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Use of satellite remote sensing for coastal conservation in the Eastern African Coast: advantages and shortcomings

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Abstract

Landsat 5 TM imagery from 2005 was used to map (at a coarse descriptive resolution) coastal habitats along the Tanzania/Mozambique transboundary zone. The map (available at <http://www.transmap.fc.ul.pt/>) was a reference for the study of environmental and social aspects, and for conservation, was disseminated among local stakeholders, ENGOs and various decision-making authorities and managers, and was used in the development of a transfrontier conservation area.

Large scale remote sensing constitutes a cost-effective approach for research and management, as, with limited human, technical, temporal, and financial resources, it provides synoptic views of territories and allows for the estimation of quantitative changes in land use.

Keywords: Landsat TM5, Tanzania, Mozambique, coastal zone management, habitat mapping, Transboundary Marine Protected Areas.

Introduction

Conservation of marine and coastal environments and of their associated biodiversity is a global priority, mostly due to their importance to human societies and to their sensitivity to direct and indirect sources of stress resulting from human activities [Spalding et al., 2007]. On the Eastern African coast, organizations such as WWF have established global coastal and marine conservation objectives, which included the creation of the Eastern African Marine Ecoregion (EAME), spanning from Somalia to South Africa, along 4,600 km of coastline [EAME, 2004]. Within EAME, a total of eight sites of global importance were identified, including the Mtwara-Quirimbas complex, located across the Tanzania/Mozambique boundary [ibid.].

Up-to-date cartography of coastal habitats on a GIS platform is a primary need for any conservation scheme, which should incorporate environmental and social information, on the distribution of coastal and marine biodiversity (including biodiversity hotspots), assessment

of ecosystem condition, human use types, and socio-economic and governance assessment. The integration of such distinct types of information should allow for the mapping of priority areas for conservation, taking into account the uses and interests of all the stakeholders involved, and the development of proposals for the definition of transboundary marine protected areas.

An assessment of existing information on the distribution of coastal habitats throughout the Mtwara-Quirimbas complex showed that, despite the existence of a vast bibliography on the various research topics, few studies presented data linked to geographic information. Those that did, constituted mainly sectoral studies, referring separately to the distribution of mangroves, coral reefs, or seagrasses [e.g. Spalding et al., 1997, 2001; Taylor et al., 2003; Wang et al., 2003, Obura et al., 2002, 2004; Bandeira and Gell, 2003; Dadouh-Guebas et al., 1999; Ochieng and Erftemeijer, 2003], or were geographically restricted to very specific locations [e.g. Gawler and Muhando, 2004]. On the other hand, the scale of most studies, often covering the entire coastlines of one or two countries, was incompatible with the higher spatial resolution required for an accurate cartography of the area.

A first approach to the distribution and extent of major coastal habitats was therefore necessary. Some of the variables considered when determining the best methodology to adopt were: i) desired end product; ii) desired accuracy; iii) extent of the study area; iv) cost (available funding); v) logistics related to field work/ground truthing (e.g. accessibility to remote areas); and vi) available time [Ferreira et al., 2009]. The objective was the production of a map of major coastal habitats to use as a background for further investigation, and for management. For such purposes, a relatively low overall map accuracy (60%) is deemed appropriate [Mumby and Green, 2000a]. The study area extends over 18,000 km² and encompasses terrestrial, coastal, and marine environments. Mapping such a large and varied territory poses a number of logistical questions, including the costs of producing the maps (operator time x no. operators), and the costs of field work required for groundtruthing, which are augmented by the variety of habitats that need to be “sampled”, the different types of vehicles necessary for such surveys (e.g., car, boat, airplane), and the sheer remoteness of some areas (poor accessibilities). Undertaking such an enormous task may then represent a significant expenditure of funds (money) and time. However, these are parameters that are typically scarce in such projects. Not only is mapping just one of the components of any conservation project, which means that it has a limited budget, it must also be one of the first tasks to be performed, as it constitutes the basis for a significant part of the research to be performed thereafter.

Considering all these requirements and constraints, a remote sensing approach was selected, as it constitutes a cost-effective method for synoptic sampling and mapping of resources over large areas and over time, for land planning and monitoring purposes [Dahdouh-Guebas, 2002; DeFries and Pagiola, 2005; Giri et al., 2008; Mumby and Edwards, 2000; Mumby et al., 1999; Thu and Populus, 2007]. Aerial photography or satellite platforms with high spatial resolution, such as IKONOS or Quickbird (with sub-metric spatial resolutions in the case of the panchromatic bands) [DigitalGlobe, 2012; GeoEye, 2012], allow for detailed habitat mapping. However, all such data sources have limited spectral resolutions (only 4 bands: blue, green, red, near infra-red), not to mention high costs of image acquisition (either flying an airplane or purchasing the necessary satellite scenes to cover the entire study area). Therefore, the costs of image acquisition and processing for such large areas add up to significant expenditures of project resources, including time, number of technicians involved in image processing, and, obviously, funds available. An approach based on large-

scale satellite imagery was selected, given the extent of the study area, the desired end product and overall map accuracy, and logistic and financial constraints. Landsat Thematic Mapper (TM) (7 bands, with a spatial resolution of 30 m x 30 m) was preferred because it compares favourably with similar platforms in terms of cost-effectiveness for mapping large areas of coastal habitats at a level of coarse descriptive resolution, where only a few classes are distinguished [Green et al., 2000; Mumby et al., 1997, 1999]. Moreover, TM imagery can be obtained free of charge [e.g., USGS, 2011].

This paper describes the remote sensing approach used for the mapping of major intertidal and shallow subtidal habitats in the Tanzania/Mozambique transboundary area (Fig. 1) and discusses its subsequent applications by researchers and authorities in coastal management. The adopted framework was the EU-funded Transmap project (www.transmap.fc.ul.pt). Relevant information on the project, and, specifically, on the habitat mapping component can be found in Transmap [2004, 2008] and Ferreira et al. [2009a, 2009b].

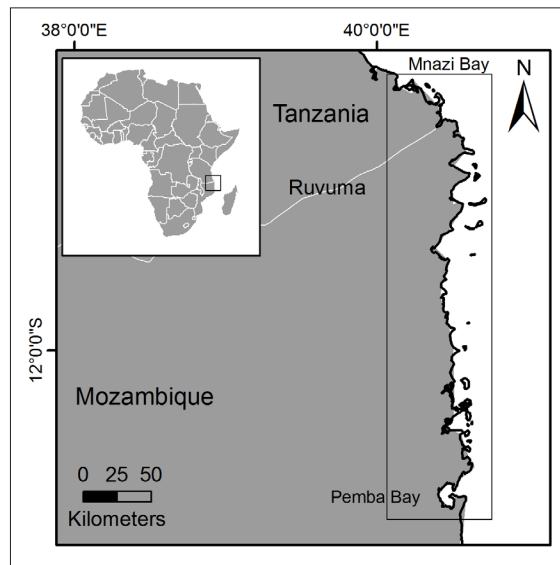


Figure 1 – Location of the study area on the African continent (inset), and detail of the study area, located in the transboundary coastal region between Tanzania and Mozambique, from Mnazi Bay, to Pemba Bay. The rectangle represents the outer limits of the study area. In this region, the Ruvuma river constitutes the border between both countries.

Methods

Study-area

Located on the Eastern African Coast along c. 350 km of coastline, the Mtwara-Quirimbas Complex, from Mnazi Bay (Tanzania) through the Ruvuma delta (Tanzania/Mozambique border), and the Quirimbas reefs, south to Pemba Bay (Mozambique) (Fig. 1) is considered

a site of global importance in the framework of WWF's Ecoregion Programme [WWF, 2002]. Situated where the South Equatorial Current meets the African coast, the site is home to a diversity of tropical and subtropical species and habitats and a growing human population. It harbours some of the most impressive coral reefs of the Western Indian Ocean (presenting high coral diversity with over 50 genera) and it is an important nursery and feeding area for turtles, birds, and whales. Its coastal islands are significantly affected by recent coral bleaching events, as well as periodic dynamite fishing in Tanzania [Transmap, 2004; WWF, 2002].

Two parks have been established within this site: the 650 km² Mnazi Bay - Ruvuma Estuary Marine Park (MBREMP) created in Tanzania in 1999-2000 [IUCN, 2005] and the 7,500 km² Quirimbas National Park, presented in 2002 by the Government of Mozambique in the framework of WWF's "Gift to the Earth" program. This park encompasses a 1,500 km² marine area with a 100 km coastline, including eleven islands of the Quirimbas archipelago [WWF, 2002].

Image processing

The image processing methodology used in this project is fully presented, justified and discussed in Ferreira et al. [2009b] and is summarized here.

Landsat 5 TM L1G scenes, data products that are provided with radiometric and geometric corrections [NASA, 2012], were used. Scenes showing low cloud coverage were selected for anniversary dates, for April-July 1995 and April-June 2005 (Tab. 1).

Table 1 – List of Landsat 5 TM imagery, including the path and row of selected scenes, and date of capture.

Image Area	Path/Row	1995	2005
Ruvuma (Tanzania/Mozambique border)	165/067	15.04.95	10.04.05
Cabo Delgado	164/067	-	06.08.04
Quirimbas Archipelago (North)	164/068	29.07.95	22.06.05
Quirimbas (South) to Pemba	164/069	29.07.95	22.06.05

Image geo-correction and co-registration to known ground control points (GCPs) was performed [USGS, 2006], using information collected in the field with a hand-held GPS (Magellan Explorist 100) in the summer of 2006, and from Google Earth (GE). Selected GCPs were clearly visible landmarks, such as crossroads, constructions, or trees. Georegistration onto local coordinates (UTM37S WGS84) was carried out with a 1st degree polynomial adjustment (the study area is mostly a low-lying territory, with limited relief) using ArcGIS 9.1 georeferencing tools. Average root mean square (RMS) error for rectified images remained within the suggested threshold of half the original pixel size [Eastman, 2003], which was kept for all subsequent analyses.

Image classification was performed using IDRISI Kilimanjaro vs. 14.02, by Clark Labs, Clark University, © 1987-2004. Rectified images were windowed to retain only the study

areas. Image destriping was attempted and abandoned since restored bands still exhibited striping and there appeared to be loss of radiometric resolution. No atmospheric corrections were applied to the images because of the relative uncertainty of currently available algorithms [Giri et al., 2007].

Classification was performed using an unsupervised classification procedure. Several procedures were tested [Ferreira et al., 2009b], and best results were achieved with the ISOCLUST classifier (similar to the ISODATA cluster routine of Ball and Hall [1965, in Eastman, 2003]). ISOCLUST was applied to all seven bands, including the thermal band [Leak and Venugopal, 1990; Alavi Panah and Ehsani, 2004], with five iterations.

This methodology was repeated in every windowed image, yielding 40-65 clusters per working area. Due to the complexity of terrestrial habitat mosaics, and in order to speed up the habitat discrimination process, it was decided to drop terrestrial habitats. Therefore, clusters corresponding to terrestrial habitats (ca. 50-66% of the total) were merged into one class; so were clusters corresponding to deep marine water and to clouds and cloud-covered areas, where no terrain information was available (usually 1-2 clusters). All other clusters inside the target area (ca. 16-30) were individually reassigned to one of eight selected intertidal and shallow subtidal coastal habitats based upon the Ramsar Classification System for Wetland Type [Ramsar Convention on Wetlands Website, 2007]: permanent shallow marine water, estuarine water, intertidal flats, sand, mangrove, supratidal bare flats, coral reefs, and marine subtidal aquatic beds (algae and/or seagrass). The distinction between potentially confusing habitats, including ecotone areas, was made on the basis of visual interpretation of the imagery available from GE, from ground-truthing information, and from the expertise of researchers familiar with the study area [Ferreira et al., 2009a].

The classified working windows were concatenated to build the mosaics for the study area. No editing was performed on the images, except on coral habitats where expert knowledge was used to compensate for problems in habitat discrimination related to the surf zone and depth.

A hand-held GPS (Magellan, Explorist 100) with a reported accuracy of between 3-30 m [Magellan, 2007], was used for ground-truthing. A total of 164 GCPs were collected throughout the study area in July and September 2006. Overall map (user) accuracy and Tau coefficient were estimated for the 2005 mosaic according to Mumby and Green [2000a].

Results and applications

The first direct result of this remote sensing approach was the production of a map illustrating the distribution of intertidal and shallow subtidal habitats of the study area, in 2005 (Fig. 2).

The Mtwara-Quirimbas area presents a diverse, rugged, albeit markedly depositional, coastline, presenting several embayments and a series of coral islands forming the Quirimbas Archipelago, parallel to the mainland. The benthic topography is shallow between the islands and the mainland, but it deepens dramatically between and offshore of the islands. The coastal habitat complexity may be viewed as a tropical seascape, with abundance of coral reefs, seagrass beds and mangrove forests. Mangroves are widespread and occur in intertidal flats in sheltered areas with freshwater runoff (e.g. estuaries, and bays). Coral reefs are present throughout most of the area, justifying its denomination of “coral coast”, and are clearly visible around the coralligenic Quirimbas islands, but also as fringing reefs running parallel to the coast of the mainland.

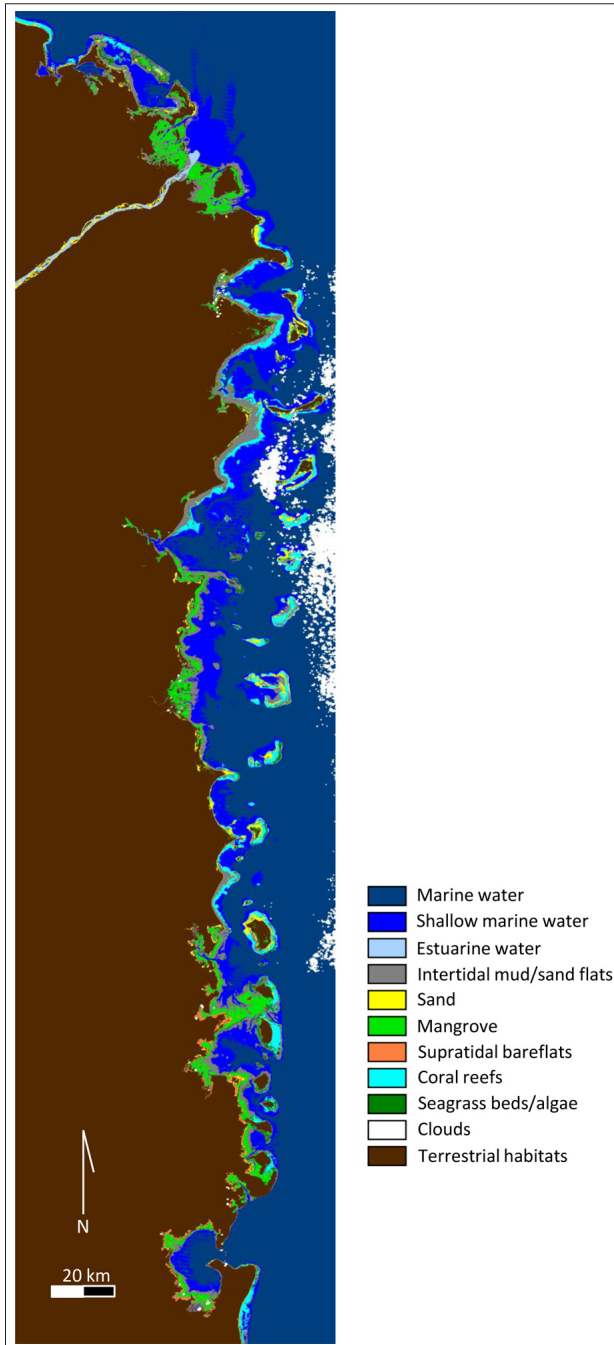


Figure 2 – Map of coastal (intertidal and shallow subtidal) habitats from Mnazi Bay (Tanzania), to Pemba Bay (Mozambique), in 2005, obtained through an unsupervised classification algorithm (ISOCCLUS) applied to the working windows of Landsat 5 TM scenes.

This map constituted a first approach to the distribution of major habitats along the study area, and allowed for a first quantitative estimation of the areal coverage of each habitat along the Mtwara-Quirimbas complex. Estimated overall user (map) accuracy and Tau coefficient for the 2005 mosaic were 77% and 73% respectively, which was considered to be satisfactory since, as Mumby and Green [2000a] suggested “Where habitat maps are used to provide a general inventory of resources as background to a management plan, a thematic accuracy of 60% is probably as useful as 80%”.

The equivalent habitats’ map for 1995 was produced using the same methodology. The original objective was to try to detect land cover change throughout the study area over a decade. However, it was found that there were a number of extraneous factors that influenced the result of the classification process, especially in intertidal and subtidal areas, such as tide level, continental runoff/turbidity, or bottom reflectance [Agostini et al., 2003; Ferreira et al., 2009b; Hedley & Mumby, 2003]. Therefore, change analysis was only addressed for areas of mangrove forest, which are mostly emerged habitats. The comparison of mangrove distribution and cover in 1995 and 2005, presented and discussed in detail in Ferreira et al. [2009a], showed an overall increase of about 3% in mangrove area estimated from large scale remote sensing alone. Integration of the results of dedicated field work, however, suggested that these results might be misleading regarding mangrove condition, as most of the sites studied in the field showed signs of disturbance due to selective logging for construction and fuel [Bandeira et al., 2009].

The map of coastal habitats for 2005 constituted a reference for subsequent studies, specifically for identifying smaller areas of interest that were looked at in greater detail. It was also the base for the development of a Geographic Information System (GIS) that integrated information obtained by the various tasks of the project, namely mapping the distribution of fauna with a special interest for conservation [Barnes et al., 2011], which allowed for the mapping of biodiversity “hotspots”, and a number of socio-economic factors, including the distribution of fishing boats and gears, and fishing intensity [Transmap, 2008]. This GIS was intended to have the highest possible dissemination among interested researchers and third parties, especially local and regional organizations and authorities. The cartography was presented in various *fora* (including technical meetings and workshops) to 27 institutions from Mozambique and Tanzania. The stakeholders included such diverse groups as i) decision-making authorities at local, provincial and national levels, such as local council and provincial governments, and the national ministries involved in nature conservation and territorial planning; ii) representatives of local communities; iii) institutions with jurisdiction on the coast; iv) fisheries research bodies; v) managers of existing Marine Parks; vi) ENGOs and other stakeholders interested in coastal conservation, such as IUCN and WWF; vii) major tourism operators and other stakeholders related to private economic activities; viii) key technical staff of local research institutions of higher education and scientific research; and ix) teachers of various school levels. The workshops were also targeted towards local inhabitants (including farmers and fishermen), and reached more than 200 participants. Perceived receptiveness of the participants to this type of product and to the information it provides was very positive.

Ultimately, the results of this remote sensing approach (habitat mapping) were used as baseline information for the development of a TransFrontier Conservation Area (TFCA), that was proposed by the Mozambican authorities. One of the overall objectives of the

TFCA was to contribute to the integrated management of a network of conservation areas in both countries [Bandeira et al., 2007]. These results were also considered in Mozambique's national assessment on the implementation of the Convention on Biological Diversity [MICOA, 2009].

Discussion and conclusions

This study provides a clear example of the interest of using satellite remote sensing in habitat mapping related to conservation projects. Remote sensing constitutes the most cost-effective method for the synoptic sampling and mapping of large areas, as it provides, like no other surveying method available, a synchronous snapshot of the territory [DeFries and Pagiola, 2005; Lillesand and Kiefer, 2000]. Large scale satellite Landsat scenes, for instance, which are reportedly the best option for habitat mapping of large areas at a coarse descriptive resolution [Green et al., 2000], are available free of charge on-line at <http://glovis.usgs.gov/>. Therefore, obtaining the images only represents an expenditure of time in selecting the most appropriate scenes for the purposes of any given study. Image analysis requires specialized technicians and computing power. Provided the output scale and the overall objectives are clearly set from an early stage of the project, a small dedicated team (1-2 people) is enough to undertake the habitat mapping task. In this study, this represented the equivalent to 6-8 man/month, which is arguably a small fraction of the budgets of multiannual projects. Moreover, the type of computing power necessary to perform image analysis (including personal computers, image analysis software and storage devices) does not represent a significant added cost. Appropriate and relatively inexpensive hardware can be easily found in today's off-the-shelf market, and software licences for research purposes are also, in many cases, less expensive than the corresponding commercial licences. Together, these expenses may add up to the equivalent to another 2-3 man/month. These costs refer to the minimum initial setup for establishing reference conditions using a remote sensing approach, and can easily be diluted over longer term monitoring schemes, either for the study of ensuing habitat evolution and land use or for post-evaluation studies (Landsat archives presently include over 30 years of imagery).

Finally, costs related to ground-truthing may be diluted among other project tasks, associated with fieldwork for the study of specific biological or social aspects. Field researchers may help in collecting GCPs that may then be used for ground-truthing and improving overall map accuracy. Furthermore online open platforms such as Google's Google Earth (GE) and Microsoft's BingMaps provide a unique opportunity for researchers (and managers) to look closely at study areas, and to take virtual aerial tours of present as well as of past conditions (using historic imagery) or planning field excursions, with minimum expenditure of time and funds in the preparatory stage of projects, when it is critical to define realistic tasks and deadlines. The high-spatial resolution imagery available in GE (which, for many areas, is sub-metric), makes it a very useful tool, as it was in this project, for ground-truthing, especially in remote and inaccessible areas. Therefore, provided proper care is taken in efficient project planning, costs associated to ground-truthing may be reduced to a minimum.

Overall, the total costs of image processing and map production are comparable to, or even lower than, the cost of acquiring imagery with higher spatial resolution, be it high resolution satellite imagery or aerial photography. Furthermore, higher resolution imagery will add to the costs of image processing because of the extra time required for analysing

the same territory (more scenes/photos for the same area). However, higher resolution imagery can be invaluable in detecting changes in habitat condition (qualitative change), whereas Landsat imagery only allows for the detection of quantitative changes [Ferreira et al., 2009b, Giri et al., 2007, Neukermans, 2004; PUMPSEA, 2007].

This paper described a case study where a single map of coastal (intertidal and shallow subtidal) habitats produced using large-scale satellite remote sensing, had diverse and far-reaching scientific and management operational applications. As a basis for research and for the project's GIS, this cartography was widely disseminated among researchers, NGOs, public and private stakeholders, and central and local governmental institutions. This is a very simple and yet straightforward example of how satellite remote sensing was put to the service of stakeholders, including regional and local authorities, as the most cost-effective way to produce a picture that was, as the saying goes, "worth a thousand words", and, in practical terms, had wide ranging applications. Further use of this information depends solely on the interest of authorities and other stakeholders. This cartography, and the associated GIS (with, i.a. biological, ecologic, and economic information) are available at the project website (www.transmap.fc.ul.pt), at the Western Indian Ocean Marine Science Association (WIOMSA), and upon request from the authors.

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