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38

GUIDELINES FOR VULNERABILITY MAPPING OF COASTAL ZONES IN THE INDIAN OCEAN

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Preface & Acknowledgements

FOREWORD

The cooperation between ACP countries and the European Union places a high priority on environmental protection and the preservation and restoration of natural equilibria in the ACP States. The EU is particularly active in the Indian Ocean, where it intervenes in several areas either bilaterally or in the framework of the Regional Environmental Programme (REP), for the promotion of a long-term natural resource management policy, particularly in coastal zones.

Protecting the environment while guaranteeing the inhabitants of these Island states an adequate standard of living - particularly inhabitants of coastal zones - requires not only a socio-economic approach, but also the implementation of rational policies concerning the use of resources, to ensure their long-term availability for future generations. Therefore, today's decision-makers must have access to viable data which can only be collected, processed and analyzed with the help of decision-aids, including the methodology described in this guide.
We hope that this guide, compiled through regional experience, will reinforce existing cooperation between the Island States in this part of the Indian Ocean and act as a forerunner for other tools of this type.

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The general aim of the Indian Ocean Commission (IOC), which consists of the Comoro Islands, Réunion/France, Madagascar, Mauritius and the Seychelles is to support the economic, social and cultural development of these Member States in a concerted, integrated and lasting manner. These Island States face common problems, including urbanization, waste accumulation, increased pollution, coastal erosion, plus water quantity and quality management. In addition, they must anticipate the probable effects of climatic changes in order to adapt efficiently and in due time, in particular as regards the development of coastal zones, where populations and economic & industrial activities are concentrated. These factors as a whole represent a challenge to decision-makers in terms of medium and long-term planning.

In this aim, the Indian Ocean Commission has implemented a regional policy intended to support and complement the efforts of the Member States and promote the lasting development of their territories via, for example, integrated coastal zone management. The promotion of harmonized methods and tools for integrated coastal zone management and suggestions for operational solutions adapted to the problems identified, are key aspects of this regional policy.

The publication of this work by the IOC's Regional Environmental Programme, in partnership with UNESCO, forms part of a spirit of exchange of knowledge and experience developed with the help of the IOC. It will, undoubtedly, prove to be an invaluable tool for actors concerned with the long-term management of IOC Member State resources.

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Preface & Acknowledgements

Thanks to the experience gained through the creation, in partnership with the IOC-UNESCO, of the Atlas of sensitivity of shallow marine zones on Mahé Island in the Seychelles (1998), the IOC's Regional Environmental Programme has decided, for educational purposes, to publicize its approach to coastal zone sensitivity and vulnerability maps for the Indian Ocean islands, and hopes this approach will also prove useful for Island states in other parts of the world. The aim of this guide is, above all, to provide an integrated coastal zone management tool and harmonize and publicize a low-cost and easily-understandable methodology.

The methodological approach provides a simplified procedure based on:
· analysis of the current state of affairs and definition of needs (bibliographical, cartographic and photographic analyses);
· data acquisition (topographic surveys, aerial photos, transect dives) for environmental assessment purposes;
· compiling, typology and analysis of the data obtained as a whole for mapping purposes.

Knowledge of the environment and the resulting availability of reliable data is fundamental to efficient decision-making in regard to optimal long-term resource management. Although land maps reaching up to the coast have existed for many decades in the IOC Member States, this is not the case for the majority of coastal zones. The development of a geographical information system, which will be integrated into a decision-making system, is therefore of undeniable value. The popularization of these methods in the form of a guide constitutes one of the Project's priorities in terms of national environmental programme support and has been made possible thanks to the comprehensive methodological data collected.

The Regional Environmental Programme hopes that, apart from its educational purpose, this methodological guide will play a practical role with regards to decision-makers and all those concerned with the coastal environment.

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The UNESCO Intergovernmental Oceanographic Commission (IOC/UNESCO) has been endeavouring to promote scientific marine research and the associated oceanographic services for forty years now, in the aim of improving understanding and management of oceans and coastal zone resources via the joint actions of its members.
Thanks to these various regional programmes and its programme devoted to integrated coastal zone management (IOC/ICAM), the Commission aims to reinforce the production, collection and exchange of scientific data on the Indian Ocean, in order to help its Member States develop integrated coastal zone management plans. In 1997, within this framework and at the request of the Seychelles Government, the IOC/UNESCO and the REP-IOC/EU, having recognized the complementary nature of their programmes, undertook the preparation of the sensitivity Atlas for shallow marine zones on Mahé Island. This type of tool provides essential data for the evaluation of coastal ecosystem sensitivity to human activities.

Whith the purpose of sharing this experience with the region's other island and coastal states and publishing the methodology developed within the framework of the Atlas, the IOC/UNESCO, in partnership with the REP-IOC/EU, decided to undertake the creation of this methodological guide.

An increasing number of countries in the Indian Ocean are now setting up proactive environmental policies, via the adoption of the national environmental programme. This political goodwill means the development of local expertise is now vital to ensure that decision-makers' demands can be satisfied. A step-by-step cartographic approach, as proposed in this guide, will help the authorities of these countries in charge of coastal zone management train personnel for map compiling. The IOC/UNESCO will continue its campaign in the area as regards both marine science training and the setting-up of operational programmes, by providing information databases and field data to aid local and regional planning.

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Introduction

Ternay Bay: one of the most remarkable sites on Mahé Island in the Seychelles. Its rich natural assets attract divers and yachtsmen.

Introduction

The coastal zone is a complex space due to its position role between land and sea and the numerous development schemes which takes place there.

The socio-economic and ecological characteristics of the coastal zone and the conflicts it generates have created a growing need for more global management, taking into account various environments and the resources and activities found there.

Integrated coastal zone management has become a major priority in the Indian Ocean's southwestern islands. The measures implemented are highly structured, in particular those relating to information management.

Environmental management requires good basic knowledge of the environment's structure, functioning and uses, as well as means for the analysis and presentation of the problems encountered, in order to identify appropriate solutions.

General information management and, in particular, information mapping are therefore extremely important; efficient use of the abundant and highly-diverse available data is imperative if operational solutions are to be found to management problems. The creation of an adapted tool, incorporating a cartographic approach, is therefore essential to the implementation of coastal zone management.

The purpose of this guide is to propose a complete methodological procedure for the creation of a database and a cartographic decision-aid system. It is illustrated by two case studies carried out in the area in the framework of the Indian Ocean Commission's Regional Environmental Programme (REP), financed by the European Union (REP-IOC/EU).

Giant gorgonians form part of the area's rich ecological assets and offer divers remarkable seascapes.
The areas in which they thrive are therefore considered as sensitive. (Réunion Island)

Methodological   principles

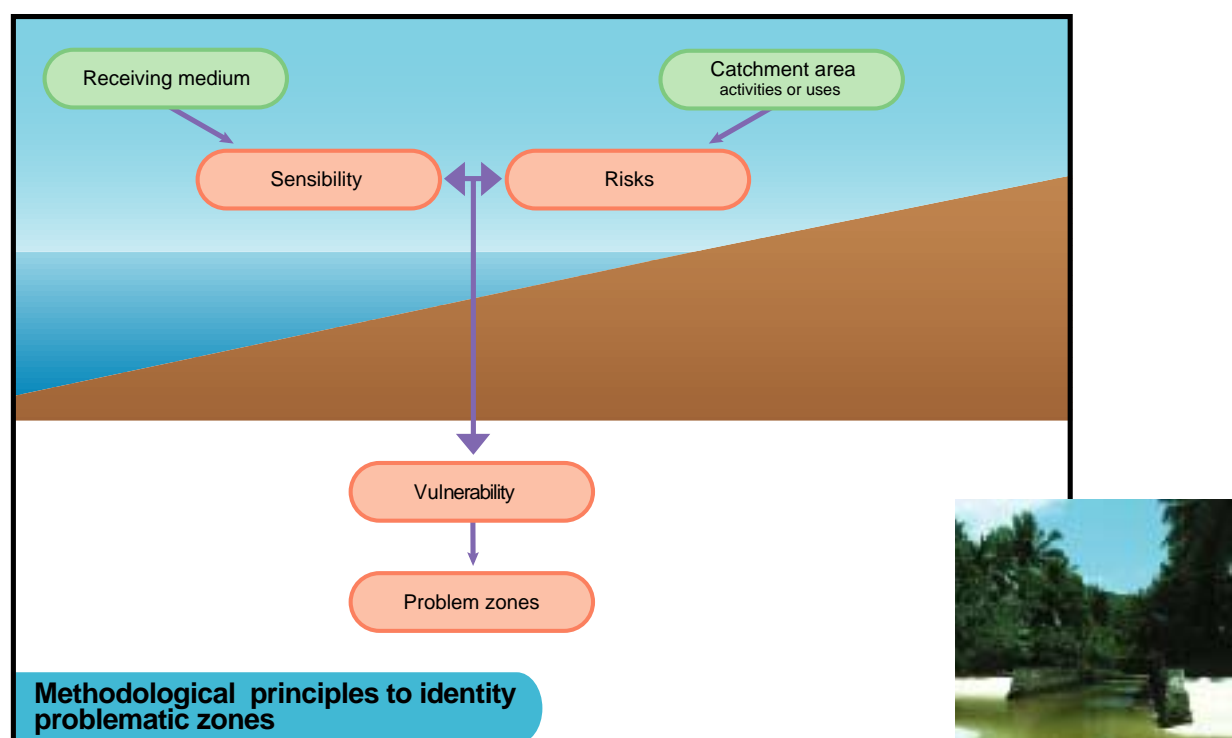The key methodological principles in this cartographic approach revolve around:

· A conceptual definition of vulnerability maps based on notions of sensitivity and risk factors.
· The operational development of vulnerability maps – this is vital whatever the final objectives may be.
· The specific use of these maps via the application of protocols in order to achieve various pre-defined objectives.

1. Conceptual   definition   of maps

The aim of the maps is to represent the reactions of the natural marine environment to the effects of human activities in the catchment area. These reactions are expressed directly according to the **sensitivity** of the receiving environment and upstream catchment area **risk** factors.

- Ecosystem sensitivity depends on the environment's intrinsic characteristics and varies accordingly to its specificities. It is defined by the environment's ability to withstand deterioration of its natural richness (or biodiversity) and its capacity to resist stresses (resilience).

- Risk factors depend on human activities in coastal zones and vary according to the types of activities developed. Risk-generating factors generally concern various types of pollution, coastal developments, the excessive exploitation of available resources, etc., but they can also be linked to natural factors, which may be worsened by human action (terrigenous inputs). By taking into account the sensitivity of various environments and the risks to which they are subjected, we are able to highlight so-called "vulnerable" zones.

Receiving medium

Catchment area
activities or uses

Sensibility

Risks

Vulnerability

Problem zones

Methodological principles to identity problematic zones

2. Mapping

A vulnerable zone can be defined as a zone which is both sensitive and subject to risks. Its degree of vulnerability depends on its degree of sensitivity and risk.
Degrees of sensitivity and risk are secondary data, drawn up by transforming representative raw data. Mapping takes place on several levels:

· Level 1:
Descriptive maps of the environment taking into account its natural components (physical and biological parameters) and anthropogenic components (socio-economic parameters relating to risk-generating activities),
· Level 2:
Sensitivity and risk maps compiled via interpretation of the above parameters according to a colour code corresponding to an ascending scale of values,
· Level 3:
Vulnerability maps of problem zones compiled by combining the two preceding types of maps.

3. Specific map uses

Protocols for the use of these maps will depend on the objectives defined at the study outset. The main objectives can be summed up as follows:

· <u>Safeguarding of the submarine environment</u> : the sensitivity map enables identification of zones possessing the greatest natural richness, which must receive priority protection. If these zones are shown to be subject to a risk (risk map), actions aiming to reduce this risk are suggested. The identification of zones requiring protection, i.e. "vulnerable" zones and corrective measures in the catchment area, could result in the creation of a Marine Park (see Mahé study).

· <u>Development of environmentally-friendly activities</u> : mapping the physical and biological characteristics of the sea beds enables identification of particularly rich and remarkable zones, including zones suitable for certain activities (e.g. scuba-diving). Comparison of these two types of map enables the identification of problematic (conflicting) zones and facilitates the implementation of regulations on the development of certain activities in the most fragile zones.

· <u>The setting-up of a monitoring network</u> : sea bed typology and coastal morphology will enable the possible setting-up of a monitoring grid. The variables selected for monitoring and measurement will depend on the types of aggressions encountered and environmental characteristics. The simultaneous consideration of these factors will optimize strategic planning (see case study n°1 then n°2).

- <u>Coastal zone management plan</u> : this involves the synthesis and integration of al previously-defined objectives. Map comparison allows the identification of vulnerable zones, i.e. zones which are both sensitive and subject to risks. Better appreciation of stakes and the drawing-up of diagnostics and scenarios with a view to offering solutions and their implementation priority then becomes possible. All the requirements for a management plan will consequently be gathered.

S-Shaped channel reserve (Mayotte)

Project stages

The compiling of sensitivity and risk maps requires the use of a structured process based on the organization and transformation of selected data. This process is comprised of the key stages outlined below:
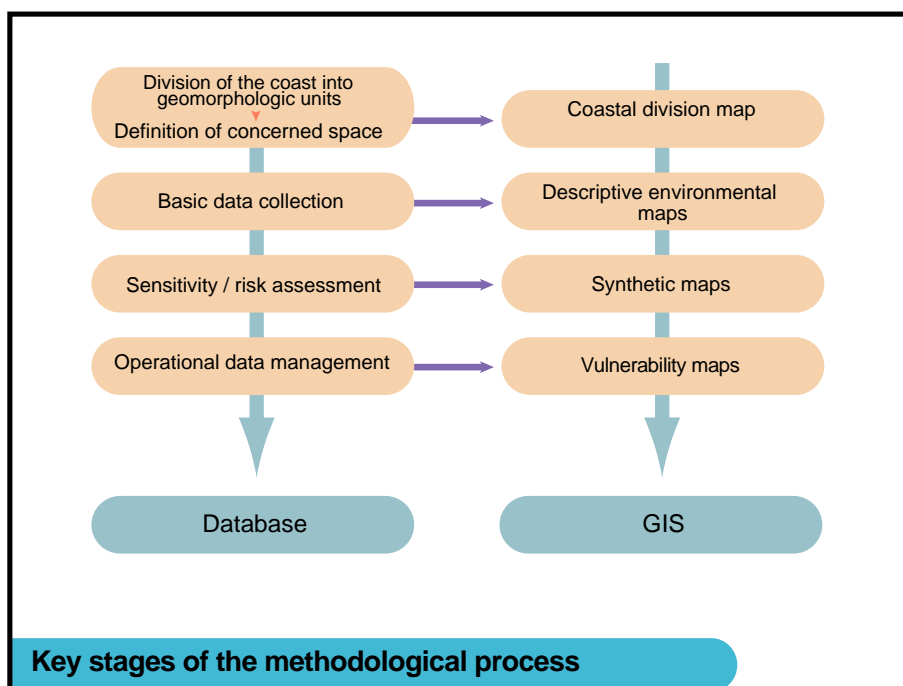
The above process will permit the creation of a complete database plus an associated Geographical Information System (GIS) for the management of data in map form.

Stage 1: Division of the coast into geomorphologic units

Why is coastal division necessary?

Space delimitation forms a key stage in the integrated coastal zone management process. This division is particularly essential to the orientation and organization of data management, from data collection to its representation in operational and synthetic form, in terms of sensitivity and risk. Delimitation will therefore provide a homogeneous framework for each unit of space, enabling recording of its main descriptor parameters on an adapted datasheet (see next stage).

How should the coast be divided up?

Delimitation is performed both longitudinally with regards to the coastline and transversely, from the coast towards the open sea.

The marine section of the coastal zone is divided up on the basis of geomorphologic, or sometimes ecological or administrative criteria. On islands with linear coastlines, as is the case for most of Réunion Island, the zones are identified longitudinally from one cape to another or to a gully, making sure a geographical coherence is respected, or an ecological coherence in the case of particular formations such as reefs.

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Project stages: coastal division

Delimitation is more complex in zones where coral reefs are well-developed and form lagoon barriers. In this case, the coastline is first of all divided up as previously. Then, the whole of the zone including the coastline and barrier reef is taken into account. These zones must then be isolated transversely after analysis of the bathymetric map to enable delimitation of homogeneous basins. The marine depth limit is fixed arbitrarily at the environmental investigation boundary, i.e. at an average depth of 15 to 20 metres.

Choosing a grid scale

A scale or an average zone size must be defined before dividing up the coastal zones. This choice will depend on the final number of zones obtained and hence the accuracy of the final operational document. The approach can be made progressively using general maps representing the studied territory as a whole, which can initially be used to pinpoint the major morphological units, then, if required, the major ecological units which may or may not be subdivisible.

This choice depends:
* on the size of the covered territory: the smaller the territory, the smaller the zones must be.
* on the accuracy of the collected data: the smaller the zone, the more accurate the data must be.
* on coastal complexity: a complex coast requires specific delimitation, taking into account a basin concept.
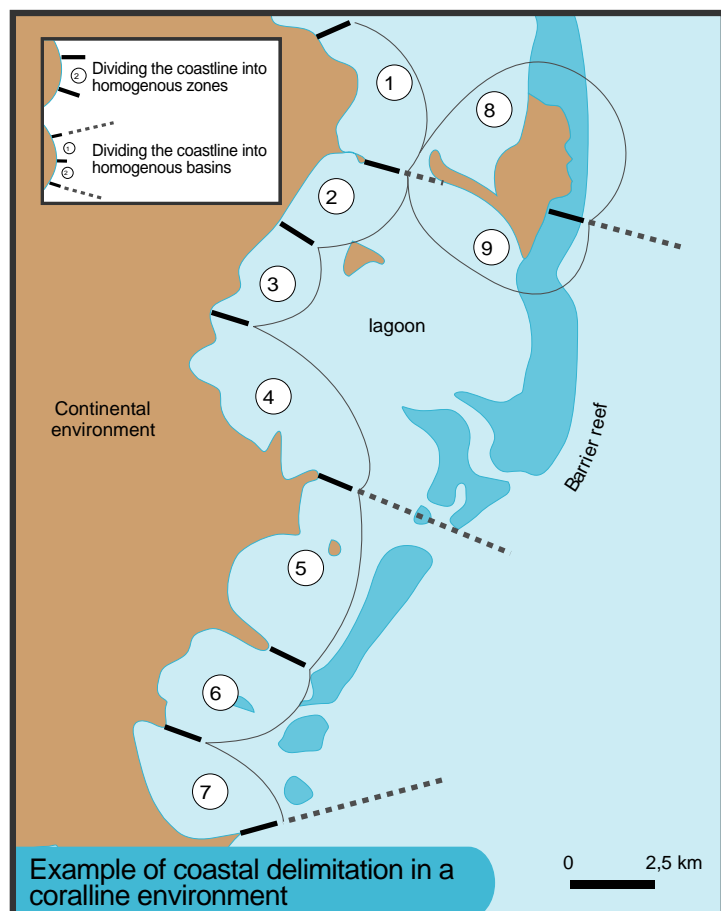
Representing coastal division

The division must be able to be represented on a map but also in table form; it is most important to be able to refer to each zone individually in order to facilitate management.
Each zone will therefore be identified:

* On a map: by lines representing their longitudinal and transverse boundaries. For basins with a larger surface area, lagoons must be represented clearly.

In a table: by a numeric identifier (zone 1, 2, 3, etc.) and a name, although it is rare to be able to name the zone as a whole. The solution consists of naming the zone according to the capes or localities marking the beginning and end of the zone. If necessary, a column can be added mentioning the name of the included islands or barrier reef. All of this data is mentioned in the first columns of a table under the heading "General Descriptors".

Dividing the coastline into homogenous zones

Dividing the coastline into homogenous basins

lagoon

Continental environment

Barrier reef

0   2,5 km

Example of coastal delimitation in a coralline environment

Stage 2: Data collection

How should data collection criteria be selected?

Faced with the amount and diversity of the data characterizing the coast, a rigorous method is required to guarantee satisfactory coherence between the data collected and the study's objectives. This method consists primarily of sorting the data per main category and then into more detailed categories. The first major task consists of differentiating data concerning **the receiving environment** from that concerning the terrestrial environment or **catchment area**. The receiving environment can be described in terms of **natural riches** versus **deteriorations**.

Natural riches are assessed in terms of the environment's physical and biological characteristics, plus the inventory of uses to which the environment is subjected. Additional information regarding legal regulations can also be added to describe existing protective measures or management programmes. Each of these factors is then adjusted to a level of accuracy compatible with the limits of scale.

A rich flora and fauna and activities linked to discovery of the marine environment often go hand in hand. (Réunion Island)

Upstream, the activities developed in the catchment area must be identified per type and characterized according to the types of waste they deposit in the natural environment. Their harmful effects cause a variety of environmental deteriorations.

Deterioration research constitutes a separate theme altogether; awareness of the environment's state of health makes it possible to pinpoint deterioration typology and appreciate its consequences: an outer slope with living and developed coral is unlike an outer slope which has been deteriorated by pollution. In these cases, diversity and sensitivity differ widely, resulting in opposing conclusions as regards the environment's future use and development. Deteriorations also concern potential resources such as fishing or aquaculture, which may be compromised by unhealthy water. Finally, they may limit other uses; e.g. water polluted by pathogenic bacteria which is unsuitable for bathing.

Coastal transformation and artificialization are often major contributors to the deterioration of the subsea environment. (Réunion Island)

Project stages: data collection

Classification of data to be collected (indicative list)

- **Receiving medium**
  - **Natural assets**
    - **Physical environment**
      - Hydrodynamics
      - Geomorphology
      - Sedimentology
      - Physiochemical chara...
    - **Biological environment**
      - Benthic populations
      - Fish
    - **Uses**
      - Leisure
      - Fishing
      - Aquaculture
      - Ports
    - **Status**
      - Legal protection
      - Flora/fauna inventories
  - **Deteriorations**
    - **Nature**
      - Organic pollution
      - Bacteria
      - Macrowaste
      - Toxic micropollutants
      - Physical pollution
      - Indicator species
      - Erosion
- **Catchment area**
  - **Anthropic uses**
    - Agriculture
    - Industry
    - Urbanization
    - Tourism
  - **Catchment area**
    - River flows
    - River quality
  - **Status**
    - Legal protection
    - Scientific inventories

Collecting appropriate data

A complete set of data is not necessarily required. According to initial objectives, it will be preferable to focus on one particular identified theme. The following table is an example of the type of data necessary for researching zones sensitive to eutrophication :

Eutrophication risks: (catchment area):	Sensitivity to eutrophication (receiving environment):
• Water treatment plants (no discharge due to absence of urbanization, compliance with norms and network functioning satisfactorily, non-compliance with norms or defective network)	• Exposure to swell (Strong, average, weak)
• Waste tips (absence, tips near coast but subject to certain regulations, uncontrolled tips)	• Exposure to wind (strong, average, weak)
• Agro-industrial structures (absence, presence of isolated structures, concentration of structures on the coast)	• Zone confinement (linear coast, bay or micro-bay, lagoons or zones protected by bordering reefs)
• Ports (absence, small ports or anchorages, busy fishing or industrial ports or marinas)	• Type of populations
• Waste water and rain water discharges (absence, presence of discharge, presence of several discharges)	
• Rivers and gullies (absence, presence of gully or river, presence of several gullies or rivers)	

The list below provides a checklist of the various descriptors which can be researched, plus their definition.

1. General Descriptors

Zone n°
Delimitation criteria
Zone name
Reference administrative area
Existing towns or agglomerations in the zone
Associated small islands
Associated barrier reefs
Lagoon/basin unit

2. Sensitivity-linked descriptors

2.1. Natural environments

Zone confinement
Remarkable species
Remarkable formations
> Richness/diversity of the mangrove
> Richness/diversity of the bordering reef and associated reef flat
> State of health of the mangrove
> State of health of the bordering reef
> Development/deterioration of the mangrove
> Ecological importance of water plant communities

2.2. Human activities

Leisure activities
Professional activities
Protective measures

3. Risk-linked descriptors

Zone's general vocation
> Size of the urban zone
> Cleanliness of the urban zone
> Urban development project
> Presence of classified industries
> Presence of unclassified industries
> Agro-industrial structures
> Impact of industries
> Industrial development projects
> Type of tourist activities
> Tourism development projects

Presence and type of ports
Significant natural discharges
Extent of terrigenous inputs
Domestic waste tips

Rich and diversified outer slope. (Mahé Island, Seychelles)

Fishing port. (Réunion Island)

Intensive shrimp farming is at the origin of major organic waste deposits. (Madagascar)

Drawing up a raw data table

The raw data collected at the start of the process is classified in two major categories according to its relation to the receiving environment or the terrestrial environment. This distinction should facilitate subsequent processing, respectively in terms of sensitivity and risk.

How to obtain data?

The data, of various type, can be obtained from different sources. It must therefore be collected from official sources – this being part of their job - or via specific research if the data is incomplete or insufficient. This data must be of the best possible quality (accuracy, reliability), without neglecting more qualitative or even approximate data. The main data sources are as follows:

- Local governments or State departments,
- Local authorities (districts, sub-regions, regions or equivalent),
- Scientific or specialized organizations (e.g. Geographical Institute, Hydrographic service, etc.),
- Naturalist societies.

Data can also be collected via user surveys:

- Fishermen, professionals or not,
- Tourist organizations and other economic concerns,
- Organizations in charge of coastal infrastructures.

Lastly, data can be collected via direct observation:

- Field data: coastal morphology, inventory of waste discharges, natural inputs, the existence of unauthorized discharges, embankments, specific industries, coastal activities, etc.
- In the aquatic environment: population inventory, environment typology, observation of deteriorations, identification of environmental disturbance or quality bio-indicators, identification of the global state of health of populations, etc.

Data acquisition via dives

Data linked to the typology of the coastal marine environments (reefs and rocky coasts) is collected by scuba-diving or snorkelling. These survey operations can be carried out:

• From the shore (subject to environmental and weather conditions). This investigation strategy is feasible for surveys on formations such as narrow bordering reefs, for shallow zones (< 2 metres) or rocky coasts accessible from the shore.

• Using a boat. This strategy is used for wider lagoons and enables surveys on larger reef zones (bordering reefs of about 1 km in width, or zones which are difficult to access from the shore). This technique also provides excellent surface logistic support from a safety viewpoint.

Sampling techniques

The various sampling techniques used to identify subsea coastal formations and their ecological characteristics are based on:

• **exploratory radials** (1 to 2 according to sector) which are representative of the sampled sector and pre-positioned (using cartographic pre-positioning / GPS). A survey of the various reef structures is performed along an imaginary line perpendicular to the shore (from a few hundred metres to over 1 km according to the sector), by swimming and/or using the "manta tow" or "rapala" techniques (surface pulling using a boat). This technique is based on the identification of main environmental and population features (predominant benthic and ichtyologic species), their qualitative and quantitative representativeness (abundance rating) and the taking of notes and underwater photos of the various structures or organisms encountered.

• **periodic additional explorations** (using cartographic pre-positioning / GPS) corresponding to particular structures identified on the maps and requiring a field check. The description of the environment's characteristics and populations is based on the preceding techniques (note-taking and photos, plus sampling for systematic identification if required).

• **simplified "linear sampling transect dives"** according to the methodological principles defined in the IOC's methodological handbook for reefs (Conand et al., 1998). Transect dives work in conjunction with the preceding exploratory techniques, enabling global identification and quantification (% of coverage) of taxons and predominant coral forms within specific reef zones (outer slopes, reef flats). If necessary, these transects could be used as references for future reef monitoring.

The standard field data acquisition protocol is based on the following methodology :

1• zone-by-zone analysis of cartographic documents (pre-mapping),
2• identification and positioning (cartographic / GPS) of two exploratory radials (or more) perpendicular to the coast and representative of the various environments to be validated,
3• positioning of localized sampling points (if necessary) corresponding to the particular environmental or population facies to be identified.
4• drawing up of complementary exploratory profiles for the validation of polygonal boundaries and their geomorphologic and biocenotic characteristics,
5• positioning of specific sampling "transects" for the benthic environment (follow-up methodology / monitoring of coral environments), representative of the environments encountered (reef flat or outer slope zone).

Identifying data sources

The data must initially be collected from competent individuals or resource organizations specialized in environmental monitoring or observation. This data may be available from one or several organizations according to theme (environment, tourism, sanitation, etc.), or be distributed throughout multiple and heterogeneous reports.

Certain countries may have already implemented a policy concerning the problem of information management in the coastal environment, thereby enabling the use of existing geo-referenced data in digital form and used in GIS. In this case, all or part of the data may already have been harmonized and adapted for mapping purposes.

An initial assessment of the existing situation can be carried out on the basis of information collected through these sources. Any missing data is then identified and a strategy for collecting complementary data can be set up. This strategy must take into account requirements and available financial means. Field measurements and observations are generally costly in terms of logistics, analysis and data processing.

Data standardisation

The data obtained generally emanates from highly diverse sources and comes in extremely varied forms.

Data may be quantitative and very accurate, or qualitative and more approximate. The global approach can only be effective if the data used is homogeneous throughout the studied zone. Data standardisation is therefore vital. This procedure generally consists of simplifying the data by transforming it into qualitative variables according to an exhaustive common denominator for the whole of the concerned zone. This preparatory task is essential to data coding.

Simulation of data harmonization			
Data: degree of confinement			
Zone n°	Data source	Raw data	Harmonized data
1	Department of the Environment (GIS)	Very confined zone	Very confined zone
2	Department of the Environment (GIS)	Little-confined zone	Little-confined zone
3	Faculty of Science (hydrology lab)	High renewal rate	Little-confined zone
4	Faculty of Science (marine biology lab)	Slight increase in trophic levels (nitrogen and phosphorus)	More or less confined zone
5	Faculty of Science (marine biology lab)	Drop in diversity over time	More or less confined
6	Field surveys	Murky water sometimes giving off nauseous smells	Very confined zone
7	Field surveys	Very intensive fishing of one species	More or less confined
8	Observations during dives	Highly-deteriorated coral species, presence of opportunistic species	Very confined zone

Stage 3 : Raw data mapping

Establishing a descriptive chart

The collected raw data is used to establish the characteristics of the coastal environment. These characteristics are then represented geographically via descriptive maps of the sea beds; these factors being essential to the setting-up of a management plan. Handling of data is facilitated if it is computerized rapidly. (Data computerization constitutes a separate task in the mapping process).

A reference map must first be drawn up using two types of sources :

· Existing cartographic data: in many cases, mapping has already been carried out on part of the coast. These maps, whether complete or incomplete, can be used as a basis for establishing a harmonized typological representation of the coastal environment.
· Aerial photographs or satellite images: this type of medium generally enables observation of the sea beds to a depth of around 15 metres, providing turbidity is low. Manual photo interpretation enables the contours of underwater formations to be traced without specifying details on their exact type. A preliminary typology is, however, conducted at this stage and will act as a basis for future investigations.

This operation results in a representation of sea bed types (rocky, sandy, sandy mud, etc), biocenosis, ecosystems, remarkable populations, etc.

The thematic geographical data obtained must then be computerized to facilitate subsequent mapping operations.

For this purpose, printed documents must be scanned and possibly digitized. According to the study's objectives and available financial means, these maps can be created using CAD (Computer-Aided Design) software or, preferably, using GIS (Geographical Information Systems), once the concerned geographical data has undergone initial processing (topology, geographical projection system, etc.).

In the latter case, the information layers are divided up per theme and the data is geo-referenced to create geographical objects.
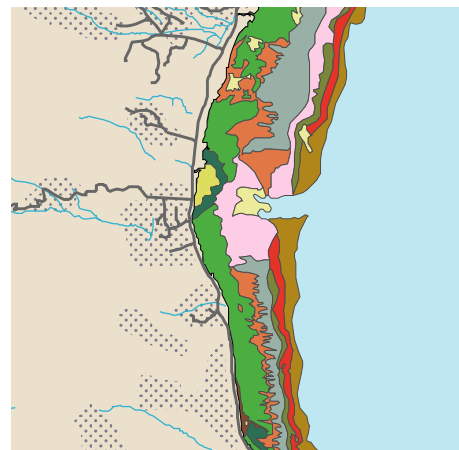
How to transform a manual photo interpretation into a computerized map composed of digitized data?

The complete procedure takes place in the following stages:

1. Scan or digitize : Digitization requires a scanner and specialized software. Hand-drawn maps in A4 format or larger (up to A1 or AO) are converted into ".DXF" format by contouring the identified thematic objects using the mouse (coastline, reefs, significant landmarks, etc.) and creating an external framework to facilitate polygonation.

2. Geo-reference : this consist of importing the reference coastline in ".DXF/DOS" format, then geo-referencing map files using the coastline and landmarks. This operation is completed by linking up and closing reef lines on the reference coastline.

3. Assemble : assemble the A4 format maps edge-to-edge.

4. Correction : internal, geometrical.

5. Polygonate : thematic objects such as reefs are transformed into geographical polygonal objects (topological) using Arcview (ESRI).

6. Index : a maximum of twelve 2-character alpha codes are available for indexing objects corresponding to reference typologies.

7. Trace : one-dimensional coloured thematic diagrams must be drawn up for correction and updating purposes, with overlaps to allow visualization of adjacent maps and correction of bordering polygons.

This procedure results in a preliminary map.
Its computerized format facilitates future modification.

Remark : all of the above operations are required in order to create metadata files (data on data).

Establishing a typology:

The integration of data from bibliographical analysis, photo-interpretation and field data (collected mostly during dives) should enable the drawing-up of an inventory of the main types of geomorphologic and biocenotic entities encountered in the study zone.

Secondly, a simultaneous analysis of the various available elements (environmental descriptions, population inventories, state of health, community quantification or ratings, aerial photos, etc.), is used to define the predominant or specific populations associated with the various types of physical environment encountered (e.g. a Thallassodendron cialiatum phanerogam community colonizing reef flats).

This integrated analysis will allow the subsequent establishment of a subsea environment typology, based in general on geomorphologic elements and their associated population components. It hence enables pinpointing of the main environmental and population characteristics in a given coastal zone.

Simple typological descriptions can then be drawn up by establishing corresponding standard datasheets associated with photographs, to facilitate user understanding.

These typologies do not in any case constitute a study of marine population biodiversity; as actual field situations are often very complex, the purpose of this work is to establish a satisfactory compromise, whereby environmental/population entities (resulting in a map in the long term) are defined in a simplified manner which is nonetheless representative of field reality.

Lastly, the initial map is compared with the various previously-defined typologies, in order to correct and validate the initial documents zone by zone.

A definitive map of typologies representing the main environments and associated populations can hence be drawn up and used as the basis for subsequent work based on the ecological sensitivity of the coastal ecosystems.

Example of Typology on Mahé Island (Seychelles)

OUTER SLOPE
The outermost part of the reef generally extends to a depth of 15-20 metres. The outer slopes around Mahé come in 3 forms:
- Outer ridge slope
- Outer loose-coral slope
- Outer glacis slope

COASTAL PHANEROGAM COMMUNITIES
The water plant community is generally located to the rear of the loose-coral reef flat. The communities are usually installed on sandy or mud & sand substrates. The communities are monospecific or mixed according to the type of substrate (type and grain size) and its hydrodynamics.

MIXED ZONE WITH COASTAL WATER PLANT COMMUNITIES AND SEAWEED FACIES
These ecosystems are formed by the association of phanerogam communities and seaweed colonies.
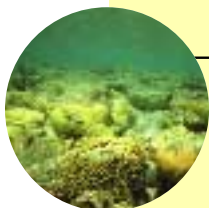
PURE CORALLINE SAND
Coralline sands occupy most of the surface area from the shore - where they comprise beaches such as Beauvallon - towards the open sea.

REEF FLAT FORMATION
Coralline formations come in the form of isolated coralline massifs with regards to other reef structures.

"SENSU STRICTO" REEF FLAT
The reef flat is the section of the reef extending from the top of the outer slope to the first phanerogam communities. It generally comprises a loose-coral reef flat (sandy, with exclusive seaweed colony or transverse alignments) and a compact reef flat, sometimes separated by a set of small basins of 2-3 metres in depth.

ARTIFICAL OR MODIFIED SUBSTRATE
These are areas of the coastline which have been subjected to embanking, damming or digging work.

SURFACE ROCKS
These may be found at shallow or deep depths. In the latter case, they are populated mainly by hard corals, soft corals or seaweed.

DELTA ZONE
These are small deltas located at river mouths near mangrove outlets or upstream marshes in the catchment area.
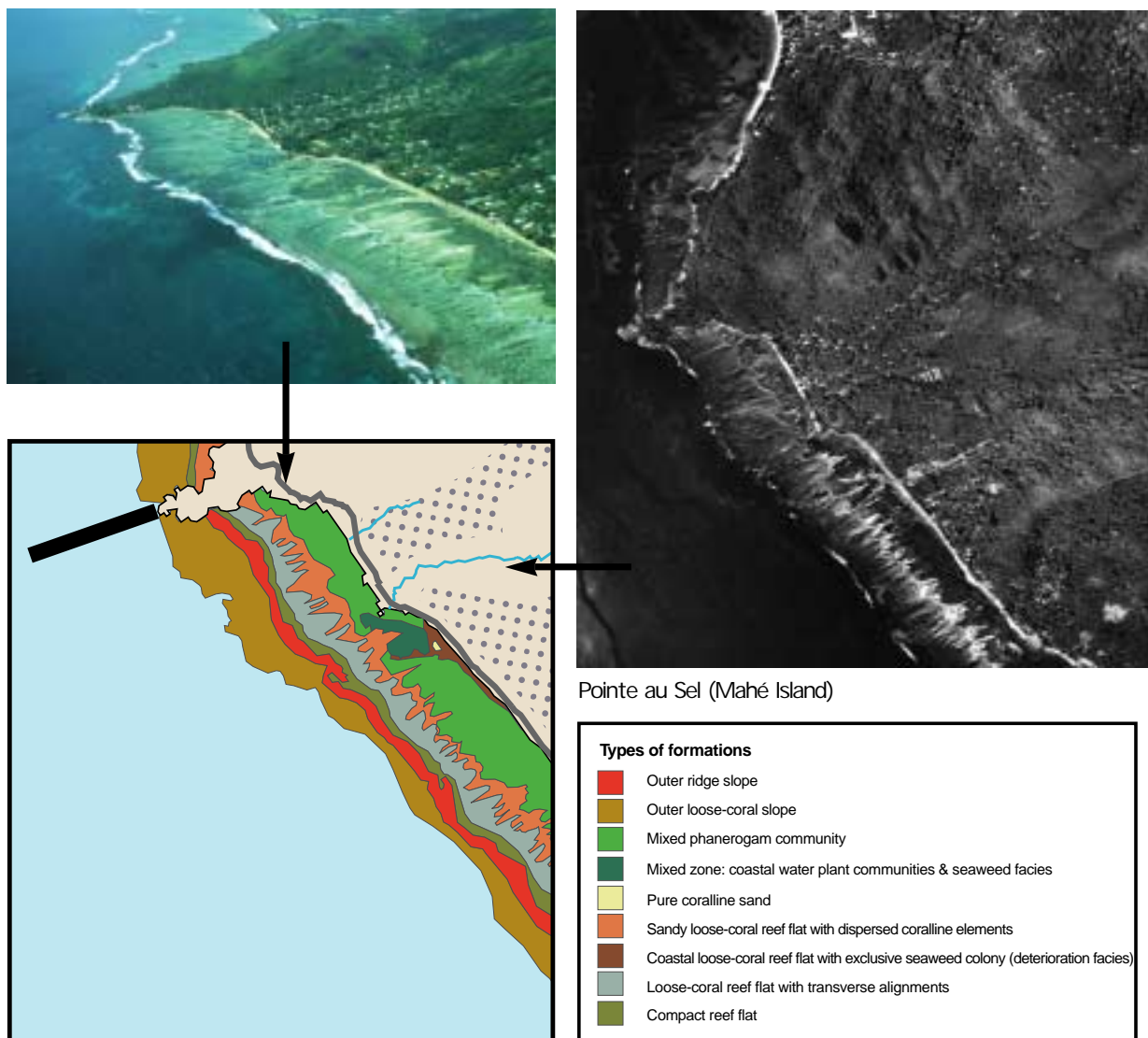
RETICULATED BORDERING REEF CHANNEL
These reef structures are composed of a complex system of channels and bays cutting into the outer reef section and sometimes leading to the isolation of coral banks.

Project stages: mapping

The initial map is a provisional document which must be validated via field observations. The established typology and boundaries of the various zones will be used as guidelines to create a faithful field representation. The studied zone cannot be covered entirely during dives. The aim of investigations, which are generally carried out via dives, will be to describe the identified environments accurately and check at certain representative points that the boundaries defined correspond to a biological and physical reality. For example, a dark area on an aerial photo may be due to a simple bathymetric change or a loose seaweed colony moving with the currents. The best way of validating this information is to carry out systematic transect dives perpendicular to the coast. These radials will cross most of the subsea formations, which are generally organized parallel to the coast. These explorations can be completed if necessary by specific dives at certain points, in particular in the deepest zones where prolonged dives are impossible.

Once this field phase has been conducted, the observations obtained are compared with the provisional map for correction and completion purposes. After association with the precise description of the various defined typologies, a definitive sea bed map is obtained.

Pointe au Sel (Mahé Island)

Types of formations

- Outer ridge slope
- Outer loose-coral slope
- Mixed phanerogam community
- Mixed zone: coastal water plant communities & seaweed facies
- Pure coralline sand
- Sandy loose-coral reef flat with dispersed coralline elements
- Coastal loose-coral reef flat with exclusive seaweed colony (deterioration facies)
- Loose-coral reef flat with transverse alignments
- Compact reef flat

Orthogonal and sidelong photos can be effectively combined for accurate mapping

Establishing a risk-factor map

The risk-factor map enables precise pinpointing of all the potential sources of environmental deterioration. Most of the harmful sources linked to the development of human activities are located on land in the catchment area, although some may be located in the sea or on the shore (excessive use of bathing or diving sites, intensive fish farming, etc.).

These risk factors are represented in the form of pictograms, enabling location and characterization of the risk zone. A graphic chart must be defined at project outset, based on previous observations and local specificities.

Stage 4 : Sensitivity and risk notions

Sensitivity assessment via sea bed typology

Initially, the environment's sensitivity must be determined as accurately as possible in terms of physical, ecological and socio-economic characteristics. Sensitivity categorization is extremely complex due to the study's highly-varied objectives. For example, a notion of sensitivity linked to human activities which must be preserved could be introduced.
This could be the case for uses requiring good water quality (bathing, aquaculture) or a rich natural environment (fishing). These zones are automatically allocated a maximum sensitivity value.
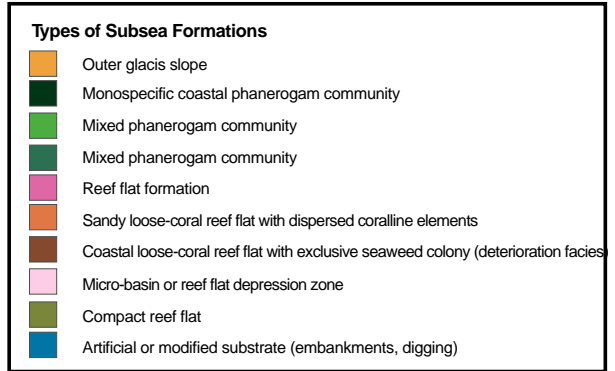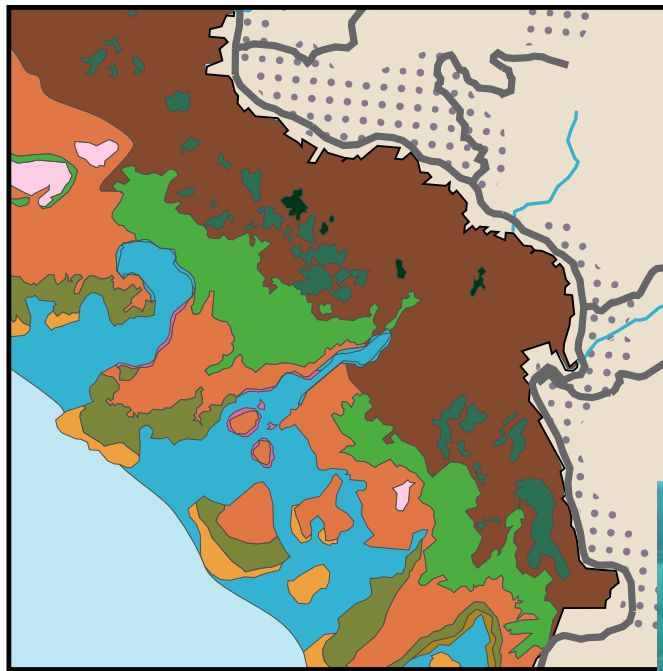
Moreover, as sensitivity is defined with regards to stress factors, it will obviously depend on the stress factor in question. A coral reef's sensitivity to urban discharges is not the same as its sensitivity to chemical or accidental hydrocarbon pollution.

Each characteristic environmental element defined during sea bed mapping must therefore be allotted a sensitivity value. In general, the simplest method is to award each element a sensitivity rating from 1 to 4, represented on the map by a colour code: 1: blue; 2: green; 3: orange; 4:red. Greater detail often proves to be useless. The initial colour of the thematic polygons can then be simply replaced on the map by the corresponding colours to obtain a synthetic map representing the required sensitivity levels. This coding process is generally decided by experts, although validation is often required by decision-makers or their partners.
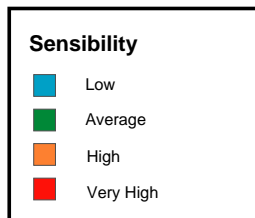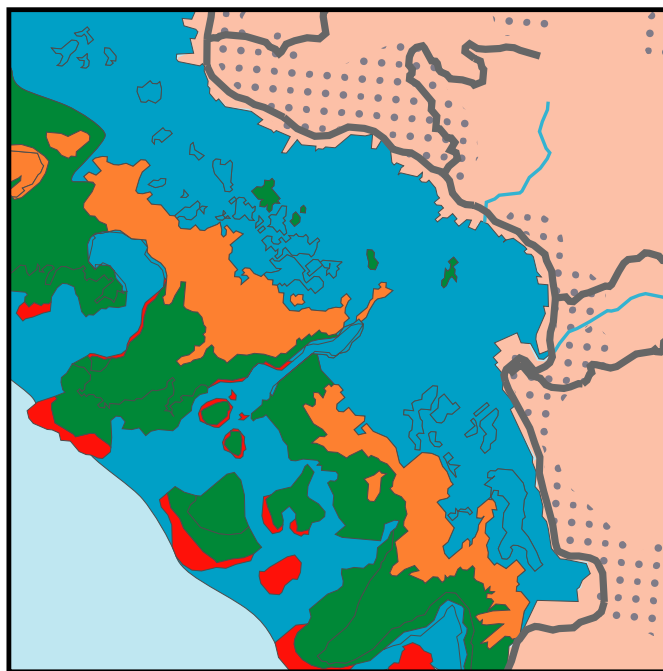

Lagoons, which are both confined and readily accessible, are both sensitive and subject to risks: they are classified as "vulnerable". (Réunion Island)

Project stages: sensitivity   and   risk

Types of Subsea Formations

- Outer glacis slope
- Monospecific coastal phanerogam community
- Mixed phanerogam community
- Mixed phanerogam community
- Reef flat formation
- Sandy loose-coral reef flat with dispersed coralline elements
- Coastal loose-coral reef flat with exclusive seaweed colony (deterioration facies)
- Micro-basin or reef flat depression zone
- Compact reef flat
- Artificial or modified substrate (embankments, digging)

Anse Etoile (Mahé Island)

Sensibility

- Low
- Average
- High
- Very High

Transforming population maps into sensitivity maps: each type of subsea formation is allotted a sensitivity rating (4 ratings).
This value is then transformed directly into a colour code by the software.

Establishing a global sensitivity map

Maps established according to the above methodology will not be suitable for direct use by decision-makers, as they will be too detailed in terms of sensitivity types. The information obtained must be simplified and associated with the corresponding coastline. A global sensitivity map must therefore be established, by transforming information relating to various forms of sensitivity into uniform data adapted to coastal zone scales. This synthetic information can then be colour-coded and allocated to a particular section of the coastline.

No automatic method exists for adaptation from fine to global sensitivity. It is therefore up to the operator to use his expertise and system analysis capabilities.

Assessing the environment's state of health

Certain ecological indicators enable evaluation of the environment's state of health. Some of these indicators can be observed directly during dives:
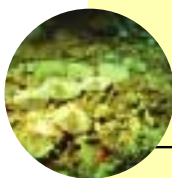
• **Thick seaweed layer:**
   sign of eutrophication

• **Proliferation of opportunistic species :**
   sign of hypersedimentation

• **Hard corals replaced by soft corals ;**
   sign of deterioration

• **Presence of carnivorous fish : sign of good health**

Project stages: sensitivity and risk

Establishing a risk map

Risk factors as a whole are represented on a descriptive map and detailed in a table. During this stage, a risk index must be allocated to each risk factor.

In general, the rating varies between 0 and 3 (0 = absence of risk, 3 = high risk). All of these individual indexes are then combined to obtain an overall risk rating. This calculation generally consists of taking into account the most representative index (highest frequency) but other systems can be adopted (in particular balanced linear combinations or most penalizing index). These combinations can be used to calculate risk levels in relation to a quality objective, or a global risk level. This choice is determined by the study's initial objectives.

Once indexes have been determined, they can be represented on a map using the same graphics as for global sensitivity: a colour code varying from blue (low risk) to red (high risk), is applied to the geomorphologic units defined at the outset. The global risk factor map can therefore be easily exploited by decision-makers.

Distillery and power station
(Réunion Island)

Stage 5 : Presentation of study results

The identification of problem or vulnerable zones results from the comparison of sensitivity and risk levels in each zone. This process will allow the singling-out of priority zones.

Comparing sensitivity and risk factors

The adopted graphic representation of sensitivity and risk factors facilitates identification of zones which are both sensitive and subject to proven or likely anthropic stresses. Total sensitivity and potential risks must therefore be represented on the same map. A combination of high sensitivity (red zone) and high risk (red zone) within the same zone will enable highlighting of highly-vulnerable zones requiring priority attention.

Secondly, a zone by zone examination must be performed in order to identify the problems behind these poor ratings and enable suggestions as to possible technical solutions.
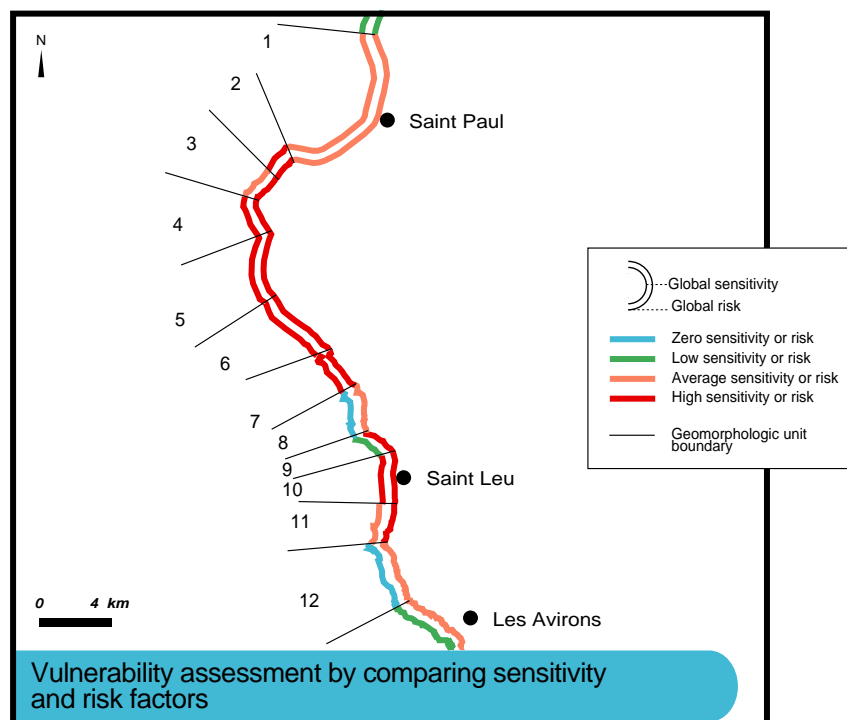
The geomorphologic units where sensitivity and risk factors both appear in red are particularly vulnerable. (Réunion Island)

Project stages: presentation

Establishing datasheets per zone

In order to identify each problem encountered, a short and synthesized datasheet must be drawn up for each zone. The contents of this datasheet must be adapted to each site, but each datasheet must contain the following elements:

- General presentation of the zone and typology (main characteristics)
- Sensitive elements
- Risk factors
- Vulnerable elements
- Actions to be implemented and recommendations

The purpose of these datasheets is to allow easy pinpointing of critical points on a given geographical site. They also facilitate building of a database, in that they contain key data on the geographical objects resulting from coastal division.

Organizing datasheets in terms of management operations or recommendations

This chapter can be considered as one of the elements of the management plan itself. Initially, all of the management operations associated with the previously-described datasheets are listed. A priority code is then allocated to each operation. This code depends on two criteria:

- the urgency of the measures to be implemented.
- chronological priorities (completion of one stage before implementing the following stage).

These recommendations may relate to very different actions such as coastal planning, the installation of monitoring networks or proposals for institutional management structures. Their orientation may depend on the objectives fixed at project outset.

Editing an atlas

In order to facilitate data distribution and consulting, the documents must be grouped in an atlas containing:

- an introduction detailing the document's objectives
- a simplified presentation of the methodological process,
- a simplified presentation of typology,
- a detailed presentation of typology including type name, a descriptive text, an illustrative photo and the sensitivity value,
- a large-scale map of underwater formations,
- a large-scale sensitivity map
- a large-scale map of risk factors
- a simplified comparison map of sensitivity and risk factors, representing vulnerability.
- a series of small-scale (zoom) maps covering the same themes, each completed by brief identity sheets.

The above documents must be created using CAD (Computer-Aided Design) software to enable easy presentation in an operational document.

Case studies

Case n°1 : Shallow marine zones on Mahé Island in the Seychelles

Mapping of coastal marine zones on Mahé Island in the Seychelles was carried out by the authors of this guide with the backing of the Indian Ocean GREEN and in partnership with IOC/UNESCO, at the request of the Seychelles National Coordination office and Regional Authorities. This study forms part of the REP-IOC/EU programme for the setting-up of an integrated coastal zone management plan for the Indian Ocean.

General principles

The study consists of drawing up an inventory of coastal environments, characterizing them (environment and population typology, inventory of uses, etc.) and associating them with an integrated environmental diagnostic (sensitivity, state of health, environmental risks, etc.). The purpose of the study is to create a cartographic atlas synthesizing the sensitivity and risk factors on coastal marine environments on Mahé Island.

Three successive phases were implemented :

• Phase I : analysis of the existing situation and preliminary mapping
Based on an analysis of existing information, this phase enables division of the coast into homogeneous geomorphological units and definition of the complementary field data acquisition programme.

• Phase II : acquisition of field data
Based on field surveys, this phase consists of describing environments & populations, plus their state of health, risk factors etc., in order to assess the vulnerability of the studied environments.

• Phase III : integrated environmental analysis
This phase consists of integrating the data collected during the previous phases in order to draw up a cartographic atlas plus coastal sensitivity and risk factor datasheets per zone, in order to facilitate choices in terms of priority sites and plans of action.

Case study: Mahé

List of data used and map keys

Sea bed map (environments and populations)

Types of subsea formations

- Outer ridge slope
- Outer loose-coral slope
- Outer glacis slope
- Monospecific coastal phanerogam community
- Mixed phanerogam community
- Mixed zone : coastal water plant communities & seaweed facies
- Pure coralline sand
- Reef flat formation
- Sandy loose-coral reef flat with dispersed coralline elements
- Coastal loose-coral reef flat with exclusive seaweed colony (deterioration facies)
- Loose-coral reef flat with transverse alignments
- Micro-basin or reef flat depression zone
- Compact reef flat
- Artificial or modified substrate (embankments, digging)
- Shallow surface rocks
- Deep surface rocks with diverse coralline populations
- Granitic surface rocks with mainly soft coral populations
- Deep surface rocks with exclusive seaweed colony
- Delta zone
- Reticulated bordering reef channel

Risk-factor map

Vulnerability factors

Pig farms
- Reproduction
- Fattening
- Project

Hotels
- 0-24 rooms
- 25-60 rooms
- 61-206 rooms

Water and waste treatment
- Reservoir
- Septic tank
- Water treatment plant
- Lagooning
- Existing rubbish dump
- Future rubbish dump

Seaside leisure activities
- Sandy beach
- Diving club
- Scuba-diving site
- Snorkelling site
- Parascending
- Waterskiing

Fishing boats
(discharging on the site)
- Under 10
- 10-19 boats
- 20-50 boats

Source : Seychelles Fishing Authority
Seychelles Artisanal Fisheries Statistics for 1996

Topography
- 700 - 900 m
- 400 - 600 m
- 100 - 300 m
- 0 m

Protected zones
- Marine Park
- Shellfish Park

- Development project

Reference map

- Urbanization
- Trading estate and embankmentss
- Mangrove and marshes
- Road
- Waterway
- Victoria zone (unmapped)

Subsea environment sensitivity map

Sensibility
- Low
- Average
- High
- Very High

Synthesis of sensitivity & global state of health of the marine environment

Sensibility
- Very High
- High
- Average
- Low
- Victoria zone (unmapped)

State of Health
- ☺ Satisfactory
- ☺ Average (signs of deterioration)
- ☹ Significant deterioration
- ☹ High deterioration

The main stages of marine environment sensitivity mapping on Mahé (Seychelles)

Sea bed map

Risk-factor map

Detailed sensitivity map

Simplified sensitivity & population health map

Case study: Mahé

• *Phase I : analysis of the existing situation and preliminary mapping*

Preliminary coastal mapping takes place in 3 stages:

• *Collection of bibliographical data :*
This stage consists of researching the main environmental component references: geomorphology, oceanography, biocenosis, human activities, etc., from various information sources: institutions, scientific circles, design offices, IOC, etc. Several types of data are collected:

- scientific and technical documents (reports, works, publications, results of investigations, theses, etc.);
- cartographic documents (National Geographic Institute, topographic, tourist maps, etc.);
- old and recent aerial images type NGI campaign or equivalent, satellite images;
- summarized atlas-type environmental documents on sensitive land areas, environmental management plans, national development plans, etc.

Analysis of this data enables integration of the Seychelles' specificities and organization of the following study phases.

• *Photo-interpretation and preliminary mapping*

Preliminary reef mapping is based on the interpretation of black & white orthogonal aerial photos dating back to 1986, which allow observation of the submarine environment to a depth of approximately 12 metres. Zones are defined and associated with an environmental typology (reef flat, outer slope, water plant community, etc.). The resulting map is used as a basis for field checks. Field data is then used to validate zone boundaries and complete the preliminary maps.

• *Coastal division*

Division of the coast into geomorphological units involves numerous criteria, the most important of which are geographical or geomorphologic boundaries, administrative boundaries or protected spaces. A total of 21 zones were identified on Mahé Island.

• *Phase II : field data acquisition*

Field data is acquired in 2 manners:

• identification and characterization of the main coastal geomorphologic facies encountered around the island via dives, plus their predominant populations and state of health. During this phase, a submarine photographic database is compiled on the environments and organisms encountered.

• research for additional information or validation of data collected from the Department of the Environment and relating to risk factors, i.e. developments or human activities affecting the coastal marine environments. Aerial photos of the coast are taken at low altitude by a helicopter. These are used to complete the list of coastal risk factors and identify reef formations which are inaccessible by sea or from the shore.

This field data is used to establish marine environment typology and validate the preliminary map.

• *Phase III: environmental analysis*

Environmental typology and mapping

The main types of geomorphological and biocenotic entities encountered around the island are listed and characterized by combining bibliographical and field data. Subsea environmental typology is based on reef elements and their biocenotic components, e.g.:

- identification of animal and plant organisms;
- definition of predominant and specific populations;
- specific quantification of characteristic populations (localized transect dives, estimation of substrate coverage, abundance rating, etc.);
- environmental characteristics.

Using the previously-defined typologies, the preliminary map is validated to form a definitive map of the main types of environment and associated populations.

Environmental sensitivity, risk factor and health assessment

The data is divided into three categories according to its relevance to environmental sensitivity, risk factors or health:

• *Data linked to sensitivity*

This data relates to the environment's intrinsic characteristics, i.e. the structure and functioning of its ecosystems (biodiversity, quantitative richness, biological productivity, structuring role, etc.). An index of sensitivity ranging between 1 (low sensitivity) and 4 (high sensitivity) is allotted to each type of environment.

Mapping is used to underline the global sensitivity inherent to each type of coastal environment found on the island. Sensitivity indexing and mapping are interfaced by allocating four respective colours according to pre-defined sensitivity (weak, average, average to high, high to very high).

• *Data linked to risk factors*

This data concerns environmental uses (industrial, agricultural, domestic). It is classified according to type and degree of environmental risks, eutrophication & population deterioration risks and health risks. A synthetic risk index divided into three categories is then allocated to each zone.

• *Data linked to environmental health*

Definition of the state of health of the studied marine environments is based on the following elements:

- the degree of vitality of characteristic populations;
- the notion of ecological equilibrium;
- signs of deterioration or global deterioration of the studied zones and their populations;
- extent of substitution populations, and/or extinction of certain species;
- proliferation of specific species (Acanthaster) or disturbance indicators (characteristic seaweed populations, Echinodermata, etc.).

Several levels of environmental health of the mediums are hence defined.

Case study: Mahé

Cartographic synthesis and identification of potential priority zones

Three types of maps are created :

- population maps
- sensitivity maps
- synthesized maps: identification of zones suitable for priority environmental programmes, by comparing population and sensitivity maps and risk data

Priority programmes include :

- long-term planning and management projects;
- assistance for the implementation of environmental norms (waste discharges, developments, etc.);
- preventive action and conservation projects (marine parks);
- research programs, etc.

They constitute the framework for a lasting and integrated coastal zone management policy (ICZM).

Zone 3
Pointe au Sel - Anse Royale - Petite Marie Louise

Sensibility
- Low (red)
- Average (orange)
- High (green)
- Very High (blue)
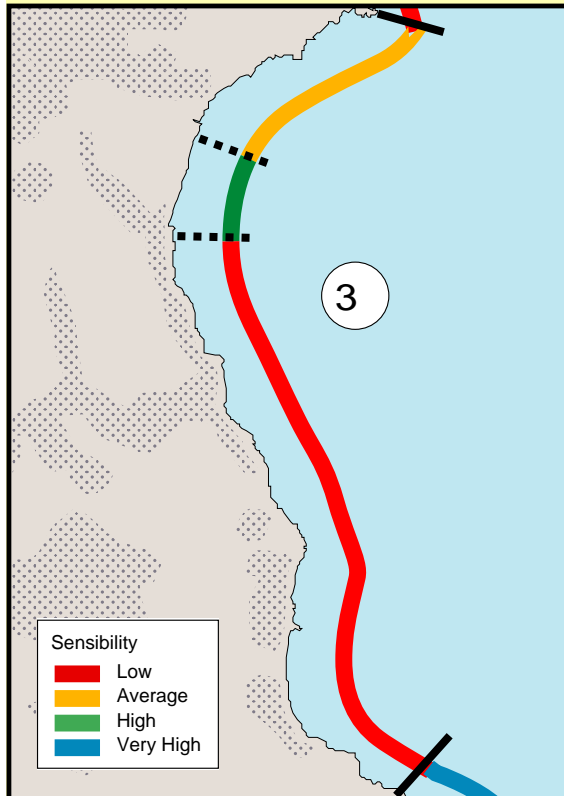
Typology

This sector is characterized by the presence of a highly-developed bordering reef in a zone exposed to prevailing winds, in particular during the Southern Hemisphere's winter months. The North of the Anse Royale is characterized by a very long outer slope, with a fairly low gradient, colonized mainly by brown Sargassum type seaweed. These colonies are also present to the South of the reef pass, although in much lower quantities. They are then replaced by soft corals (Alcyonaria) and banks of hard coral (Poritidae). The reef flat zone is, on the other hand, characterized by a rear depression forming a well-developed lagoon, colonized mainly by brown seaweed and dispersed coral colonies. The phanerogam community (mixed water plant community with predominant Syringodium), is definitely less abundant than in zone 1, and is found primarily to the South of the pass, up to the Anse Forban. Very locally, the water plant communities nearest the coast are deteriorated as a result of enrichments (pass zone, natural outlets, waste discharges, etc.). They are, however, well-developed and in good health.

Sensibility

This zone is characterized by its high ecological sensitivity, related to the presence of a bordering reef and well-developed lagoon favouring the development of leisure activities.

Risk factors

The environment is subject to high anthropic stresses. Urbanization is particularly dense and aquaculture and leisure activities (coveted resort) are highly-developed. In addition, the lagoon's closed character means pollutants are confined along the shore, thereby favouring environmental enrichment and population deterioration. Environmental pollution risks are high in this zone.

Recommendations

In order to reduce the impact of discharges in a confined zone of this type, major water treatment efforts are required. These treatments must cover all levels of reduction of Suspended Matter (population deterioration), Organic Matter, substances containing nitrogen and phosphates (eutrophication) and all residual matter representing a potential health risk.

Case n°2 : Réunion Island coastal management

Réunion Island's aquatic environment and in particular the coastal marine environment, were considered for many years as practically bottomless pits for numerous solid wastes and liquids. Inland, the island's deep gullies are still widely used as unauthorized rubbish dumps, while the marine waters are the final receptacle for large quantities of domestic and industrial waste.

Over the past few years, the environment has become a major factor of quality of life, resulting in a real awakening to the damage caused and the setting-up of think-tanks for integrated coastal zone management. The study presented below, conducted in 1995 on the initiative of the DIREN-Réunion (Department of the Environment), comes within the framework of the SDAGE (Planning and Water Management Plan); it has enabled identification of the zones at risk and proposals for actions to improve the quality of the marine environment on Réunion Island.

General principles

In accordance with general methodology, the coast is initially divided into geomorphologic units. A total of 52 zones were identified on the Réunion's coast. This groundwork is followed up by zone by zone environmental data acquisition. The acquired data (descriptors) is classified into two categories:

- data relating to environmental **"sensitivity"**, i.e. intrinsic characteristics (typological data, biological richness or hydrodynamism);
- data relating to **"risk factors"** threatening the environment, i.e. uses (fishing, leisure activities, etc.), and discharges affecting the coast (water treatment plant waste discharges, industrial structures, etc.).

The subsequent analysis of this data enables:

- validation of coastal division or its modification according to the data collected;
- representation of key data in map form, to allow a simple and practical visualization of the coast's characteristics and uses;
- identification of the marine environment's main quality descriptors likely to affect the coast.

The cartographic comparison of zones which are both sensitive and subject to risks should enable the identification of vulnerable zones and the proposal of adapted environmental programmes.

Stage 1: Coastal division

Environmental typology and mapping

The aim of geomorphologic unit division is to organize data collection in a rational manner. This delimitation procedure is subject to three criteria:

• Size:
the boundaries between zones are determined so as to obtain, as far as possible, zones ranging between 5 and 10 kilometres.

• Geomorphology and geography:
zone delimitation is carried out according to major landmarks (capes, gullies).

• Administrative boundaries:
in the aim of fitting in with the administrative division of each zone, zone boundaries are based on administrative boundaries. A single administrative division can however include several zones.

A total of 52 zones were identified as illustrated on the following chart.

Réunion Island: Geomorphologic units
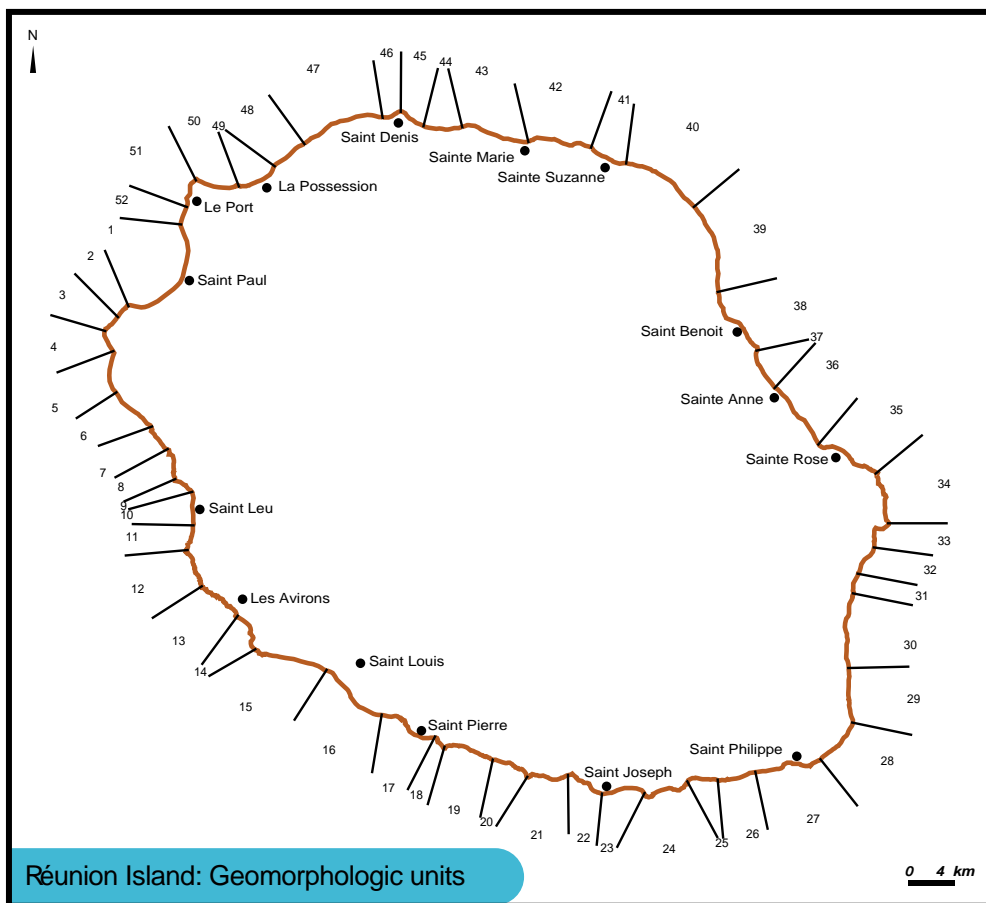
Case Study: Réunion Island

Stage 2 : Data collection

Data is collected from various sources:

• *multidisciplinary bibliographical research*
scientific and technical documents, various original maps, summaries or monographs;
• *concerned departments and organizations:*
Regional Council, Department of the Environment, Veterinary Services, General Council, research laboratories, associations, etc;
• *field investigations*

Various types of data are collected:

• *data on the physical and biological environment:*
      - coastal geomorphology;
      - environmental biological typology;
      - hydrodynamic phenomena (exposure to winds, swell, general current patterns, confinement);
      - existence or not of coastal erosion;
      - presence of running or dry rivers and gullies;
      - coastal and subsea fresh water inputs.

• *data on environmental uses:*
      - fishing zones or use of marine resources;
      - touristic and leisure zones: bathing, diving, surfing, etc.
      - aquaculture zones;
      - zones of particular cultural or historical interest;
      - protected zones, etc.

• *data on human activities:*
      - urban centres (location, population size, etc.);
      - Industrial zone (type of industries, possible types of pollution, etc.);
      - urban waste water and rainwater discharge points (flows, type of waste, etc.);
      - the presence and working condition of sanitation and household refuse disposal infrastructures;
      - ports;
      - major building works (in progress or planned);
      - zones where raw materials are exploited : embankments, mines, etc.

Stage 3 : Drawing up tables
The above data is compiled in two different tables; one relating to the environment's natural and anthropic characteristics and another relating to proven and potential environmental threats.

Stage 4 : Data mapping and GIS

The most significant data is represented graphically on a map of the island (scale 1:100 000). All collected information is also entered in a database integrated in the Geographical Information System (GIS) Map Info, managed by the DIREN.

Data linked to sensitivity

Data linked to risk factors

Choice of environmental descriptors for each environmental quality objective

SENSITIVITY

RISK

Sanitation

- Coastal activities
- Exposure
- Confinement

Eutrophication

- Exposure
- Confinement

Populations

- Typology

Sanitation

- Sanitation
- Population
- Water treatment plant Industries
- Ports
- Coastal activities
- Waste and rain water discharges
- Rivers and gullies

Eutrophication

- Water treatment plant
- Discharge
- Industries
- Ports
- Waste and rain water
- Discharges
- Rivers and gullies

Populations

- Water treatment plant
- Discharge
- Industries
- Ports
- Coastal activities
- Waste and rain water discharges
- Rivers and gullies

Allocation of a sensitivity rating to each descriptor

- 0: zero rating
- 1: low rating
- 2: average rating
- 3: high rating

Allocation of a global rating per zone for each parameter

SENSIBILITY

RISK

- Sanitary sensitivity rating
- Eutrophication sensitivity rating
- Population sensitivity rating

- Health risk rating
- Eutrophication risk rating
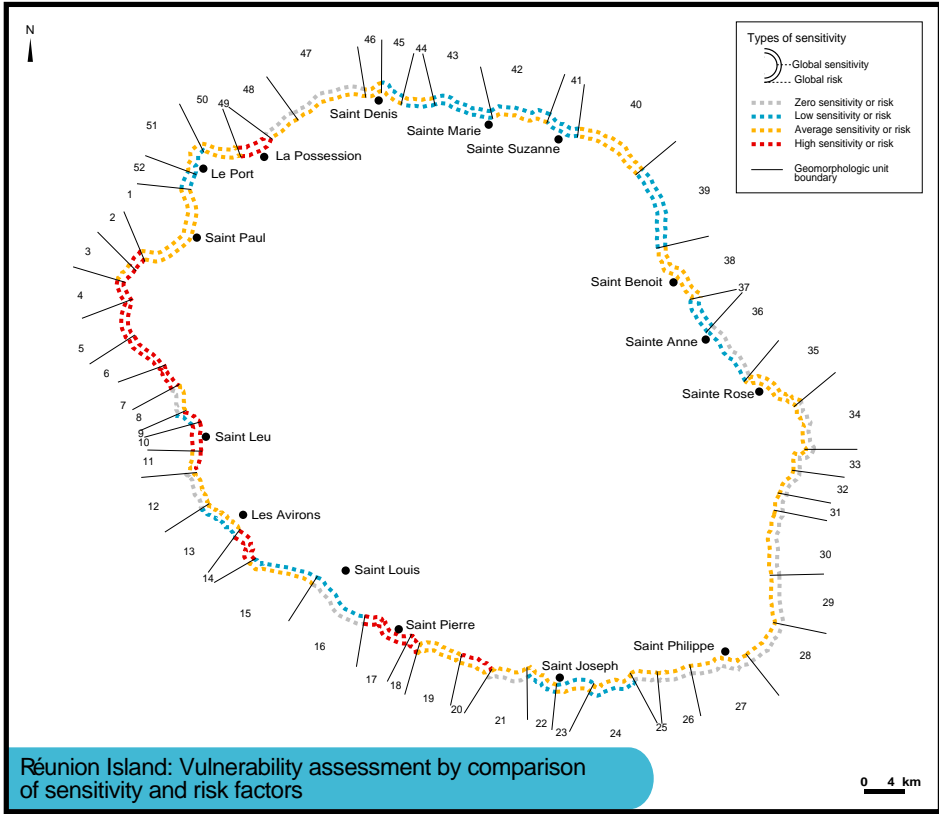- Population risk rating

Réunion Island : Assessment process

The following two maps are graphic representations of raw data. For presentation reasons, key data only is shown.

Vulnerability mapping for the Réunion Island coast
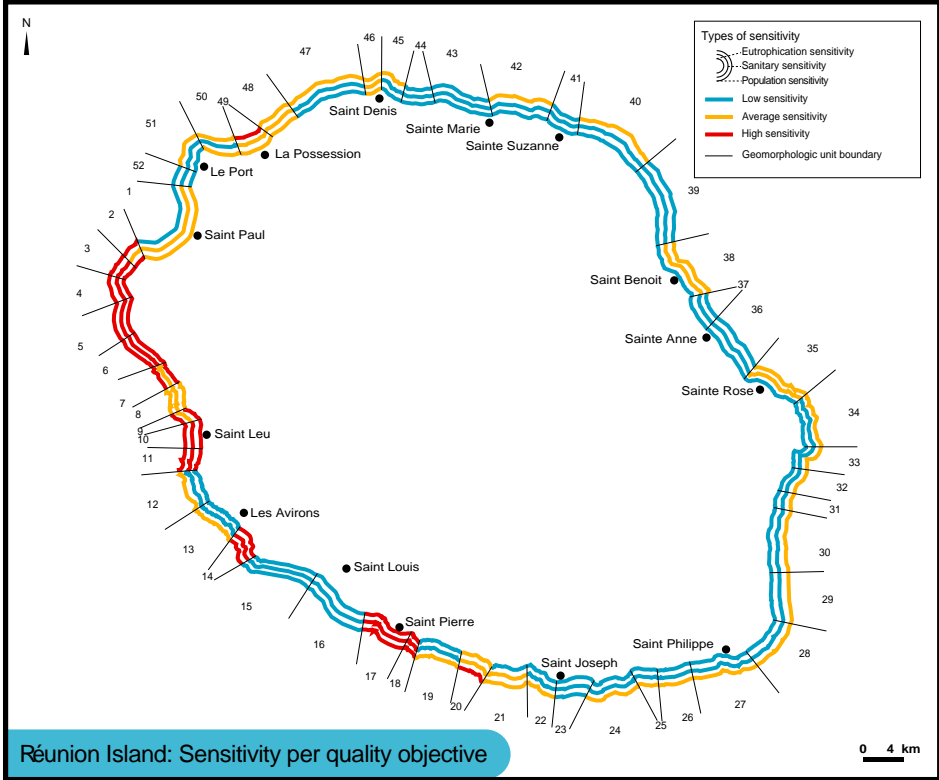
Réunion Island: Sensitivity per quality objective

Réunion Island: Vulnerability assessment by comparison of sensitivity and risk factors

Example of programme sheet : Zone n° 49

PORT-LA-POSSESSION ZONE

Vulnerability: high. This zone is highly industrialized and urbanized. It is also the subject of various development projects.

Sensitivity: high. Several zones are extremely ecologically rich, in particular the Pointe des Galets and the Ravine des Lataniers gully, as well as a deep outer reef slope in the sea adjacent to the new port.

Uses: coastal and underwater fishing.

Scientific data: the environment has been described briefly in various scientific surveys. Its sensitivity is therefore already recognized.

Type of study to be set up: complementary surveys of unexplored zones, accurate inventory of populations, monitoring.

Priorities: in view of the numerous existing development projects, it would appear urgent to set up a monitoring system.

Partners: University, design offices for the setting-up of monitoring methodology, design offices and other local partners for the setting-up of monitoring systems, inventories and complementary surveys.

Budget (over 2 years): 300 KF (excl. VAT)

Financial partners: in addition to the DIREN and the Regional Council, financial backing may be provided by certain concerned industries (SRPP).

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1 rev. 2	Guide to IGOSS Data Archives and Exchange (BATHY and TESAC). 1993. 27 pp. (English, French, Spanish, Russian)
2	International Catalogue of Ocean Data Station. 1976. (Out of stock)
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4	Guide to Oceanographic and Marine Meteorological Instruments and Observing Practices. 1975. 54 pp. (English)
5 rev.	Guide for Establishing a National Oceanographic Data Centre, 1997. 42 pp. (English)
6 rev.	Wave Reporting Procedures for Tide Observers in the Tsunami Warning System. 1968. 30 pp. (English)
7	Guide to Operational Procedures for the IGOSS Pilot Project on Marine Pollution (Petroleum) Monitoring. 1976. 50 pp. (French, Spanish)
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