the depth data were extrapolated, they were modelled as a digital elevation model (DEM). The satellite imagery was then draped over the DEM producing a 3-dimensional representation of Velondriake's seafloor.



## Results

Figure 3. Habitat map of Velondriake, and location in Madagascar








## Habitat map (figure 2)


Analysis of the underwater videos and QuickBird imagery produced 14 distinct habitat classes, which were grouped into four main categories, dependent on water depth and location: reef flats (<1m depth); reef flats and isolated accretionary mounds (5 to 10m depth); inshore embayments (1 to 8m depth); and continental shelf (10-30m water depth).


### Reef Flats: <1 meter water depth

 Sand (flats) - Shallow seafloor characterised by unconsolidated carbonate sand sheets. This class dominates the flats of offshore islands, as well as the shallows of coastal fringing reefs and the interior of mangrove-dominated embayments.


 Red-algal ramparts – An elevated margin bordering the seaward periphery of reef flats. This slightly elevated structure is built by actively growing calcareous algae. Powerful wave energy during high tides and sub-aerial exposure during low tides inhibit the colonisation of coral communities along these algal ridges.

 Macro-algae 10-50% on rubble patches - Metre-sized patches of coral rubble within unconsolidated sand sheets. Rubble patches typically provide hard substrate onto which a sparse *Sargassum* spp.-dominated algal assemblage adheres.


 Macro-algae 50-100% with sand/rubble patches - Very dense macro-algae, typically *Sargassum* spp., atop expansive patches (>5m diameter) of coral rubble. The *Sargassum* spp. typically forms dense meadows, growing up to a meter tall. Sparse rubble and sand intersperses the fields of algae.


 Seagrass patches (10-50% cover) - Patches consist of a combination of *Syringodium isoetifolium*, *Thalassia testudinum*, and


*Thalassodendron ciliatum*, and attain patch diameters of several meters.

 Seagrass meadows (>60% cover) - Dense seagrass meadows with a shoot density that greatly exceeds 100 per m<sup>2</sup>. Dominant species is *Thalassodendron ciliatum*, with sub-dominance by *Thalassia testudinum*. *Syringodium isoetifolium* was infrequently observed in association with *Thalassia*.

### Reef Slopes and Isolated Accretionary Mounds: 5-10 meters water depth


 >50% live coral cover - Abundant and diverse live stony coral interspersed with sponges, turf algae and sparse stands of macro-algae. This assemblage sits atop a stable eroded dead reef framework, the existence of which provides evidence for a previous period of high-cover by massive corals. The dead framework typically provides several metres of relief above a seabed of unconsolidated sand.


 Coral framework with turf algae and 5-30% live coral cover - Dead coral framework covered with turfing algae and sparse macro-algal stands. Sporadic and isolated patches of dense macro-algae atop the framework were occasionally encountered. Live stony corals are present at low density and particularly prevalent in association with spur-and-groove morphology. Sub-meter patches of live coral cover exceeding 50% were rarely encountered.


 Isolated mounds of semi-consolidated *Acropora* rubble – Mounds of up to a hundred metres diameter rising tens of meters above a sandy seabed, composed entirely of dead *Acropora* fingers. The rubble is semi-consolidated to the point that the flanks of the deposits can slope steeply. These mounds are cemented and presumed stable. Both a red-algal crust and turfing algae are abundant. Occasional isolated fist-sized colonies of regenerating *Acropora* are observed. Settlement by massive corals is notably absent. The mounds are exclusively found on the leeward side of the offshore reefs, but

separated by several hundred meters from the true reef slope.


#### Inshore Embayments: 1-8 meters water depth

 Scoured channel-beds with soft corals and algae - Channels with high velocity tidal flow capable of removing unconsolidated sediment and scouring the seabed. The result is a flat, bare, low-relief hard-ground, providing settlement opportunity for a high-flow assemblage of soft corals and well-rooted patches of *Sargassum* spp.. The soft coral *Xenia* spp. dominates.

 Tidal muds - Intertidal lime muds onlapping mangrove mangals. This class fringes the perimeter of lagoonal embayments and is prevalent in the southern coastal zone of the study area. These muds are submerged at high tide.

 Mangroves - Mangrove mangles thrive along tidal muds with high organic contents and are commonly found in bays and inlets, which are protected from high wave energy. These trees obtain

fresh water from sea water by secreting excess salt through their leaves or blocking absorption of salt at their roots. The mangrove forests near Andavadoaka consist of five species including: *Avicennia marina*, *Bruguiera gymnorrhiza*, *Ceriops tagal*, *Rhizophora mucronata*, and *Sonneratia alba*.

 Sand (flats) - As for the reef flats, this class is composed of expansive unconsolidated sand sheets in water depths < 1 meter. It is associated with areas seaward of the tidal muds.

#### Continental Shelf: 10-30 meters water depth


 Sand (shelf) - This class encompasses the expansive areas of seafloor that separate the landward fringing reefs from offshore reef systems. Water depth varies from 10 to 30 meters and the substrate is unconsolidated carbonate sand. In areas of low hydrodynamic flow, dense cyano-bacterial mats establish, serving to bind the sand sheets. Mobile shelf sands gather near topographic highs and occur along the base of reef slopes, beyond the framework-to-rubble interface.

Figure 4. QuickBird imagery draped over the bathymetric digital elevation model (DEM) of Andavadoaka, Nosy Hao and surrounding coastline. Land areas are masked (black in colour).

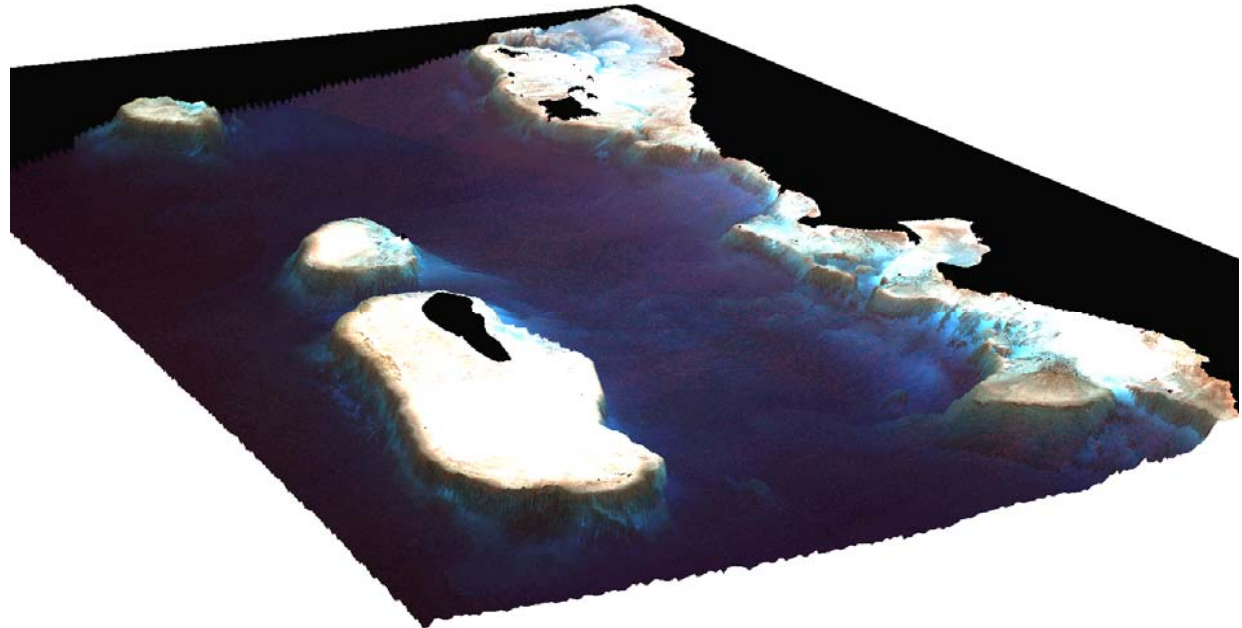
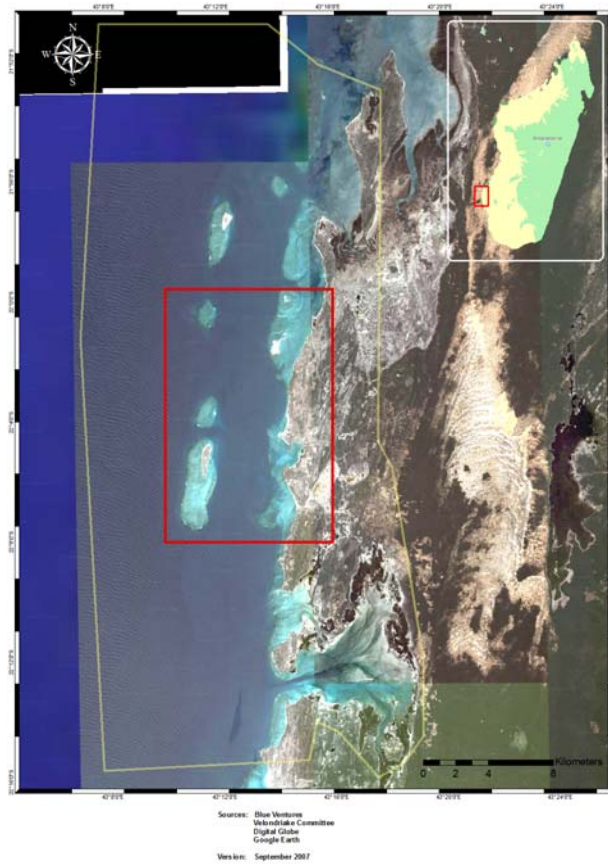
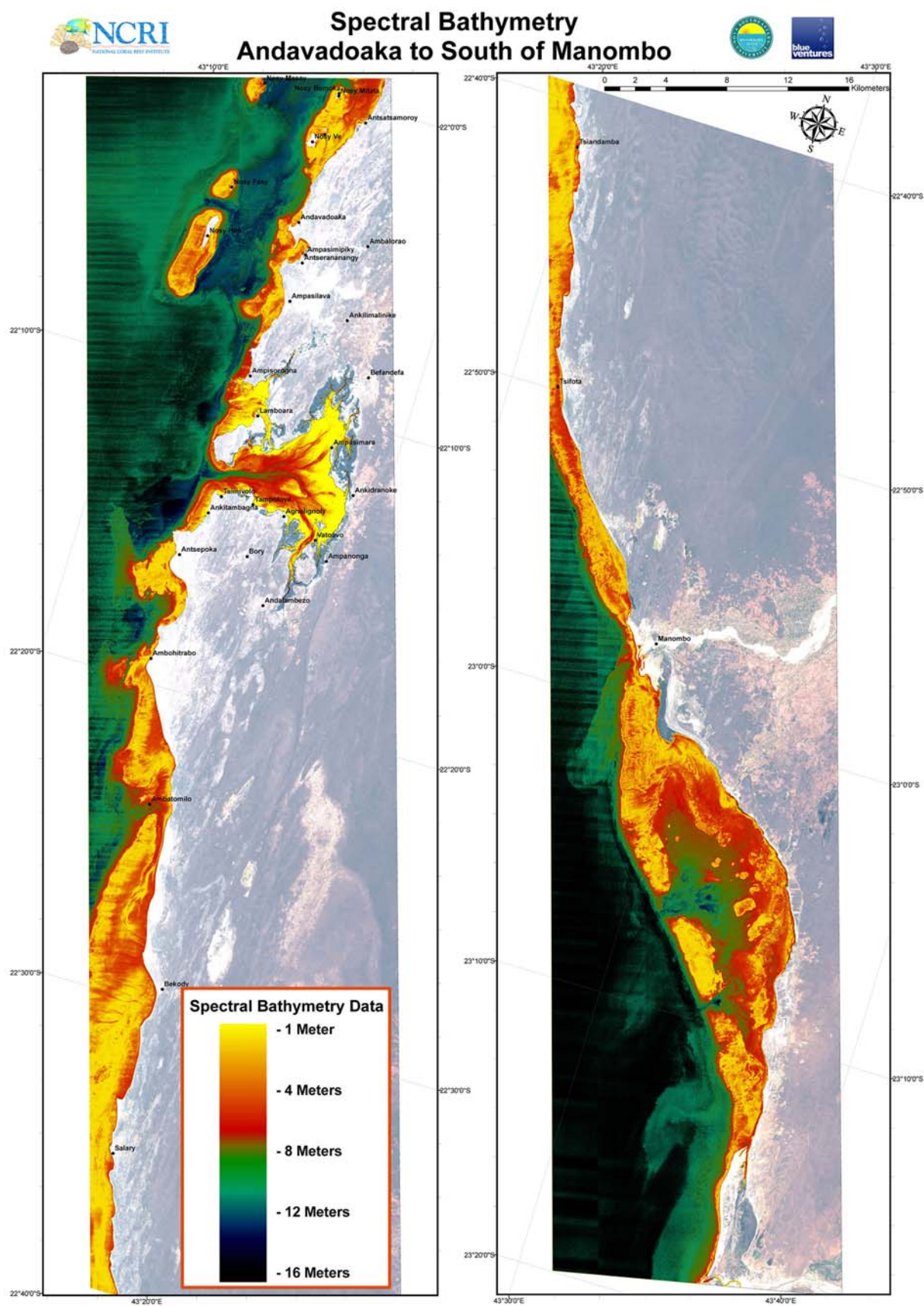




Figure 5. Bathymetry extrapolated from target region (Velondriake) to Baie de Ranobe (north of Toliara).



## Digital elevation model (DEM) and spectral bathymetry (figures 3 and 4)

The extent of the Velondriake network is outlined in yellow in figure 3, left. The image in figure 3, right, shows an extract of the Velondriake region. The QuickBird imagery has been draped over the top of a DEM of the bathymetry.

Figure 3 shows the entirety of the QuickBird swathe, from the island of Nosy Masay in the north, to the Baie de Ranobe in the south (near the village of Manombo), a distance of approximately 150km. This extrapolated bathymetry is based on readings taken from around Velondriake, but applied to a much larger area. The imagery was acquired on 11-Sep-2005, with a cloud cover of 0% and environmental quality of 99 (ID 1010010004834D00). Bathymetric groundtruthing was carried out between 27-Feb-2008 and 5-Mar-2008. The imagery and

groundtruthing generated a bathymetric model to 16m depth.

Although we obtained QuickBird imagery for the north of Velondriake, the only available swathe (acquisition date 29-Sep-2002, cloud cover 0%, environmental quality 90, ID 10100100014C3100) contained excessive sun glint, obscuring marine features, which didn't prove possible to remove. Both satellite images were acquired in the same month (September) and at a similar time of day (07:26 and 07:41 GMT; Madagascar is GMT+3) during the dry season in Madagascar. Ocean conditions are much calmer in the morning than the afternoon, and it was unfortunate that marine analysis couldn't be performed on the second scene.

## Discussion

### Accuracy & limitations

The QuickBird imagery used in this project was acquired on 11-Sep-2005, but groundtruthing was carried out between 27-Feb-2008 and 5-Mar-2008 – 2.5 years later. Ideally, imagery acquisition and groundtruthing should be carried out within the same time period (e.g. month) to reduce any variability in results.

For this project, the imagery was very kindly donated by DigitalGlobe, and there were only a limited number of swathes of the target area available. Blue Ventures has been carrying out ecological assessments in the area since 2003, and there have been no major shallow-water bathymetric changes, although habitat coverages have changed. Habitat types are likely to remain the same (e.g. location of seagrass meadows), but there is variability in habitat cover both intra-annually (e.g. seasonal differences in growth), and inter-annually (e.g. for live coral cover as a result of bleaching, sedimentation or overfishing). Because of these differences, the accuracy of the spectral bathymetry is likely to be higher than the accuracy of the habitat map for the Velondriake region.

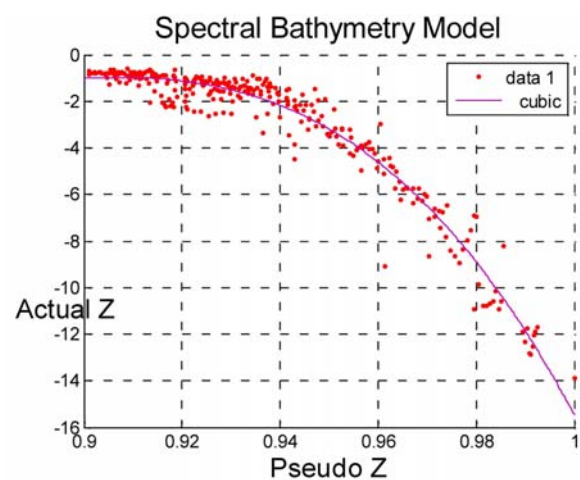
### Bathymetric model

For this project we generated two DEMs: one for the Velondriake network, and one for the entire QuickBird swathe (figure 4). Bathymetric recordings were taken solely in the Velondriake region, and were extrapolated further south, to the Baie de Ranobe. The degree of accuracy for estimated bathymetry in the Velondriake region will therefore be much higher, but it was considered worth producing a regional spectral bathymetry for future application. This area remains to be groundtruthed, but from reef survey transects conducted in this region by Blue Ventures and Reefdoctor, habitat types and bathymetric

characteristics have been reported to be very similar to those found in the Velondriake network.

The following graph shows the goodness of fit between the predicted depth (pseudo Z) and the actual, recorded depth (Actual Z), for the Velondriake region (please see figure 2 for the path of the boat around Velondriake).

Figure 6. Actual Z (in-situ readings) vs pseudo Z (derived from the imagery)



Pseudo values were generated by calculating a ratio between the blue and green bands for each Actual-Z associated pixel in the imagery, taking advantage of the differential attenuation of light through water. This provided a regression equation, which was used to calculate depth values for the entire image.

The correlation between the model and the observed values is very high to 10 metres depth ( $R^2 = 0.8940$ ), and to 16 metres depth remains high ( $R^2 = 0.7731$ ).

One limitation of this model is that there are many more recordings for shallow depths (0 to 10m) than there are deeper depths (10 to 16m). This is due to several limitations. With good atmospheric and water conditions, QuickBird sensors can only accurately penetrate to a depth of 16 metres. At depths greater than 16m, there are visible striations (artefacts) in the spectral bathymetry, where the remote sensor is at the very end of its range.



Due to logistical constraints, such as distance from shore and increasing wave power, it is much easier to survey representative habitats within the lagoon, which accounts for a larger number of depth recordings to 10m, as the marine environment is shallower than outside the lagoon. As the QuickBird sensor has a maximum depth penetration of 20m, it is more cost effective to spend a greater amount of time surveying shallower habitats which are more likely to be discernible on the imagery.

An analysis biased towards shallower areas provides a classification which coincides with the position of local community fishing sites, which are more likely to be situated closer to the shore for ease of access. As one of the project aims is to provide a habitat map as a support tool for zoning marine resources, an emphasis on habitats closer to shore provides a more detailed and accurate habitat classification for near-shore resources.

### Habitat classification

From previous studies in the Red Sea using this technique (Purkis & Pasterkamp, 2004), bathymetric accuracy where water depth was unknown was evaluated at 53%. When water depth was known, the accuracy increased to 76%. The 2004 study was completed using Landsat 5 imagery, with a 30m pixel resolution, whereas this study used QuickBird imagery with a much higher 2.4m pixel resolution. Results from this study suggest similar levels of accuracy, between 70% and 80%.

With remote sensor accuracy constantly improving, increased resolution and depth will undoubtedly be achievable in the near future. Hyperspectral sensors have been used to capture reef locations at a depth of 30m (pers. comm., Dr Terry Cocks, HyVista Corporation), but this technology is not easily deployable, and requires specialised equipment to be flown over the target area.

## Cost effectiveness

### Habitat map for Velondriake

**Coverage:** 33,371ha (333.71 km sq)

**Cost per ha:** £0.32

### Habitat map and Bathymetry for Velondriake

**Coverage:** 39,311ha (393.11 km sq)

**Cost per ha:** £0.27

### Habitat map and Bathymetry for Velondriake; Bathymetry for entire QB swathe

**Coverage:** 108,615ha (1,086.15 km sq)

**Cost per ha:** £0.08

The costs above are area-specific, rather than the cost of generating just the habitat map or the bathymetry. For example, the costs for 'Habitat map and Bathymetry for Velondriake', i.e. £0.27/ha, take into consideration the project cost and the area covered by the two outputs.

It doesn't make sense to split the costs (for example, to work out costs solely for the habitat map) as data were collected for both outputs simultaneously. However, if necessary, assuming equal costs for the generation of each output, £0.27/ha can be halved.

If we take into account the spectral bathymetry for the entire QuickBird swathe, costs reduce to £0.08 per hectare ('Bathymetry – Project'). However, the area covered by the habitat map (33,371ha) remained unchanged.

These costs are low due to the donation of the QuickBird imagery; if the approximate cost of the imagery is factored into cost effectiveness, production costs increase to:

- Habitat map: £1.30 / ha
- **Velondriake Habitat map & Bathymetry: £1.11 / ha**
- Project Bathymetry: £0.40 / ha

The cost per hectare for the Velondriake Habitat map & Bathymetry – either taken as £0.27/ha or £1.11/ha - compare very favourably with a more extensive study undertaken in Kimbe Bay (Green et al, 2007), where estimated costs were \$2.39/ha for shallow water habitats (<200m).

## The remote sensing toolbox: application of the habitat map and bathymetric model

- **Ecological monitoring:** analysis of the habitat map provides highly accurate spatial habitat coverage data for each type of benthos, substrate and coastal vegetation. Underwater video footage records detail on benthic composition and a snapshot of topographical complexity. The DEM provides a highly accurate bathymetric overview, especially for shallow-water habitats.
- **Coral reef exploration:** remote sensing reduces the number of man-hours required to ground-truth habitat coverage and bathymetry by extrapolating from surveyed data to unsurveyed locations. This method exposes sites of potential interest and conservation importance which may have not been previously identified.. For example, resilient coral reef areas with high coral cover appropriate for inclusion in protected area zoning plans; areas with high coverage of target habitat types (e.g. mangrove, coral and seagrass) which are located some distance from villages/settlements; sites with unusual topography suited for recreational diving.
- **Comparison between participatory and scientifically-derived maps:** within Velondriake, local communities have created participatory maps of their marine resources, providing local knowledge of fishing site names and locations, species commonly encountered at each site, and habitats considered to be of conservation importance. An effective coastal management plan must incorporate recommendations provided by scientific surveying and mapping (such as areas of high live coral or seagrass cover, or high topographical complexity), but must also acknowledge social needs, such as access to fishing sites. By overlaying participatory maps with habitat maps derived from ecological and scientific surveys, this approach reveals areas of potential conflict that must be resolved prior to consideration for inclusion within an MPA – for example areas with high biodiversity which are subject to high levels of fishing. Conversely, this approach also facilitates identification of areas ideally suited for management, such as areas which are of scientific importance, but are not regularly fished. In this way it is possible to suggest socially acceptable sites for inclusion in a protected area network, since it is vital that the location of any reserves areas have the agreement and understanding of local communities.
- **Training and educational programmes:** maps produced from this project are being used to help local communities orientate, assess and plan their resource use; increase awareness of the threats and problems associated with overfishing and foster discussion into sustainable fishing techniques; and provide communities with a visual reference for the location of protected areas.
- **Lessons learned and regional application:** Blue Ventures is committed to local and regional capacity building by facilitating community-centred management, of which this tool plays a large part. The results from this work establish a baseline and will help us to repeat this process in the future. Work is underway to establish guidelines for community habitat mapping relevant to the broader western Indian Ocean region, and this work will form part of a larger awareness-raising initiative.

## Future projects

This mapping project is precursory to a more in-depth management plan, which will incorporate feedback from the local communities regarding protected area location, size and category. Since the first octopus no-take zone was established in 2004, locally-managed marine areas have been embraced by the local community, which culminated in the inception of the Velondriake network in 2006. The network has won international recognition (UN SEED Award, 2005; UNDP Equator Prize, 2007; WWF Getty Award, 2008) and continues to evolve.

### Terrestrial Extension of the habitat map

A terrestrial habitat map for Velondriake, produced by the Institut de recherche pour le développement (IRD) using remote sensing and groundtruthing techniques based on SPOT imagery, classifies 7 predominant habitat classes within Velondriake (mangrove, grassland, xerophilus spp., desert shrubs, bare ground, high salinity/halophile-dominated, and wetland areas). Merging the coastal and marine habitat map generated by this project with this terrestrial map will produce an integrated habitat map for the entire Velondriake terrestrial and marine network. An elevation model for the terrestrial component will also be added based on NASA's shuttle topography data (e.g. CGIAR-CSI v4 – Jarvis et al, 2008).

### Regional extension of the habitat map and bathymetric model

Combining these two outputs with socioeconomic and ecological monitoring provides a unique baseline which facilitates the establishment of an integrated community-run MPA zoning plan. These techniques are key for assessing the spatial distribution and complexity of marine habitat types, and nothing on this scale currently exists.

Blue Ventures is currently engaged with the Wildlife Conservation Society (WCS), the World Wildlife Fund (WWF) and Reefdoctor in establishing further MPAs and NTZs with Vezo communities elsewhere in southwest Madagascar over the next 4 years. These additional regional MPA development programmes could benefit equally from application of this mapping technique.

### Regional metadatabase and clearinghouse

The development of a regional marine and coastal metadatabase to support the creation of a regional MPA network has been discussed and welcomed by all of the institutions and NGOs active in the region, including WCS, WWF, Reefdoctor, the Institut Halieutique et des Sciences Marines (IH.SM), and Madagascar's Park Service (MNP-ANGAP).

A national metadatabase has been identified as a high priority for Madagascar (Marchesi, 2007), especially for marine and coastal areas, and will allow organisations working in the region to collaborate more effectively and efficiently, as available data will have increased visibility. Madagascar's National Office for the Environment, ONE, has started setting up a metadatabase, with help from UNEP-DEWA, but it will be some time before this is operational.

The Network of Environmental Information Systems (ARSIE – [www.arsie.mg](http://www.arsie.mg)) does have an online metadatabase to which WCS, WWF and PNM-ANGAP currently contribute data. However, this database is currently geared towards the terrestrial environment. From the 18,000 articles currently indexed, 441 documents were returned for the category “fishing and aquaculture”, but only 20 for “marine biology”, 10 for “coastal ecosystems” and 2 for “coral reefs”. This result serves to highlight the clear need for an integrated marine and coastal database.



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## Online resources

A web portal has been set up at <http://gis.blueventures.org>, where the data layers from this report have been published. This portal is currently in development, although a live preview version is available.

Blue Ventures research reports are also available at: <http://blueventures.org/our-research/res-updates.html>