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# GUIDELINES FOR THE STUDY OF SHORELINE CHANGE IN THE WESTERN INDIAN OCEAN REGION


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# FOREWORD

Shoreline change, in particular coastal erosion, impacts on coastal communities and ecosystems worldwide. Related problems are reported by all countries within the Western Indian Ocean region (WIO). The effective management of shoreline change within the context of Integrated Coastal Area Management (ICAM) demands input from a wide range of scientific, engineering and socio-economic disciplines.

During the IOC-UNEP-WMO-SAREC planning workshop on an integrated approach to coastal erosion, sea level changes and their impacts, held in Zanzibar in 1994 for countries of the WIO, the production of guidelines covering a structured methodology for the assessment of shoreline change within the region was recommended. The methodology was expected to address both immediate and the long-term information needs. In this regard, the meeting specified that the methodology should be realistic, taking into account the nature of the problems in different countries and the resources likely to be available to undertake assessment studies.

The IOC Assembly supported this recommendation and initiated, under the Ocean Science and Non-Living Resources (OSNLR) programme of IOC, the development of these guidelines to be based on experience from within the region. The terms of reference for the project were, firstly, to develop a common structured methodology for undertaking short-term studies aimed at characterising shorelines and determining their vulnerability to coastal erosion. Secondly, they were to develop a common methodology for identifying, and undertaking long-term monitoring of, the processes that brought about shoreline change.

The step-by-step, practical approach set out in this manual is not exhaustive, but aims to provide a basis for the scientific field assessment of specific problems of shoreline change that would reliably inform the ICAM process. The guidelines have been compiled from the contributions and recommendations of coastal scientists from Comoros, Kenya, Madagascar, Mauritius, Mozambique, the Seychelles and Tanzania. The combined experience of this regional group of scientists forms the backbone of this guide.

# INTRODUCTION

Physical shoreline change, including the erosion of beaches and coastal land and the accretion of sediment to form new land, is a natural phenomenon in the evolution of coastal areas. It follows the variations in relative sea level, climate and ecosystems that occur over a wide range of time-scales, from geological time to short-lived, extreme events. It may be exacerbated by human activities, either at the coast itself, e.g. by engineering works, or within the adjoining catchment, e.g. by river impoundment or changes in agricultural practice affecting freshwater and sediment discharge at the coast.

The range of distinctive contemporary coastal types within the Western Indian Ocean region reflects the considerable differences in coastal geology and sediment supply, in climate, in ocean temperature and turbidity, and, as a consequence of many of these factors, in the coastal ecosystems. There are, for example, rocky shores, low-lying sandy shores and fringing reef shores. Some coastal types, notably fringing reef shores, are made up of several different geomorphological components or facies, each representing a distinctive ecological habitat. Every type of shoreline is susceptible to change, but in different ways, at different rates, and with different socio-economic consequences. This manual covers the classification of the main coastal types of the region and the assessment of their susceptibility to contemporary physical change, in particular beach wasting and the marine erosion of coastal land.

The formulation of management solutions that address the problems of shoreline change at the regional to site-specific scale demands reliable information on the factors responsible for such change. Knowledge both of the processes involved, and of the spatial and temporal scales over which those processes occur, is an essential prerequisite in the management process. The forcing processes may be due to extreme events, such as tropical cyclones leading to damaging tidal surge and severe wave conditions impacting the shore; or they may be of a long-term nature, such as a change in relative sea level. The impacts of natural forcing may be exacerbated by human activities or interventions, especially locally in the coastal zone, but also further afield in the catchments, e.g. modifying the discharge of sediment to the coast. The information gathered should aim at refining the likelihood of physical change occurring and recurring as well as providing an understanding of the processes involved.

This manual sets out an approach to the identification and monitoring of shoreline change and its causative processes at local and regional scales that is appropriate to the coastal management problems of the region as reported by the regional contributors. The approach aims to promote the targeting of sparse resources on the acquisition and provision of information that is most relevant to the management of the problem. The procedures for monitoring shoreline change and its contributory processes are described, including the use of accessible relevant regional information and data or meta-data sets.

The prioritization of remedial or adaptive actions to cope with shoreline change requires knowledge of the value of the coastal resources vulnerable to such change. The total value of the resources at risk relates to factors such as population density, agriculture, engineering infrastructure, port development and tourism-related investment. It includes the important non-marketable values of the coastal ecosystem components – in this region, especially the coral reefs, seagrass beds, mangrove forests and sand dune fields. Sustainable solutions for the management of coastal areas that are susceptible to physical shoreline change must aim to safeguard the natural capital represented by such resources.

Solutions for mitigation and adaptation need to be environmentally sensitive and affordable over the long-term, developed within the context of national policies for integrated coastal zone and river basin management. The manual addresses the issue of whether, in the light of the scientific information in local and regional perspectives, management intervention to counter shoreline change in specific instances is beneficial and sustainable, or whether policies of adaptation through long-term planning and, if appropriate, relocation are the more sensible options.

# READER'S GUIDE

This manual is intended to provide coastal scientists and coastal management practitioners in the Western Indian Ocean region with a systematic approach to the analysis and appraisal of erosion and sedimentary accretion in the coastal environment. It also presents and discusses possible options for mitigating, or adapting to, these physical changes in the context of Integrated Coastal Area Management (ICAM).

The manual provides general reference information in support of studies relating to shoreline change in the region. It is not, however, intended as a text book. A general bibliography is included, but detailed descriptions and supporting documentation for the various topics and procedures referred to, as well as information on specific techniques and tools, may be found in the relevant scientific literature and other specialized sources.

The *Environmental and Socio-economic Background* is a geographical overview of the coastal zones of the Western Indian Ocean region and their resources that provides a context for the *Guidelines* that follow. It briefly reviews the various influences on the nature of the region's shorelines. These include the geology, climate, hydrology and oceanography, as well as biological and socio-economic factors.

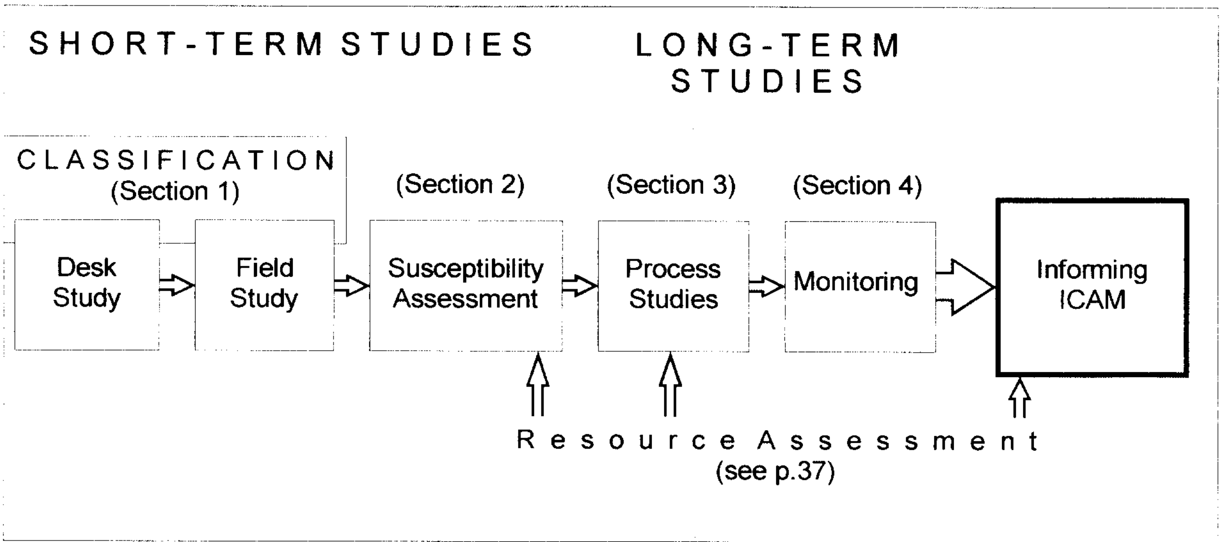


Figure 1: Action sequence for the shoreline change studies covered by these guidelines

The *Guidelines* sections provide outlines of approaches to a sequence of short- and long-term studies of physical shoreline change (Figure 1), whether these are the consequences of erosion or sedimentary accretion. The suggested study procedures for each section of the Guidelines are set out in respective text boxes. The guidance is not intended to be prescriptive and accepts the need of individual coastal scientists and institutions to maintain flexibility.

*Sections 1 and 2* deal with *short-term studies* that facilitate coastal characterisation and an assessment of the susceptibility of the various coastal types to physical change. The criteria by which the various coastal types may be recognised are set out within a classification framework that is appropriate to the region. The various coastal types and their component units or facies are illustrated by examples from the region.

*Sections 3 and 4* of the *Guidelines* deal with *long-term studies* that aim to identify and investigate the processes and conditions causing, or contributing to, erosion and sedimentary accretion in the coastal environment. The practical steps needed to identify the likely responsible processes and contributing factors are described and discussed in *Section 3*. Then, in *Section 4,* shoreline monitoring procedures that are appropriate to assessing present shoreline change and to forecasting the rate and extent of future change are described.

Finally, the manual reviews the options for *mitigation and adaptation* to shoreline change within the context of Integrated Coastal Area Management, appraising possible actions in terms of environmental and socio-economic impacts and benefits.

The manual is supported by two *Appendices* – one that contains the contributions of regional experts describing problems of shoreline change in the various countries of the Western Indian Ocean region and one that lists sources of information, data and meta-data appropriate to studies of shoreline change within the region.

# ENVIRONMENTAL AND SOCIO-ECONOMIC BACKGROUND

## The geological background of the region's coasts

The geological setting of the Western Indian Ocean region (Figure 2) differs from one area to another. The geology reflects the growth of the Indian oceanic plate since Mesozoic times and the consequent migration of the Indian, Australian and Antarctic continental plates over millions of years to their present positions. The continental shorelines of the region are typical of passive continental margins that have been broadly shaped by faulting and subsidence, and modified by phases of marine incursion and sedimentary deposition.

The width of the present continental shelf varies from less than 1 km along much of the Kenya coast to several tens of kilometres along much of Mozambique and in western Madagascar. The shelf platform around the granitic Seychelles islands is more than 200 km wide. Several erosional and accretionary steps, representing different sea-level stands, are observed around the shelf in areas of low sedimentation.

Much of the mainland coast is characterized by the low-lying sandy shores associated with deltas and estuaries where river-borne sediments are discharged to the sea, as for example in southern and central Mozambique (see cover image) and the northern part of the Kenyan coast (Figure 3). From northern Mozambique northwards to Somalia coral reefs are mostly widespread, either at the seaward edge of fringing platforms or as patch reefs on the continental shelf. The reef coasts are associated with fossil reef limestone that forms extensive platforms, cliffs and hinterland terraces (Plate 11).

Though the geological evolution of the island states is closely linked to the spreading of the Indian oceanic crustal plate, the styles of individual islands are varied. The Seychelles and Madagascar are stranded continental fragments comparable to the adjoining mainland, the other islands have little in common with the mainland geology. The Mascarene Plateau and Chagos—Laccadive Ridge are associated either with oceanic volcanism at hot spots or with volcanic activity at crustal spreading centres. Among the latter are Mauritius, Réunion and Comoros – groups of islands with central mountainous areas surrounded by low-lying coastal plains. Some islands are now represented by atolls, maintained above sea level through the upward accretion of reef-related sediments. These different styles of evolution have influenced the nature of these islands' coastal zones, and consequently the nature of shoreline change that affects them.

## Climate, hydrology and oceanography

The climate of most of the region is tropical humid. It is dominated by movements of the Intertropical Convergence Zone and the monsoons. Broadly the north-east monsoon affects the region from November to February or March and the south-east monsoon (trade winds), from April to September. The intervening periods are generally the calmest. In Kenya and Tanzania the main rains fall between March and July. The southern part of the region, including southern Mozambique, Madagascar, Comoros, Réunion and Mauritius, lies within a belt affected by tropical cyclones. These extreme events may cause storm surges, pronounced waves and accelerated coastal currents and are the most important agents of coastal change in this part of the region. The cyclones enter the region during the

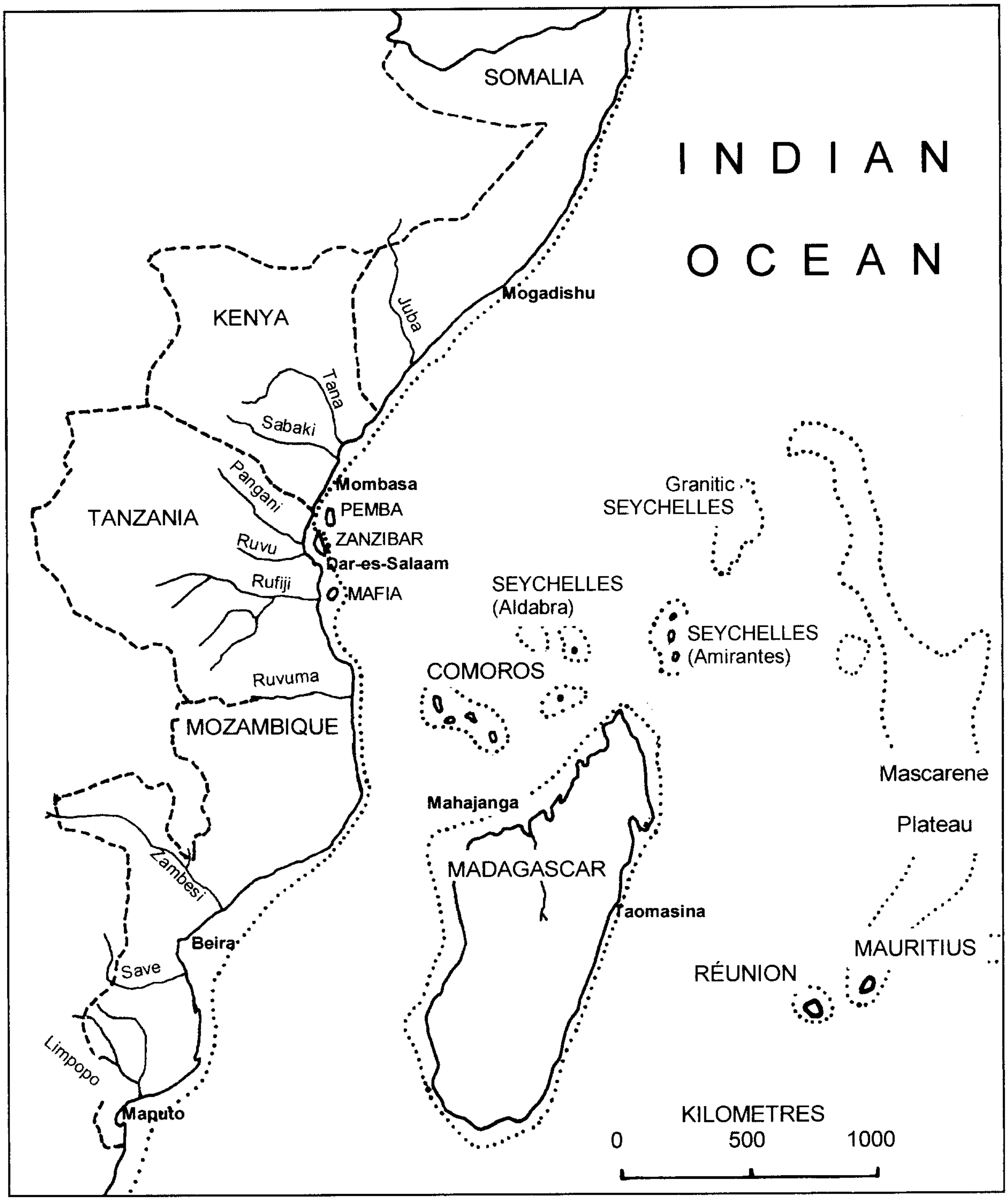


Figure 2: Sketch-map of the Western Indian Ocean region, showing the principal locations referred to in the manual. Dotted line indicates limit of continental shelf.

months of September to December from the north-east, usually following curved tracks that turn first southwards then south-eastwards. They are associated with exceptionally high rainfall, with consequential landslides, flooding of low-lying areas and major sediment discharge to the sea.

Many important rivers draining the continental hinterland discharge to the sea within the region (Figure 2), the largest of these being the Zambesi in Mozambique. Other large rivers include the Rufiji in Tanzania and the Tana in Kenya. These rivers and their transported sediments have a strong influence on the coastal environment through the creation of productive brackish water habitats in estuaries, the maintenance of beaches and deltas with their associated mangrove stands, and tidal flats with their seagrass beds. Much of the coastal land of the region comprises terraces of fossil reef limestone. Rain falling on these terraces drains, not by surface flow, but internally, to issue as groundwater either intertidally or subtidally in the coastal zone.

The region is subject to a complex system of oceanic currents which changes according to the seasons. Seasonal change is notable off the Kenyan coast, where a swift northern current (the East African Coastal Current) during the south-east monsoon is replaced off northern Kenya during the north-east monsoon by the southward flowing Somali Current. In general, oceanic currents are not considered significant direct contributors to physical shoreline change, though they may influence the distribution of turbid plumes of suspended fine sediment discharged from river mouths.

The magnitude, frequency and approach direction of waves impacting the coast are significant factors in shoreline change, at both local and regional scales. The regional wave climate is divisible into three distinct areas – Northwest Indian Ocean, Northern Madagascar and Southern Mozambique Channel. The Southern Mozambique channel has strong seasonal and spatial variations. The Kenya, Tanzania and northern Madagascar data show strong monsoonal influence, with larger waves approaching predominantly from the south-east dominating during the south-east monsoon. During the inter-monsoon period, wave heights are smaller and approach directions more variable. During the north-east monsoon, waves approach almost exclusively from the north and have lower wave heights (c.90% <1.5 m). The Southern Mozambique Channel shows a strong influence from the south-easterly trade winds with waves from easterly or south-easterly directions.

Most of the region's coasts are subject to semi-diurnal tides, with tidal excursions (the difference in levels between High Water and Low Water) ranging from less than 2 m at Neaps to about 4 m at Springs. These coasts are classified as mesotidal. The coast of southern Mozambique has a higher tidal excursion – 6.4 m at Springs in the Bight of Sofala, while the range at Springs locally on the west coast of Mozambique is 7 m. Tidal currents are generally weak on exposed shorelines, but in creeks and estuaries, and, in lagoonal channels, tidal currents may reach as high as 2 m/s, in places playing a significant role in shoreline change.

## The biosphere

The coastal geomorphology of much of the region has been shaped to some extent by biological factors. Paramount among these is the role of the biota that thrive in the turbulent shallow water conditions at the ocean margin. Some of these biota deposit calcium carbonate in a rigid reef framework, some encrust or otherwise colonise the substrate formed by that framework and its derived debris, while others – both plants and animals – secrete carbonate in their tissue that becomes translated on withering or ingestion by grazing fauna into detrital carbonate sediment. The constructional products of coral reef-related ecosystems, built in most cases on foundations composed of their former (geological) counterparts – fossil reef limestones, form the characteristic landforms of the reef coasts of the region. These biota thus have, and have long had, a very important influence on shoreline stability and change. The integrity of coral reef ecosystems in the region is currently under threat.

There are reports of widespread coral death manifest in bleaching (thought to be due to unusually high water temperatures), land-based and marine-sourced pollution, and siltation – notably high levels of turbidity caused by high concentrations of suspended sediment discharged from the region's rivers.

Other important biological factors affecting the stability of the shore are the colonisation of suitable brackish water environments by mangrove, mostly in creek, estuarine and deltaic situations, but also on some more exposed shores. The mangrove stands form effective traps for sediment. Seagrass meadows and *Halimeda* (calcareous algae) thickets in intertidal environments, and the plants that colonise coastal sand dunes and backshore beach sands have similar sediment trapping and stabilizing roles.

## Socio-economic aspects of the region's coasts

There is a common trend of migration of the populations of the mainland countries of the region to their respective coastal zones. While this applies to rural areas, it is urban growth that is the more significant – in particular Mombasa, Dar-es-Salaam and Maputo. This urban growth is accompanied by increasing industrialisation, by greater demands for construction materials and fresh water, and by increasing problems of sewage and other waste disposal.

For rural communities fisheries and agriculture remain as the principal livelihoods, with aquaculture becoming important locally. Along parts of the mainland coast, notably in Kenya, and, on many of the islands, tourism and its supporting activities are becoming increasingly important to local economies. There is considerable scope for growth in the tourism sector throughout the region, the principal constraints being the absence of infrastructure for transport and other services, such as water and waste disposal. Knowledge of the potential for shoreline change is considered to be a prerequisite in the planning and management of tourism development in the region's coastal zone.

Specific development pressures that may impact on shoreline stability include the use of explosives in fisheries, over-harvesting of mangroves stands, the mining of beach and dune sands for construction materials and minerals, indiscriminate dredging for port approaches and harbours, and the construction of inappropriate sea defences and other coastal engineering infrastructure. Land-use changes in river basins, whether of an agricultural or an engineering nature, may also impact on the physical stability of the shoreline through long-term changes in the volumes of sediment discharged at the coast.

# GUIDELINES FOR STUDIES OF PHYSICAL SHORELINE CHANGE

## SECTION 1 – Classifying coasts

Scientists have developed various classification schemes to describe the coast. Most schemes have coastal geomorphology and the degree of exposure to wave energy as their basis. The classification adopted by UNEP in its Eastern African Atlas of Coastal Resources for Kenya, for example, elaborates these essential elements with information about ecological value and biodiversity. For the purpose of these guidelines it is appropriate to classify coasts by the use of a scheme that adequately characterises the physical nature of the land-sea boundary in terms of its geology and geomorphology, while providing a framework that relates well to the wide range of disciplines involved in integrated coastal area management.

The classification should convey information that is meaningful to many different users. These users include land-use planners (socio-economic implications), developers (e.g. impacts on, and due to, tourism-related investment), engineers (impacts on, and due to, coastal infrastructure), ecologists (habitat implications), hydrologists and hydrogeologists (river discharge information and groundwater potential), and so on.

### 1.1 Recognising primary coastal types and their component facies

The scheme used in these guidelines has the geology and its geomorphological expression as the basis of its primary class units or *coastal types*. The degree of exposure to marine forcing is generally implicit in the geomorphological expression. The coastal types recognised in the scheme may incorporate several component sub-units or *facies*, each with its characteristic morphological, sedimentological and ecological attributes. Fringing reef coasts tend to be the most complex, some including as many as ten component facies.

The classification scheme, including the principal component facies, their resource implications and their susceptibility to physical change, is set out in Table 1. Descriptions of the coastal types and their component facies are given in the following text, illustrated by examples occurring within the region. Shore-normal sections showing typical representations of the primary coastal types with component facies are shown in Figure 4.

### 1.2 Classification procedure

Effective coastal classification is a fundamental precursor to any study of shoreline change. This approach is simple to apply and requires few special resources. The range of primary coastal types and component facies as described above and included in Table 1 should prove adequate for most classification tasks within the region. Some additional units may be considered necessary and these should be added as appropriate within the framework as set out. The means of recording and displaying in-

Table 1: Primary coastal types of the Western Indian Ocean region and their component facies in relation to their resource implications and susceptibility to physical change (courtesy, R S Arthurton)

| Primary coastal type | Component facies | Resource implications (in addition to fisheries) | Susceptibility to physical change |
|---|---|---|---|
| **Exposed low-lying sandy coasts** | Sand beaches including spits and delta barriers | Tourism, recreation, sand mining | Shoreface erosion/accretion |
| | Sand dunes | Groundwater, minerals, coastal defence | Beach head erosion/accretion, aeolian deflation/construction, degradation by Man |
| | Beach plains, delta plains and hinterland | Agriculture, settlements, tourism | Beach head erosion/accretion |
| **Exposed rocky coasts** | Pocket beaches | Recreation | May be ephemeral |
| | Rock shores/platforms | | Resistant |
| | Rock cliffs | Coastal defence | Resistant except where soft/weathered |
| | Hinterland | Maybe groundwater | " |
| **Fringing reef coasts** | Forereef and reef apron | Coral reef ecosystem | Dynamite fishing, bleaching, pollution and siltation affecting coral growth, storm damage |
| | Reef bar | " | |
| | Backreef lagoons | " | Tourism-related damage |
| | Backreef platforms and associated channels (sediments) | *Halimeda* thickets, seagrass meadows, seaweed culture | Sediments may be ephemeral |
| | Backreef rock platforms | | Resistant |
| | Beach rocks | Coastal defence | May be resistant |
| | Sand beaches | Tourism, recreation, sand mining | Shoreface erosion/accretion |
| | Sand dunes | | Beach head erosion/accretion, aeolian deflation/construction |
| | Beach plains | Agriculture, settlements, tourism | Beach head erosion/accretion |
| | Rock cliffs | Coastal defence | Resistant except where soft/weathered |
| | Hinterland, reef limestone terraces | Groundwater, tourism infrastructure | " |
| **Patch reef coasts** | Offshore patch reefs | Coral reef ecosystem | Dynamite fishing, bleaching, pollution |
| | Intertidal flats (sediments) | Mangrove stands, seagrass meadows | Sediments may be ephemeral; erosion exacerbated by mangrove clear felling |
| | Rock platforms | | Resistant |
| | Beach rocks | Coastal defence | May be resistant |
| | Sand beaches including spits | Tourism, recreation, sand mining | Shoreface erosion/accretion |
| | Beach plains, delta plains | Agriculture, settlements, tourism, | Beach head erosion/accretion |
| | Rock cliffs | Coastal defence | Resistant except where soft/weathered |
| | Hinterland, reef limestone terraces | Groundwater, tourism infrastructure | " |
| **Inlets, estuaries and creeks** associated with primary coastal types | Swamps and marshes | Mangrove stands | Erosion exacerbated by clear felling |
| | Channels, tidal inlets | Ports, industry, urban development, aquaculture | Possible lateral channel migration |
| | Rock platforms | | Resistant |
| | Rock cliffs | Coastal defence | Resistant except where soft/ weathered |
| | Older beach plains and dunes | Agriculture, minerals, groundwater | Erosion due to channel migration |

formation relating to the classification are flexible and do not presume access to computerised geographical positioning (GPS) and/or information (GIS) systems.

The approach adopted in these guidelines includes a *desk study* as the first stage. An outline of the desk study procedure is set out in Box 1.1. In most cases this procedure should permit the classification of primary coastal types and, in some instances, the identification of component facies. Further resolution of facies and confirmation of the identification of the primary coastal type(s) are the aims of the second stage in this approach – the field survey, an outline of which is presented in Box 1.2. For the effective use of limited resources the field survey should be planned on the basis of the results of the desk study.

## 1.3 Exposed low-lying sandy coasts

This coast type (Table 1) is characteristic of the low-lying terrain formed by the long-term accretion of sandy sediments on *beaches* and the consequent progradation (seaward migration) of the shoreline. The sediments are sourced in the hinterland, discharged at the coast from major rivers and their deltaic distributaries (see cover image), and transported alongshore by wave-induced currents and wind. This type of coast is unprotected from ocean waves and generally associated with a broad continental shelf (Figures 4 and 5).

Figure 3: Aerial view of the mouth of the Sabaki River on the exposed low-lying sandy coast north of Malindi, Kenya.
Note associated sand dunes, coastal sand bars and hooked spits. Approximate scale 1:7500
Photo: courtesy of UNEP

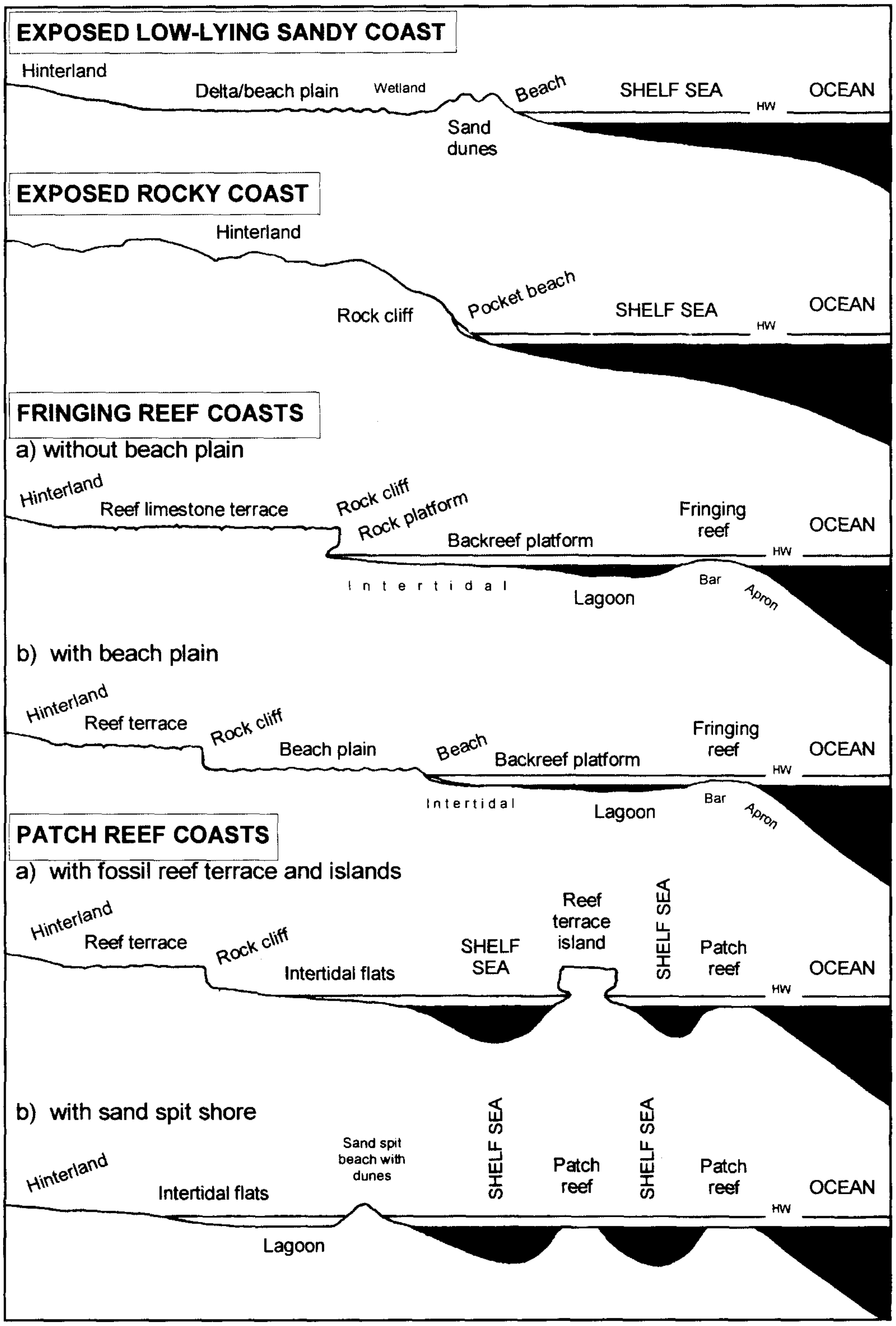


Figure 4: Comparative shore-normal sections showing relationships of the various component facies of the primary coastal types. Vertical scale exaggerated. HW indicates High Water level of ordinary tides. Lagoons, shelf sea and ocean to Low Water shown in black. (Courtesy, R S Arthurton)

Exposed low-lying sandy coasts are predominant in southern and central Mozambique – associated particularly with the outflows of the rivers Incomati, Limpopo, Save and Zambesi (see cover image) – and extensive along much of the northern Kenyan coast, north of Malindi, where the rivers Sabaki and Tana discharge to the sea (Figure 3). They are also reported along parts of the Tanzanian coast. Typically the beaches extend without interruption over many tens of kilometres and are commonly flanked by belts of *sand dunes*, the most seaward of which actively exchange sand to and from the adjoining beach (Figure 5, Plates 2 and 3). Together with the dune belts, the beaches define extensive *beach plains* with characteristic parallel sets of former beach ridges, and, in the vicinity of the major rivers, *delta plains* and *wetlands* with distributary channels and mangrove stands. Where they enclose, or partially enclose, lagoons, the beaches are termed *barrier beaches* (Plate 4). Where the beaches project into embayments they are termed *spits*, or hooked spits, depending on their form.

## 1.4 Exposed rocky coasts

Exposed rocky coasts (Figure 4, Table 1) are the least common of any of the coastal types in the region. They occur more particularly in some of the island states. They are reported from the Comores, where low cliffs of volcanic rock dominate most of the shorelines, especially in Grande Comore. They occur around the north-eastern part of Madagascar and they are conspicuous on some of the shorelines of the granitic Seychelles islands, notably the western coast of the main island, Mahé (Plate 5), where pocket beaches are well developed (Plate 6).

The exposed rocky coasts are associated with strong wave energy and are present in both broad and narrow continental shelf conditions. They are a somewhat rare feature on the mainland coast, one example being the shore at Vuma, on the Kenyan coast south of Mombasa, where cliffs of raised fossil reef limestone are, unusually, exposed to ocean waves without the protection of any significant fringing platform (Plate 7). Similar though more extensive occurrences are reported from the northern coasts of Mozambique.

## 1.5 Fringing reef coasts

Coasts that are protected by fringing reefs are characterised by a rich variety of component facies (Table 1). The seaward margin may be marked by a low, flat-topped *reef bar* that is composed of algal-bound debris of coral and other biogenic carbonate material that has been eroded and transported from the ocean-facing forereef by extreme waves (Figure 4). The bar forms a breaker zone for ocean waves (Plate 8), effectively dissipating this wave energy except in high tidal and storm surge conditions. Where fringing reefs are developed at the continental shelf edge, as is commonly the case, oceanic water depths are attained abruptly offshore.

The fringing reef forms the seaward limits of, and provides shelter to, a typically extensive intertidal to *lagoon*-covered *backreef platform* (Figures 4 and 5). The platforms are formed of rock (generally an erosion surface of fossil backreef limestone) but carry a varied veneer of sediments that provide a substrate for a wide range of intertidal and shallow subtidal habitats (Plates 9 and 10). These include coral gardens, *Halimeda* thickets and seagrass meadows. The landward part of the platform may be masked by a *sand beach* and a *beach plain* (Figures 5 and 9), forming a surface a metre or two above normal high water and typically with traces of former shore-parallel beach ridges preserved. In the Seychelles such beach plains are referred to as 'coastal plateaux'. In some places, e.g. on Diani

Beach in Kenya, former beach sediments resting on the platform have become lithified and are termed *beach rock* (Plates 15 and 16). The platform is usually bounded to landward by low *rock cliffs* of fossil reef limestone forming an extensive coastal *terrace*, usually at heights of 5–12 m above the High Water level of Spring tides. The cliffs are typically undercut by wave erosion at their base (Plates 13 and 14).

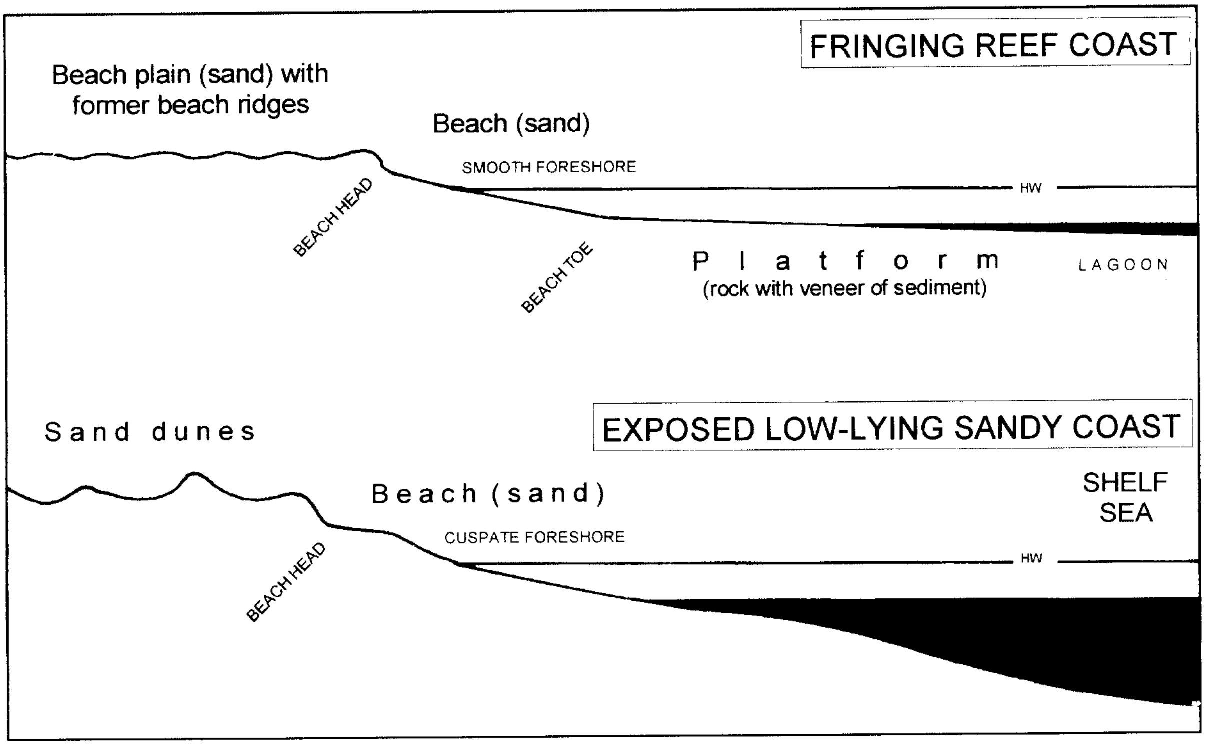


Figure 5: Comparative sections illustrating typical beach morphologies and settings on fringing reef coasts (top) and exposed low-lying sandy coasts. Vertical scale exaggerated.
HW indicates High Water of ordinary tides. Shelf sea and lagoon to Low Water shown in black.

The platform width ranges from a few hundred metres to more than 10 km, as locally on the northern Mozambique coast. A prime example of fringing reef coast is that in Kenya extending between Watamu and Chale Point – a distance of about 150 km. This type of coast is also particularly well developed around parts of Zanzibar's islands, along much of the southern Tanzania coast, on the south-eastern coast of Mahé in the Seychelles, around much of Mauritius, on the western coast of Madagascar (where there is a wide continental shelf) and in parts of the Comoros. In places, the platforms and their fringing reefs are interrupted by tidal inlets connecting with mangrove-fringed creek systems such as that at Mombasa in Kenya.

## 1.6 Patch reef coasts

Patch reef coasts (Table 1) are characterised by their physiographic and environmental diversity. Unlike the fringing reef coasts, they lack the continuity of physical protection afforded by extensive reef bars and fringing platforms. Instead these shores interface with bathymetrically varied shelf sea waters typically up to 40 m deep, with complex shoals, patch reefs and islands (Figure 4). Some of the islands are formed of raised fossil reef limestone, with typically undercut bounding cliffs.

## Box 1.1: **Classifying coasts: the desk study**

**Aims**

The objective of the desk study is to compile information relating to coastal classification from sources that are published or otherwise accessible. Compilation should be systematic, the information transferred to a base map, plan or chart, the scale of which is appropriate to the length of coast or area of coastal zone under study. The base map may be either a paper copy or a GIS file.

**Information sources**

Sources of information should include modern *topographic maps* and *hydrographic charts* that show not only the study site but also its wider setting or regional context. For the wider view it may be helpful to refer to *satellite imagery* such as 'Landsat' or 'EOSAT'. *Aerial photographs* may prove to be a useful source of more detailed information. *Geological maps* are a possible source of information on the nature of the hinterland.

**Results**

The compiled information should provide a clear indication of the *primary coastal type*. This may be verified by subsequent field investigation (see Box 1.2). The desk study may also provide a clear indication of the occurrence and distribution of the specific component *facies*, though a follow-up field survey of their occurrence and distribution is advisable.

**Display**

The way in which the results of the desk study are best displayed on the base map depends on the map scale and the extent of the coast under scrutiny, whether this is for a national overview study, for example, or for an intensive local investigation. Small-scale maps such as 1:100,000 are usually appropriate for the indication of the primary coastal types. However, only maps at scales of about 1:25,000 or greater are likely to provide the scope on the map face to indicate facies distribution, except in the simplest cases.

A convenient, simple way of portraying a primary coastal type on the map face is by use of type-specific, coloured or ornamented banner line against the coastline. For the provisional (prior to field survey) depiction of component facies on the map face, the use of facies-specific colours or ornaments for the areas of supposed occurrence is appropriate.

## Box 1.2: **Classifying coasts – the field survey**

### Aims

The field survey is a follow-up of the desk study and is a supplement to the information compiled by the desk study. The aim is to confirm the interpretations from the desk study, in particular, the identification of the primary coastal type and the occurrence of the component facies (see Table 1 and Figure 4). The field survey should aim to identify, and map the distribution of, the various facies occurring within the study area, noting any areas of uncertainty. The field survey provides an opportunity to identify and note any sedimentary and erosional features that may be relevant subsequently in the appraisal of the shoreline's susceptibility to change (see Section 2, p.19).

### Survey methods

Survey traverses carried out on foot perpendicular to the shore from the beach head are usually an effective, practical way of mapping the types of coast occurring within this region. Depending upon the terrain it may be feasible and informative to extend the traverse landwards from the beach head as well. Suitable positions of, and spacing between, traverses may be apparent from the results of the desk study.

For the best survey results, it is important to carry out the work during low tidal states. If possible the survey period should be arranged to coincide with Spring tide conditions, during which the emergence of intertidal ground at Low Water is at a maximum. The potential dangers of working in extensive intertidal areas should be appreciated, particularly in areas where the tidal excursions are large. In some cases, a shallow draft boat may be needed, both for access and safety back-up.

Traverse courses may be maintained and positions fixed simply by the use of compass bearings to identifiable fixed points. Alternatively, the use of a geographical positioning system (GPS) may provide relatively accurate position fixes and can be especially useful in areas without reliable reference marks.

### Results

The information generated from the traverses should confirm the desk study identification of the *primary coastal type* and permit the distribution of the various facies to be mapped with confidence, except where boundaries are submerged. The range of component facies included in Table 1 should prove adequate for most classification assignments within the region. Additional units, e.g. for urbanised or engineered shores, may be considered necessary, however, and these may be used as appropriate within the framework.

### Display

Maps at scales of 1:25,000 or greater are suitable for the display of coastal facies distribution. These may be paper copies or computer generated displays perhaps as part of a GIS. As with the desk study, a convenient way of portraying component facies on the map face is by the use of facies-specific colours or ornaments for the areas of occurrence. For widespread classification assignments, it may be appropriate to characterise the coast by the use of two or three different map scales – a relatively small scale to show the *primary coastal types* in an extensive context; a medium scale to display the facies of wide coastal zones, for example, with intertidal platforms or coastal dunefields; and a relatively large scale to display *beaches* and their adjoining coastal features.

The shores of this type of coast may be partially sheltered and are characterised by a wide variety of facies including *rock cliffs* with only limited platform development, *intertidal flats* with mangrove stands and seagrass meadows, *sand beaches* (including *spits*) and related *beach plains* and *delta plains*, *beach rocks* and *reef limestone terraces*. The shores may be interrupted by tidal inlets and creeks, including deltaic distributaries, as around the Rufiji delta in Tanzania.

Patch reef coasts occur along the shores of Kenya south of Chale Point, and predominate along the Tanzanian mainland shores between the border with Kenya and the vicinity of Songo Songo Island. They also occur around much of Zanzibar's island shores and along parts of the northern coast of Mozambique. The 'coral' islands of the Seychelles Bank are patch reefs and atolls that are themselves susceptible to shoreline change.

## 1.7 Inlets, estuaries and creeks

With the exception of the exposed rocky coasts, the primary coastal types as described here may host sheltered tidal inlets (Table 1). In many instances these inlets are the sites of urban and port development, for example Beira, Dar-es-Salaam, Tanga and Mombasa.

On exposed low-lying sandy coasts, the inlets are generally those of river estuaries or deltaic distributaries, and may be marked by sand bars termed tidal deltas at their channel mouths and hooked spits on flanking sand beaches. Mangrove stands are commonly widely developed along the sheltered channels (see cover image). Good examples of these features occur on several of the inlets that interrupt the exposed low-lying sandy coasts of central Mozambique (Plate 4).

On fringing reef coasts the inlets occur as deep channels, flanked by rock platforms and cliffed terraces of raised reef limestone, and connecting with broad tidal creek systems that may extend several kilometres into the hinterland. The creek inlets of Mombasa, Mtwapa and Kilifi on the Kenyan coast are examples. A similar deep channel inlet flanked by limestone terraces on the Tanzanian patch reef coast at Dar-es-Salaam provides the setting for that natural harbour and its sheltered port facilities.

# SECTION 2 – Assessing susceptibility of coasts to change

The coasts of the region, in common with those of the rest of the world, have changed over millions of years in response to changes in their natural environment. Such changes have occurred over a wide range of temporal and spatial scales, such as movements of the earth's crust and variations in sea level and climate. In some parts of the region shores have migrated over tens of kilometres in recent geological time. Physical shoreline change continues at the present day and is influenced now by human activities as well as natural forcing processes.

The studies outlined in Sections 3 and 4 of these guidelines (pp.23 and 31) aim to lead to an understanding and quantification of those processes, both natural and human-induced, causing shoreline change. As a preliminary step, this section focuses on the susceptibility of the existing shorelines of the region to physical change, building on the coastal classification information generated by the desk and field studies described in Section 1 (p.9).

Some primary coastal types are more susceptible to change than others, *exposed rocky coasts* unsurprisingly being the least prone, except locally where the rocks are soft or highly weathered. Shores dominated by unconsolidated sediments are the more susceptible. These include the *exposed low-lying sandy coasts* but also certain facies components of *fringing* and *patch reef coasts*. An indication of the general susceptibility of the various coastal facies of the region to physical change is shown in Table 1.

The shoreline changes that are usually of greatest concern to coastal managers are due to the erosion of sand beaches, beach plains and sand dunes. In some cases, the *accretion* of sand on these facies is a process of comparable importance, the example of Malindi in Kenya being especially pertinent (Plates 17 and 18). Critical locations for erosion or accretion in the various primary coastal types are shown in Figure 6. In Table 1, no discrimination is shown between erosion and accretion, and no indication of the rate of change is implied.

A suggested procedure for assessing susceptibility is set out in Box 2.1. The assessment takes into account the classification of *primary coastal types* and their component *facies* as a guide to the likelihood of shoreline change. This approach combines an extension of the desk study carried out for Section 1 with a local consultation process.

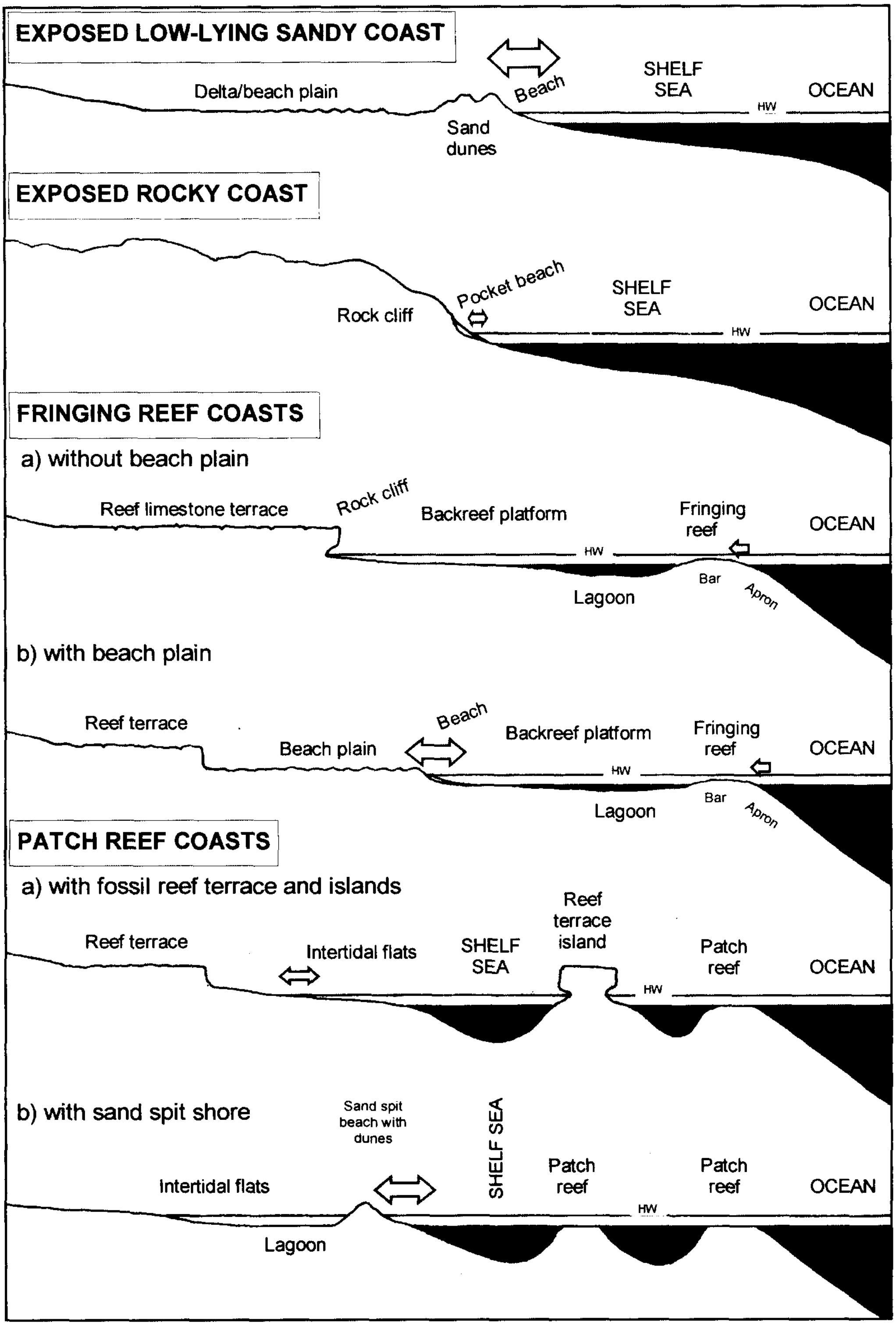


Figure 6: Comparative shore-normal sections of the primary coastal types with arrows indicating the principal sites of potential shoreline erosion (arrowheads pointing to left) or accretion (arrowheads pointing to right). Vertical scale exaggerated. HW indicates High Water level. Lagoons, shelf sea and ocean to Low Water shown in black. (Courtesy, R S Arthurton)

## Box 2.1: **Assessing the susceptibility of coasts to change**

### Aims

The purpose of this study is to provide, for coastal management, an assessment of the potential for erosion and accretion within or between the various facies of the coast under scrutiny (Table 1 and Figure 6). The study may yield information on the history of shoreline change in geological to recent perspectives; also provisional information on present and likely future change, including its time-scale, that may be further investigated under Sections 3 and 4 of these guidelines (pp. 23 and 31).

### Methods and information sources

Information relating to shoreline change gleaned from the systematic comparative study of coastal features such as the High Water Mark as indicated on *sequential maps* and *aerial photographs* may be incorporated on the map outputs of the coastal classification. This information may be elaborated as appropriate following *consultation* with local communities and experts, and administrators concerned with planning and land use issues in the coastal zone. Care is needed in the interpretation of changes apparent from map comparison, in case these may be due to surveying inaccuracies or inconsistencies in surveying practice. The scale of the aerial photographs will determine the resolution to which shoreline changes may be detected. Photos at the scale of 1:5000 are generally suitable for detailed comparative analysis but care is needed to cope with possible photographic distortion effects in the transfer of information to the base map. Historical records and reference to the relationship between engineered coastal structures and the shoreline can provide good evidence of rates of shoreline change.

### Results

The compilation should aim to indicate, for lengths of shore exhibiting a common response, whether change occurs at the present day, and if so, the nature of that change (erosional, accretionary or alternating) and its degree of severity or rate. Any special circumstances, e.g. human interventions, and any uncertainties in interpretation, should be noted, these being possible subjects of further investigation under Sections 3 and 4 (pp.23 and 31).

### Display

The *coastal classification* map (excluding the primary coastal type banner) with the *field survey* information incorporated should be used as the base for the display of the susceptibility assessment. Coloured or ornamented banners stretched along the line of shoreline change (in many cases this will be the beach head – the boundary between *sand beach* and either *beach plain* or *sand dunes*) are a convenient device for conveying the assessment information. Net erosion or net accretion may be indicated by arrowheads from the appropriate edge of the banner, and from both edges for alternating conditions. The severity or rate of change may be conveyed by banner width or by the size of arrowheads. In some circumstances there may be a requirement to represent additional lines of susceptibility, e.g. migrating sand dunes or platform sand bars.

# SECTION 3 – Identifying processes responsible for change

What are the causes of shoreline change at the local scale? The answer is that there may be many contributory factors. These may include those that are *global* in scale, e.g. sea-level rise as a consequence of global warming; some may be of a *regional* nature, e.g. changes in the rate of sediment discharge from rivers at the coast as a result of land-use changes far away in the hinterland; and others may be of local origin, for example, due to human activities, such as the installation of coastal defences that interrupt the supply of sand that may have previously nourished the shoreline's beach.

The impacts of the various causes at the local level are determined by the physical properties of the shoreline. Most important of these properties are the *materials* of which the coastal zone is composed and the *processes* active in the coastal zone that are responsible for erosion, and sediment transport and accretion. The materials of the coastal zone – implicit in the component facies of the various primary coastal types – and their susceptibility to change have been considered in Sections 1 and 2 of these guidelines (pp.9 and 19).

This section presents an outline study procedure appropriate to the region for identifying the processes that are responsible for change. The results of the study should provide a basis for the planning and execution of a programme for monitoring the changes for the purpose of forecasting the nature and rate of shoreline evolution. The monitoring is the subject of Section 4 of these guidelines (p.31). A suggested procedure for identifying the processes is given in Box 3.1. The roles of sea level and the various forcing agents (waves, tidal currents, wind, etc.) in influencing the processes are reviewed briefly below, followed by a consideration of sediment budgets.

## 3.1 What is the influence of sea level?

Over recent geological to historical time scales, changes in sea level have caused lateral migration by several tens of kilometres in the position of some of the region's shorelines. At the end of the Earth's last glacial period, some 15,000 years ago, the sea stood more than 100 m below its present level, with much of what is now the region's continental shelf area forming land. Conversely, during the previous interglacial period, the sea stood several metres above its present level and the region's shorelines lay to landward of their present positions. In addition to sea-level changes at the global scale, there have been regional and local contributions to sea-level change due to changes in ground level, for example, through the differential tectonic displacement of the Earth's crust or through the consolidation and subsidence of sediments in the coastal zone.

The changes in sea level have left their record around the regions coasts in two different ways. Some levels are marked by erosion surfaces – shelves (or platforms) and cliffs cut in coastal rocks. Others are marked by accreted sediments (some now formed into rocks), for example, the terraced fossil reef limestone of many of the mainland's tropical shores or today's beach plains. Sea level at the global scale is said to be rising currently at 1–2 mm per year, though this rate may not necessarily apply throughout the region. While the impact of such a change on the region's shores may be difficult to distinguish from the contributions due to factors other than sea level change, the possible effects of a global sea level rise of between 0.5 m and 1 m on the region's shores over the next 100 years should be borne in mind in any long-term forecasts of shoreline change.

## 3.2 What are the forcing agents – wind, waves, tides?

Geologically and historically, the level of the sea surface has determined the gross positions of the region's shorelines. However, the climate and, to a lesser extent, the forces of gravity have exerted modifying influences. The climate, through its *wind* regimes, and the *waves* generated by those regimes at regional to local scales, are of fundamental importance in the understanding of the processes that drive shoreline change. In certain coastal situations the tidal regime (and its consequent *tidal currents*) is also important, particularly over broad intertidal zones and in creeks and estuaries, and particularly where the Spring tidal excursion is high. Ocean currents usually have little direct physical influence in coastal waters. They are not considered to be significant agents in the processes of shoreline change in the sea-level high stand conditions of the present day.

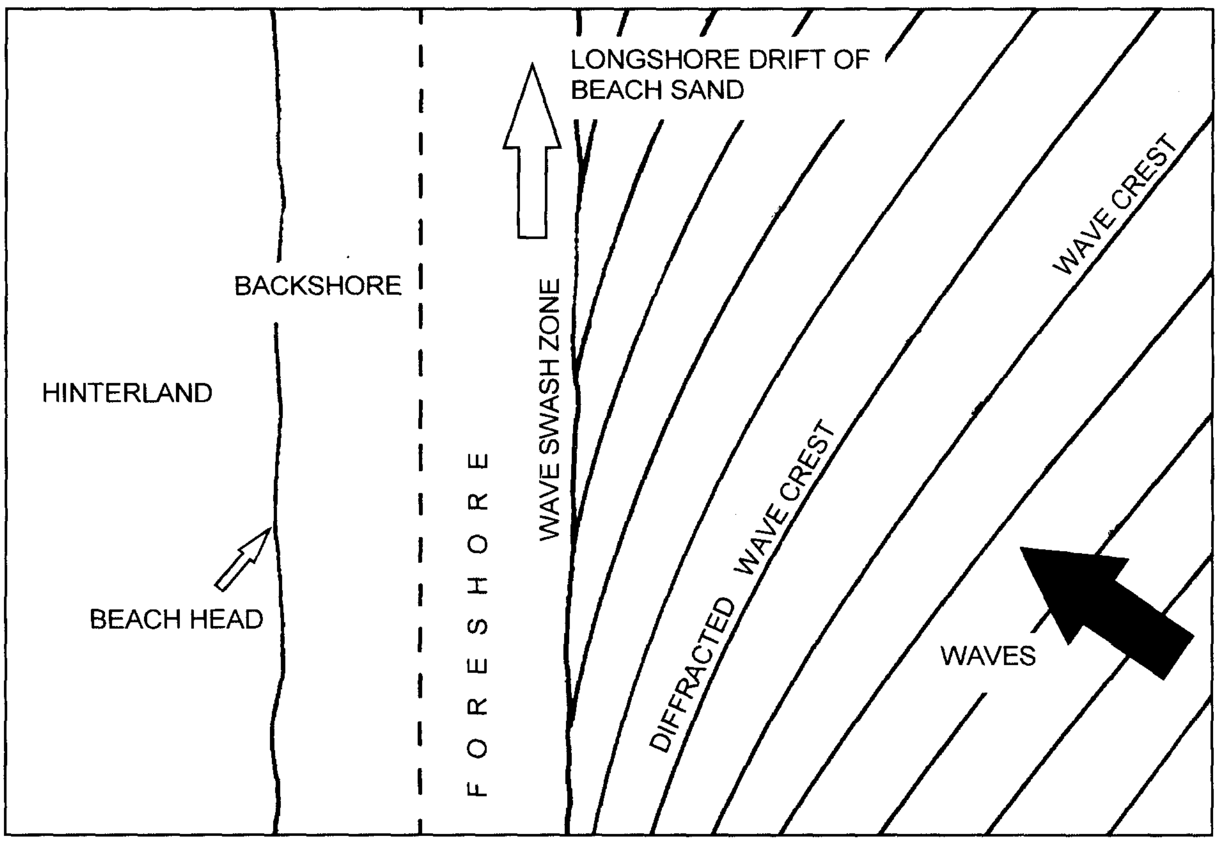


Figure 7: Diffraction of waves approaching a beach obliquely and the longshore drift of beach sand in the wave swash zone

The waves that impact a shore may have been generated in one of several different ways. They may be simple, as, for example, waves generated on an enclosed lagoon with a short wind fetch, or composite, as, for example, long wave-length swell waves generated in oceanic conditions onto which shorter wave-length local regimes have been superimposed. The waves may be diffracted where islands, reefs, shoals or promontries interrupt their transit. An effect of diffraction is that the obliquity of the wave crest to the shore is progressively reduced as it is transmitted across the shallowing water at the shore (Figure 7).

On the region's fringing reef coasts, the forereef and reef bar of the fringing reef form the front line in

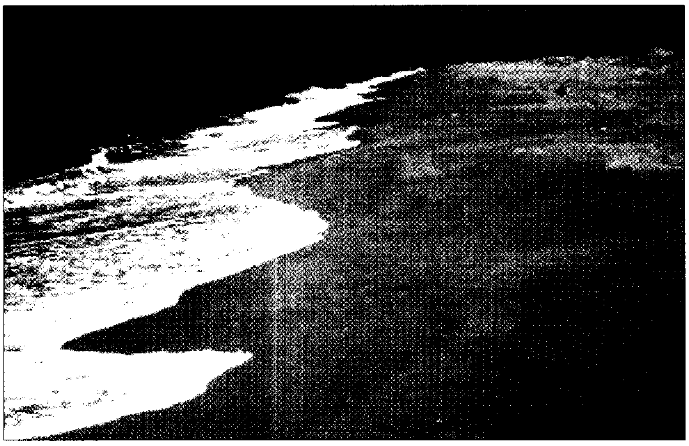

Plate 1: Sand dunes flanking the beach on the exposed low-lying sandy coast at Macaneta, near Maputo, Mozambique.

Photo: R S Arthurton

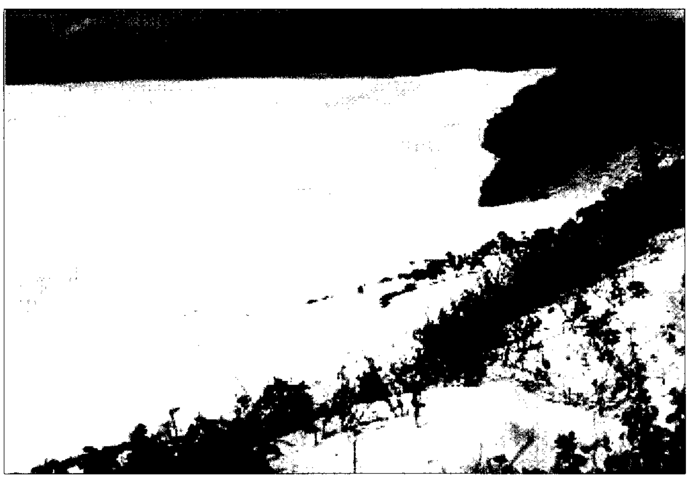

Plate 2: Sand dunes extending onto the backshore on the exposed low-lying sandy coast at Mambrui, near Malindi, Kenya.

Photo: R S Arthurton

Plate 4: Barrier beaches with hooked spits flank a tidal inlet with mangrove on the exposed low-lying sandy coast of southern Nampula province, Mozambique.

EOSAT imagery: Courtesy of UNEP

Plate 3: Sand dunes flank the beach sands at the southern mouth of the Tana River on the exposed low-lying sandy coast of Ungwana Bay, Kenya.

Photo: Courtesy of UNEP

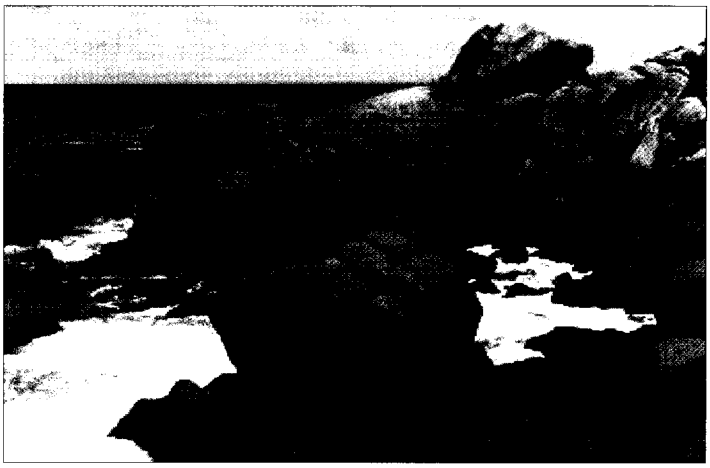

Plate 5: Granite headland on an exposed rocky coast.
Anse Intendance, south-western Mahé, Seychelles.

Photo: R S Arthurton

Plate 6: Pocket beach on an exposed rocky coast.
Anse Intendance, south-western Mahé, Seychelles.

Photo: R S Arthurton

Plate 7: Fossil reef limestone forms cliffs on the exposed rocky coast at Vuma, near Mombasa, Kenya.

Photo: Courtesy of UNEP

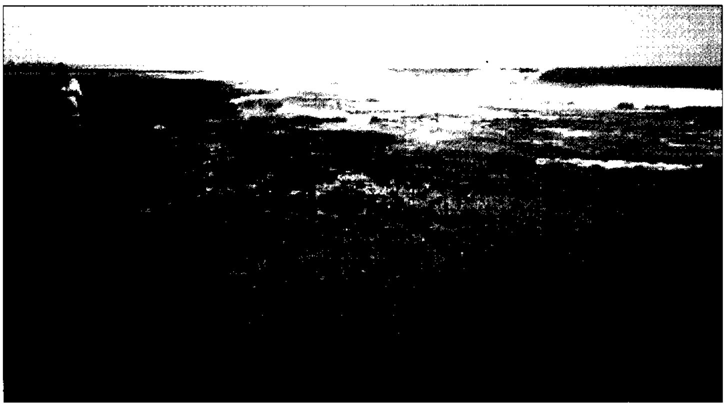

Plate 8: Emergent reef bar at low tide on the fringing reef coast at Nyali, north of Mombasa, Kenya.
Photo: R S Arthurton

Plate 9: View across intertidal platform and lagoon to reef bar on the fringing reef coast at Diani, south of Mombasa, Kenya.
Photo: R S Arthurton

Plate 10: View across the lagoon and intertidal platform to the beach and hinterland on the fringing reef coast at Nyali, north of Mombasa, Kenya.
Photo: R S Arthurton

Plate 11: Intertidal platform and cliffs formed of fossil reef limestone near Ras Nungwi, Zanzibar, Tanzania.
Photo: R S Arthurton

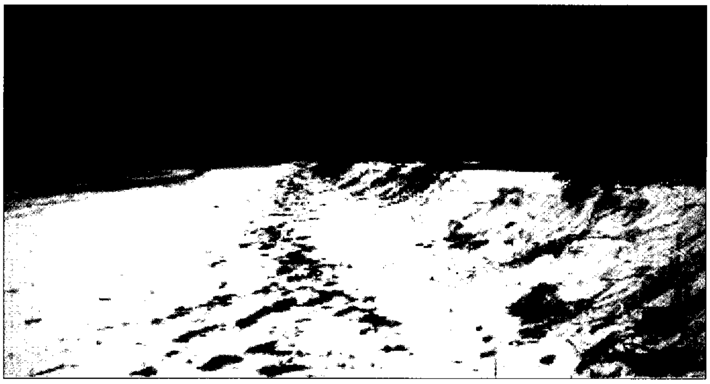

Plate 12: Beach head erosional scarp in beach plain sands on the fringing reef coast at Diani, south of Mombasa, Kenya

Photo: R S Arthurton

Plate 14: Undercut cliff of fossil reef limestone flanks the intertidal platform of the fringing reef coast at Diani, south of Mombasa, Kenya

Photo: R S Arthurton

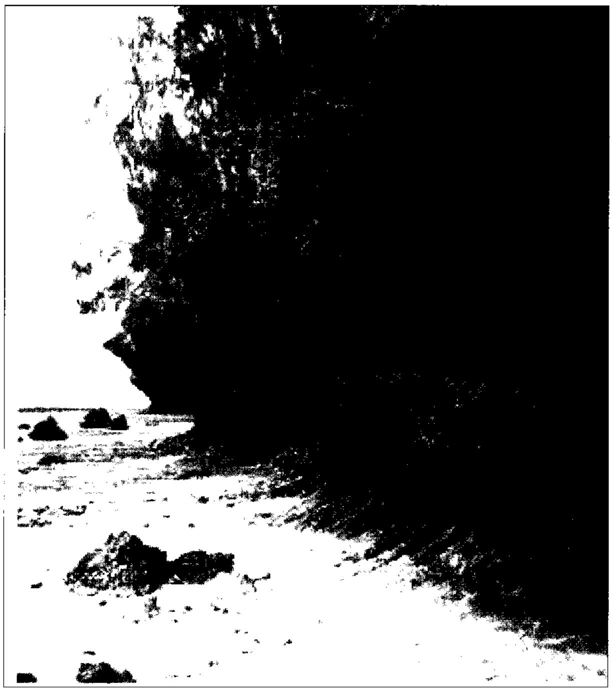

Plate 13: Undercut cliff of fossil reef limestone bounds the intertidal platform on the fringing reef coast of north-west Pemba, Tanzania

Photo: R S Arthurton

Plate 15: Eroded beach rock formed of sandstone on the intertidal platform at Diani, south of Mombasa, Kenya

Photo: R S Arthurton

Plate 16: Beach rock mimicking a modern beach flanking intertidal mud flats on a patch reef coast south of Zanzibar Town, Tanzania

Photo: R S Arthurton

**Plate 17: The waterfront at Malindi, Kenya, in the early 1960s**

Photo: R C Mills

**Plate 18: The waterfront at Malindi, Kenya, in 1992, showing the extent of sediment accretion over 30 years**

Photo: R S Arthurton

**Plate 19: Beach head erosion of beach plain sands undermining a dwelling on La Digue, Seychelles**

Photo: R S Arthurton

**Plate 20: Catastrophic drainage of a freshwater lagoon impounded by beach sand on the pocket beach of Anse Takamata, south-western Mahé, Seychelles**

Photo: R S Arthurton

Plate 21: Sea wall constructed from quarried fossil reef limestone forms a defensive beach head on the fringing reef coast near Mtwapa, Kenya

Photo: R S Arthurton

Plate 22: Concrete-faced vertical sea wall forms a defensive beach head on the fringing reef coast near Mtwapa, Kenya

Photo: R S Arthurton

Plate 24: Rock-filled wire gabions form a defensive revetment on an eroding shore in Mauritius

Photo: Courtesy of L Joottun

Plate 23: Rock-filled wire gabions form a defensive retaining wall for a coastal roadway in Mauritius

Photo: Courtesy of L Joottun

Plate 25: Groynes of granite blocks constructed to promote the retention of sand on the beach at Anse Kerlan, Praslin, Seychelles

Photo: R S Arthurton

Plate 26: Groynes of quarried fossil reef limestone constructed to promote the retention of beach sand on the Kunduchi shore, north of Dar-es-Salaam, Tanzania

Photo: R S Arthurton

Plate 27: Groynes constructed of granite blocks on the shore of Anse Kerlan, Praslin, Seychelles

Photo: R S Arthurton

Plate 28: Detail of rock groyne on the Kunduchi shore, north of Dar-es-Salaam, Tanzania

Photo: R S Arthurton

Plate 29: Piles of sand excavated from a beach plain in the Comoros
Photo: Courtesy of A A Fatouma

Plate 30: Beach head erosion scarp in beach plain sands on the fringing reef coast at Kenyatta Beach, north of Mombasa, Kenya
Photo: R S Arthurton

Plate 31 (above): Erosion scarp in beach sands banked against a defensive revetment constructed of limestone blocks at an hotel at Diani, on the fringing reef coast south of Mombasa, Kenya
Photo: R S Arthurton

Plate 32 (below): The toe of a beach resting on a rock platform at Oyster Bay, on the outskirts of Dar-es-Salaam, Tanzania
Photo: R S Arthurton

respect of wave attack. Under normal conditions, the waves provide the turbulent conditions that are conducive to the health of the forereef ecosystem and the consequent growth of its rigid substrate. Under extreme wave conditions, erosion of this substrate occurs. Derived biogenic carbonate debris, ranging from suspended fine sediment to blocks, is transported onto and over the reef bar (Plate 8), on which it may subsequently become enveloped or encrusted by algae.

At Low Water, fringing reefs, and to a lesser extent patch reefs, partially or wholly dissipate the energy of ocean-generated waves. At High Water ocean-wave energy is at least partially transmitted across intertidal platforms to the beach. In such high tidal states, particularly when these coincide with storm surge conditions, the beach deposits are prone to erosion. Beach sands are drawn down to form a relatively shallow profile. The beach toe (Plate 32) progrades over the platform or shelf and the beach head becomes vulnerable to erosion (Figure 8). Subsequently, the former, steeper beach profile may be re-formed by less extreme waves. The draw down of beach sand may be exacerbated by vertical sea walls constructed for coast protection.

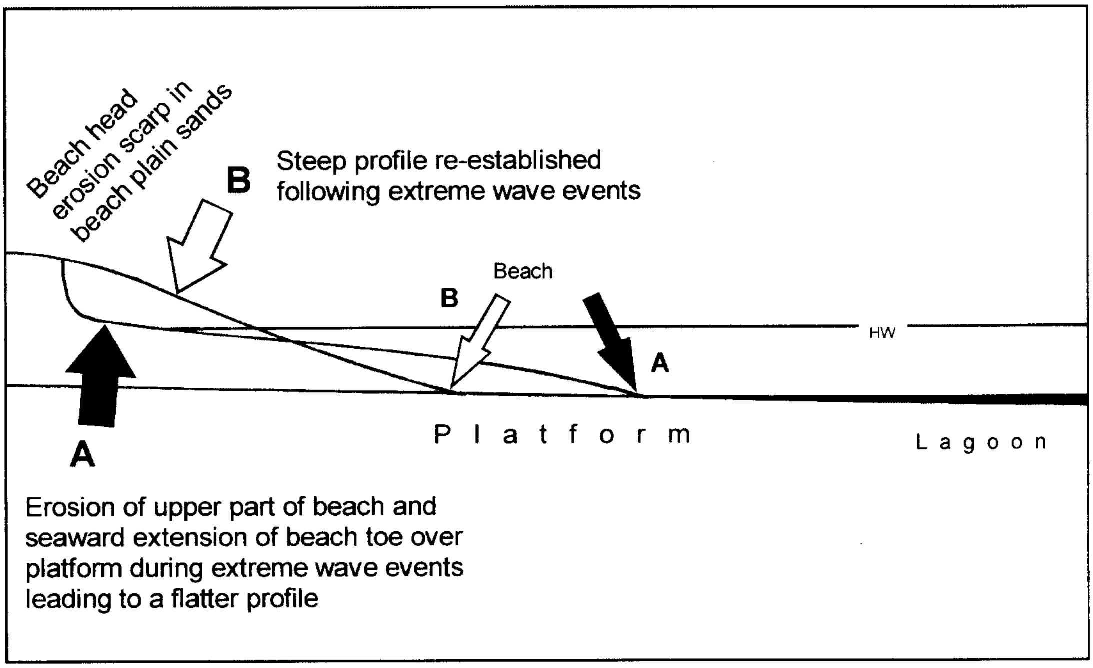


Figure 8: Illustration of the responses in a beach profile to changes in wave impact on a fringing reef coast at high tidal/surge states. HW indicates High Water level. Lagoon to Low Water shown in black.

In extreme wave conditions, beach draw down may affect the beach up to the beach head (Plates 30 and 31). In less extreme conditions the inshore limit of draw down is marked by an intermediate beach scarp, or, if more than one limit is preserved, scarps. The shelves forming the tops of these scarps are termed *berms* (Figure 9).

Wherever waves impact the beach obliquely, the ensuing currents flowing both over the foreshore (between normal High and Low Water) and in the swash zone cause sand to be transported alongshore (Figure 7). This effect is termed *longshore drift*. In many parts of the region, the wave climate changes in direction and strength according to the monsoon seasons. Any change in the wave climate is reflected in the scale and direction of the longshore drift. Despite these changes, a net annual drift of sand may be apparent. This process is particularly important in determining the supply of sand to (and from) beaches and is a key target for monitoring.

On exposed low-lying sandy coasts, beaches are commonly characterised by serial foreshore cusps (Figure 5). Individual cusp hollows attract swash drainage from the beach and the resulting flows may develop into powerful offshore rip currents.

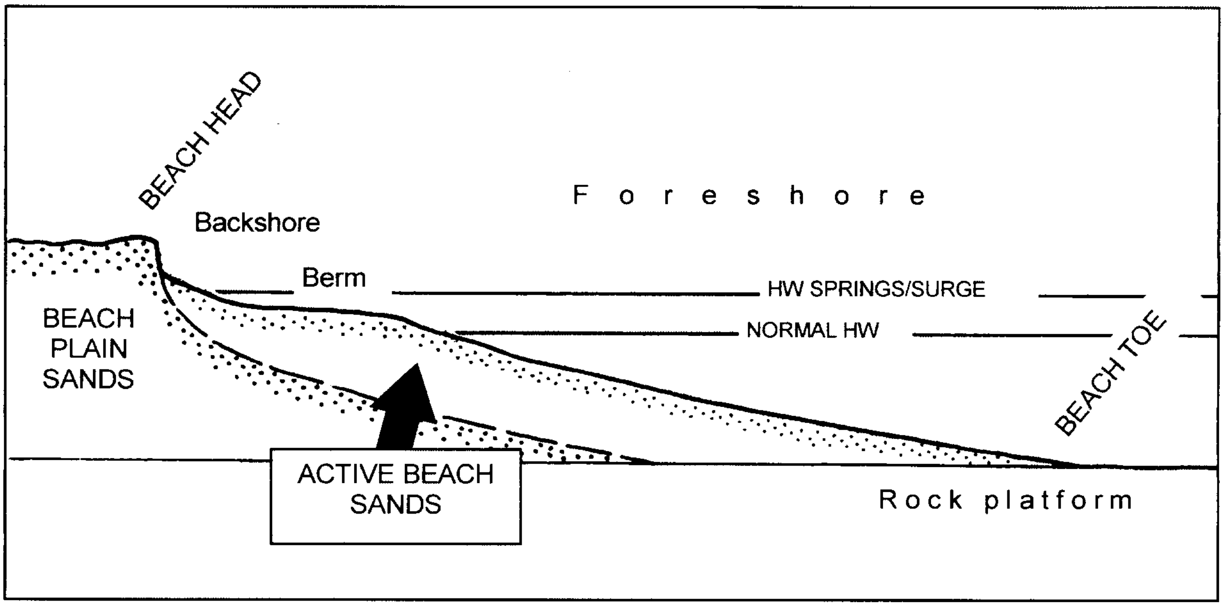


Figure 9: Shore-normal section showing a typical distribution of active beach sand on a fringing reef coast. Vertical scale exaggerated. HW indicates High Water level.

In addition to the action of wave-induced water currents on the beach, the transport of sand on beaches by the wind is significant on many of the region's shores – especially on exposed low-lying sandy coasts. Dry sand on the backshore (the upper part of the beach subject to only intermittent wave impact) is deflated from the beach surface and transported either along the backshore or landwards off the beach to become incorporated in a shore-parallel sand dune belt (Figure 3, Plates 2 and 3). The sand dunes represent sand reserves, for, under conditions of strong offshore winds or beach head erosion of the dunes by wave attack, sand is transferred back to the beach (Figure 6, Plate 2).

An unusual incidence of shoreline change due to water currents occurs on some pocket beaches of the Seychelles, where fresh water that has been ponded in lagoons behind beach barriers breaks through the barriers catastrophically, eroding a channel through the beach sands as it surges to the sea (Plate 20).

## 3.3 What are the sediment sources, budgets and sinks?

As well as their obvious resource values in tourism and recreation, sand (and shingle) beaches, or beach deposits, play an important role in protecting beach head sediments (and weak rocks) from erosion by waves. They form a natural buffer that dissipates the wave energy. The maintenance of the beach sediments is thus an important objective in the management of susceptible shores. To assist in this aim, it is helpful to gain knowledge of where the beach sediment comes from, how it is transported in the beach environment, and where it is lost from the active beach sand budget (Figure 9).

The sediment budget in respect of a particular shore is an estimate of the total amount of active sediment present. The budgets can apply to sand, gravel or mud, but, in the context of this study, its most useful application is to sand in the beach environment. Sand budgets for beaches can reduce or increase as a consequence of natural and/or human factors. If sediment gains outweigh losses, then the beach will accrete. Conversely if losses outweigh gains, it will erode.

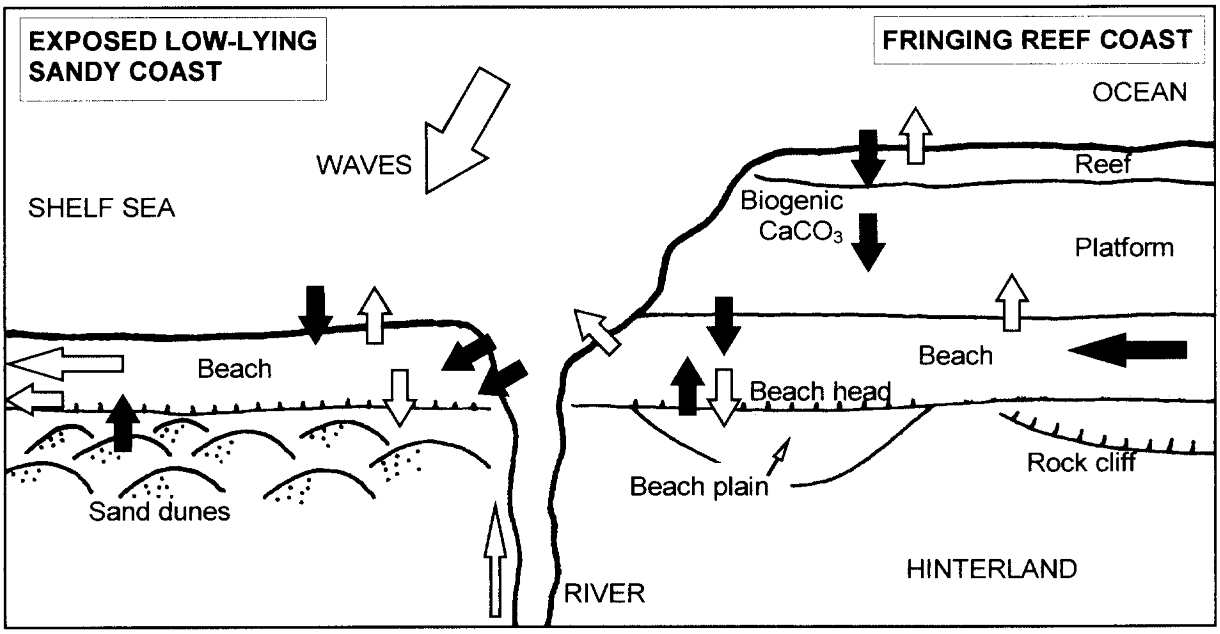


Figure 10: Potential additions to, and losses from, the beach sand budgets of an exposed low-lying sandy coast (to the left) and a fringing reef coast. Black arrows represent additions, grey arrows, losses. Losses from beach sand mining are not indicated.

In estimating sand budgets it is important to distinguish beach sands from sands forming the beach head where, for example, the beach head comprises beach plain or coastal dune sands (Figures 9 and 10). It is also important to be aware of seasonal or longer-term variability in beach morphologies and sediment budgets. Changes in beach profiles do not necessarily imply changes in the sediment budget, but may simply be the manifestation of a temporary, seasonal cross-shore redistribution of sand (Figure 8). Examples of longer-term variation in the sediment budget have been described from Malindi in Kenya, where major beach accretion of micaceous sand has occurred since the 1960s (Plates 17 and 18), and from Zanzibar, where an erosional regime that threatened the village of Nungwi in the early 1990s has been replaced by accretion. Similar variability has been noted on the Kunduchi shore, north of Dar-es-Salaam, where hotel investment has been destroyed by erosion (Plate 26). Information on beach accretion in historical to recent geological time scales may be apparent from the analysis of aerial photographs; the crests of former beach ridges on beach plains are represented by light-toned lineations.

Assessments of the sediment budget, and of the rates at which sediments are being added to, and removed from, the budget, are useful steps in identifying the processes of shoreline change. Knowledge of where the sand is being sourced, and to where it is being lost, are also key elements (Figure

10). Sediment sources may include adjoining beaches and shorefaces, adjoining platforms and fringing reefs, rivers and streams discharging to the shore (Figure 3), adjoining sand dunes (by wind transfer) and eroding beach head materials, whether these are beach plain sands or older geological materials. The sourced sediments may be wholly siliciclastic with quartz sand predominant, as, typically, on exposed low-lying sandy coasts and on the mainland reef coasts; or they may include greater or lesser amounts of detrital calcium carbonate, derived from the carbonate-fixing biota of the reefs and platforms. In some cases, e.g. on beaches forming the eastern shores of the Zanzibar islands, carbonate sands predominate.

The losses of sediment from a specified shore may be difficult to identify, yet alone quantify. It is, however, important to gather as much information as possible on the nature of sediment loss in preparation for possible monitoring. The losses may be due, for example, to the transfer of sand to adjoining beaches and dunes, the effective removal of sand from the shore through its transport to deep water, or through sand mining. The loss of calcium carbonate sand through the abrasion of its component grains is another potential loss factor, particularly on beaches where quartz sand predominates.

## 3.4 Are there any human factors?

The construction of seawalls, jetties and groynes may interfere with the process of longshore drift, modifying the sediment budget and exacerbating erosion of the adjacent beach or beach head in a down drift direction. Sea walls increase reflected wave energy, leading to the erosion and flattening of the adjoining beach, as near Mtwapa in Kenya, where walls have been built to protect shoreline properties (Plate 22). Sloping revetments constructed from quarried rock (Plate 21) and stone-filled wire gabions, as used in Mauritius (Plates 23 and 24), are alternative forms of protection that have lesser negative impacts on beach stability. Groynes are designed to impede the movement of beach sand by longshore drift where shores are vulnerable to erosion. Examples are the quarried limestone groynes constructed to protect hotels on the Kunduchi shore, north of Dar-es-Salaam (Plate 28), and quarried granite groins installed to protect a roadway and property on the island of Praslin in the Seychelles (Plates 25 and 27). Beach, and beach head, erosion down drift may be induced or exacerbated by such structures.

The modification and deepening of inlets for harbour development, and the installation of jetties and other harbour works, can also interfere with sand transport, depriving adjoining shores of a sand supply that may have been necessary for the maintenance of beach stability. An example has been noted at the harbour on the island of La Digue, in the Seychelles (Plate 19).

Muddy shores, as well as sandy beaches, may suffer as a result of human intervention. Where mangrove stands that front the shore have been indiscriminately felled, the cohesive muddy intertidal sediments in which they were rooted become prone to erosion through wave attack, leading to shoreline recession. There are many instances of such erosion on mainland shores and in Madagascar.

Beaches have long been recognised as convenient sources of sand for construction. Where extraction takes place intermittently and on a small scale, the impact on the sediment budget may not be significant. However, with increasing urbanisation, a greater demand for sand means that beach sand mining now represents an appreciable threat to the maintenance of the sediment budget on many shorelines, in particular periurban shores. The extraction of beach plain sands (Plate 29) and of coastal dune sands for commercial mineral extraction may also have an impact on the shore's sediment

## Box 3.1: **Identifying the processes responsible for change**

### Aims

The objective of this study is to investigate the nature of the processes and factors that determine, or otherwise influence, the incidence of shoreline change (or changes) that have been identified or recognised on any specified length of coast. The study is a precursor to a study programme for monitoring shoreline change as described in Section 4 (p.31). It builds on a coastal classification and susceptibility assessment carried out for the study site according to the procedures set out in Sections 1 and 2 (pp.9 and 19).

### Methods and information sources

Despite the diversity of sites where shoreline change occurs, there is merit in adopting a common methodology in this study. The key elements for consideration or investigation are the physical forcing agents – *wind, waves* and *tides*; the *sediment budget* and *sediment sources and sinks*; and the *human factors* that might be contributing to the change, either through their influence on forcing agents or their effect on the sediment budget. All of these elements should be viewed in both regional and local perspectives, so that the full range of possible causes is considered.

All of these study elements involve field observations as well as compilation or review of relevant published, or otherwise accessible, information, including that on climate and waves, tidal predictions and sediment discharges. Of particular importance are field observations made during, and immediately following, extreme climatic, wave and tidal events, for it is in these conditions that the greatest changes in coastal morphology occur. In the identification of the processes responsible for shoreline change, it is important to note if and how the processes change with the seasons, for example, changes in the directions of dune sand transport and longshore drift on beaches according to the monsoon seasons.

Investigation of the various human interventions as contributors to shoreline change demands a sensitive approach in view of a possible need for changes in management- or development practice, whether in coastal and river basin engineering (including coastal defence), agriculture or non-living resource development (including sand mining).

### Results

The study should aim to produce information that identifies the contributory processes, with indications of their relative importance both spatially and temporally, of how they may change according to the seasons or over the longer term, and of sites where the impacts of the processes, and in some cases the processes themselves, could be monitored to provide information relevant to coastal management.

### Display

As with the results of the susceptibility study, the *coastal classification* map (as a paper copy or GIS) provides a convenient base for the display of the results of this study. The information should be clearly categorised, e.g. by the use of colour coding, according to its type – forcing agents, sediments or human factors. Directional information should be included where appropriate, and the positions of potential monitoring stations indicated. Any uncertainties should be clearly flagged. The map display should be accompanied by an explanatory report, in which the main conclusions of the study are set out and discussed, and the principal requirements for monitoring identified.

budget, though over the longer term, in addition to the possible disruption of local groundwater resources. The dredging of sand for construction from the sea bed is not a usual practice in the region, except perhaps opportunistically, in association with navigational or capital dredging schemes. The dredging of sand shoals may reduce their effectiveness in dissipating wave energy, resulting in increased shoreline erosion.

In assessing the processes that affect shores whose stability depends on the discharge of sediment from rivers (in particular the exposed low-lying sandy coasts), it is important to be aware of the possible impacts of human interventions in the river basins. For some basins, the construction of dams in the hinterland has considerably reduced the natural discharge of sediment to the sea, while in others, for example, the Tana River in Kenya (Plate 3), changes in agricultural practice, notably the tillage of previously uncultivated land flanking the rivers, are said to have led to increased sediment discharge.

# SECTION 4 – Monitoring change

## 4.1 Planning the programme – what needs to be measured and why?

As with any long-term studies, monitoring programmes require careful planning. It is important that the resources that are made available to such programmes are dedicated to gathering information that is directly relevant to the issue of shoreline change and not unwittingly spent on collecting extraneous data, whatever its scientific interest might be.

Thus it is necessary, as a precursor to monitoring, to identify the physical processes and conditions that are the prime contributors to shoreline change. Such identification should be an output from the type of study outlined in Section 3 of these guidelines (p.23). Based on this knowledge, the monitoring programme should aim to measure, or otherwise quantify, the effects of those processes.

The output of the monitoring programme might comprise information on how, for example, the positions of identified boundaries such as the beach head (Figure 9) or the limits of sand dunes are changing with time. It might include information on how beach profiles and sediment budgets for specified lengths of shore are changing. It might even include records relating to the forcing agents – wind speed and direction, wave height and direction and High Water level, at least covering periods of extreme events. Beach monitoring programmes often include measurement of the grain size of beach sediment, yielding additional information on how sediment is transported in the coastal environment. While grain size monitoring may be helpful in some extensive studies, it is not considered a priority task for general assessments of shoreline change within the region.

The aim of the programme is to provide coastal management with a clear analysis of the shoreline change (or changes), including an assessment of the contributory factors, so that appropriate mitigation actions or adaptive measures may be considered.

## 4.2 Setting the boundaries – space and time

The monitoring programme should preferably not be an open-ended venture. If possible its boundaries should be defined at the outset so that resources can be sensibly assigned. The spatial boundaries – the length of coastline, the distance of landward penetration from the beach head and the width of the shore – are likely to reflect the coastal classification (see Section 1, p.9) and/or the specific requirements of coastal management, assessing, for example, the likely impact of a proposed coastal engineering scheme, or the threat of damage to hotel buildings through beach head erosion.

Definition of the time scale over which the monitoring should extend is less straightforward. Shoreline change takes place over a wide range of time scales. At one extreme, the impact of tsunami waves (generated by submarine earthquakes) on a shoreline can be devastating over just a minute or so. In contrast, the impact of global sea level change, while it may be clearly significant on a century time scale, may be scarcely perceptible within the span of a monitoring programme extending over, say, ten years. If the monitoring programme is set to last, say, five years, then obviously it is only those changes that are appreciable within that period that can be measured.

The difficulty of choosing a time span for monitoring that is representative from a coastal management perspective is compounded by the occurrence of extreme climatic events, notably, in this region, the cyclones that affect its southern part. Another difficulty is the need to cope with natural variability, e.g. in a sediment budget, whose cyclicity exceeds the monitoring period. Despite these constraints, a well planned programme is likely to yield relevant information on the scale and direction of sediment movement in the coastal zone; also to show the trend of any migration of the beach head within the monitoring period as a consequence of erosion or the accretion of beach sand.

## 4.3 Choosing the monitoring sites

Monitoring sites should be representative of the shore under study and, because of the need to revisit, they should be readily accessible. The sites should ideally be clearly identifiable in relation to conspicuous mapped reference points to landward of the beach head. On shores without suitable existing reference points, it may be necessary to construct temporary reference marks. These should be in secure positions.

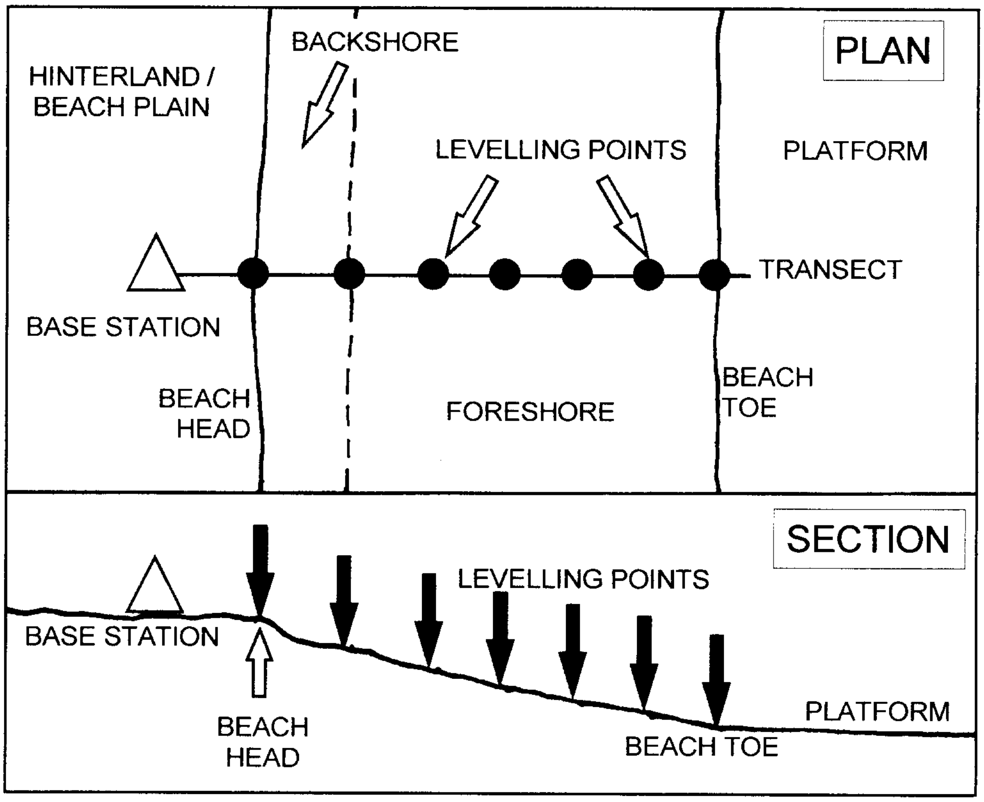


Figure 11: Beach profiling: array of beach levelling points on a shore-normal transect from the base station on a beach plain to the beach toe on a backreef platform (fringing reef coast). Plan view (above) and section (below).

The monitoring site comprises a transect extending, normal to the shore, seawards (and landwards as necessary) from a secure base station on the landward side of the beach head (Figure 11). The transect should extend over the beach head, and at least across the width of the beach – if a platform shore, to the beach toe (Figure 9, Plate 32), and if a shelf sea shore to the Low Water Mark (Figure 5). The numbers of levelling points on any one transect, and their positions in relation to the base station, will depend on the specific shore morphology and should be at the discretion of the surveyor.

However, the use of a consistent array of levelling points on any one transect is suggested, with additional points at the beach head and beach toe as appropriate.

The optimum spacing of transects alongshore will also depend on the specific shore morphology. Transects that are too close to each other may be wasteful of monitoring resources; those that are too widely separated may fail to capture crucial information. For extensive studies over, say, a 2-km length of shore, a spacing of 100–200 m may be appropriate, while for intensive studies, for example, investigating the impact of a specific coastal defence structure, a closer spacing – perhaps 50 m – may be desirable.

## 4.4 Choosing the tools

Apart from a possible requirement to measure wind and wave parameters, the equipment needed for such a monitoring programme is simple and easily procured.

For position fixing at the base station and the fixing of levelling points on the transect, simple surveying instruments are the basic requirement – if nothing else, a compass and tape measure. The use of a GPS or a *Total Station* instrument may aid position fixing and the transfer of data to a GIS, though it is by no means an essential tool and may not provide the required accuracy of resolution. For measuring ground levels (including beach levels), an engineer's level and standard surveying poles are all that is necessary.

Regional wind and wave parameters are likely to lie outside the scope of the monitoring programme and information on these may be available from external sources. If it is required to monitor these parameters, and tidal levels, in shoreline situations, again simple tools will suffice – a compass for directional information and levelling equipment for tidal levels. The continuous monitoring of wave heights by the use of a wave rider buoy might be feasible, but there would need to be compelling reasons for the deployment and maintenance of expensive equipment of this type. Visual estimates of wave height with the aid of surveying poles may yield the required information in shoreline situations, except perhaps in extreme conditions and with safety considerations in mind.

## 4.5 Deciding the monitoring schedule

The optimum frequency at which monitoring is carried out at specific sites may be difficult to foresee at the planning stage. Information from studies identifying the processes responsible for shoreline change (Section 3, p.23) may provide indications of the rates of change and thus guidance on determining an appropriate frequency for monitoring rounds.

Information from the first few monitoring rounds, carried out at say two- or three-monthly intervals, is likely to provide a rationale for establishing the subsequent monitoring schedule, whether this needs to be more intensive or more protracted. Such a frequency should ensure that data representing seasonal changes in the profile are captured by the programme. Monitoring at regular intervals is suggested, but there may be a case for additional rounds during, and after, the passage of extreme events. High tidal events are predictable and may be planned for in the schedule. High wind and wave events (including storm surges) may offer little warning and require 'emergency' responses.

The monitoring of fringing reefs may best be geared to the passage of extreme events, although the

## Box 4.1: **Monitoring shoreline change**

**Aims**

The objectives of this study are to collect and supply for coastal management quantitative information on, or relating to, shoreline change over specified lengths of shore and over agreed time spans. Parameters to be monitored include the position of the beach head and ground/beach/dune levels on surveyed coast-normal transects. In some cases, monitoring waves, wind and tides may assist the interpretation of shoreline change.

**Tools and procedure**

The basic surveying equipment required comprises compass, tape measure, surveying poles and engineer's level. More sophisticated instruments – a *Total Station* or a *GPS* may be used for spatial fixing to advantage, depending upon the required accuracy of resolution.

The planning stage involves deciding what can be monitored within the available resources, the positions and spacing of the transects to be used, and the frequency of monitoring rounds. The results of an initial trial period may indicate an appropriate monitoring schedule. Additional monitoring rounds made during and following extreme climatic, wave and tidal events may prove especially useful. In executing a monitoring round, position fixing and ground levelling on transects should be carried out using systematic, standard procedures.

The data to be recorded from individual transects at each monitoring round comprise: the surveyed position of the base station; the measured distance from the base station to the beach head; the measured distance from the base station to each levelling point on the transect; and the ground level at each levelling point relative to the level of the base station. A graphic profile of the transect is prepared from the recorded data (Figure 11). Time series profiles on individual transects are compared and any changes noted, then interpreted in terms of beach head migration and cross-shore beach changes with time. The changes are compared with those from adjoining transects, trends noted and interpreted in terms of alongshore beach (and beach head) changes with time.

**Display**

The coastal classification map as produced in the study outlined in Section 1 (p.9), but at an enlarged scale if appropriate, would form a suitable base for the display of the transects (including the base stations and levelling points) that have been the subjects of the monitoring programme (Figure 11). The map may be in paper copy or GIS format.

The display of beach head migration information and the beach plan shape may be as mapped time series lines, perhaps flagged with figures representing the measured distance of landward or seaward migration between monitoring rounds. The profile records may be shown in time series as graphic plots, annotated to highlight any significant cross-shore beach changes with time, including overall gains or losses to the sediment budget.

The display of the trends of overall gains and losses over time alongshore, as interpreted from the comparison of the profiles from adjoining transects, may be shown by annotation of the map.

return period of events that cause significant, measurable, morphological change may exceed the life span of the monitoring programme.

## 4.6 Analysing the results

The time series data from an individual transect provides a record of ground level (or beach level) change, upwards or downwards as a consequence of erosion or accretion respectively. The records, or profiles, might be interpreted as indicating, for example, an overall loss, or an overall gain, of beach sand, and/or a redistribution of sand on the line of the transect (*cross-shore*). Additionally, the records might show either a landward or a seaward migration of the beach head.

Time series data from individual transects are valuable in themselves for the information that they yield on cross-shore changes, but are all the more valuable when compared with counterpart time series data from adjoining transects. Taken together, the time series profile records present an opportunity to assess and quantify beach sand gain or loss *alongshore*, thus yielding information on any changes to the sediment budget; also providing an alongshore assessment of beach head migration.

The results of the monitoring programme should provide coastal management with quantified information on the nature and rate of shoreline change as it affects beaches and beach heads over the monitoring period; also changes affecting sand dunes. They should assist in the distinction between long-term changes and seasonal or other cyclic variability, and in the assessment of the impacts of human interventions. The results should also provide a basis for forecasting the nature and rate of future shoreline change.

# MITIGATION AND ADAPTATION IN THE CONTEXT OF ICAM

## What is Integrated Coastal Area Management?

Integrated Coastal Area Management (ICAM) can be defined as a continuous and dynamic process by which decisions are made for the sustainable use, development and protection of coastal and marine areas and resources. First and foremost, the process is designed to overcome the fragmentation inherent in both the sectorial management approach and the splits in jurisdiction among levels of government at the land-sea interface. This is done by ensuring that the decisions of all sectors and all levels of government are harmonised and consistent with the coastal policies of the country. A key part of ICAM is the design of the institutional process to accomplish this harmonisation in a politically acceptable way.

The goals of ICAM are to achieve sustainable development of coastal and marine areas, to reduce the vulnerability of coastal areas and their inhabitants to natural hazards, and to maintain essential ecological processes, life support systems and biological diversity in coastal and marine areas. ICAM is a multipurpose oriented concept that analyses implications of development, conflicting uses and interrelationships among physical processes and human activities. In addition, it promotes linkages and harmonisation between sectorial coastal and ocean activities.

ICAM focuses on three general principles:

- strengthening inter-sectorial management;
- preserving and protecting productivity and biological diversity of coastal ecosystems mainly through prevention of habitat destruction, pollution and over-exploitation; and
- promoting rational development and sustainable utilisation of coastal resources.

It is within the context of these ICAM goals and principles that the decisions concerning the management of shoreline change should be made.

## What is the shoreline change affecting?

This is a key question in the appraisal of shoreline change. Its answer should be an important factor in determining the scope of mitigation or adaptation, or, indeed, whether the best management action is '*no action*' – that is, to let nature take its course without human intervention.

Evaluation of the resources on coasts that are subject to shoreline change, and particularly coastal erosion, is a fundamental step. Sustainability in the coastal zone implies the maintenance of its *natural capital* – the *total resource*. Coastal areas are special in the wide range of resources they contain, and thus the wide range of opportunities that they present to the ecosystem. From an anthropocentric viewpoint, such opportunities include fisheries, aquaculture, sand mining, mangrove harvesting, port and industrial development, tourism development, recreation and groundwater resources.

An aim of ICAM is to at least maintain the total resource value, and preferably enhance it, for the benefit of future generations – the concept of *intergenerational equity*. The translation of resource value into societal benefit is complex and subject to many variable factors. The results can be nothing more than generally indicative. Despite these difficulties, there is merit in considering the value of the specific resources threatened by shoreline change, together with the possible changes in their value over time, so that the management responses may be prioritised to the benefit of the community.

The resource evaluation should answer two questions. Firstly, does the resource (or development investment) that is under threat merit any mitigation or adaptive action on the part of coastal management? If so, what is the scope of mitigation or adaptation that should be instituted? These questions should properly be asked early in the assessment of shoreline change, for, in some cases, the allocation of scarce resources to a long-term monitoring programme may be considered inappropriate, or of low priority.

## Options for the management of shoreline change

Depending on the resources at risk, 'doing nothing' may be the sensible option in some cases of shoreline change. However, where communities are vulnerable, or, for example, tourism related infrastructure is threatened, this is generally not an option.

Local management interventions are of three main types:

- planning and regulation that involves the relocation of people, and development (or redevelopment) using *setback* policies, thus reducing vulnerability in relation to shoreline change;
- regulation of practices that lead to beach- and beach head erosion, including sand mining from beaches and adjoining river courses, the construction of inappropriate sea defences, and the indiscriminate dredging of sand in inshore areas; and
- control of wave impact and/or the sediment budget in the coastal environment, by the use of vegetation as a natural stabiliser (mangrove husbandry, sand dune flora) and by engineering means (construction of suitably designed sea walls or revetments, groynes and detached breakwaters, or by beach renourishment).

Any controls on the rates of sand and suspended sediment discharge from rivers – a significant concern in the coastal environment – are beyond the scope of local intervention and require a regional, river basin management approach.

*Setback* strategies involve the restriction of development of certain types within a prescribed distance from the shoreline. The coastal classification map and its derivative susceptibility assessment – the outputs from the studies described in Sections 1 and 2 of these guidelines (pp.9 and 19) – provide important guidance in the placing of setback limits. The setback distance from the shore should reflect the susceptibility of the shore to change, taking into account any additional monitoring information on the rates of change and their trends.

The use of hard engineering structures, such as seawalls, revetments, groynes and detached breakwaters to control wave impacts and sediment movement may be warranted only in situations where existing high value investment is at risk. The impact of such installations should be carefully assessed, not only on the immediate site but also on adjoining parts of the shore. The use of *beach renourishment*, whereby sand is transported by truck or barge from a remote borrow area and placed on a beach that has a depleted sand budget, is an option that might be considered, for example, to reinstate an important recreational beach following extreme event related degradation. On sites where the nature of longshore drift has been clearly established, the possibility of *recycling* sand from 'down drift' to 'up drift' parts of the beach may be considered.

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# APPENDIX 1

## Country synopses of shoreline change

## COMOROS

The Comoros comprise of a group of small volcanic Islands with a total land area of 2236 km$^2$ and 350 km of shoreline. The islands face a limitation in terms of developable land due to their small size, their mountainous terrain and poor eroded soils. Over 80% of the population of over 500,000 people live within the narrow coastal zone.

### Geology and geomorphology

The geology of the Comoros is predominantly volcanic. Lava outflows overlain by reefal limestone and carbonate platform deposits cover the limited coastal zone. High volcanic cliffs cover the rest of the islands. On the narrow coastal lowlands, weathered volcanic rocks, carbonate or volcanic sands may be observed. Clays occur in areas within the river drainage basins and cover most mangrove areas. The Comoros islands were formed as the Indian Ocean Plate moved over a centre of volcanism. The islands rise abruptly from the sea. They have no continental shelves nor expansive coastal lowlands. Low cliffs of volcanic rock dominate most of the shorelines especially in Grande Comore. In the rest of the islands, which are relatively older, steep mountains merge seaward into narrow coastal lowlands that comprise recent unconsolidated deposits derived from the interior highlands and the coastal reefs. For all the islands, unless degraded, a fringing reef protects the limited beaches and coastal lowlands. Some of the older islands have a relatively broad submarine platform. Around Mayotte, one of the older islands, there is an internal lagoon.

### Coastal typology and shoreline change

The coastal zone in the Comoros is represented by cliffs or very narrow coastal plains. The coastal lowlands comprise recent terrestrial sands and clays, or carbonate sands derived from reefs. For most of the islands, unless degraded, a fringing reef forms the only protection from wave attack in the absence of a continental shelf. Mayotte and the other older islands have developed a relatively broad submarine platform. For most of the islands, low volcanic cliffs dominate the coastline, especially in Grande Comore. Erosion of coastal lowlands is observed in many areas. A good example is observed in Anjouan Island where coastal lowlands are threatened. On many of the islands, very few of the beaches recorded in history exist today. The systematic removal of sand and coral heads for the building industry and pollution from the major human centres has transformed beaches and beach plains (Plate 29), reef areas and lagoons into mud flats, especially where this is associated with a rapid build-up of sediments transported from the bare slopes of the central mountains in Anjouan Island. Given the traditional method of construction in the Comoros, which relies on use of reef rock, and the absence of alternative limestone material on land, the continued use of beach sands and reef rock for new buildings will exacerbate the erosion problem.

## KENYA

The Kenya coastal zone is located between latitudes 4° 21' N and 4° 28' S. The country's population is over 24 million, of whom over 1.8 million live in the coastal zone. In the last three decades, rapid development in the tourism industry has taken place along the coastal zone. Most of the development is sited on beaches experiencing increasing coastal erosion problems.

### Geology and geomorphology

The central Kenya highlands drop from an elevation of over 5000 m through a series of steps, the Nyika, the foot plateau and the low-lying coastal plain at an elevation of 0-60 m above sea level. The geologic evolution of the Kenya coast is tied to the opening of the Indian Ocean. Fault movement in the Pleistocene was associated with displacement of coastal reefs. For most of the coastal area faults have been relatively inactive, though earth tremors with epicenters along the coast have been recorded in the last few years. In the north, the coastal plain receives large volumes of terrigenous sediments from the Tana and Sabaki rivers (Plate 3, Figure 3). Southwards from Malindi to the Tanzanian border, raised reef limestone forming a series of terraces at elevations ranging from below sea level to over 200 m O.D. characterises the shoreline. The area extending northwards from Malindi to Lamu has long been one of accumulation of river derived sediments. The Tana river delta has accreted appreciably, resulting in an extensive coastal plain over 60 km wide in the central sector and a continental shelf over 40 km wide in the Lamu depocentre. The shorelines there are wave and tide influenced. Barrier beach systems have been associated with river estuary migration from Pleistocene to recent times. These are represented by a chain of islands fronting the shoreline from Lamu northwards to the Somali border. The Lamu archipelago comprises of cemented sands and limestones overlain by reefs and wind blown sands. Modern evolution of barriers is observed in Ungwana Bay, where migration of the river mouths has occurred in recent history (Plate 3). The southern sector from Malindi to the Tanzanian Border from Pleistocene to recent times has been dominated by extensive reef proliferation associated with the deposition of carbonate platform and lagoonal deposits.

### Coastal typology and shoreline change

The coastline in the southern sector is defined by Pleistocene to recent geology, comprising a mixed suite of rocks that range from pure carbonate to carbonate cemented sand. These form the coastal cliffs (Plate 7), the intertidal platform and raised coastal terrain. The nearshore platform is overlain by a veneer of sediment, and is bounded landwards by a cliff of fossil reef limestone. Lagoonal deposits occur behind a north–south trending reef complex . Periodic fluctuations of sea level have cut terraces 50–2000 m wide that extend from the land to the fringing reef (Plate 10). In areas where this platform environment is well developed, a remnant wedge of Holocene sands or clays up to 4 m thick overlies the platform. The northern sector is dominated by the deltaic deposition of a thick suite of recent unconsolidated deposits ranging from coarse- to fine sands, silts, clays and wind blown sand (Plates 2 and 3) that overlie well- to poorly cemented beach rock. Clays and silts are observed in mangrove areas and form thick units in Ungwana Bay. Limestones that form the edge of the 0–5 m terrace are observed 500 m inland at Kipini.

Coastal erosion is widespread along areas where unconsolidated deposits form the low-lying environments. Old (Swahili-Arab) settlements at Ungwana and Mwana are built on Holocene deposits 400–500 m inland. The modern settlements north of Kipini, built on the shoreline, have been eroded and local legend has it that older settlements lie offshore. The deltaic setting of the areas north of Malindi to the Lamu archipelago has extensive low-lying coastal plain environments with dune fields (Figure 3), beaches and mangrove areas that fall within the erosional regime. Many of these low-lying shores are vulnerable to coastal erosion. Lamu town, Mambrui and many ancient villages of the Lamu archipelago that were built on ancient deltaic settings are threatened by coastal erosion. In the southern sector, the narrow low-lying coastal belt, the beach areas and the coastal mangroves are affected by erosion. Investments in the southern sector built on raised beaches overlying Pleistocene terraces are experiencing rapid coastal erosion. Wise construction of the permanent infrastructure on less vulnerable areas could have minimized the socio-economic impact of coastal erosion. Unplanned attempts at coastal protection have resulted in accelerated coastal erosion, more so in important tourist centers like Diani and Bamburi. As the situation stands, in some of the areas, well planned protection is the only viable option to save the affected areas.

## MADAGASCAR

Madagascar is the largest island of the Indian Ocean with a shoreline of over 5000 km. During the opening of the Indian Ocean and movement of the Indian sub-continent, Antarctica and Australia, the movement of Madagascar failed. Geologically, Madagascar is therefore related to continental Africa.

### Geology and geomorphology

The Precambrian shield extends over central Madagascar and the east coast. The west coast is covered by a thick Permo-Triassic Karoo system that overlies faulted Precambrian rocks. These two old formations are closely related to the geology of continental Africa and predate the opening of the Indian ocean. The Karoo sequence is overlain by Jurassic and Cretaceous sediments and lavas that were deposited in NE-SW depositional basins. Younger deposits including deltaic alluvium, windblown sands and limestone that form the top sequences of the coastal zone overlie these older sequences and form the top sequences of the continental shelf and coastal zone of the western section. Recent deposits (Holocene) cover the lower coastal plain that includes coastal lowlands and beaches.

The central mountainous region has a south-west facing drainage basin. The distribution of coastal morphology is very strongly controlled by this regional physiography. On the east coast the continental shelf is relatively narrow and grades into sandy beaches and coastal cliffs. In some localities they are backed by mangrove swamps, short stretches of headland or embayment. The west coast consists of a wide coastal plain and continental shelf. The wide shelf has promoted the development of extensive tidal flats, mangrove swamps, fringing reefs, offshore reefs and cays. Strong currents of the Mozambique Channel and the prolongation of the South Equatorial Current trap warm waters along this coast, raising the mean temperature to 25°C and generating a high tidal range of up to 7m. These conditions have supported proliferation of reefs and extensive mangroves. In the extreme north, mangroves have evolved in the limited areas protected by barrier islands. Extensive dune fields occur in the backshore areas of the arid, south-western section of Madagascar.

### Coastal typology and shoreline change

Madagascar exhibits diverse coastal types compared to the rest of the islands. The east coast has a relatively narrow continental shelf. The coastline is marked in the northern part by steep cliffs interspaced with long beaches and a succession of barrier islands and headlands. Coral reefs occur in the north-east. The west and north-west coasts have a wide continental shelf and coastal plain. Barrier islands and mangroves cover the extensive intertidal plain and deltaic systems. The south-west has extensive low-lying areas fronted by sandy beaches and sand dunes. Madagascar is exposed to semi-diurnal tides with amplitudes of between 2.6 m and 3.9 m on average on the west coast and 0.6 m to 0.9 m on the east coast. The water movement associated with the swell of the south-west region during the southern winter and those of the north-west region during the southern summer are important factors. The swell has the strongest effect on the south-west region and cyclones are servere in the north-west. Madagascar lies within one of the most severe cyclonic belts, with about 2-3 cyclones per year. This has a strong influence on periodic shoreline changes.

Historical accounts dating back to as early as the 19th century indicate that coastal erosion has been active for a long time. No systematic studies of coastal erosion exist in Madagascar. Coastal erosion is observed in many locations on the east and west coasts. The Marondava region of central west Madagascar, which has a recent wide low-lying coastal area (at 4 m above sea level) with coastal lagoonal systems, has experienced severe erosion dating back to the 19th century. Severe cases are reported during storm events of 1953, when over 100 m of shoreline was lost, most of it attributed to the swell and storm events. Areas with severe erosion include the coast of Marandova and Point Tonio on central west Madagascar. The Marondava city area has sectors at an altitude of 4 m comprising mostly of unconsolidated sand. The erosion problem in this sector date back to the 1950s, when stabilization works were undertaken. The current estimated rate of erosion may be up to 10 m/year. The swell is generated by cyclones. Cyclones have generated the most rapid erosion. During a cyclone the swell amplitude may reach 4 m. Unwise coastal protection which has an old history in this sector has also contributed to coastal erosion.

The port of Toamasina on the east coast, built on the northern part of a large tombolo linked offshore to the Hastie reef, has reported severe erosion. The tidal amplitude in the area falls between 0.45 m and 0.83 m, reaching 10 – 13 m during cyclones. In the 1970s the port jetty was extended. A permanent recession of 25 m was recorded after storms in 1986. Interference with sediment dynamics by the new jetty is thought to have worsened the problem of port sedimentation and an acceleration of the erosion problem. Coastal erosion is also reported in Manakara but this is not as well documented as the Morondava case. Anthropogenic and natural factors, vulnerable coastal terrain, the swell and periodic cyclones all contribute to the coastal erosion recorded in most sectors of Madagascar.

## MAURITIUS

Mauritius is part of a group of islands in the Western Indian Ocean located on latitude 20°S, 800 km east of Madagascar. These Islands evolved through alternating phases of volcanism and reef rock formation. The main island, Mauritius, is volcanic and reaches a maximum elevation of 817 metres. There are five other inhabited large islands, Rodriguez, St Brandon Agalega, Diego Garcia and Tromelin. In addition, the Mauritian waters are dotted by many other smaller pristine coralline islands. The total land area is over 1865 $km^2$. The coastline is about 200 km long, almost completely surrounded by a fringing coral reef system that encloses a lagoonal area of 243 $km^2$. Mauritius has a population of over 1.03 million people, over 60% of whom live in coastal districts. The islands are subject to tropical cyclones and strong winds with speeds of up to 250 km/hr. The official cyclone season extends from 1st November to 15th May.

### Geology and geomorphology

Mauritius is volcanic except for some areas of uplifted wind-blown and beach deposits and raised reef limestones. The coastal strip comprises of sedimentary deposits of Pleistocene to Recent age. Two distinct generations of fossilized coral reefs were deposited during the Mindel-Riss (250,000 years B.P.) and Riss-Wurm (120,000 years B.P.) periods of sea-level highstand. The older deposits, observed in the region of Port Louis, lie 6–8 m above mean sea level. The younger can be seen discontinuously at Vieux Grand Port, Baie du Cap to Baie du l'Arsenal and Flic-en-Flac. The uplifted wind-blown deposits occur in discontinuous patches, while the Recent sandy beach deposits are common all along the coastline, except for small patches at Case Royale, La Mecque, Pont Naturel and Haute River, where the shoreline deposits are muddy and/or rocky. All of the islands have a fringing reef that forms a ring, broken only at the river estuaries. The reef forms an important natural barrier providing the beaches, coastal ridges and dunes with protection against wave onslaught. The sand dune ridges and mangrove complex further inland form the next defence.

### Coastal typology and shoreline change

The coast of Mauritius is marked by coastal cliffs or narrow coastal lowlands formed of Pleistocene and Recent rocks and sediments. Unlike the continental shorelines, those of the islands receive a very low supply of sediment from the hinterland and have a net sediment deficit. Coastal sediments are predominantly coralline. Loss of sand through mining and entrainment into the deep offshore cannot be compensated by the productive capacity of coral reefs that are subject to severe environmental stress. This is the reason why erosional scarps carved out during the past decade have not been recouped with sand accretion. Wherever the beach deposits are sandy, erosional features are predominant, as evidenced by a wave-abraded platform, piedestal weathering, coastal caves and discreet stacks.

In normal conditions most of the coastal zone of Mauritius is protected by the fringing coral reef, except in the south, where the coral reef is absent over 15 kilometres. During rough weather conditions, especially during cyclonic conditions and heavy swells from the south, large sections of the shoreline are influenced by heavy wave action that gives rise to widespread shoreline change including erosion. The erosional problem is compounded by many factors, including irrational human activities on the coastline such as the planning of residential and hotel development in vulnerable dune areas and the mining of sand from beaches and lagoons. Damage to the coral reefs through the discharge of industrial and municipal waste into the sea, inappropriate construction at the high water mark, and reclamation and dredging of the seabed are also critical contributors to the problem.

The following coastal segments have suffered severe erosion since 10th February1994, with the passage of cyclone Hollanda. In Rivière Noire, the coastline has eroded over a length of at least 1 km with a scarp height of 1.0–1.2 m and a coastline retreat 2.0–5.0 m. At La Prairie the length of coastline eroded is 300 m, the scarp height is 1.2 m and the coastline retreat is 2.0–3.0 m. Similar observations are recorded in Rivière des Galets, with an eroded shoreline length of 600 m, Pomponette–1.5 km, Riambel public beach–1.1 km and Riambel cemetry–450 m. During the passage of cyclone Daniella on 8th December 1996, the following three sites were severely eroded; Tamarin–500 m of shoreline with a scarp height of 1.2–1.5 m and a coastline retreat of 2.5–3.2, Les Salines Martelos Tower–300 m, a scarp height of 1.5 m and a coastline retreat of 3.0–3.5m. At Le Morne (Berjaya Hotel) the length of coastline eroded is 800 m, the scarp height is 0.5–1.2 m and the coastline retreat is 2.0– 4.5 m. Other erosional sites, including Grand Baie, Cap Malheureux, Rivière de Galets and Flic-en-Flac have been stabilised with gabions (Plates 23 and 24).

## MOZAMBIQUE

Mozambique has the third longest coastline in Africa, approximately 2500 km, stretching from the tropics (10°27'S) in the north to the sub-tropics (26°52'S) in the south. Over 90% of the coastline consists of low coastal plain with extensive mangrove forests that cover 1194 km$^2$. Over 70% of the Mozambique population, estimated at 15,166,000, resides in the coastal zone.

## Geology and geomorphology

The oldest coastal rocks are of Karoo age. These occurs inland overlain by thick Cretaceous and Tertiary sediments. For most of the coastal area from the South African border to just south of Nacala the lower coastal plain (up to 200 m above sea level) is dominated by Quaternary sediments (Pleistocene and Holocene to Recent), unconsolidated or poorly cemented deposits, deltaic alluvium and recent, poorly consolidated or unconsolidated layered sand and clay sequences typical of the Beira area. The shoreline sector from Nacala northwards to the Tanzanian border is dominated by a Pleistocene sequence of cemented sands and mixed calcium carbonate rocks.

The Quaternary deposits that overlie the Tertiary rocks in most of the coastal area cover wide areas of the coastal plain and river valleys rejuvenated during Tertiary faulting. Major rivers from the central highlands, the Maputo, Incomati, Limpopo, Save, Zambezi and Ruvuma discharge large volumes of siliclastic sediment to the sea. The coast of Mozambique comprises three major elements. The northern coast, covering 600 km southwards from the Tanzania border, is an embayment coast with extensive cliff shorelines and fringing reef and reef platform development, separated by low coral rock headlands. The middle sector, Maputo–Nacala, covering 900 km, is dominated by deltas and large rivers, Zambezi, Maputo and Save. The numerous deltas have developed extensive low-lying coastal plains with widths of over 100 km in the Maputo area. This sector has a wide continental shelf, 130 km in the Bight of Sofala, but becomes narrow at the vicinity of Nacala. The southern coast is dominated by linear beaches or barrier-swamp coasts (Plates 1 and 4) and large fields of parabolic dunes in the backshore. There is evidence to indicate that Inhaca Island represents part of an ancient barrier island system that stretched from South Africa, now represented by abandoned river channels and lakes stretching along the coast that were breached as the sea level rose to its present-day level. The southerly discharging Incomati and Save rivers indicate southward longshore drift, however, in Maputo Bay, northward longshore drift has been proposed. A similar southerly longshore drift is indicated south of Maputo.

## Coastal typology and shoreline change

The Mozambique shoreline is subject to a characteristically high tidal range, strong channel currents and strong spatial variation in physical processes. Spring tides range from 3.1 m in the north to 6.4 m in the Bight of Sofala and 2m at the southern border. Trade winds affect the southern shoreline that also falls within the southern cyclonic belt. Wave exposure is variable. The southern portion is exposed to swell from the Indian Ocean generated by the south-east trade winds, whereas the northern portion of the coast is affected only by locally generated waves. As such, sediment transport is complex, with several longshore divergence and convergence points. The occurrence of coastal erosion and the vulnerability of the coastal area to erosion are closely related to the coastal geology.

The northern sector from the Ruvuma river to Mozambique Island, is cut from cemented beach rock (limestones and sandstones) and reef rock. This suite of rocks provides relatively stable shorelines apart from areas where recent deposits form lowlands overlying the lower coastal terraces. Most of the major rivers of Mozambique drain into the middle sector, entirely comprising Pleistocene, Holocene and Recent low-lying deltaic and associated beach plain environments. Coastal change is significant where Recent unconsolidated deposits form spits, barrier islands and coastal lowlands. Rapid erosion is common in major areas like Beira. On the Zambezi delta (see cover image) accretion of 1 m per year has been noted in the last 40 years. The southern sector has a low-lying coastal terrain. Cemented Pleistocene sand dunes are fronted by a lagoonal marsh zone enclosed by a narrow, sea-fronting belt of Holocene to Recent dunes that extend from Ponta de Ouro in the south through Inhaca Island to Mozambique Island. This coastal type is very vulnerable to shoreline change.

# SEYCHELLES

The Seychelles is an archipelago of islands on the Seychelles Bank in the Western Indian Ocean, lying between 4°S and 11°S. They comprise 41 granitic islands with altitudes ranging to 900 m and 74 coral islands with altitudes in the range 0–5 m above sea level. The continental shelf around the islands is extensive, over 1,374,000 km$^2$. The total population, estimated at 68,600, is concentrated on the granitic islands. Mahé has the largest population—60,400, Prasline—5600 and La Digue—1900.

## Geology and geomorphology

The continental fragment that forms the shelf of the Seychelles Bank broke from India and Africa during the opening of the Indian Ocean. The Bank has since been subjected to extensive subaerial and marine erosion as sea level has changed, leaving the resistant outcrops that form the granitic islands. Periods when sea level has been higher than that of the present day are marked by wave-cut terraces and the deposition of reefal limestone, forming raised cliff features and occurring as remnants up to 20 m above mean sea level. Beach sands have accumulated on the terraces during the last 6000 years giving the 'coastal plateau' morphology, which rises from the sea through the beach and dunal ridges and which lies 2 m above mean sea level, sloping down to near mean sea level towards the landward edge of the terrace. Around river mouths, quartz sands and clays from the interior highlands have accumulated to form relatively wide coastal lowlands. The main town, Port Victoria on Mahé, is built on such deposits. The coral islands are low-lying, rising no more than 5 m above sea level and comprise calcium carbonate sands of biogenic origin. The seaward edges of the islands have raised beach ridges that slope to the low-lying central parts of the islands, typical of atolls.

## Coastal typology and shoreline change

Except where coastal cliffs occur, reefs and partially intertidal reef platforms protect the coastal plateaux of the granitic islands from wave attack except in extreme conditions. The maintenance of the low-lying coralline islands above sea level occurs through the accumulation of biogenic calcium carbonate sands. The unconsolidated nature of the sands of the coastal plateaux and coralline islands makes these shores vulnerable to coastal erosion. Though comprehensive and systematic data on coastal erosion is lacking, scientific observation have recognised that most of Seychelles beaches are eroding. The observed beach erosion has both natural and anthropogenic contributions. However, in some locations the contribution from human activity has played the crucial role. Harbour construction in La Digue Island (Plate 19), dredging and coastal protection on Mahé and on Cerf Island and beach sand mining on most of the islands are cases in point. On Bird Island, a low-lying coralline island, a natural shift and recession of its south-western shoreline and accretion on its north-eastern shoreline has been noted. This, and the case of the Anse Kerlan (Plates 25 and 27) and Amitie beaches of Praslin Island that have delicate sand budgets, are cases of natural recession. Fortunately, while the southern outer islands are located on the fringe of the Southern Indian Ocean cyclonic belt, the granitic islands and the northern coral islands lie outside the belt.

# TANZANIA

Tanzania lies south of the equator between latitudes 1°S and 11° 45'S. The total length of the Tanzanian coastline is about 1100 km on the mainland, 430 km around Unguja and 450 km around Pemba. Numerous rivers drain through the Tanzania coastal plain. About 3.6 million people, out of a national population of more than 23 million people, live within the coastal zone.

## Geology and geomorphology

The coastal zone of the Tanzanian mainland comprises a belt of Jurassic to Recent rocks and sediments, more than 150 km wide around Dar-es-Salaam and flanked westwards by an interior plateau of metamorphic crystalline rocks. The position of the coast is strongly determined by faulting, adjustments perhaps extending into the Holocene period. The islands of Zanzibar were formed by this faulting and warping during the Eocene period. Faulting has influenced the formation of coastal terraces, with displacements of up to 75 m on raised Pleistocene reef limestones north of Dar-es-Salaam. Extensive coastal lowlands associated with present-day deltas are dominated by siliclastic sandy shorelines and lagoonal systems, associated with large beach ridge plains and mangrove forests, especially around the outflows of the Rufiji, Ruvu and Pangani rivers. The lowlands reach widths of over 16 km in the Rufiji delta. Modern reefs and associated largely intertidal reef platforms occur on the coasts of the islands of Zanzibar and at many locations along the mainland coast. Some of the beach sands of the Zanzibar islands are composed of calcium carbonate of biogenic origin.

## Coastal typology and shoreline change

Coastal erosion has affected different coastal sectors from Pangani southward through Dar-es-Salaam to Mtwara over a hundred years or so. Though the destruction of protective coral reefs as a consequence of dynamite fishing may be a contributory cause of coastal erosion, some shores with intact coral reefs are also subject to erosion. There is also evidence of erosion in the 1930s, well before the incidence of dynamite fishing of the 1980s. Erosion of Maziwi Island and Kunduchi beach (Plate 26), north of Dar-es-Salaam, are important reference sites. The erosional character varies from place to place and from season to season in response to the coastal configuration, the sedimentary regime and climatic variation. The erosion is attributed to both anthropogenic and natural causes. There are four factors considered to be possible causes for coastal erosion along the Tanzanian coastal zone, though none has been proved beyond doubt. There are some areas where neotectonics appears to be the significant cause. North of Dar-es-Salaam, there are descriptions of tectonically deformed Holocene beach ridges in an area that is subsiding differentially. Tectonic subsidence may also have occurred on the western coast of Mafia Island, where old Arab buildings now lie under several meters of water.

Coastal erosion in the Mtwara-Mikindani sector has destroyed old settlements, including historical structures and part of an old railway line. The same picture is observed in Lindi and Kilwa, where a sea wall built at Kilwa Kivinje during the German administration has been eroded. Several ancient houses, including the foundation of Songo Mnara at Kilwa Kisiwani, have also been affected. In the Dar-es-Salaam—Bagamoyo area, erosion has been reported at several localities along the coastal strip (Plates 26 and 28). The significant tourism investments of the Kawe Beach, Africana, Kunduchi, Silver Sands and Bahari Beach hotels are facing a severe erosion threat. Some hotel buildings, such as those of the Africana Hotel, have been destroyed, though the beach has since been reported as accreting. The beach in front of Silver Sands Hotel has been subject to alternating erosion and accretion, but for the last 12 years or so there has been net erosion of up to 5 m per year. In the Tanga area several localities including Mwambani, Kigombe and the Pangani delta are affected by erosion. Maziwi Island, off Pangani, is known to have disappeared in 1977–78, apparently through erosion. Several localities on the eastern and western coasts of Pemba and Unguja islands have reported cases of erosion. With the exception of Mkoani in Pemba, the erosion there is attributed to natural processes. On Unguja island, on the other hand, sand has been extracted directly from the beach for road construction, with direct negative impact on the stability of the nearby shore. Though such anthropogenic activities may have exacerbated coastal erosion, the evidence indicates that coastal erosion is not a new phenomenon on Tanzanian shorelines.

# APPENDIX 2

## Information and data or meta-data sources

### General national information sources

- Historical series (to present-day) of published and unpublished topographic maps and hydrographic charts, for information on shoreline and bathymetric change, and guidance in coastal classification.
- Survey and planning departments/offices, coastal development authorities for aerial photographs and information on land-use, land-use change and shoreline change.
- Geological survey maps and reports for information on hinterland/river basin rocks and sediments.
- Local meteorological stations/offices for records and forecasts of winds including extreme climatic events.
- Marine departments or harbour masters for tidal records and predictions.
- Agriculture and power departments, and university departments for information about river basin hydrology and sediment discharge.
- World Wide Web for information on ocean wave climates.

### IODE Data Centres

Most countries of the Western Indian Ocean region have national oceanographic data centres – NODCs. The centres are associated through a network supported by IOC known as IODE – International Oceanographic Data and Information Exchange. The centres are generally in the early stages of development, facilitated by the IOC's ODINEA project – Ocean Data and Information Network for Eastern Africa, coordinated from KMFRI (Kenya Marine and Fisheries Research Institute) in Mombasa. While their main focus is on ocean data and information, the data centres may hold information, data or meta-data that is relevant to their respective coastal areas. Contact information and holdings (to November 1999) at the data centres that may be relevant to shoreline change studies are summarised below.

### Kenya

The Kenya National Oceanographic Data Centre,
Kenya Marine and Fisheries Research Institute, Mombasa.
E-mail: kenodc@recoscix.com

Products and services available include:

- Coastal Resources Database containing over 30 GIS maps covering physical environment, biological resources, minerals, cultural and recreational aspects and socio-economy.
- Eastern Africa Atlas of Coastal Resources published through UNEP's EAF/14 project.
- Marine and Coastal Directory of Kenya.

### Madagascar

Madagascar National Oceanographic Data Centre (proposed)
Institut Halieutique et des Science Marines (IHSM), Toliara.

E-mail: ihsm@syfed.refer.mg

- Possible SPOT imagery of coastal areas.
- Meteorological data including wind parameters – data from METEO (Centre Météorologique).

Information relating to coastal areas may be available from ONE-EMC (Office National pour l'Environnment Marin et Côtier).

### Mauritius

Faculty of Science
Department of Biological Sciences
University of Mauritius (UoM)
Mauritius
E-mail: mitra@uom.ac.mu

### Mozambique

Centro Nacional de Dados Oceanográficos (CENADO),
Instituto Nacional de Hidrografia Navegação (INAHINA), Maputo.
E-mail: sitoe@inahina.uem.mz

- Meta-database including meteorological, geological, biological, tidal, fisheries and physical oceanographic meta-data.

### Seychelles

Seychelles Oceanographic Centre (SOC),
Seychelles Fishing Authority (SFA), Victoria.
E-mail: sfasez@seychelles.net and rpayet@hotmail.com

- Meta-database in course of development.

### Tanzania

Institute of Marine Sciences, University of Dar-es-Salaam,
Institute of Marine Sciences (IMS), Zanzibar.
E-mail: masalu@zims.udsm.ac.tz

- Meta-database with pointers to data and information sources
- Maps of coastal resources and Marine Protected Areas
- National archives of oceanographic data and information

In cooperation with Tanzania Coastal Management Partnership (TCMP) of the National Environment Management Council (NEMC).

## Other Databases

The **Coastal Management Database for Eastern Africa** (developed by SEACAM) can provide information on:

- Projects/programmes
- Institutions
- Research activities
- Practitioners
- ICZM documents
- Web sites of the region

The SEACAM database can be consulted at : **http://www.seacam.mz/database.htm**

## Regional Co-operation in Scientific Information Exchange in the Western Indian Ocean (RECOSCIX-WIO)

The RECOSCIX-WIO project (developed by IOC, LUC, and KMFRI) which, in the IOCINCWIO region, has developed a regional network providing bibliographic information services and producing information products such as :

- Provision of bibliographical search and document delivery services
- Development of the regional director of marine scientists (GLODIR)
- Development of a regional holfding database (WIOLIB)
- Publication of the Newsletter WINDOW (Western Indian Ocean Waters)
- Publication of WIOBASE (Integrated Western Indian Iocean data and information sources CD-ROM)

Contact:
Dr. Mika Odido
Project Coordinator RECOSCIX-WIO
P.O. Box 95832
Mombasa, Kenya
E-mail: m.odido@unesco.org

# IOC Manuals and Guides

| No. | Title |
|---|---|
| 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)* |
| 3 rev. 3 | Guide to Operational Procedures for the Collection and Exchange of JCOMM Oceanographic Data. Third Revised Edition, 1999. 38 pp. (English, French, Spanish, Russian) |
| 4 | Guide to Oceanographic and Marine Meteorological Instruments and Observing Practices. 1975. 54 pp. (English) |
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