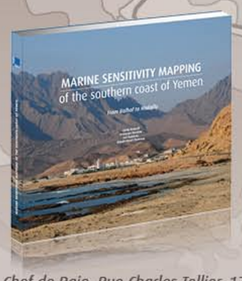

Marine sensitivity mapping

of the southern coast of Yemen

From Balhaf to Mukalla

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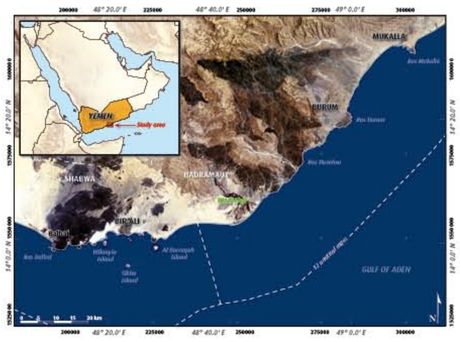
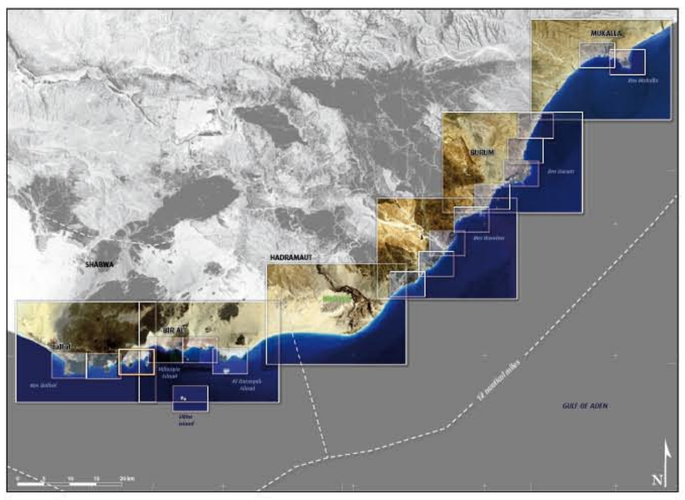


INTRODUCTION

The Gulf of Aden is characterized by a highly dynamic oceanographic setting and the study of its coastal ecosystems is only relatively recent and still largely incomplete. In Yemen, the coast from Balhaf to Mukalla along the north-western Gulf of Aden is a naturally rich and diverse area with a high potential for the development of fisheries, coastal infrastructures including roads and port facilities, coastal settlements and tourism. This coastal area spans aesthetically impressive mid and high energy beaches and rocky shores, and encompasses different ecosystems. Mangroves, wadi estuaries, high and low cover coral communities (Benzoni *et al.*, 2003, Pichon *et al.* 2010) supporting locally and commercially important fisheries, algal beds (Ormond and Banaimoon, 1994), and soft bottom benthic ecosystems are all found along this approximately 250 km long stretch of coastline.

OBJECTIVES

In order to be able to manage coastal ecosystems, a good knowledge of their richness and biodiversity is the preliminary step enabling the implementation of protective measures. However, comprehensive biodiversity studies are very time consuming and cannot be applied in a short time frame to a very large territory. Sensitivity mapping using a multi-disciplinary approach is a tool leading to large scale cartography, allowing the identification of the most sensitive locations, where priorities can be assigned. Therefore, the aim of this study was to provide an accurate mapping of the habitats encountered and of their sensitivity.



Marine and terrestrial coastal features were delineated using Very High Resolution composite images issued from Quickbird and WorldView-2 (WV2) satellites. Terrestrial features outside the limits of the Very High Resolution images have been completed using AVNIR and ASTER images.

APPROACH

The process for the sensitivity mapping of the coast consisted in several sequential steps according to a methodology initially described by Dutrieux *et al.*, 2000. The coast between Balhaf and Mukalla was split into functional geomorphological units. The result is a geographical region divided into six main zones mapped at the scale of 1/100 000; each zone being divided into areas zoomed to the greater scale of 1/25 000. The obtained map grid delineated the framework of the atlas.

STEP 1: preliminary mapping

The first step consisted in proposing a provisional typology based on remote sensing data. High Resolution satellite images were purchased and analyzed by a remote sensing specialist leading to the production of provisional habitat maps.

STEP 2: field truth validation

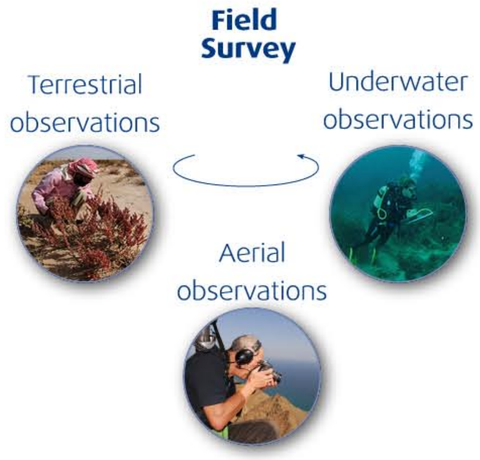
The results of the satellite image analyses were checked through several field campaigns. A total of 128 marine and 99 terrestrial stations were investigated along the coast between Balhaf and Mukalla and allowed subsequent adjustment and validation of the typology based on the photo-interpretation. Final habitat maps were then produced.

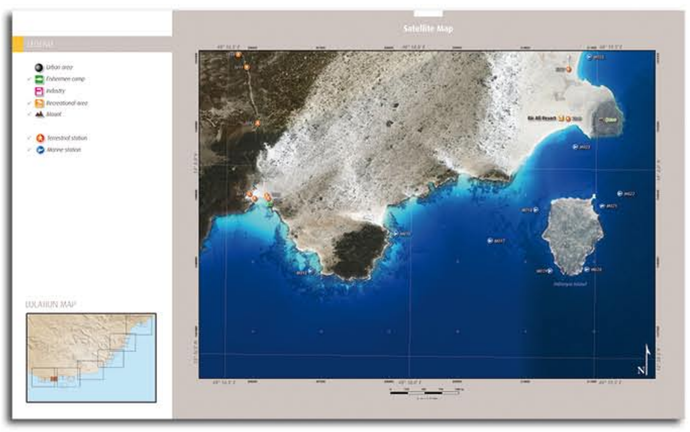
STEP 3: creation of a sensitivity scale

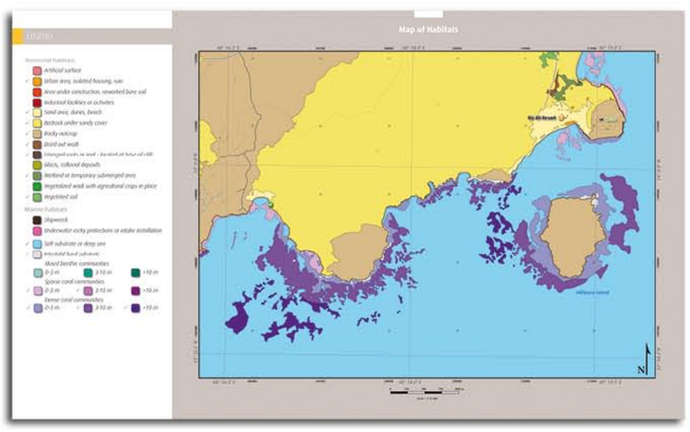
The third step consisted in the application of an environmental sensitivity scale to each type of sub-littoral habitat, based on the presence of endangered or highly sensitive species, interest for biodiversity and rarity. Therefore, a further set of maps were edited to illustrate these conclusions.

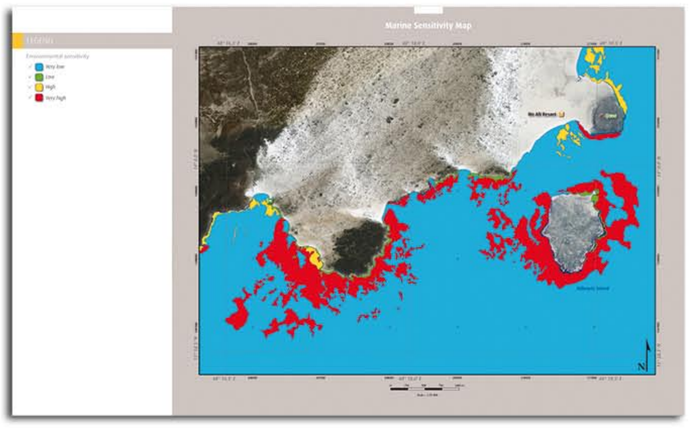
STEP 4: creation of a GIS database & edition of an operational atlas

Pictures and observations associated to the surveyed stations were referenced geographically using GPS technology and included together with the maps in a GIS database.









MAPPING RESULTS

Overall, 250 km of coast were mapped for the first time in this area. Previously un-described marine communities including peculiar coral formations were localized and identified as sensitive areas for further protective measures. The final atlas is composed of a large introductive section including a detailed description of the environment of the studied area followed by a total of 63 maps. The last section of the atlas is dedicated to the biogeography study outcomes.

BIOGEOGRAPHIC PATTERNS

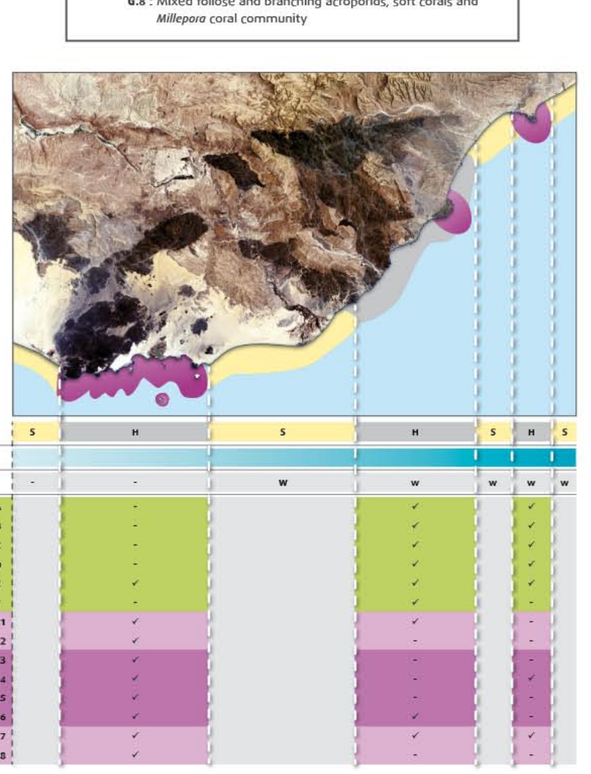
In this study, the marine species and the benthic assemblages appeared to present a zonation influenced by the presence of different substrate typologies, terrigenous inputs, depth and by the effects of the seasonal upwelling. These different factors co-occur and contribute to a complex pattern along the coast and along the depth gradient.

The most striking pattern emerging is perhaps the predominance of macroalgae dominated hard substrate benthic assemblages in the east and the dominance of scleractinian coral dominated hard substrate benthic assemblages in the west. A combination of seasonally lower sea temperatures and of the wadi driven terrigenous/high nutrient input described in the previous section could explain this marked predominance of macroalgae in the east sectors.

Not only are corals the dominant benthic organisms in the Balhaf- Bir Ali sector, but they also form the most diverse and high cover of scleractinian corals encountered in the whole study area. Only four of the eight coral dominated benthic assemblages described here are found between Burum and Mukalla, while all of them were observed in the Balhaf-Bir Ali area. A typical feature of the Balhaf-Bir Ali sector is the presence of thick coral carpets generated by a single species (e.g. *Pocillopora damicornis, Goniastrea retiformis, Acropora muricata, Stylophora pistillata*) and of "giant" colonies of different genera (mainly *Porites* but also *Galaxea astreata*, *Millepora*, and *Lobophyllia hemprichii*) which are not found in Mukalla or Burum.

HS BA : Hard Substrate Benthic Assemblages

- **A** : Mixed algal communities
- **B** : Mixed algal and scleractinian communities
- **C** : Mixed algal and non scleractinian invertebrates communities
- **D** : Mixed benthic cnidarians and sponges communities
- **E** : Mixed antipatharians and scleractinian communities
- **F** : *Sabellaria* formations
- **G** : Scleractinian coral dominated HS BA
  - **G.1** : *Acropora* coral carpet
  - **G.2** : *Stylophora* coral carpet
  - **G.3** : *Pocillopora* damicornis coral carpet
  - **G.4** : *Porites* coral carpet
  - **G.5** : *Goniastrea* coral carpet
  - **G.6** : *Porites, Stylophora* and faviids coral carpet
  - **G.7** : Mixed massive tabular, massive and encrusting coral community
  - **G.8** : Mixed foliose and branching acroporids, soft corals and *Millepora* coral community



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