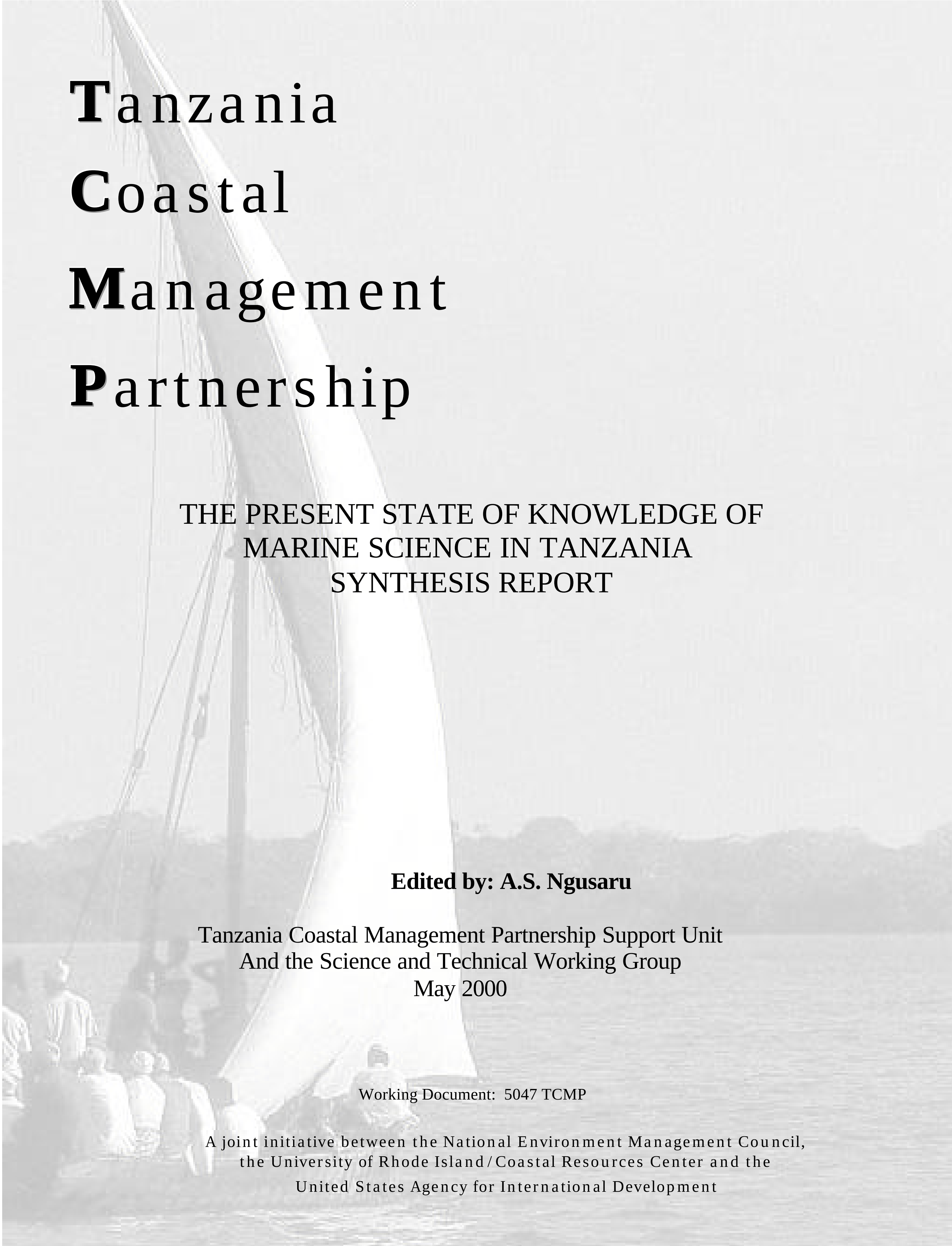

Tanzania **C**oastal **M**anagement **P**artnership

THE PRESENT STATE OF KNOWLEDGE OF MARINE SCIENCE IN TANZANIA SYNTHESIS REPORT

Edited by: A.S. Ngusaru

Tanzania Coastal Management Partnership Support Unit
And the Science and Technical Working Group

May 2000

Working Document: 5047 TCMP

A joint initiative between the National Environment Management Council,
the University of Rhode Island/Coastal Resources Center and the
United States Agency for International Development

Tanzania

Coastal

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PREFACE

The Tanzania Coastal Management Partnership (TCMP) established Science and Technical Working Group (STWG) in July 1999. TCMP is a joint initiative between the Government of Tanzania, the National Environmental Management Council, the United States Agency for International Development (USAID) and the Coastal Resources Center (CRC) of the University of Rhode Island (URI). The main goal of TCMP is to establish the foundation for effective coastal management in Tanzania. TCMP is committed to working with the existing network of Integrated Coastal Management (ICM) programme and practitioners to facilitate a participatory transparent process to unite the Government and the community, science and management, sectoral and public interests with a primary goal of conservation and development of coastal ecosystems and resource. STWG is intended to provide the primary bridge between coastal managers and the science community studying coastal marine issues at the local and national level. More specifically, STWG provides a clearinghouse mechanism for the integration of science and better coastal management. The Institute of Marine Sciences (IMS) of the University of Dar es Salaam provides the Secretariat to the STWG and the IMS Director is the Chairperson of the Group.

This document contains the synthesis reports based on the available marine science literature in six thematic areas: shoreline erosion, water quality and pollution, marine fisheries, coral reefs, mangroves and other marine living resources. These were selected as natural science topics with relevance for coastal management in Tanzania. The syntheses were prepared after careful reviewing of a comprehensive list of literature with the goal of establishing the state of existing scientific knowledge in these themes. Therefore the syntheses exhausted most of the existing literature (publications, reports, grey literature, proceedings, etc.) that were readily available in major libraries and marine research and teaching institutions in Tanzania.

The information presented is the summary of the considered papers and followed the same format for all themes.. The literature reviews work started in 1999 and involved the formation of a team of six "Theme Expert Leaders" (TELs), all members were from the University of Dar es Salaam under the coordination of the Science and Technical Working Group. The TELs worked together with their graduate students in expanding the list of scientific references and synthesizing the information. The theme expert leaders and their respective themes were, Dr. Narriman Jiddawi (marine fisheries), Dr. Salim M. Mohammed (water quality and pollution), Dr. Yunus D. Mgaya (other marine living resources), Prof. A.K Semesi (mangroves), Dr. Alfonce M. Dubi (shoreline erosion), and Dr. Greg Wagner (coral reefs). The information from all these themes were later compiled and edited by Dr. A.S Ngusaru of TCMP/University of Dar es Salaam. Dr. Jim Tobey of the Coastal Resources Center, University of Rhose Island provided the scientific advisory during the period of preparation of this document.

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Chapter 1

COASTAL EROSION

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1.0 Background information

1.1 Introduction

Communities living in coastal areas are often faced with the problem of coastal erosion. This is a condition whereby the shoreline position changes with time. Such problem of shoreline retreat, commonly known as beach or coastal erosion, often results in the loss of land area and property. The consequence is an immense pressure for the concerned society and coastal managers to undertake protective measures. In the absence of proper knowledge for the design principles of the protective structures and the consequences associated with the adopted measures, any attempt to abate erosion may end up being costly and useless. It is therefore a general recommendation that prior to any design of shoreline protection structures, geological and hydrodynamic conditions should be well studied to prevent unexpected results.

Tanzania lies south of the Equator, between latitudes $4\text{-}12^0$ S and longitudes $29\text{-}40^0$E, covering an area of approximately 945,200 km^2, of which 883,500 km^2 is land and 61,500 km^2. is covered by water. Unguja and Pemba Islands, which constitute Zanzibar, cover an area of 1,500 km^2 and 900 km^2 respectively. The total population of Tanzania, according to 1988 census, is about 24 million, of which approximately 3.6 million people live within the coastal zone (Bureau of Statistics, 1988).

The coastal zone is defined as that area surrounding the interface between land and sea. It typically includes coastal plains, river deltas, wetlands, lagoons, beaches, dunes, mangroves, reefs and other coastal features, as well as the continental shelf. The coastal zone of Tanzania includes a land area of approximately 30,000 km^2, three major islands, viz. Unguja, Pemba and Mafia and numerous small but beautiful islands and reefs such as Latham, Tutia, Songosongo, Mbudya, Pangavini, Bongoyo, Inner and Outer Nyakatombe, Kendwa, Inner and Outer Sinda. The Tanzania coastal zone is characterised by coastal forests, thickets, mudflats, seagrass beds, coral reefs and wetlands.

Numerous rivers entering the Indian Ocean drain the coastal plain. Some of the major rivers include Pangani Wami, Ruvu, Rufiji, Matandu, Mbwemkuru and Ruvuma. The width of the coastal zone varies between 20-70 Km, while the width of the continental shelf ranges between 4-35 nautical miles with a total area of about 17,500 km^2. The total length of the Tanzania coastline is about 800 km extending from the border with Kenya in the north to Ruvuma River in the south on the mainland, 430 km around Unguja and 450 km around Pemba.

The East African coastal waters are subjected to the East African Coastal Current (EACC) with two alternating seasons; the southern and northern monsoons (Newell, 1957). The southern monsoons, which begin in April and end in October/November, are usually strong and are predominantly southerly. The northern monsoons, which begin in November and end in March, are lighter and are predominantly northerly (Figures 1a and 1b). Dubi (1998) analysed 25-year wind data collected between 1972-1996 at Tanga, Dar es Salaam, Zanzibar and Mtwara and found the 50-year return wind speeds to be 26 knots for Tanga, 27 knots for Dar es Salaam, 29 knots for Zanzibar and 36 knots for Mtwara.

Newell (1957) describes the East African Coastal Current as a current that moves northward throughout the year, but changes speeds during the two monsoons. During the southerly monsoons, it moves with a speed of about 4 knots after being accelerated by the trade winds. The current is pressed in towards the western side of the ocean. During the northerly monsoons, the current is retarded by the northerly winds along the coast. From the equator northwards, it is reversed to flow in the southerly direction. The reversed current meets the much-decelerated EACC at about 1^0S, where both are deflected out to the sea forming the Equatorial Counter Current (Figures 1a and 1b). About 2/3 of the coastline has fringing reefs, often close to the shoreline and broken only by river outlets like the Rufiji delta. Mangrove forests are found along sheltered parts of the coastline, in bays and estuaries, protecting the shore and coastal low-lying areas from storm surges, thereby giving a natural barrier against eminent erosion. Despite of the protection by fringing reefs and mangrove forests, the coastline has been eroding at various rates in different areas. Examples of affected areas include Mtwara, Kilwa, Dar es Salaam and Tanga in the mainland and Maruhubi, Nungwi, Paje and Jambiani in Zanzibar. Given the potential socio-economic impacts of coastal erosion, stakeholders have adopted defensive measures that seek to maintain shorelines in their present position. This is done either through building protective walls or strengthening of the natural protective features. These measures have, in most cases, been designed without due consideration of sound scientific knowledge, which raises a serious concern for coastal planners.

1.2 Basic causes of coastal erosion

In general, the boundary between land and oceanic water often shift its position with time as a result of natural and man-induced processes. When the shift advances seaward, it is refereed to as accretion and when it advances landward, it is refereed to as erosion. Since shoreline advances can be short- or long-term, it is important to determine the nature of the cause before attempting any protective measure. Erosion is a result of several factors that can act independently or in conjunction. These factors can be divided into two categories; natural causes and human induced causes (e.g. non-sustainable developments and resource use).

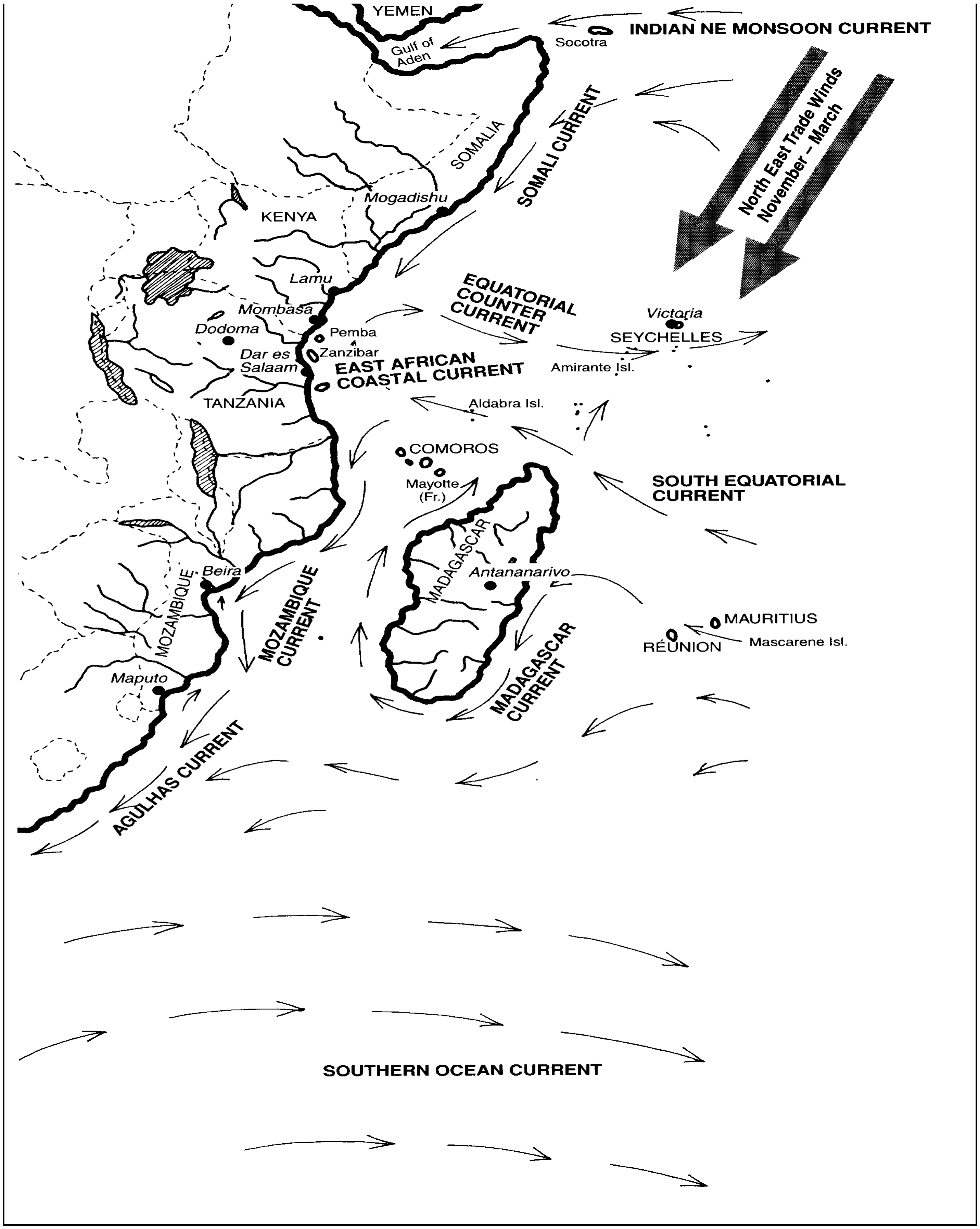

Figure 1a. Northeast trade wind (From Linden and Lundin, (eds.), 1996)

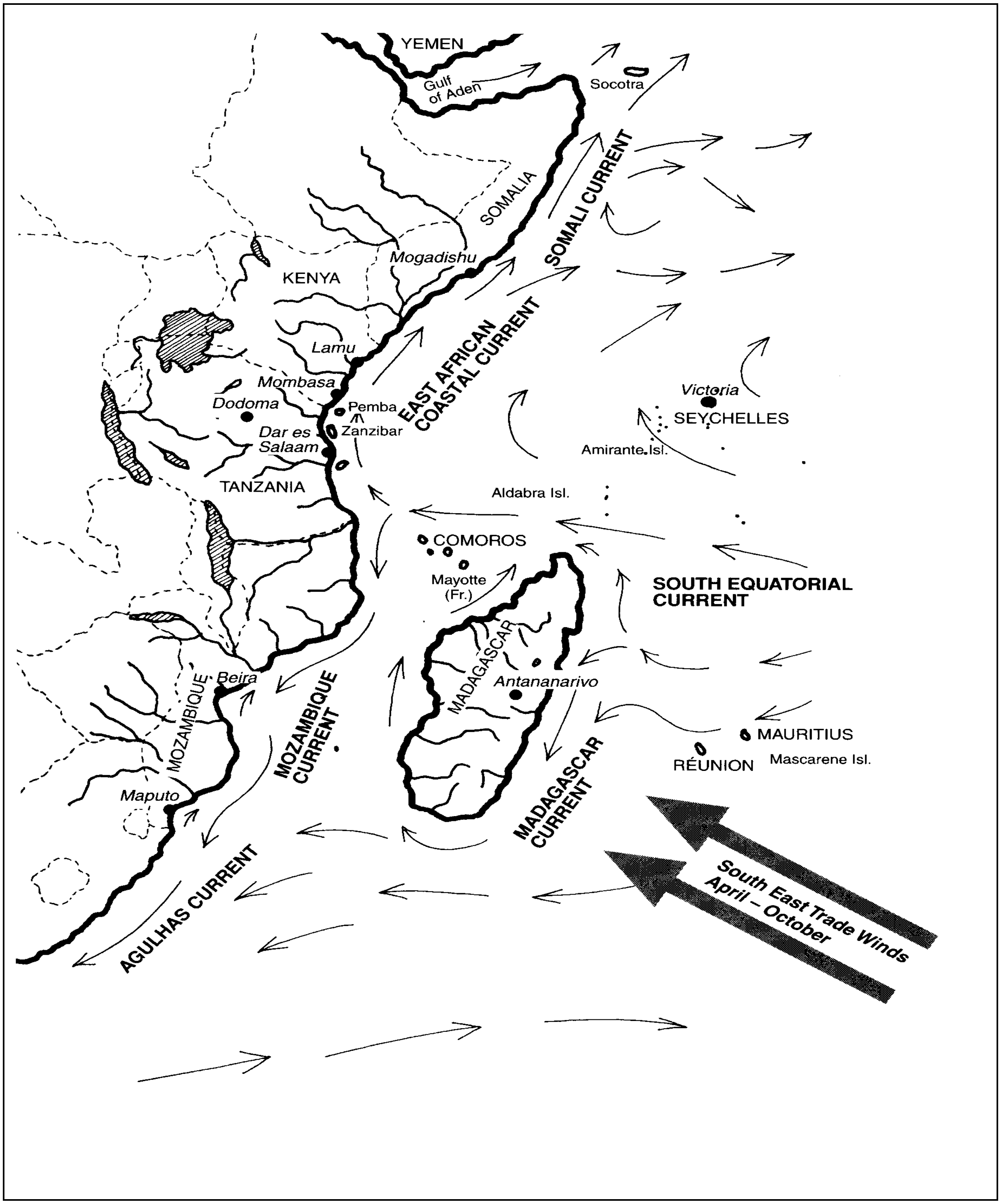

Figure 1b. Southeast trade winds (From Linden and Lundin, 1996)

1.2.1 Physical conditions and forces of nature

Physical Conditions

Geology, Geomorphology and Topography: There is a complex interaction between the various elements defining the coastal environment. Coastal physical features such as topography and bathymetry, in conjunction with geological properties of the nearshore sediments result in different erosion and accretion patterns. The near-shore bathymetry and topography determine the way in which waves and currents approach the shoreline. The response of the shoreline will in turn depend on the geological properties of the beach material.

Hydrographic conditions: This includes bathymetry, ocean and physical properties of seawater (salinity and temperature). For coral reefs and atolls, increasing seawater temperature could be important because this could adversely affect the growth potential of the coral, which will in turn reduce the protective ability from the wave force and processes associated with sea level rise. Since the EACC flows almost parallel to the coastline, a slope perpendicular to the direction of the current will be created. Due to the Coriolis effect, water mass will be deflected to left in the southern hemisphere, when looking in the direction of the current (Lisitzin, 1974). As a result of this deflection and considering that the current passes in the Zanzibar and Pemba channels, locations on Mainland Tanzania will experience sea level rise while those on Zanzibar will experience a fall in sea level. This phenomenon, though theoretically possible, has not yet been investigated in Tanzania coastal waters and can have significant practical implications. In summary, the information on spatial and temporal variations of hydrographic conditions of the coastal area of Tanzania is necessary for a proper evaluation of its vulnerability to erosion.

Forces of nature

These are shoreline-induced changes that occur as a result of the response of the shoreline to the forces of nature. The forces include changes in the *climate, hydrology* and *coastal processes.* For coastal areas, it is always worthwhile to consider climatic changes over a long period of time to avoid the disastrous century events. Climate-induced causes include changes in meteorological conditions (winds intensity and direction, rainfall, barometric pressure and storms), El-Nino related changes and accelerated sea level rise (Klein and Nicolls, 1998) is just an example of what can happen due to these type of changes. Hydrologic changes include variability in water discharge and sediment transport. these can have a myriad of effect on the nearshore zone. The nearshore waves and currents in essence control the coastal processes.

Climate change

The wind has multiple effects on ocean circulation, waves and sea level. It is important in the generation of wind-induced currents, waves, wave-induced currents, water levels and the translation of coastal dunes. Wind determines the predominant or resultant wave direction. In near-shore zones, waves and currents play a major role in sediment movement and the resulting natural beach geometry. The wave climate at any given location depends on the wind speed, fetch and duration. It is wind that determines the wave height, wave period and the predominant wave direction. Steepness and direction of the incident waves are the major parameter in the generation of longshore currents and corresponding longshore drift. When wind blows over the sea surface, it induces a steady movement of the upper ocean. This movement is generally known as wind-induced current, which flows in the same general direction as the wind. Surface currents are typically 3 % of the wind speed. So, 10 m/s wind is likely to generate surface flows of up to 0.3 m/s (Bowden, 1983). This type of water movement often influences the drifting of floating matter such as oil slick, buoys and sewage solids.

Tangential stress on surface water leads to accumulation (if winds blow towards land) or depletion (if winds blow away from the coast) of water and the development of surface slopes. The surface slopes in turn create horizontal pressure gradients that drives local currents. The effect of wind shear stress associated with strong winds and storms is very important when considering water levels and the associated shoreline changes. In shallow seas, storm surges due to wind shear stress can be particularly dangerous. Since wind set-up is directly proportional to the square of the wind speed and inversely proportional to water depth (Silvester, 1974). A drop in barometric pressure often results in a temporary increase in the water level. The piling of water at the coast as a result of this process is known as wave set-up. The steep waves generated by coastal storms can transport sand offshore with a temporary storage in sandbars or shoals. The sediment material deposited offshore in this way may later be recovered by the action of longer period processes, but in most cases the material may be lost permanently.

The tangential wind shear stress also leads into the generation of waves. The growth of wind-generated waves is not well understood. During the Second World War, the forecasting of wave conditions on beaches was very important for planning the operations. It was at this time when Sverdrup and Munk derived an empirical method for predicting wave height and for a given wind speed, duration and fetch. Later, with increased number of observations, Bretschneider improved the method, which became to be known as the Sverdrup-Munk-Bretschneider (SMB) method. Under certain assumptions, simplified wave growth formulas have been derived to give quick estimates of wave parameters in deep and shallow water. Simplified versions of the wave growth are found in *Shore Protection Manual* (SPM) of 1984 and Vincent (1984). For proper evaluation of wind-generated wave conditions, it is necessary to collect information on wind speed (intensity), direction and fetch. This information is useful for hindcasting and statistical analysis of extreme wind events.

Sea level rise: Over the last 100 years, the global sea level rose by 1.0-2.5 mm/yr (Warrick et al., 1996). Estimates of future sea level rise as presented in the IPCC Second Assessment Report range from 20-86 cm for the year 2100. This effect is about 2-5 times the rate experienced over the last century. When it comes to assessing the impact of sea level rise, it is the local change in relative sea level that matters, not the global average. Relative or observed sea level is the level of the sea relative to the land. Regional sea level changes are highly uncertain and could therefore best be considered zero until more concrete evidence emerges (Warrick et al., 1996). Values for vertical land movements can be assessed from a number of different sources, including geological analysis, geodetic surveys and analysis of long-term tide-gauge records.

A natural coastal system that experiences sea level rise can be affected in several ways. From an erosion perspective, the most important physical effects are: *A slow, long-term recession of the shoreline:* This is due to direct flooding and partly to profile adjustment to the higher level. Bruun (1962) suggested that a 1-cm rise in sea level would result in a 1-m shoreline retreat. Representative recession rates for exposed shores like those of the Atlantic, the Pacific and the Indian Oceans were found to be

Sea level rise per year (cm)	**Shoreline recession per year (m)**
1	1-1.5
2	2-3
3	3-4.5
10	10-15

Increasing inundation and flood-frequency probability: Low lying coastal areas will experience the risk of flooding. The degree to which a coastal land is at risk depends on morphological and meteorological factors, including coastal slope, wind and wave characteristics. Information on these factors can be used to plot a flood-frequency probability curve, from which the design water levels can be plotted on a topographic map. The design water levels are contour lines that indicate with which probability a particular area could be flooded (Hoozemans et al., 1993). Other effects of sea level rise, which are not directly related to erosion are rising water tables, salt water intrusion and biological effects. The potential socio-economic impact of sea level rise includes: direct loss of economic, ecological, cultural and subsidence values through the loss of land, infrastructure and coastal habitats, increased flood risk of people, land and infrastructure, and impacts related to change in water management, salinity and biological effects.

Hydrology

Rainfall: Rainfall in Tanzania comes in two regimes (Mwandosya et al., 1998). One sector of the country receives bimodal rainfall normally referred as long rains or *Masika* during the months of March, April and May and short rains or *Vuli* during the months of October, November and December. The areas which receive bimodal rainfall are confined to the north eastern parts of the country comprising of Arusha, Moshi, Same; the north western areas including Lake Victoria basin and the northern part of the coastal belt comprising of Tanga, Morogoro and Dar es Salaam. The other rainfall regime has a unimodal pattern and covers the southern, central, western and south-eastern parts of the country. These areas receive most of their seasonal rainfall during the months of December, January, February, March and April. Changes in global weather patterns can result in the variability of water discharge and sediment supply to the coastal zone. Droughts will result in the reduction of sediment supply to the coastal zone through rivers. Information on both changing rainfall pattern and seawater temperature should therefore be obtained from meteorological stations and also from general circulation models (Klein and Nicolls, 1999) in order to design warming and forecasting systems.

Coastal processes

When waves reach the coast, they generate a variety of currents in the nearshore zone. Wave-generated currents tend to dominate water movements in the nearshore zone and therefore are important in the dispersal of sediments, pollutants and biological nutrients. These currents can also carry sediments if their speed reach the threshold speed at which sediments on the seabed can be moved. If the quantity of sediment carried away by such currents exceeds the amount naturally supplied to the beach, erosion will occur. In addition to dispersing sediments, these currents interact directly with the wave orbital motion to influence the resultant direction of the movement of beach sediments, and as a result act to mould the nearshore topography. The beach topography in turn becomes an important factor in controlling the current patterns.

1.2.2 Man-induced factors

The potential impacts of climate change by itself may not always be the largest threat to coastal systems. However, in conjunction with other stresses, such as the actions of man, they can become a serious problem for coastal communities. The areas where the adaptive capacity of natural coastal systems has been reduced are particularly in greater danger (Bijlsma et al., 1996). Factors that interact with climate change are non-sustainable resource use and developments that adversely affect the natural capability of these systems to adapt to climate change. Following Goldberg, 1994, these factors include: over-exploitation of resources (sand and coral mining, mangrove cutting, groundwater and hydrocarbons); pollution; decreasing freshwater availability; sediment starvation and urbanisation (dam construction, construction on beaches, human settlements. Existing policies and practices can also increase the coastal zone’s vulnerability to climate change. These practices include: investments in potentially hazardous zones; inappropriate coastal defence schemes and coastal habitat conversions

1.3 Type of data/information gathered and time of collection

Studies related to coastal erosion are expected to contain information on the status and causes of erosion. Once the status and causes are known, it will be easy for scientists, engineers and managers to take appropriate measure for the control and sustainable management of the coastal zone. The studies that were considered in this review are grouped following the logical sequence in the background information on causes of coastal erosion, namely; Geology and geomorphology of the coastal zone. Hydrology (river discharge, sediment transport and estuarine hydrodynamics). Climate change (winds, rainfall, atmospheric pressure, sea-level rise). Hydrography (bathymetry, ocean circulation, temperature, salinity, density and general oceanography). Coastal Processes (Near-shore Waves, Currents, Sediment transport). Resource utilisation (non-sustainable resource use, construction of dams, building on beaches, coastal protection, mangrove cutting and coral/sand mining). Some studies have crossed borders and touched some aspects of another groups.

Depending on the research methodology, most of the studies have been baseline and applied studies, while a few of them fall under experimental and review studies. Figure 2 shows the frequency of articles falling under the above-discussed groups.

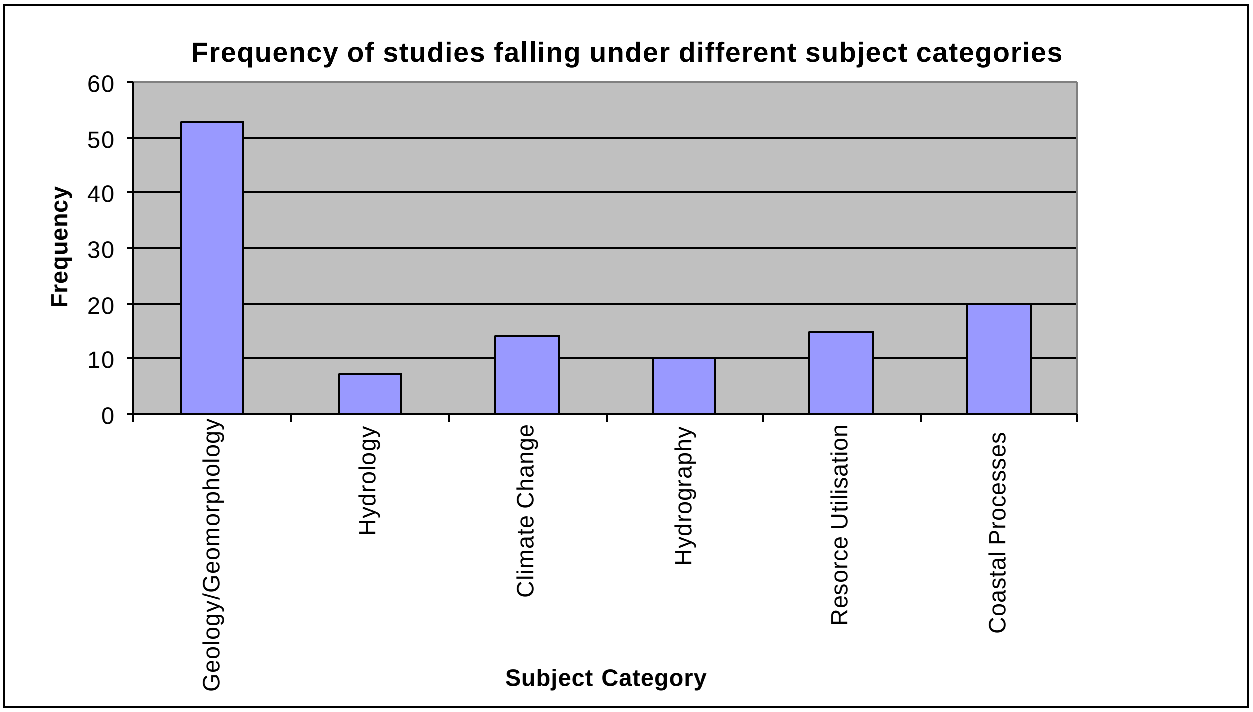

Figure 2. Frequency of studies falling under different subject category

1.3.1 Baseline studies

A good number of studies in Geology and Geomorphology of the coastal zone of Tanzania have been baseline. Some of these studies are focussed on the origin and manner of preservation of beach reaches of Mtoni terrace extending from Dar es Salaam to Tanga (Aleaxander, 1966, 1968, 1969), geomorphological development (Cilek, 1971, 1976), seasonal variation in beach configuration (Hemed, 1987), geology and tectonics (Mruma, 1996)), sediment distribution and transport (Shaghude and Wannas (1995), Ngusaru (1995), coral reefs of Dar es Salaam (Ortman, 1892).

On Climate Change, some studies have dealt with general climatological statistics for example E.A.M.D (1964) and the frequencies of surface wind speeds and direction for Tanganyika and Zanzibar (E.A.M.D., 1964). Others for example, Lwambuka (1992) and Dubi (1998) evaluated wind data records to predict extreme wind speeds in Tanzania. Mwandosya et al. (1998) assessed the vulnerability and adaptation to climate change impacts in Tanzania by applying General Circulation Models (GCMs) for various scenarios of climate change.

One of the pioneering studies in hydrography of the East African coastal waters is that of Newell (1957). Thereafter, several years passed before the hydrography of the East African coastal waters were studied again. Leetmaa and Truesdale (1972) studied the change in currents in the East African coastal waters with the onset of the Southeast monsoon and Harvey (1977) studied some aspects of the hydrography of the waters off Tanzania. Very few studies have dealt with the hydrodynamics of deltas and estuarines (Hepworth, 1993). Nearshore bathymetry has been studied for Zanzibar (Shaghude, 1995) and for Kunduchi (Dubi and Nyandwi, 1999). No publications were available on nearshore bathymetry of other parts of the coastal waters of Tanzania.

Baseline studies in resource utilisation include those of Mwaiseje (1973), Francis et al. (1997), Semesi at al. (1998) and Dubi and Nyandwi (1999). These studies provide information on some aspects of sandy/muddy intertidal zone, coastal resources utilisation, conservation issues and coastal protection methods and management in Dar es Salaam area. Baseline studies in Coastal Processes have included those of Mushala (1978), who investigated the factors that influenced coastal erosion, sediment transport and deposition along Kunduchi Beach Dar es Salaam. Other studies were aimed at getting baseline data for the mitigation and control of coastal erosion (Dubi and Nyandwi, 1999), causes of the disappearance of small islands like Maziwi Island in Tanga (Fay, 1992). Baseline studies in hydrology began in the 1960's and continued in the 1970's with the search of suitable sites for hydropower stations. These included studies by Otnes (1960) on general hydrology and water resources in the Rufiji basin. Temple and Sundborg (1973) studied discharge and sediment load analysis for the Rufiji river and Page (1994) studied the hydrodynamics of the delta. Two mathematical models for the Rufiji river are presented by Shayo (1979) on the time-dependent river discharge and Chen and Dyke (1996) on the multivariable time series sediment dynamics and its classification.

1.3.2 Visual observations

Visual observations have mainly been in geology and geomorphology studies. These include Alexander (1966, 1968 and 1969) who gave a descriptive method for shoreline classification and mapping of the Northeast coast of Tanganyika. Alexander also described the marine terraces and beach ridges in the northeastern coast of Tanganyika. Using visual observation for some aspects Cilek (1971, 1976) described geomorphological development of the seashore in the vicinity of Dar es Salaam. He also described the development of beach mineral deposits in Tanzanian. Using partly the method of visual observation, Kaaya (1982) studied the influence of geological structure on submarine topography of the northern part of Zanzibar Channel. Lwiza (1994) used visual observations in investigating the patterns of winds, currents, waves and tides in combination with drogues and wave staff. Most of these studies are considered to be baseline.

1.3.3 Experimental studies

Very few experimental studies have been undertaken with relation to coastal erosion in Tanzania. The only study in ecology and coastal zone management with some aspects of sediment transport and sedimentation is that of Nzali et al. (1998). The experiment in this study included determination of sedimentation rates at the Taa reef in Tanga. In coastal processes and engineering, Edet (1991) introduced an experimental groyne system using standard principles of groyne design.

1.3.4 Applied studies

Applied studies are those, which uses various methods for establishing the status of parameters and conditions of the coastal zone. For example, Kaaya and Boenigk (1986) analysed aerial photos to study geomorphology of the Pleistocene Tanga terrace, north of Dar es Salaam using stereoscopes. In this study, grain size analysis was conducted using standard methods, such as those of Muller et al. (1967), Folk (1974) and Carver (1971). Heavy metals were separated from light minerals using bromoform following the method of Carver (1971). Th/U dating was carried out in the laboratory. Similarly, applied studies in climate change include those of along the coast of Tanzania, Lwambuka (1992) on the evaluation of wind data record to predict extreme wind speeds in Tanzania, Dubi (1998) on evaluation of extreme wind speeds in relation to the design of coastal structures. In hydrology, applied studies have dealt with multivariable time series of river discharge and sediment dynamics in the Rufiji delta (Chen, 1996 and Shayo, 1979), discharge and sediment load analysis for the Rufiji river (Temple and Sundborg, 1973). On coastal processes, Dubi and Nyandwi (1999) carried out a multidisplinary study aimed at mitigation and control of coastal erosion at Kunduchi beach north of Dar es Salaam. Likewise, Edet (1991) studied coastal processes such as direction and height of breaking waves, currents and sediment transport.

1.3.5 Review studies

Several review studies are found in the areas of geology and geomorphology. These include summaries of the geology of Tanganyika, e.g. Harris (1961) and Quennel et al. (1956 & 1960); geomorphology and sources of beach sediment, e.g. Arthurton (1992, 1996); reviews on the coastal erosion problem in Tanzania, e.g. Kaaya (1996), Mruma (1996). There are also a few review studies on climate change. These include Thompson (1965) on the weather of East Africa. Review studies in coastal processes and engineering include those of Dubi (1998) on ocean wave measurement systems and analysis for climate evaluation, Bryceson and Stoemer (1980) on recommendations for beach erosion control at Silversands Hotel. Schiller and Bryceson also reviewed the problem of beach erosion in the Dar es Salaam area. On resource utilisation, Linden and Lundin (1996) gave a review of various issues including the status and underlying causes of coastal and marine resources degradation. Recommendations for control of coastal erosion in Tanzania were also given. Pattantyus (1988) reviewed the problem of beach erosion in the northern parts of Dar es Salaam area.

1.4 RESEARCH METHODOLOGY

Research methodology has been varied depending on the field of study. Field research methods also depend on the parameters being investigated, instrumentation and data analysis tools.

1.4.1 Sampling aspects/parameters

In geology and geomorphology, Cilek (1976) investigated heavy mineral content in Tanzania beach sand deposits. Since beaches are affected by hydrodynamic factors (waves, tides and currents), heavy mineral content on beaches is depends on the coastal processes. Cooke (1974) studied geomorphic features of the Tanga coastal zone and suggested a scheme of alternating sea levels phases in the geologic past. Kaaya and Boenigk (1986) also studied modes of sedimentation in relation to terrace formation and sea level rise along the Tanzania coastline and only recently, Shaghude and Wannas (1995) put together the sediment distribution and transport in the Zanzibar channel.

In Climate Change, Dubi (1998) and Lwambuka (1992) evaluated extreme wind speeds and return periods from available wind data. Nieuwolt (1973) investigated the general circulation of the land and sea breezes along the Tanzanian East Coast. He also studied the effects of these winds, especially the sea breeze on the physiological temperature conditions near the coast. Also, Mwandosya et al. (1998) studied the impact of climate change on the coastal zone due to the doubling of CO_2 and a sea level rise of 0.5m and 1.0m. In Hydrology, Shayo (1979) studied the best time-discharge relationship of the dam in connection with flood control, agricultural and hydropower production on the Rufiji river. Temple and Sundborg (1972) studied the water and sediment discharge characteristics of the river and their influence on the morphology and soils of the lower flood plain and delta. In Hydrography, sampling parameters have included temperature-salinity relationship and distributions, seasonal variations of thermal characteristics and currents in the Zanzibar Channel (Harvey, 1977 and Newell, 1957, 1959). Nearshore bathymetry has been studied by Shaghude (1996) and Dubi and Nyandwi, 1999. On resource utilisation, Mwaiseje (1973) examined ecological parameters such as times of low and high tides, beach profiles, substrate particle sizes, burrowing forms, flora and fauna; and pattern distribution of animals and plants in Dar es Salaam beaches. Sedimentation rates on corals have been studied by Nzali et al. (1998) while Semesi et al. (1998) studied mangrove and fisheries resources, salt production and tourism. In Coastal Processes, investigated parameters include currents, waves, bathymetry, grain size distribution and profiles (Dubi and Nyandwi, 1999; Hemed, 1987; Lwiza, 1987; Fay, 1992), ocean wave measurement systems and wave parameters (Dubi, 1998), sediment transport and optimal design (Edet, 1991), Mushala (1978) and Shufaa and Betlem (1996).

1.4.2 Instrumentation and techniques of sampling and data collection

On geology and geomorphology, instrumentation and sources of information have included drills (Cilek, 1976), admiralty charts and survey levels (Cooke, 1974), aerial photographs (Mushala,1978, Shufaa and Betlem, 1996), topographic maps, stereoscopes, sieves, diffractometer and bromoform (Kaaya and Boenigk, 1986). Techniques of sampling have included air survey, drilling and shallow pits (Cilek, 1976). On climate change, instrumentation has included rotating cup anemometers for measuring wind speeds; theodolite and aerial photos (Pethick and Spencer, 1990), General Circulation Models (Mwandosya et al., 1998). On hydrology, Temple and Sundborg (1973) used data collected using gauges and sediment samplers. Shayo (1979) and Chen (1996) mathematical modelling techniques to study river water discharge and sediment load prediction. On resource utilisation studies, Mwaiseje (1973) used automatic level, graduated pole and improvised syringe to study ecological parameters. Nzali et al. (1998) used terracota tiles, steel racks, thermometer, secchi disc, sediment traps and dissecting microscope to study coral recruitment and sedimentation rates. On coastal processes, instrumentation included self recording current meters (RCMs), wave gauges, surveyor's level, echosounders, and global positioning systems (Dubi and Nyandwi, 1999). Earlier works used drogues, wave staffs and visual observation (Lwiza, 1987).

1.4.3 Data analysis methods and procedure

Methods of data analysis varied much the same as the data collection methods. In geology and geomorphology studies, Cilek (1976) used laboratory methods for the separation of heavy minerals from light minerals. The minerals of heavy fraction were divided into five groups depending upon their electrical and magnetic properties. Kaaya and Boenigk (1986) dried and later sieved clay-free loose sands, while clayey sands were wet sieved using a whole phi interval from –2 phi to 4 phi. Graphical methods were used to present the cumulative weight percentages. Heavy minerals were separated from light minerals using bromoform. Clay minerals were analysed using a diffractometer. In Hydrology studies, Temple and Sundborg (1972) used graphical methods and hypsographic analysis methods to present data. In Climate Change studies, probability distribution functions have been used to evaluate extreme wind speeds and return wind speeds (Dubi, 1998 and Lwambuka, 1992).

In Hydrography studies graphical methods have mostly been used while in Coastal Processes, computer and mathematical methods have been used (e.g. Dubi and Nyandwi, 1999). In Resource Utilisation, laboratory and graphical methods have been used to find ecological parameters. Table 2 shows some of the research methodologies applied in different studies.

1.5 Quality, usefulness and reliability of data/information

The quality, usefulness and reliability of data collected during research depend on comparability of the research methods, temporal variation (sampling frequency and duration) of the investigated parameter, the age of the information and most of all the capability of scientists.

Table 1.1: Summary

	Sampling aspects/parameters	**Instrumentation/ Source**	**Data analysis methods and procedure**
Cilek (1976)	Heavy mineral content	Air survey, shallow pits, drills	high tension and magnetic separation of different heavy minerals
Coke (1974)	Geomorphic features in relation to sea level rise	Drills, admiralty charts, survey level	Cross-section graphs, sediment analysis
Dubi (1998)	Extreme wind speeds, return wind speeds	Rotating cup anemometer	Computer program, statistical methods
Dubi and Nyandwi (1999)	Currents, waves, bathymetry, winds, grain-size distribution	Current meter (RCM9), wave (Pressure) gauges, sieves, surveyor's level, echo-sounder, GPS	Computer methods, sieving, graphs, spectral methods
Edet (1991)	Wind, waves, currents, sediment transport, design parameters	Wind meter, drogues, wave staff, visual observation	Mathematical
Harvey (1977)	Temperature, salinity relationship, Currents and other hydrographic conditions	Data from UK ships, drogues, reversing thermometers, secchi disc, T-S bridge, cup anemometer	Graphs
Kaaya and Boenigk (1986)	Mode of sedimentation in relation to terrace formation	Stereoscope, topographic maps, sieves, diffractometer, Th/U dating,	Graphical, bivariate diagrams
Mwaipopo (1984)	Surface Ekman layer, interior flow, wind stress	Mathematical modelling	Computer methods
Mwaiseje (1973)	Ecological paramaters	Automatic level, graduated pole, smell & colour, improvised syringe	Laboratory methods
Nzali et al. (1998)	Coral cover & community, coral recruitment, sedimentation rates	Line-intercept, terracota tiles, steel racks, Thermometer, secchi disc, sediment traps, dissecting microscope	Tabulation, laboratory methods
Semesi et al. (1998)	Mangrove resources, salt production, fisheries resources, tourism	District data, interviews, field surveys, logbooks	Graphs, tables
Shayo (1979)	Time-discharge relationship	Mathematical modelling	Mathematical and computer methods
Temple and Sundborg (1972)	Water, sediment discharge	Gauges, sediment samplers	Graphs, hydrographic and spectral methods

1.5.1 Comparability of research methods

Different research scientists have used different methodologies depending on the parameters being investigated. Most researchers have used comparable methods. However, there are some methods that are not so comparable. For example, in measuring waves, Lwiza(1987) and Edet (1991) used graduated wave staffs. In cases like these, the results are rather subjective and hard to compare simply because the wave heights are observed visually, a method that has high degree of uncertainty.

1.5.2 Sampling frequency and duration of studies

Sampling frequency has been varied depending on the type of study. In some studies, like those applying General Circulation Models, Computer and Mathematical are used. In this case there is no sampling frequency involved. The same is true for the review studies. In some studies sampling frequency is not stated completely (e.g. Edet, 1991). The sampling frequency available in many studies varied from half hourly measurements (e.g. Hravey, 1977) to monthly measurements (e.g. Mwaiseje, 1973). Others followed monsoon seasons (e.g. Newell, 1957, 1959; Dubi and Nyandwi, 1999).

The duration of many studies has not been long enough to warrant long-term evaluations. For example, in the investigation of heavy mineral content of Tanzanian beach sands, Cilek (1976) took approximately one year to conduct that study. But since heavy mineral composition is dependent on hydrodynamic conditions, the study is only good for baseline purposes. The situation could change after say, 20 years. This is the same situation for most other studies.

1.5.3 Capability of researchers

Highly qualified scientists have carried out most of the studies. Even in cases where research has been done by students, supervision has been done by capable scientists and most of works have led to postgraduate degrees (e.g. Edet, 1991; Nzali, 1998).

1.5.4 Age of information

Information, which is older than 20 years, is considered old and its reliability is questionable. An exception to this fact is of course on geological studies. An overview of the status of some selected studies is summarised in Table 1.2.

Table 1.2: Example of the sampling frequency and duration of some studies, where (P) indicates published articles and (G) is grey literature. The age of information is classified as either old or recent.

Article	Duration of studies	Sampling frequency	Publication	Age of information
Cilek (1976)	1 year	-	P	Old
Cooke (1974).	1 year	-	P	Old
Dubi (1998)	25 years	Monthly maximum values	P	Recent
Dubi and Nyandwi (1999)	1 year	*Tides, Currents*: monthly. *Waves*: every two-month. *Profiles and Sediment*: neap and spring tides	P	Recent
Edet (1991)	2 years	-	MSc. Thesis	Recent
Harvey (1977)	20 years offshore data 4 years Zanzibar Channel 3 months at Kunduchi	Half hourly for a period of 25 hours Positions of drogues taken at 45 min. intervals. Temperature, turbidity and water sample taken at 2 hours interval	P	Old
Kaaya and Boenigk (1986)	1 year	-	P	Old
Mwaipopo (1984)	2 years	Computer sampling	P	Old
Mwaiseje (1973)	1 year	Monthly	P	Old
Nieuwolt (1973)	4 years	3-hourly intervals	P	Old
Nzali et al. (1998)	1 year	Every two-months for recruitment rates four times a month for temperature and transparency once every 4 – 5 days for sedimentation rates	P	Recent
Shayo (1979)	-	Computer sampling	P	Old
Temple and Sundborg (1972)	7 years data	Gage (continuous?) sampling	P	Old

1.6 Main findings/observations

1.6.1 Physical conditions and forces of nature

Physical conditions

Geology and geomorphology of coastal Tanzania

The coastal setting of Tanzania is defined as a narrow coastal belt (of Jurassic to recent age) and an interior plateau that extends from southern Kenya. It increases in width from 17 km at the Kenyan border to over 150 km in the vicinity of Dar es Salaam area (Kapilima, 1984; Kent, 1971). The shoreline is strongly controlled by faulting and sea level fluctuation. Tectonic adjustments appear to have extended through into the Holocene (King, 1962; Kent et al, 1971; Alexander, 1969). The faulting events (King, 1962) mark the major coastal boundaries between the metamorphic crystalline rocks of the interior and the sedimentary rocks of the coastal basin (Alexander, 1969; Kent, 1971). Faulting and warping in the Eocene formed the islands of Unguja, Pemba and Mafia. The faulting and sea level fluctuation have influenced the formation of the coastal marine terraces (Alexander, 1969). The coastal plain of Tanzania has experienced vertical displacements of up to 75m on reefs North of Dar es Salaam in post Pleistocene times. The general trend of the coastal plain follows that of the older faulting trends. Extensive coastal lowlands associated with deltas have resulted in the development of low lying coastal terrain dominated by sandy shorelines and lagoon systems associated with large beach ridge plains, especially in front of the Rufiji, Ruvu and Pangani rivers. They reach a width of over 16 km. in the Rufiji Delta. Modern reefs occur on the coasts of Zanzibar, Pemba and in discontinuous location all along the coast of Tanzania in the southern sector.

Sediment types vary greatly, from the clay bound sands and gravel probably of Mio-Pliocene age to the far more unconsolidated suite of recent times. The unconsolidated suites include the river alluvium and terraces; lagoon sand, clays and silts; beach ridge sands, sand dunes and beach deposits; and some superficial white bluff sands all belonging to the Holocene. The types of shoreline with unconsolidated suites tend to suffer most from erosion. However, the extent of erosion varies from place to place and from season to season. Beach sands vary from silicilastic in river dominated areas to predominantly carbonate sands in Unguja and Pemba Islands.

Temple (1970) describes the Dar es Salaam coastline as being characterised by an invariably developed fringing reef. Kunduchi lies in an area where the continental shelf width increases rapidly seawards to include the Islands of Unguja and Mafia. At Ras Ndege, approximately 20 kilometres south of Dar es Salaam, the 200 metre contour, which indicates the approximate edge of the continental shelf, lies only 3 kilometres offshore, while at Kunduchi the 200 metre contour lies 16 kilometres away and therefore the intermediate area consists of relatively shallow water. The Zanzibar Channel, which separates Zanzibar from the Mainland, has depths hardly exceeding 60 metres at the northern and southern entrances, while the mean depth of the Channel is 20 metres.

Available records (Grifiths, 1987; Alexander, 1966 and 1969; Fay, 1992 and Stuhlman, 1894) indicate that coastal erosion has affected different coastal sectors extending from Pangani in the north southward through Dar es Salaam to Mtwara in the south since the early part of this century. Maziwi Island and Kunduchi beach are important recent reference cases. The erosion character, however, varies from place to place and from the season to season in response to the coastal configuration, sedimentary regime and hydrodynamic conditions.

Hydrographic conditions

Shelf features, particularly submarine depressions, banks and reefs are important features that influence coastal processes. Information on shelf features can be obtained from Admiralty Charts. However, detailed information for accurate description of the bathymetry and topographic forms of the nearshore waters and beaches along the coastline of Tanzania must be obtained by conducting collecting echosound data and routing nearshore profiles.

From the Admiralty Charts, the general configuration of the continental shelf can be obtained. The entire coastline of Tanzania is characterised by fringing reefs except in the vicinity of river mouths, where there is a seasonal increase in suspended sediment, falls in salinity, radiant energy and light intensity. Inshore reefs are absent where the coastline is formed of sand barriers such as those found at Kunduchi. Most reef flats are not coral at all, but calcite-cemented coralline sands or beach rock.

Dubi and Nyandwi (1999) studied the Admiralty Chart of 1954 (Approaches to Dar es Salaam), and concluded that there are two main submerged channels off the coast of Dar es Salaam. The main shipping approach to Dar es Salaam is a zigzag channel with depths of almost 40 metres. Beginning south of Bongoyo, another channel can be identified. It is a 15-metres deep channel that passes west of Bongoyo running almost parallel to the coastline and passing between Pangavini and Mbudya islands. A shallower channel with a depth of 10 metres branches off the main channel to pass between the coastline and Pangavini as shown in Figure 24. Both channels have steep banks on their western sides.

Harvey (1977) studied hydrographic conditions in the Zanzibar Channel and in the Kunduchi coastal waters and found that Zanzibar channel is the main feature separating the island of Zanzibar and Tanzania mainland. The depth along the axis of the Channel decreases from over 500 m at the southern entrance to about 30 m in latitude 6^{o} 15´ S and then increases again northwards to more than 300 m at the northern entrance. Along both sides of the Channel, particularly the eastern side, and in the shallow section in the centre, are numerous coral reefs and islands. Flood streams enter the Zanzibar Channel from both the north and south whilst ebb streams flow out of both ends of the Channel. The maximum speeds were observed where the streams flow past the north – east corner of Zanzibar at between 2 and 4 hours before and 2 and 4 hours after H.W. at Zanzibar. Where the streams meet – between latitudes 6^{o} 10´ and 6^{o} 15´ S – the tidal currents are very weak throughout the tidal cycle.

The predominant direction of the water flow off Kunduchi is parallel to the coastline but there is also a tendency for offshore displacement offshore, which if it is real, must indicate either on-shore transport in deeper layers or convergence of the flow in this region. The flow speed varies from 0.5-0.9 knots. The water temperature indicates diurnal warming at the surface. Water temperatures of more than $29.^{0}$ C is common during March, the temperatures decreased thereafter to 25.3^{o} C towards the end of July. The individual surface salinity values ranges from $\pm$ 0.06% of the mean values.

Newell (1957) studied hydrographic conditions of the waters extending from the southern border of Tanganyika to the northern border of Kenya and to a distance of 30 miles from the shore, including the islands of Mafia, Latham, Zanzibar and Pemba. Below are his results.

The East African coastal current moves northwards throughout the year in the survey area, but differs markedly in its characteristics in the two monsoons. During the southern monsoon, the current has a greater velocity of up to 4 knots, being accelerated by the trade winds. During the northern monsoons the current is impeded by the northerly winds along this coast and is reversed from the equator northwards. There is a surface temperature maximum in March and April (the end of the northern monsoon) and a surface temperature minimum in September (the end of the soutern monsoon). The highest average temperature was 29.1^{o} C in March and lowest average temperature was 24.8^{o} C in September. Bathythermograph tracings from four stations (Lamu in December 1953 and September 1954, Mtwara in January 1953 and Kilwa 1954) showed that beneath the surface there is a marked thermocline both in the north and southern sections. However the depth of the thermocline varies from station to station and from season to season, but on the average, it is 100m below the surface. The tracings showed triple thermal stratification of the coastal surface water during the northern monsoon and almost isothermal water column during the southern monsoon. Surface salinity reaches maximum in about November in the south, intermediate waters in the same months and in the north in December. The lowest surface salinities of the year are found in May, both in the south and in the intermediate water region. Beneath the surface there was seen to be a salinity maximum at 150-200m with the water beneath this gradually decreasing in salinity. Salinity maximum values appear in April and May, diminishing after this until it reaches its minimum at the end of the year.

In yet another cruise at a location approximately 25 miles east of the southern end of Unguja Island, Newell (1959) observed that water mass immediately beneath the thermocline (the "Arabian Sea Water") also undergoes annual fluctuation, reaching it maximum salinity and depth range at or about the end of the north-east monsoon, and its minimum salinity and depth range towards the end of the year. The current measurements made off Zanzibar indicate that during the north-east monsoon, the coastal surface current tends to a direction obliquely onshore (13.3 cm/s), whilst during the south-east monsoon the surface current tends to a direction parallel with the shore (about 1m/s). The direction of movement of water veers to the left with depth as far as the thermocline. The water beneath the thermocline tends to flow in a reverse direction to that at the surface. Internal waves occur in the East African coastal waters. These can be of a magnitude up to 30m though this is exceptional. The more usual amplitude is about 10 to 20m.

1.6.2 Forces of Nature

Climate Change

The coast of Tanzania is influenced by the northerly and southerly trade (monsoon) winds. From May to October, the Southeast trade winds blow with great strength and constancy of direction. The Northeast winds are weaker and blow from November to April. There are two short transition periods between the two seasons. The Southerly monsoons are said to strengthen the northward moving East African Coastal Current, which can possess a velocity of up to 2 m/s. This current is only retarded, and never reversed, by the Northerly monsoons. The winds tend to deflect it out to sea and reduce its speed to less than 0.2 m/s (Newel, 1957). The northward movement of water if complicated by the changing alignment of the coast, the effects of rivers especially during the rainy seasons in April/May and October/November and the presence of submerged channels, reefs and islands.

Lwiza (1987) observed that during the Northeast monsoon winds, wind speeds varied between 1.5 m/s and 8 m/s with an average of 5 m/s. Generally, wind blew from the North except in the afternoon when it blew from the East. The Southeast monsoon winds had an average speed of 8 m/s and blew mainly from the South. Since the data lacked temporal variation, no statistical analysis can be performed to find return wind speeds for the area.

Dubi (1998) collected and analysed wind data for the period 1972-1996 for Tanga, Dar es Salaam, Zanzibar and Mtwara. The 50-year return wind speeds were found to be 13 m/s for Tanga, 13.5 m/s for Dar es salaam, 14.5 m/s for Zanzibar and 18 m/s for Mtwara. Figure 32 shows the maximum wind speeds recorded for each month for the 25-year period of 1972-1996. It can be seen that generally the coast of Tanzania experienced the peak speeds during the July and August except Zanzibar, which experienced the peak speeds during the Northeast monsoons in January. Dar es Salaam had peaks in February, April and July. In short, Tanga and Zanzibar experience peak speeds during the Northeast monsoons, while Mtwara experience peak speeds during the Southeast monsoons. Dar es Salaam experiences peak speeds during both seasons. There seems to be no published information on directional distribution of winds.

Information on the sea level for the coast of Tanzania can be obtained from two sources: Admiralty Charts, predicted tidal heights, which are published by the Tanzania Harbours Authority. Information on sea level changes can be obtained from tide gauges. The Admiralty Chart No.3310 shows the mean water levels at various locations on the coastline of Tanzania. It shows that Dar es Salaam has the lowest water level after Lindi, while Bagamoyo has the highest water levels. Spot observations also give indications of sea level. For example, Hartnoll (1974) reported that the time of low water always falls between 10.00 and 12.00 and again between 22.00 and 24.00; and the highest water levels occurred at around 3.00 and again at 15.00. Dubi and Nyandwi (1999) found that the highest water levels are observed just before the winds change direction, i.e. in March/April and October/November. The maximum tidal range was over 4 metres (4.25 metres in 1989)

Sea level monitoring in Tanzania has been inadequate and unreliable. Mahongo (1999) reported that currently there are only two operational stations: one in Dar es Salaam and another on Zanzibar (in Malindi Harbour). The tide gauge in Dar es Salaam is located at the Ferry Terminal of the Harbour. The gauge is a mechanical SEBA float type and was installed in 1997 after the old Leupold and Stevens float gauge was damaged by a boat. The old gauge had worked for only 5 years (1986-1990) with gaps in between. It is only the gauge in Zanzibar that has been working since 1984, of course with some gaps. The data collected from the two stations have not been analysed with a view to assess trends in sea level. In earlier times, there were several tide gauges that had been installed, but are now not operational. These were at Mtwara (1956-1957, 1959-1962), Tanga (1962-1966) and at

Mkoani Pemba (1991) but would not function due to an incorrect installation. The small spatial and temporal scales of the data reduce the reliability of its application at larger scales.

Hydrology

Temple and Sundborg (1972) conducted a study on the water and sediment discharge characteristics of the Rufiji River. They found that the average daily discharge is highest in April and lowest in November. On average, the April discharge accounts for nearly 25% of the annual total compared to 2% in November. The maximum for mean monthly discharge was recorded in January 1961 (5173 m^3/s) and the minimum in November 1959 (76 m^3/s). The dispersion graphs indicate that over the recorded period, the month of January was subject to by far the greatest fluctuations of mean discharge and the month of October to the least. The graphs also indicate that, on the average, the months June through November are not subject to floods. The period December through May has experienced high average discharges, in excess of the highest floods of some dry years of the record. On the basis of the 24–hour mean discharge values from these gauging stations, flow duration curves have been constructed for each of the 16 hydrological years. In 1961/62 time period, 5% of the time experienced discharges exceeding 5320 m^3/s. In 1960/61, the discharge value within the 5% duration was only 1435 m^3/s. Floods with discharge of 5,000 m^3/s have a return period of about 5 years and floods with discharges of 7,000 m^3/s a return period of about 13 years.

Suspended sediment load data at Rufiji River indicates a maximum daily transport of approximately 1,000,000 tons during the investigated period. Sediment – rating – curve and duration – curve analyses indicate that some 250 – 300 million tons of suspended sediment have passed through Stiegler's gorge in the 16 years covered by discharge records. To this figure should be added the bed load transport and probably also a certain increase due to inaccuracy in the sampling and analysis procedures. Heaviest loads of sediment are related sudden flash floods. The suspended sediment peaks are out of phase with the flood peaks, indicating an early annual flushing of the sediment from the system with the onset of the flood season. The sources of this sediment and the characteristics of the tributary basins are dependent on relief, geology and seasonal rainfall regimes.

Mwandosya et al. (1998) selected and evaluated climate change scenarios, which were arrived at by taking into account nearly all factors. The climate change scenarios compared baseline climate with that climate that could be expected to be obtained if anthropogenic greenhouse gases in the atmosphere increased to twice the baseline concentration, ($2xCO_2$), and the associated changes in temperature and rainfall. Scenarios for climate change were developed using UK89 general circulation models (GCMs). The climatological baseline for Tanzania was identified as the period between 1951 and 1980. The baseline data was for the monthly temperatures and precipitation. The 1951-1980 data meet the criteria for Tanzania because it was long enough to have a good representation of wet, dry, warm and cool periods and even had some cyclicity at the decade time scale.

The north-eastern sector of Tanzania experience an increase of 25-60% rainfall during *Vuli and 20-45%* increase during *Masika* rains. The north coastal sector would get an increase of between nil and 20% in *Vuli* and a decrease of between nil and 10% in *Masika* rainfall. Lake Victoria basin would have an increase of 30 to 40% in *Masika* and 10 to 25% in *Vuli.* The unimodal sector would experience rainfall changes during the *Vuli* and *Masika* months. In October, November and December rainfall would decrease by between nil in the central regions and 15% up to 25% in the western sectors of the country. The south eastern sector would get between 5 and 45% increase in rainfall. In March, April and May, unimodal rainfall areas in the central sector of the country would have a 15% increase in rainfall over and above baseline values for the period, while the western and south-western sctors would get between 5 and 20% increase. The south-eastern sector would get between 10 and 15% increase in rainfall. A small area about 200 km radius from Mahenge would receive between 20 and 50% rainfall increase in *Masika*.

Mwandosya et al. (1998) also studied the effect of climate change on river runoff in three basins in Tanzania. These basins are Ruvu, Pangani and Rufiji. Simulation of "$2xCO_2$" was conducted by using temperature and rainfall data for the period 1973-1977. Using the Water Balance Model (WATBAL), Mwandosya et al. (1998) found the following results for the three basins:

Ruvu and Pangani basins showed an overall decrease in runoff, while Rufiji had an increase in runoff. The summary for runoff change due to doubling of carbon dioxide is given in Table 4. The reasons for an increase of river runoff in the Rufiji basin can be attributed to an increase in rainfall of between 10 to 50% shown by the GCMs rainfall scenarios. This occurs during the period of high flows (November-March). In addition to this, Rufiji basin has relatively lower mean temperatures hence contributing to lower evapo-transpiration rates. The effect on runoff due to changed land use and urbanisation was not taken to account. These factors will influence the hydrology of the basins.

Table 1.3. Summary of runoff impacts (Mwandosya et al., 1998)

Catchment	Runoff change (annual change in %)
1. Ruvu river at Morogoro Road bridge	-10
2. Kikuletwa river at Weruweru	-9
3. Pangani river ar Korogwe	-6
4. Ruaha river at Mtera	+5
5. Ruaha river at Kidatu	+11

Coastal Processes

The coast of Tanzania experiences a semi-diurnal tide with two almost equal maxima and two minima during a lunar day (24.8 solar hours). There is a considerable rise and fall of water against the coast of Tanzania, which has important geomorphologic and hydrodynamic repercussions when combined with the inter-tidal profile and the prevailing winds. While the ebb and flood tidal movements tend to be self-balancing on the open coast, individual features will influence the extent of fluctuations. Tidal currents in estuaries and areas with islands and sand spits such as at Kunduchi are localised and important in their effect on coastal and offshore shelf topography.

Lwiza (1987) measured tide heights using a self-recording tide gauge, which he installed in the harbour of Dar es Salaam. He found the annual mean water level as 1367 mm, the maximum as 1487 mm and the lowest as 1264 mm above datum. The zero of the tidal staff at the tide gauge was assumed to be 1 metre below datum. The measured tidal currents for 30 days using drogues cast at about 800 metres from the shore. He found that during the Northeast winds the current speed, averaged over one tidal cycle, was 0.25 m/s and the maximum was 0.5 m/s. There was, however, no big change in current speeds and direction during the Southeast winds. Ebbing speeds in the Kunduchi-Manyema creek reached as much as 3.5 m/s. The measured waves at Kunduchi Beach at about 1 metre below datum using an 8-metre graduated wooden staff for only ten days after which the staff was stolen. Waves in other locations collected from visual observation. During the Northeast winds, he found that waves were low with an average height of 0.2 metres south of Mbezi River. The height increased northward such that at Africana Hotel, it was about 0.4 metres. Between Bahari Beach and Ras Kiromoni, waves were observed to have heights of about 1.2 metres. Near Kunduchi, at the sand spit, waves were choppy and confused.

1.7 Resource utilisation

1.7.1 Over-exploitation of natural resources

Human activities, such as the exploitation of groundwater and hydrocarbons (oil, gas and coal) may cause subsidence of sedimentary basins. This subsidence would have the same effect as sea level rise. However, no published information is available in this area.

1.7.2 Sediment supply to the coastal zone

Interruption of sediment supply to the coastal zone is experienced in many areas along the Tanzania coastline and seems to occur in various forms. The construction of protective features at the source of littoral material may disrupt the sediment supply. Such features include the construction of dams which normally traps a large quantity of sediments. In Tanzania dams are commonly constructed for production of electricity, irrigation and fisheries. These dams exist in most of the rivers entering the Indian Ocean as also mentioned in Linden and Lundin (eds.), (1996). Table 5 summarises the main dams and rives where they are constructed.

Table 1.4: Major dams in Tanzania and the rivers where they are constructed.

Hydroelectricity Dam	**River**	**Status**
Nyumba ya Mungu	Pangani	Multipurpose, built 1969, surface area 142 km^2
Pangani Falls	Pangani	Built 1938
Hale	Pangani	Built 1964, Multipurpose, Surface are 10 km^2
Pongwe	Wami	Surface area 600 km^2
Kidatu	Great Ruaha (Rufiji Tributary)	Operational
Mtera	Great Ruaha	In progress
Lower	Great	Proposed
Kihansi	Ruaha	Proposed
Lower Ruvu	Ruvu	Proposed
Ruvuma	Ruvuma	Proposed

The extraction of sand from feed rivers and streams deprives the beaches the much needed sand and silt required for maintaining equilibrium. Since the beginning of the 1980s, there has been a boom in construction all over Tanzania, especially in Dar es Salaam. The boom in construction is obviously associated with a great demand for construction material such as sand, cement, coarse aggregate and stone. A field survey conducted by Griffiths (1987) shows that a minimum of 100,000 m^3 of sand was extracted annually from the four streams (Tegeta, Mbezi, Mlalakuwa and Kijitonyama) that drain the hinterland of Kunduchi Beach. Nyandwi (1996) investigated human activities including removal of beach material, removal of protection against wave breaking, and obstruction of sediment supply, that contributed to beach erosion problems on Zanzibar (Unguja and Pemba) beaches. He reported the following results. Beach structures that were considered to contribute to erosion in Zanzibar were the Mkoani jetty, Mtoni jetty, Jambiani seawall and Maruhubi seawall. At Mkoani, the erection of the jetty had led to concentration of wave energy leading to accelerated erosion. The jetty-like structure at Mtoni impeded longshore sand supply leading to intensive erosion at Maruhubi. Although the Jambiani seawall had been effective in protecting a section of a beach from erosion, the effect had shifted to the northern end of the wall where loss of land amounted to about 10m in width in 19 years since 1977. At Maruhubi, erosion at the ends of the seawall was reported to continue unabated.

The effect of sand mining was also mentioned at Unguja Ukuu, where a 5m wide coastal strip had been lost due to shoreline erosion between 1997-98, trees were also uprooted in the process. A similar process was expected at Chuini where sand extraction was also taking place. The cutting of mangroves and its effect on erosion was also discussed. At Mbweni beach, the area was experiencing serious erosion. Mangroves usually acted as buffer against wave battering and their removal aggravated the problem. Lastly, erosion was also linked to poor planning. There was a trend of erecting beach hotels and residential houses directly on or very close to the beaches. The hotels at Uroa, Chwaka and the bungalows at Uroa were cited as examples.

Construction of buildings on dunes and eroding cliffs also decrease sediment supply to the littoral zone. A survey conducted by Dubi and Nyandwi (1999) shows that some structures such as residential houses and hotels are built directly on the beach and some of them on potentially unstable landforms, such as sand dunes.

Coastal protection methods are varied and take many forms. A method of protection can comprise one or more options that fall under three categories, viz. protect, retreat and accommodate. Table 6 shows some of the options falling under the three categories.

However, in an attempt to control erosion in Tanzania, coastal structures such as groynes and walls, whose design leaves a lot to be desired, have been erected. Such structures change the sediment dynamics regime and realign the shoreline. Some of the typical protection measures employed in Tanzania include stone and masonry seawalls in Tanga and Bagamoyo, groynes, concrete and masonry seawalls in Dar es Salaam, Zanzibar, Lindi and Mtwara.

1.7.3 Sea-level rise

Sea-level variation can be increased through construction of boat channels and deepening and widening of navigation channels. This activity increases the tidal range, thereby permitting larger waves to enter the harbour area and adjacent beaches. Larger waves may cause a change in beach profile. The entrance to the harbour of Dar es Salaam is said to have been dredged to increase its water depth. No published information is available on the impact of this activity.

Table 1.5:Examples of coastal protective, retreat and accommodative technologies

Application	**Technology**		
	Hard structural options	**Soft structural options**	**Indigenous options**
Protect	• Dikes, levees, floodwalls (for low countries) • Seawalls, revetments, bulkheads • Detached breakwaters • Flood gates and tidal barriers (for tidal inlets) • Saltwater-intrusion barriers	• Beach nourishment • Beach drainage concept • Dune restoration and creation • Wetland restoration and creation • Afforestation	• Coconut-leaf walls • Coconut-fibre • Stone units • Wooden (Mangrove) • Stakes walls • Stone walls
Managed (Retreat)	• Increasing or establishing set-back zones • Relocating threatened buildings • Phased-out or no development in susceptible areas • Wetland creation, managed realignment • Creating upland buffers		
Accommodate	• Emergency planning • Hazard insurance • Modification of land use • Modification of building styles and codes • Strict regulations of hazard zones • Desalination		

1.7.4 Natural protection

Coral reefs act as barriers against wave forcing, once they are destroyed, they may not be able to keep pace with the rising sea level and hence more intense wave energy will cause major erosion to occur. Similarly, shoals and sandbars dissipate wave energy that would otherwise reach the shoreline. Dredging of the nearshore shoals and bars can change the pattern of energy dissipation on a beach which can in turn have a negative impact on shoreline stability. Natural protection is also weakened when dunes are levelled, this includes destruction of beach vegetation and paving of large backshore areas.

Coastal and marine resources degradation is a result of many human activities such as agriculture, forestry, urbanisation, fishing and tourism (Linden and Lundin, 1996). These activities result in coastal erosion, physical destruction of mangroves, beaches, sea-grass beds and reefs, biodiversity loss, land degradation and depletion of fish stocks. Agricultural activities and fishing appears to be particularly important contributors to coastal degradation in Tanzania. Rural poverty is increasingly pushing people toward unsustainable farming on fragile land. In the Rufiji delta and to a lesser extent in Pangani, Bagamoyo, Kisarawe, Kilwa and Lindi, clearing of mangroves for rice cultivation is often done on a seven-year cycle, from clearing to time of abandoning.

Fishermen often use destructive techniques such as explosives and small mesh nets, which destroy sensitive habitats and catch juvenile fish. In Tanga, up to 95% of all coral reefs have been destroyed by destructive fishing practices. Tourism development without proper planning destroys habitats during construction, and unmanaged tourism damages reefs and has a negative impact on local people.

The institutional capacity and legal framework for integrated coastal zone management is clearly inadequate in Tanzania. Sectoral policies fail to take into account inter-relationships among resources. For example, siltation of rivers like the Rufiji and Pangani are caused by agriculture and energy policies, but affect mangroves and coral reefs further offshore. People cut mangroves for fuel-wood, boiling brine for salt production and agriculture, particularly in Tanga, Bagamoyo and Rufiji. The loss in mangrove leads to disturbances in the ecosystem, degradation of fisheries, increased sedimentation on reefs and damage caused by flooding.

1.8 Rates of coastal erosion

Information on the rates of coastal erosion could have been obtained from two main sources: through critical examination of any available material such as topographic maps, aerial photos and satellite images for the last 40 years or so. The study could reveal areas that experienced accretion and those, which experienced erosion. Secondly, rates of erosion can be deduced from continuous monitoring of threatened locations of the coastline. In Shufaa and Betlem (1996) aerial photos for Zanzibar were examined for the period between 1947-1989. They found that over 60 kilometres of the coastline of Zanzibar are affected by erosion. Most of the surveyed beaches have become smaller compared with earlier years. The southern part of Nungwi showed 40-50 metres of sedimentation, while the northern part showed serious retreat of the beach back to the position of the beach in 1947 or even further. In Kigomasha Tondooni area, the outer beach line has been on retreat since 1977. More that 50 metres has been lost since 1977 and in other section the 1989 limits were more or less equal to those of 1947. Mnemba Island showed continuous erosion on the North West side and a continuous sedimentation on the east side of the Isaland. The average speed of movement of the northern point of the island since 1947 was found to be 3.6 metres per year. It seemed that the speed had increased during the period 1977–1989 compared with the period 1947-1977. Around Chwaka, a serious reduction of the beach area was noticed since 1947. In general the beach has become smaller on an average of approximately 50 metres since 1947. Other areas were also found to be affected, e.g. Bububu, Bwejuu, Kigomani, Gulioni and Mkoani areas.

Fay (1992) examined aerial photos and maps of areas surrounding Maziwi Island off Tanga, dating back to the early colonial times of East Africa (1894). Originally, the shape of the island was roughly circular with a diameter of 500 to 600 metres, corresponding to a terrestrial surface area of 20 to 28 hectares. The island was elevated about 2 metres above the maximum high tide level, it base was the reef flat surface, about 4 metres below the maximum high level. By the time of the study (1992), the largest part of the remaining Maziwi Island was a reef flat reaching the sea level only at neap tides. On the western margin of the reef platform a sand spit composed of carbonate particles occurs. From the air this sand spit looked tongue-to-hook shaped, its convex side pointing north and westward. The length of the sand spit exposed to air during low tide (E-W) was about 320 metres, its width (N-S) 130 metres. The vertical distance between low tide level and the top of the sand spit was about 70 metres (E-W) by 40 metres (N-S). Occasionally, during extreme spring tides, this part of the sand spit seemed to be submerged. Assuming a constant rate of erosion between 1968 and 1982, the island must have lost about 100,000 cubic metres per year into the surrounding lagoon. Since 1982 the sand spit has not changed its position significantly.

The University Exploration Society (1991) found erosion of an average of 4 metres a year for the last 14 years near the Kunduchi-Manyema Creek and 1 metre a year directly in front of the Kunduchi Beach Hotel. At Silversands Hotel the crest had recede 13 metres in 13 years (between 1978 and 1991). Hemed (1987) studied variations in the beach configurations through repeated observations of spot levels along seven fixed profiles of beaches north of Dar es Salaam. He found that there were large variations on spot levels only on the first 40 metres or so from the crest on most profiles with points farther down showing little or no variation at all. During the rains in March, April and May there was an accretion of an average of 30 cm depth of sand along the first 30 metres of the profiles at American Club; near the southern fence of Bahari Beach Hotel; between Rungwe Oceanic and Silversands Hotels and at the Boathouse of the Kunduchi Fisheries Institute. However, at the southern end of the Kunduchi Beach Hotel, there was an erosion of 30 cm depth along the first 10 metres of the profile. But in August and especially during high tides, the beach lines receded 1.5 metres at the American Club; 10 metres near the southern end of Bahari Beach Hotel; 2 metres at the Boathouse of the Kunduchi Fisheries Institute and 2 metres at the southern end of the Kunduchi Beach Hotel. However, at the Africana Hotel the situation was different from what happened on other profiles. The high tides of August resulted in an accretion of sand of about 30 cm depth along the entire profile. At Msasani Beach, there was a steady accretion of sand along the profile until mid-June when erosion started. The August high tides affected mainly the crest and 20 cm depth of sand was washed away.

On assessing aerial photos, Mushala (1978) found that over a 20-year period there was a recession of the shorelines of more than 50 metres at both the Siversands and Kunduchi Baech Hotels. Mushala (1978) observed seasonal changes in profiles at fixed points along Kunduchi Beach from October 1977 to April 1978. He found that erosion, accretion and sediment transport were taking place simultaneously at varying rates. The maximum rate of erosion was a 4-metre loss in thickness between two consecutive profiles over one month. The minimum rate of erosion was 0.2 metre. The maximum rate of accretion was a vertical increase of 2.2 metres in a month while the minimum rate was 0.1 metre. These rates had a direct relationship with changes in the monsoon winds. Severe erosion was observed during the SE monsoons, while accretion took place at time of transition of wind direction of the monsoons.

Mwandosya et al. (1998) conducted a study on the impacts of sea level rise on the coastline of Tanzania. The analytical approach (topographic maps) showed that in Tanga region, Moa was the most vulnerable coastal unit area while Kigombe was the least vulnerable. In Lindi and Mtwara, Nangurukuru was most vulnerable followed by Mnazi Bay while Lindi was the least vulnerable. In Dar es Salaam and coast regions, Salale was the most vulnerable followed by Mbwera while Kawe was the least vulnerable. On the whole of the Tanzanian coastline, mangroves were the most vulnerable coastal resources and Dar es Salaam/coast area was the most vulnerable while Tanga was the least vulnerable.

Mwandosya et al. (1998) also examined two sea level rise scenarios of 0.5 m and 1.0 m. The study suggests that a 1.0 m – rise in sea level would permanently flood about 500 km^2 of land, most of which is wetlands. Inundation would claim about 250 km^2 for 0.5 m of sea level rise and about 490 km^2 for 1 m rise of sea level. Future erosion rates were projected using the Bruun Rule for Dar es Salaam in response to global warming and accelerated sea level rise of 1 m to about 9 km^2. Aerial videotape-assisted Vulnerability Analysis (AVVA) together with ground truthing exercise for Dar es Salaam suggested an area of about 12 km^2 of land would be lost for the same rise in sea level. This land loss would claim buildings and other structures valued at about Tsh. 50 billion and Tsh. 86 billion for 0.5m and 1.0m of sea level rise respectively. Expected storm surges of 5m would bring a damage of over Tsh. 200 billion for Dar es Salaam.

1.9 SCIENTIFIC AND MANAGEMENT RECOMMENDATIONS

Major recommendations based on this literature review are summarised below.

Geology and Geomorphology studies:

Complete appreciation of the history for the whole Mtoni terrace will be required. In addition to systematic geomorphic and sedimentological research work, reliable radiometric dating will need to be redone (e.g. Kaaya, 1986). Sea level fluctuations have probably been eustatic. Therefore, much more detailed field work at many other sites, with careful instrumental levelling from agreed datum and with intensive studies of the post-Miocene reefal material and other deposits are required. (e.g. Cooke, 1974).

Climate Change studies:

In monitoring sea level fluctuations, Mtwara and Tanga tide gauge stations should be rehabilitated and together with Dar es Salaam should be linked to the GLOSS network of tide stations. More stations should be established at other sites, such as Chole Bay (Mafia Is.), Lindi, Kilwa Masoko, Bagamoyo and Latham Is. (e.g. Mahongo, 1999). A single agency should be commissioned to co-ordinate the installation and operation of tide gauges to harmonise levelling, analysis and training of personnel. In Hydrology (e.g. Temple and Sundborg, 1972), sediment transport in rivers needs full consideration in any feasibility study concerned with water development on river basins. There is a need to establish gauging stations on major rivers to monitor accurately the river discharges. It is recommended to establish water quality and sediment sampling programme for major rivers. It is also recommended to do as full an analysis as possible of the probable sedimentation in the proposed reservoirs. A summary of major recommendations is given in Table 7.

1.10 INFORMATION GAPS

This section gives a general observation on the information availability and coverage. A summary of information gaps is given in Table 8. Geology and Geomorphology are well covered for Dar es Salaam and northeastern Tanzania. Hydrology is well covered only for Rufiji and only at that time. Information is readily available. *Climate Change* (Winds, Rainfall, Atmospheric Pressure, Sea Level rise): Winds are analysed only for extreme speeds. Statistical analysis of directions is not covered. Rainfall, atmospheric pressure and sea level trends are not covered. *Hydrographic Conditions* (bathymetry and general oceanography): Nearshore bathymetry is not covered. Information on general hydrographic conditions is available. *Ecology and Coastal Zone Management:* Well covered. There are few publications on this subject. *Coastal Processes* and Engineering (waves, currents, and sediment transport): Studies on waves and currents are localised and are lacking enough temporal variations to warrant statistical analysis. Sediment transport (volumes, direction and distribution) not well covered.

1.11 RECOMMENDATIONS FOR FUTURE WORK

1.11.1 Data acquisition

A good assessment study will start with the acquisition of basic data on a number of important parameters that characterises the study area. Relevant characteristics of a natural coastal system include: coastal geomorphology and topography, historical relative sea level changes, trends in sediment supply and erosion/accretion patterns, hydrological and meteorological characteristics and ecosystem characteristics

It is also important to collect data on the important socio-economic characteristics of the study area and to develop scenarios of their future development. These include: demographic development, trends in resource use and economic development, land use and ownership, infra-structural and other economic assets, cultural assets and institutional arrangements Once the data is collected, a GIS database should be created for management and further analysis.

Table 1.6: A summary of major recommendations.

Subject	**Scientific recommendation**	**Conservation/ Protection**	**Local awareness/participation/training**
Geology, Geomorphology and Hydrology	• Expand geographic coverage • Geological, sedimentological and radiometric dating to establish conditions of sea level rise • Mathematical modelling as a tool for hydrological studies • Sediment transport consideration in any development on the river sites • River gauging stations for water quality sampling	-	-
Climate Change	• Investigate variability of winds, rainfall and sea-level change.	-	-
Hydrographic Conditions	• Investigate the relationship between the shores and hydrographics	-	-
Ecology and Coastal Zone Managemet	• Scientific evaluation of shoreline erosion • Interdisciplinary oceanographic research is required	• Install low-cost, low-tech. Control measures • Establish the 200-m buffer zone • Enforcement of existing regulations • Address issues related to zonation of areas suitable for various activities	• Promote education on the impact of erosion and coastal developments • Promote consultation process with local people • Create awareness at all levels of ecosystem functioning, threats, values and policy changes
Coastal Processes and Engineering	• Further studies to determine sediment budgets in rivers and estuaries • Wave hindcasting, refraction and diffraction analysis • Develop mathematical and physical models	• Detailed engineering designs based on scientific data are necessary • Groynes have not solved erosion problems	• Promote awareness on the effects of different protection methods on shorelines • Include coastal protection design and management in the engineering curriculum

Table 1.7: Summary of information gaps.

Subject category	**Geographical coverage**	**Subject coverage**	**Age of studies**	**Duration of studies and information accessibility**
Geology, Geomorphology and Hydrology	Mainly Dar es Salaam and northwards Hydrology is covered only for Rufiji area	Satisfactory	Old	Short (statistically). Information accessible
Climate Change	Winds: Major coastal locations (Tanga, Dar, Zanzibar and Mtwara) Barometric pressure: unknown Sea level: Zanzibar and partly Dar	Winds: 25 years. Sea level: 7 years for Dar es Salaam and 15 years for Zanzibar	New	Statistically short duration. Information is accessible
Hydrographic Conditions	Mainly Dar and particularly Kunduchi	One year average	Old	Short. Information is available
Ecology and Coastal Zone Management	Mainly Dar and Tanga	One year average	New	Short. Information is available
Coastal Processes and Engineering	Only Dar	One year	New	Short. Information is available

Table 1.8: Summary of recommendations for filling the research gaps in reasonably short period of time.

Subject category	**Methods**	**Geographical coverage**	**Subject coverage**	**Monitoring**	**Training**
Geology, Geomorphology and Hydrology	-	Expand coverage to southern parts of Mainland, whole of Unguja, Pemba and Mafia. All major rivers should be gauged.	Well covered	Monitoring of water quality, volume and sediment transport is required	-
Climate Change	-	Establish new stations to cover other areas like Mafia, Lindi, and Bagamoyo	Record all aspects of climate	Establish and maintain tide gauges Provide low-tech and low-cost monitoring equipment	Train ordinary people to record data and maintain instruments. Manufacture (improvise) some instruments
Hydrographic Conditions	Use modern instruments	Cover entire coastal and offshore waters	-	Establish monitoring stations	-
Ecology and Coastal Zone Management	-	Cover all areas	-	-	Seminars and workshops School curriculum to include coastal zone management
Coastal Processes	Use modern instruments Mathematical and physical modelling Wave hindcasting analysis	Cover all areas	Should cover all aspects	Establish offshore station Establish stations at some designated locations	Train local people in simple methods of monitoring Introduce coastal processes and engineering in school and University curriculum Organise workshops and Seminars

1.11.2 Recommended future work to fill in the information gaps for management

First and foremost, it is essential to review critically any available material such as topographic maps, aerial photos and satellite images. Use may be made of the World Wide Web sites of various national and international organisations. The web sites may contain coastal bibliographies, databases, and tools as well as numerous links to other relevant information and organisations on the Internet. Examples include the Dutch Coastal Zone Management Centre (http://www.minvenw.nl/projects/netcoast), the Coastal Services Center of the US National Oceanic and Atmospheric Administration (http://www.csc.noaa.gov), and the Land-Ocean Interactions in the Coastal zone core project of the International Geosphere-Biosphere Programme (IGBP) (http://www.nioz.nl/loicz).

On global sea level changes, there are a number of databases that may provide information. Examples include the Permanent Service for Mean Sea Level (PSMSL) and the World Atlas of Holocene Sea Level Changes. Although all these sources could provide an indication of long-term, regional and relative sea-level changes, it is recommended to use this type of information with caution because, especially for Tanzania, the small spatial and temporal scales of the data reduce the reliability of its application at larger scales. The only option for Tanzania is to install additional tide gauges and commission an institution to manage and analyse the data. Suitable stations are Tanga, Pangani, Bagamoyo, Kilwa and Mtwara.

On topography, geomorphology and land use, ordinary surveying can be conducted to provide basic and essential data. In combination with elevation data derived from satellite measurements r vertical aerial photography, surveying and echo-sounding can yield topographical and near-shore batymetric maps that can be used in refraction and diffraction analysis of waves and currents. Aerial video-tape-assisted vulnerability analysis (AVVA) method in combination with ground-truthing can be used to characterise the coastal topography and geomorphic features of the coastline. This study also allows for estimates of the biogeophysical effects of different sea level scenariosn and provides information on the types of coastline environments, land-use practices, infrastructure and population indicators. Mwandosya et al. (1998) did the AVVA only for Dar es Salaam and it is recommended that it be done for the entire coastline of Tanzania.

1.11.3 Strategies for sustainable coast protection

In Tanzania, and elsewhere in the world, the coastal ecosystem has a tremendous value from environmental, biological and socio-economic point of view. The coastal zone is increasingly becoming a sitting of industries and commercial activities and, consequently, this trend results in the increase of human settlement, more intensive land use, sea-borne transport and even mining. The recreational value of beaches is growing fast due to new beach development schemes, development of marinas and other socio-economic activities. With this in mind, the following strategies are designed to encourage the provision of adequate, technically, environmentally and economically sound and sustainable coast protection methods and management in Tanzania.

Need for legislative and administrative framework

A survey conducted along the entire coastline of Tanzania shows that various structures have been erected close or on beaches and dunes. Due to shoreline retreat, these structures are threatened by the advancing sea. Although the primary responsibility for dealing with coastal erosion at a given location rests with the land owner, a statutory law which will vest powers in specific local authorities and bodies should be passed. This law which could be known as *The Coast Protection and Management Act* will have the function to define, protect and regulate the use of the shore areas. In particular, it should ensure and safeguard the public nature of the beaches, preserve its natural features, balance the need of development with conservation.

After the enactment, a department of the Government should administer the legislation through the creation of a central body, e.g. *Coast Directorate*, with objectives to spearhead co-ordinated planning, finance and administration. It should be the duty of this body to define the rights, obligations and responsibilities of all parties concerned in coastal development. One of the priority tasks of this body, immediately after its formation, should be a survey to identify Erosion Prone Areas (EPA) and compile a coastal vulnerability data base containing information on several variables relating to inundation and erosion risks of the different areas along the entire coastline. Such variables could be, for example, relief (elevation), lithology (rock type), coastal landforms (e.g. dunes, escarpments, etc.), vertical land movement (relative sea level changes), horizontal shoreline changes (erosion and accretion), tides, wave heights, data on storm frequency and intensity, storm surges and sediment transport (quantity and direction) and climate change (variability of winds, waves and storm surges). Local authorities should obtain the views of the Coast Directorate with respect to town planning matters affecting land in the EPA. Property holders should require permit to erect or alter buildings in the EPA. Once the EPA have been identified, buffer zones of the appropriate width are determined to define areas where controls are required.

Need for establishing a Coastal Observation Programme

The next step following the identification of EPAs is the establishment of a Coastal Observation/Monitoring Programme. This programme will contribute to technical aspects of the Coast Directorate's operations and management. Its functions should be to: Establish an extensive data collection programme to include nation-wide wave recording system using waverider buoys for offshore waters and pressure gauges for coastal waters at representative locations. Wave measurements could be supplemented by a network of voluntary observers who would make regular beach and surf zone observations at specific sites. Collect and archive historical, geological, geomorphologic, botanical and meteorological aspects of the entire coast as well as normal engineering aspects. Install storm tide recorders at all major coastal population centres as the basis of a warning and response for impeding disasters from tropical-cyclone-induced storm surges. There is also a need to introduce awareness workshops, introduce coastal processes and engineering in university curriculum, install hydraulics laboratory for physical modelling and manufacture simple instruments and the use numerical modelling

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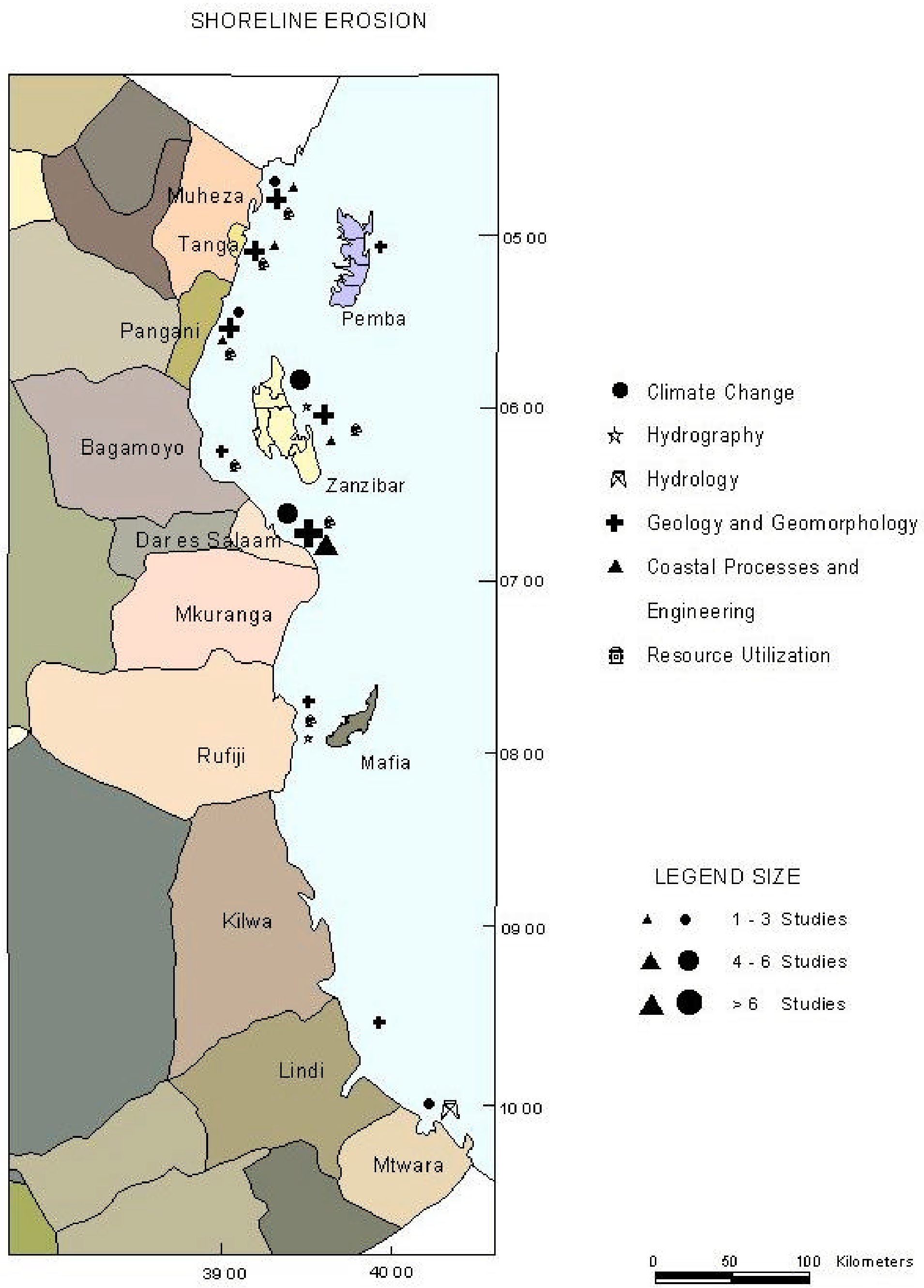

Figure 1.3. Tanzania coastal base map showing the distribution of research works that has been conducted in relation to coastal erosion. This includes all the available literature that was used in the preparation of the shoreline erosion synthesis.

Chapter 2

WATER QUALITY AND POLLUTION

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2.0 Background information

The coastal areas of Tanzania encompasses a number of habitats that include coral reefs, mangroves, seagrass beds, sand banks, and beaches. These coastal habitats support various resources, both living and non-living. The coastal waters are also important sites for mariculture and tourism development as well as for general recreational activities. The wellbeing of these habitats and resources and the various activities taking place within or near coastal waters depend, to a large extent, on good water quality.

However, expanding coastal populations are exerting an ever-increasing pressure on coastal waters thus negatively affecting water quality. As a result coastal pollution is increasingly becoming a major issue in Tanzania. Reports indicate that coastal waters fronting such cities and towns as Dar es Salaam, Tanga, Zanzibar and Mtwara are said to be grossly polluted (see below). Other coastal towns could also be sources of domestic pollution. Furthermore, land-based activities such as agriculture, industry, and mineral exploitation have further contributed to the degradation of coastal water quality. This report gives a summary of the available information about water quality and pollution in Tanzania.

2.1 Type of data/information gathering and time of collection

The papers and reports on water quality and pollution give results of baseline studies, experimental studies, applied studies and reviews. Some of the papers are both on experimental and baseline studies. However, baseline studies by far form the bulk of the studies, as they constitute 45 % of all the papers. These are followed by reviews and applied studies at 23% each. At 4% experimental studies and combined experimental and baseline studies are the least.

2.1.2 Baseline studies

Baseline studies on pollution and water quality of coastal waters have been carried out mainly in Dar es Salaam, Zanzibar, and Tanga. Several studies have been carried out in Dar es Salaam to assess water quality as well as to determine sources of pollution. Msimbazi Creek is the most studied area of Dar es Salaam.

In Dar es Salaam, Kondoro (1997) assessed heavy metal (Pb, Cd, Zn, Cu, Cr) distribution along Msimbazi River. Mwandya (1996) determined the concentrations of heavy metals Pb and Cd in the soft tissues of *Saccostrea cucullata* in Ocean Road beach and Msimbazi Creek. Other studies in include that of Wekwe *et al* (1989) who assessed heavy metal content of several species of algae along the coast of Dar es Salaam. Heavy metal pollution was also studied by Machiwa (1992) who assessed anthropogenic input of Fe, Mn, Zn, Pb, Cr, Cd and organic carbon in Dar es Salaam coastal sediments. Machiwa (1992) also investigated the possibility of the occurrence of toxic materials (PCBs) and organic carbon and pathogenic microbes in the marine sediments off Dar es Salaam.

In other studies, Lyantagaye (1996) invested the distribution of dissolved inorganic nutrients and dissolved oxygen in Mzinga Creek and Ocean Road coastal waters while Mamboya (1996) investigated wet and dry season variations of those parameters in Mbezi Creek. Mlay (1997) assessed the interrelationship between environmental conditions and algal abundance and Chlorophyll *a* concentrations in the University of Dar es Salaam wastewater sedimentation ponds.

Several pollution assessment studies have been carried out in Zanzibar, mostly in the waters fronting the Stone Town in the Zanzibar Municipality. Among the earliest such studies is that carried out by Van Bruggen (1990) who measured water temperature, DO, conductivity, pH, BOD, COD, heavy metals and faecal and total coliforms. This study was commissioned by the Zanzibar Department of Environment to facilitate the formulation of the Zanzibar Environmental Policy. This study was followed by that of Mohammed (1990), who investigated pollution by industry and other users of chemicals in Zanzibar. Mohammed *et al* (1993) looked at the impact of pollutants (nutrients and coliforms) on the reefs fronting the Zanzibar Town. Another study was by Walvoord (1993) who measured baseline concentrations of dissolved nutrients, BOD, salinity and dissolved oxygen at 14 sites in the same area. Anderson (1994) carried out a two-week measurement of pH, dissolved nutrients, temperature, salinity, turbidity and dissolved oxygen at the Zanzibar harbour. Johnstone and Suleiman (1997) measured nutrient concentrations near the islets of Bawe and Chapwani (off the Stone Town). They also examined nutrient dynamics and community response to nutrient loading. Mmochi and Francis (1999) undertook a long term monitoring of water quality also in the Stone Town area of Zanzibar.

Studies carried out outside the Zanzibar Town area include those by Kastner (1996) who compared nitrification rates in an unpolluted environments (a mangrove stand at Chwaka Bay and a beach at Fuji Beach) and a polluted beach (Stone Town, Zanzibar). Water quality studies in the Chwaka Bay area are those by Mohammed and Johnstone (1995, 1998a, 1998b), Mohammed *et al* (1998) and Johnstone *et al* (1998). Mmochi (1997, 1998) studied pesticide and nutrient pollution of ground water in the Chwaka Bay, Paje, Fumba and Mahonda-Makoba basins in Zanzibar. Mmochi *et al* (1999) assessed the quality and effects of groundwater outflow on the near shore biota of Paje, Fumba and Makoba in Zanzibar. At Maruhubi, Machiwa (1999) measured lateral fluxes of organic carbon.

2.1.3 Impact studies

Impact studies on flora and fauna as well as on ecosystem scale are relatively few. A few examples of such studies include that of Machiwa (1999) who examined the effects of sewage dumping on the levels and rate of mineralisation of organic carbon in mangrove soils and by Kangwe (1999) who studied the effects of mercury, lead and cadmium on calcification rates of the reefs building calcareous algae *Amphipora tribulis*. Other studies include that which looked at the impact of pollution on plankton biomass and composition at Kunduchi and the harbour area of Dar es Salaam (Lugenda, 1998) and port development in Tanzania and their impacts on marine environment (Shanmungam, 1981). Bryceson (1982) assessed the impact of effluent (domestic, industrial) disposal on the ecology of Dar es Salaam coastal habitats. Chande (1994) identified and assessed the magnitude of activities that had an impact on the marine environment. Shunula and Ngoile (1989) assessed the consequences of human activities on the marine environment of Zanzibar.

2.1.4 Experimental studies

Experimental studies on water quality and pollution are limited to few studies in Zanzibar and Dar es Salaam. For example, Johnstone and Mohammed (1997) investigated different aspects of nutrient dynamics and community response to nutrient loading in tworeefs in Zanzibar. In a study to assess the fate of organic carbon in a tropical mangrove ecosystem, Machiwa (1999) used core incubation techniques to measure remineralisation rates of organic carbon in a partly polluted mangrove stand in Maruhubi mangrove stand in Zanzibar.

2.1.5 Review studies

Many review studies have been carried out to assess the pollution problem especially in the Dar es Salaam area. Uronu (1995) analysed the development of the sewerage system in Dar es Salaam, from its construction in 1948 through its different extension phases in the 1970s. The report also assessed domestic sources of pollution along the coast of Dar es Salaam. Another review of the development of the sewerage system of Dar es Salaam was done by Martinez (1998).

Other reviews include that of Bryceson (1981a) who assessed the state of the marine environment in the East African Region, including Tanzania. In another study, Bryceson (1981b) reviewed some problems of marine conservation with particular reference to Tanzania. A comprehensive review of the sources of pollution in Tanzania mainland was conducted by Mgana and Mahongo (1997), who quantified all major human activities that contributed to pollution of the marine environment. A similar kind of review was carried out in Zanzibar by Mohammed (1997) who investigated land based sources of pollution affecting coastal, marine and associated freshwater environments on the islands. Other reports from Dar es Salaam are those by Bwathondi *et al* (1991) who compiled all available data at that time on pollution of the Msimbazi River and advised on the need for a comprehensive multidisciplinary research. Mashauri and Mayo (1989) discussed the potential impact of discharging raw sewage into the Indian Ocean. In Tanga, Shilungushela (1993) made an inventory of destructive activities to the marine and freshwater bodies in the Tanga region.

2.1.6 Applied research

Applied research in water quality and pollution consist of those that were carried out with the prime objective of assessing the social impacts of pollution. These include those of Chaggu (1993) who studied ground water pollution in Majumbasita in Ilala District, Dar es Salaam and JICA (1996) who assessed environmental and sanitation conditions in Dar es Salaam. Outside Dar es Salaam, there were only a few studies. These that by Munisi (1998) who made a comparative study of intertidal floral communities in polluted and unpolluted areas near Tanga Municipality. Hoskoning and M-Konsult (1988) solid waste management and pollution by sewerage system in Dar es Salaam. Hoskoning and M-Konsult (1988) assessed solid waste management and pollution by sewerage system in Dar es Salaam. In Zanzibar, Gillian (1998) made an assessment of waste disposal practices in hotels located in four tourist zones on Unguja, Zanzibar.

2.2 Research methodology

2.2.1 Sampling aspects/parameters

Sampling aspects and sampling parameters dealt with in the various studies depended on the type of information gathered. Whereas baseline and experimental studies gathered quantitative data on pollution indicators or their impacts on flora, fauna or on whole ecosystem, applied and review studies mainly gathered non-quantitative data on other aspects of pollution. The later is exemplified by the study by Hoskoning and M-Konsult (1988) which looked at some aspects of solid waste management and pollution by sewerage system in Dar es Salaam. Quantitative data were gathered through collection of samples, mainly water samples, and in few cases sediment samples, and their analysis for their concentrations of nutrients, heavy metals, organo-chemicals, and coliforms. In addition to such basic data on pollution indicators, some studies have also collected data on environmental conditions, such as water temperature and current patterns in their reports.

Some studies were of socio-economic focus and these relied on formal and informal interviews. Interviews were carried out through standard techniques. In his study on waste disposal practices in hotels in Zanzibar, Gillian(1998) interviewed hotel personnel and government officials to assess these practices in tourism zones in Zanzibar. Chaggu (1993) partly used questionnaires for user utilisation surveys to assess pollution at Majumbasita in Dar es Salaam.

2.2.2 Instrumentation and techniques of sampling and data collection

With regard to instrumentation, most studies relied on basic equipment for sampling and analysis. In most cases water sampling was effected through the use of a simple bucket or beaker and as such sampling other than surface water was impossible. Similarly, sediment sampling was done with the use of hand operated plastic corers. An ordinary thermometer was used widely to read water temperatures and this measurement was therefore limited to surface water temperatures. Many studies measured turbidity and this was effectively done with the help of a secchi disc. Hand held refractometers were used widely to take salinity measurements.

The most widely used analytical instrument was the spectrophotometer. This was mainly used for nutrient analysis. There was very little automation. Consequently only few studies used the auto-analysis technique for nutrient analysis for example. The absence of the auto-analyser in many labs was a serious limitation in that in cases where samples to be analysed were very small, for example from pore water, some nutrients especially nitrates in sediments could not be analysed. Sophisticated instruments were used only rarely and in many cases samples had to be sent abroad for analysis. For example, in his studies on organic carbon distribution, mineralisation, and fluxes in Maruhubi mangroves, Machiwa (1998, 1999) relied on a TOC analyser that was available in Stockholm. Similarly, Mohammed (1998) used a CHN analyser for the analysis of total nitrogen and total carbon also in Stockholm.

Generally, the different methods employed in the above studies discussed gave more or less accurate data. Having said that however, there is a need of conducting regular inter-calibration exercises among different laboratories in the country to ensure further improvement in the quality of data generated by different researchers.

2.2.3 Sampling frequency, time of collection and duration of study

Generally, in most studies sampling was of short duration ranging from a few days to weeks. For example, Anderson (1994) in his monitoring of sewage pollution exercise took measurements for a period of two weeks. Similarly, the studies by Kastner (1996), Gillian (1998), Munisi (1998), van Bruggen (1990) were all of short duration. Third year projects by University of Dar es Salaam students were slightly longer. For example, Mwandya (1996) conducted a three months study taking measurements during the later part of 1995 to early 1996. Some studies were seasonal in nature and compared results between wet and dry seasons or between monsoons. For example, Mohammed and Johnstone (1995, 1999) measured wet and dry variations of water column nutrient variations and sediment-water exchanges in the Chwaka Bay mangrove forest while Mamboya (1996) compared wet against dry season variations of nutrients and dissolved oxygen in Mbezi Creek in Dar es Salaam. Only few studies were of longer duration of one year and longer. Kangwe (1999), Mmochi (1999) carried a two-year study to looked at the effect of land based pollution on reef building calcareous algae in the refs near Zanzibar Town. Mmochi (1999) carried out a one year monitoring study of water quality in Zanzibar.

2.2.4 Data analysis methods and procedure

Data analysis techniques varied from study to study depending on the type of information gathered, the number of factors involved and the nature of data, among others. In general however, there were few studies that had good statistical analysis of their data while majority of the studies did not apply any statistical treatment of their data atall. A few that had statistics include studies by Machiwa (1999). In his study in the Maruhubi mangrove forest, Machiwa used parametric one way analysis of variance (ANOVA) to test the difference in his measurements in the different zones of the forest. He also used Tukey test to compare sample means. ANOVA was also used in the studies by Mohammed and Johnstone (1995,1999) and Mohammed *et al* (1999). Nzali (1994) used the F-test to compare variations in nutrient concentrations between the dry and wet seasons. He also used the non-parametric Mann Whitney U-test to compare nutrient concentrations at various tide levels.

2.3 Quality, usefulness and reliability of data/information

2.3.1 Capability of scientists/researchers/reporter

Many of the studies synthesised in this report were carried out by students either under the supervision of their tutors or, in the case of visiting students, at some institutions by resident researchers. Others are those by senior researchers and consultants. Students' reports falls under three categories. These are academic reports produced by students from the University that report results of their field exercises; reports by visiting students; and Masters and PhD theses. Many of the studies, especially those by senior researchers, are of a good quality. The quality of studies that were closely supervised by capable scientists is also commendable. Masters and PhD theses from the University are normally examined both locally and externally. This also ensures quality products.

2.3.2 Comparability of methods

In almost all the studies nutrient analyses were carried out by the methods presented in the *Manual of Chemical and Biological Methods for Seawater Analysis* by Parsons *et al* (1984). These are standard methods. In this respect the methods used in these studies are comparable. This is also true for other analytical techniques such as those used for the analysis of heavy metals and coliforms. In the case of applied studies where information gathering was through interviews and questionnaire, the basic approach was similar in all the studies, even though variations in the interview techniques were apparent. All in all, the methods used in the various studies were comparable and hence may cause little problems in the interpretation of results in the future. It is noteworthy, as mentioned above, that the principal methods used in various studies, though standard, are quite old and lack any sophistication. This is a common problem that can be attributed to inaccessibility of new and better techniques. Improvement of analytical techniques will help produce better and more accurate results.

2.3.3 Publications/grey literature

In this synthesis, the literature is classified into seven categories. These are those that have been published in refereed journals (including those published locally), books/book chapters, papers in conference proceedings, reports, undergraduate research reports, Diploma thesis, Masters and PhD theses. Out of the nearly 130 references that have been examined, 23 are papers in journals, 25 in conference proceedings, 1 as a book chapter, and 59 reports. These publications are mainly from work carried out by senior researchers. Other reports were by students. These include 15 undergraduate research reports, 2 MSc theses, 2 PhD thesis and 1 diploma thesis. Consequently, reports, of which most are in grey literature, form the bulk of the references.

2.3.4 Age of information (old/recent)

Research in pollution and water quality does not have a long history in Tanzania. During a literature search preceding this synthesis, the earliest records found on this aspect were from the early 1970s. A 1971 report by the Danish Isotope Center gives results of a feasibility study that assessed receiving water supply for Dar es Salaam. Another study by Steinbach (1974) reported on the relationship between industry and environment in the Msimbazi Valley drainage area. Ngoile *et al* (1978) discussed aquatic pollution in Tanzania. These studies were followed, in the 1980s, by a number of investigations on different aspects of the environment (eg. Shanmungam, 1981; Shanmungam, 1983;UNIDO/UNEP, 1982). Then beginning the early 1990s, there was an upsurge of publications on the topic making this period by far the most productive in terms of literature on pollution and water quality. There is no significant difference in terms of quality of data/information generated in the 1970s and that generated more recently. This could be said to reflect uniformity and accuracy of the methods used. However, improvement of analytical techniques/ changing of technology may improve accuracy, limits of detection, and consequently overall value of the data collected.

2.4 Main findings/observations

2.4.1 Types of resource use

The coastal waters have many uses. Almost the entire fisheries industry of Tanzania for example, is artisanal and is based within the inshore waters. The coastal waters are also important for recreation activities, for tourism development, aquaculture and for transport. Many of these activities require good water quality.

The picture that emerges from the various studies show that in general the coastal waters in many parts of Tanzania are in a pristine condition. The exception is coastal areas bordering major tows and cities that are recipients of untreated municipal and industrial wastes and those receiving agricultural wastes. These include the main coastal towns of Dar es Salaam, Tanga, Mtwara and Zanzibar. In Zanzibar, faecal coliform and total coliform levels of up to 70/100 ml and numerous thousands per ml of seawater respectively have been reported in the waters fronting the Zanzibar Municipality (Mohammed, 1997). Nutrient levels are also higher than normal for tropical seawaters indicating anthropogenic inputs. Concentrations of nitrate of up to 7.8 µ-at N/l and phosphate levels of 4.0 µ-at N/l have been reported (Anderson, 1994). Likewise,it has been reported that there is a proliferation of macroalgae in Tanga coastal waters due to excess nutrient loadings from discharges from a fertiliser factory and from the municipality (Munisi, 1999). Coastal pollution in Tanga is also caused by discharge of effluents from sisal decorticating plants in the area. Up to twenty plants discharge their wastes onto the coast via the Pangani, Sigi, Mruazi/Mnyuzi and Mkurumzi Rivers (Shilungushela, 1993).

In Dar es Salaam, domestic waste is the most serious source of pollution. The west generated by 15% of the city residents who are connected to the sewer system is discharged into the sea untreated. As a result, the coastal waters off the city especially the harbour area is heavily polluted. Discharges untreated sewage in Dar es Salaam has resulted in high faecal and total coliform levels in the same areas. The situation is made worse by a broken sewer pipe which discharges untreated sewage on sandy-mud flats near the harbour which is said to threaten invertebrates and fish (Bryceson, 1981, Bryceson *et al*, 1990). It has also been reported that chlorinated organic compounds are at alarming levels in the harbour areas as are heavy metals, Pb, Zn and Cu (Machiwa, 1992). The harbour area also suffers from oil pollution from the refinery at Kigamboni, and industrial wastes from Keko, Chang'ombe, Kurasini, Mtoni and Temeke. These discharge heavy metal, pesticide, organic, and paint wastes into the nearby area (Bryceson, 1992).

Msimbazi River and Creek are also among the most polluted water bodies in Dar es Salaam. The river and creek receives large quantities of untreated domestic wastes from the city's residents in addition to industrial wastes from various industries. The river and creek receive such pollutants as dyes and paint wastes and strong alkalis (from textile factories), oil and tars, (from vehicle depots and power stations), organic wastes (from breweries and meat plants). Other industrial and agricultural chemicals that pollute the river and creek include heavy metals, PCBs, cyanides, pesticides, and detergents (Bryceson, *et al*, 1992).

Other coastal areas of Tanzania outside the major cities and townships though free from domestic wastes do suffer from input of agricultural wastes, including pesticides and fertilisers, via rivers and streams. Most major rivers in the country drain agricultural lands and deposit their waste loads on the coast. Unfortunately, this area of concern has not received sufficient attention in the literature. Riverdischarges on coastal areas also carry with them industrial wastes. An example cited in the literature is Kilombero River, which transport wastes from the Mufindi Pulp and Paper Mill from the hinterland to the coast (Bryceson *et al* (1990).

The coastal waters of Tanzania are also subjected to input of heavy loads of sediment especially in areas where major rivers enter the sea. Even though such inputs can be a result of natural events such as storm events and rains in upland areas, poor agricultural practices have been known to play a leading role in water quality degradation due to sedimentation (Bryceson, 1981). A direct consequence of this is the smothering of corals and other organisms as well the reduction of aesthetic value of the water thus making it less attractive for such activities as tourism as well as for general recreational activities.

2. 5 Scientific and management recommendations

There is no specific scientific recommendation given in the literature reviewed for this report. However, recommendations for management purposes have been given in a number of papers and reports. An important recommendation given in various reports is the need for the treatment of municipal waste before it is disposed of into the sea. In view of this recommendation, some reports have recommended the installation of primary waste treatment facilities to facilitate initial waste treatment before discharge.

Many reports have strongly recommended the promotion of local awareness of the dangers of pollution and thehealth risk associated with the problem. Specifically, Chaggu (1993), in her study at Majumbasita area, has recommended that that there should be formulated guidelines on the design and construction of wells and pit latrines with the view to reduce pollution in the area. She also recommended that people should be discouraged from using shallow hand-dug wells and that a monitoring program to study the fluctuation of ground water levels and quality should be initiated. The study further recommended thatthe public should be advised on the health risks associated with using water from shallow wells.

In order to alleviate the pollution problem in the coastal waters of Zanzibar, Walvoord (1993) recommended that leaks in sewage disposal pipes should be repaired and that faecal coliform concentrations in the water be reduced below health risk levels. Walvoord further recommended that the public is made aware of the risk of swimming in sewage contaminated waters.

Similar recommendations as above were given by Anderson (1994) and Mohammed *et al* (1993). Anderson recommended the rehabilitation of the Zanzibar sewerage system to reduce further pollution of Zanzibar coastal water. Mohammed *et al* (1993) recommended that the construction of discharge pipes should be such that it observes current patterns in the area of concern so that sewage is flushed out to the open sea. Another useful recommendation was given by Powell (1997), who studied ocean sewage pollution and composting toilets in Zanzibar. In that study it was recommended that the use of composting toilets be promoted in order to reduce the volume of sewage discharged into the sea and hence contamination risks. It should be noted, however, that not a single city or town in Tanzania has a sewage treatment facility and most of these cities/towns discharge their waste untreated into the environment. Dar es Salaam has a few stabilisation ponds. For the long-term sustainability of the coastal zone it is important to develop better facilities including treatment plants.

2.6 Information gaps

2.6.1 Geographic coverage

Most of the studies on water quality and pollution have been carried out either within or next to major towns and cities. Invariably, most of the studies reported in the literature have been carried out in Dar es Salaam, Tanga, and Zanzibar. One study was carried out in Mtwara. In that regard, geographical coverage of these studies can be termed as very poor. It can be argued that the most affected coastal areas are those that are located next to these densely populated towns and cities. Without doubt these are the principal sources of municipal wastes and hence the need for the studies. However, since little is known of the conditions of other areas, it is imperative that such studies be extended to cover a broader geographic area. Moreover, even in Dar es Salaam, Tanga, and Zanzibar, not all areas have been covered by these studies, both in terms of subject and geographic coverage. For example in Dar es Salaam, major efforts have placed at studying water quality problems in the harbour area and in the Msimbazi River and Creek at the expense of other area. The same can be said of Zanzibar and Tanga. In Zanzibar, the majority of the studies have been carried out in the waters fronting the Stone Town in the Zanzibar Municipality. These include both baseline and monitoring studies. In Tanga, the studies carried out in that municipality focussed specific target areas that are recipients of either municipal wastes or wastes from the local fertiliser factory (Munisi, 1998). However, one study whose aim was to assess the current state of the aquatic environment in Tanga looked, among other things, at pollution emanating from agricultural and industrial sectors. According to this study, effluents from the industries, mainly located within the Tanga Municipality, are either discharged directly into the seaor into rivers and streams which later find their way into the sae via run-offs (Shilungushela, 1993). It is obvious then that there is a need to broaden the geographic coverage of water quality studies not only in Dar es Salaam, Tanga and Zanzibar, where only a very limited area has been covered, but also in other parts of Tanzania where virtually no information on this subject exists.

2.6.2 Subject coverage

Most of the studies reported in the various papers and reports covered the area of pollution, mainly that emanating from sewage. Fewer studies have looked at other sources of water quality degradation and their impacts on the natural environment and on human health. Consequently, there are reports on nutrient loads and distribution, BOD levels and coliforms. Studies on heavy metal pollution and that emanating from organic compounds and agrochemicals are few and far between. These include a study by Mmochi and Mberek (1998) on pesticide pollution and those by Machiwa (1992a,b) which assessed pollutionby heavy metals and toxic material. Moreover, there are only few studies that have looked at the effects of pollutants, on the water quality in Tanzania. A good example is a report by Munisi (1998) who discussed the results of a determination on the effects of discharges from a fertiliser factory on intertidal floral communities in Tanga. Both Tanga and Dar es Salaam have relatively high concentrations of manufacturing concerns. Since few industries in Tanzania treat their wastes before they are discharged into the environment, it is obvious that they are principal sources of industrial pollution in the country. Given the current pace of industrial development in the country and the fact that only few studies on industrial pollution have been done, it is important that more studies should be carried out to generate both baseline information as well as to follow trends on the impact of these wastes on the water quality.

2.6.3 Duration of studies (long/short)

A great majority of the studies are of short duration. Given that most of the studies reported in this review were carried out by students either on short (weeks) study programs or on field attachments, invariably the studies tended to be very short. Where researchers did the studies, the duration of the studies was determined by the amount and source of funding. For obvious reasons, studies for Masters and PhD theses tended to be comparatively longer than, for example, undergraduate reports and degrees. Similarly, studies that aimed to monitor long- term effects of a contaminant on the environment were longer than the average consultancy report. On the whole though, long term studies were very rare.

From the above discussion it is obvious that specific efforts need to be taken to address the issue of time frame for sampling. It is important to identify which aspects or parameters that deserve to be addressed through long term and which through short-term studies. The question of seasonality is also important. In Tanzania, seasonality is intrinsically linked to study duration. The annual weather cycle in the east African coastal areas is generally made upof two periods of rainfall alternating with periods of dry weather. This cycle is essentially driven by the monsoon winds. Conceivably, this weather pattern has a large influence not only on waste discharges including that from upland agricultural areas but also on dispersal patterns along the coast. Few studies that looked at temporal patterns are available. Consequently, temporal variation/seasonality studies should be carried out when addressing both agricultural as well as municipal waste discharges. Such studies are also important when assessing waste dispersal patterns and their effect on the biota.

Point source discharges are inherently long-term events. They are therefore ideally examined through long-term studies. Long-term studies (over one or two years) are also essential when one requires basic data to help prepare a model of waste discharge and dispersion patterns. Long-term data therefore affords predictive capability.

2.6.4 Age of studies

As mentioned earlier, most of the available information in the literature is quite new as the bulk of the studies were carried out relatively recently. Of notable absence is historical information on the amounts and effects of different contaminants on the natural environment.

2.6.5 Information accessibility

Information on water quality and pollution is generally buried in private files and records and hence inaccessible to the general public. Poor organisation of reports in many departmental libraries makes the situation worse. University theses are only available at the university and have proved less readily available to people outside the university community.

2. 7 Recommendations for future work

2.7.1 Methods (quality, comparability)

As mentioned earlier, the methods used in the different studies are generally accepted as of good quality. However, it is important to ensure comparability of results from different researchers/laboratories. This can only be achieved by standardising analytical techniques. In this regard, the following are recommended.

- All laboratories use internationally accepted standard analytical techniques.
- To eliminate systematic errors, regular inter-calibration exercises should be conducted in the country. Such exercises can be internal (between a number of scientists in a laboratory) or can be between laboratories.
- The use of internationally recognised reference standards where available. This will eliminate errors that can arise from use of locally prepared standards.

2.7.2 Geographical/ Subject coverage and duration of studies

Geographical coverage has been discussed in detail above. Obviously however, some guidance is needed to direct research in areas where gaps in knowledge exit. TCMP is obviously better placed to lead such efforts.

With regard to subject coverage, there is a need for studies on other water contaminants such as pesticides, fertilisers, toxic chemicals and sediments. These have so far received only minimal attention. Agricultural chemicals in particular, could be important contributor to water pollution in coastal waters that are recipient of input from farm lands, through rain and river run-offs.

To start with, priority should be given to filling gaps in areas where there little or no data available before embarking on long term studies. Consequently short-term, studies should take priority over monitoring programs. However, this should be decided on a case by case basis, as there are areas that urgently require monitoring of both pollution inputs and its effects on natural environment. Because of the severity of the situation in such areas as Tanga and Dar es Salaam, these areas qualify for long term monitoring of water quality.

With regard to instrumentation and techniques of sampling, priority should be given to the later as poor sampling techniques and sampling regimes can lead to unnecessary errors as well as render results very difficult to interpret and hard to relate to management decisions.

2.7.3 Sampling frequency and duration and data analysis

Adequacy of sampling is a prerequisite of any scientific investigation. Most of the studies synthesised in this report had relatively short sampling frequency. This is may be due to the nature of these studies, mostly being short-term consultancies and students' projects. It is recommended that in future work more rigorous sampling should be adopted to ensure good representation of the process or aspect under study. However, one should always be mindful of the logistics involved in taking the samples and their subsequent handling. Sampling frequency is also dependent on the nature of the investigation. For example, a study the water quality of a lagoon would have a different sampling regime as that of a mangrove region and much more different to that of a point source such as a sewage outfall. Moreover, sampling frequencies will depend on whether the study is looking at tidal, seasonal, or even annual variations.

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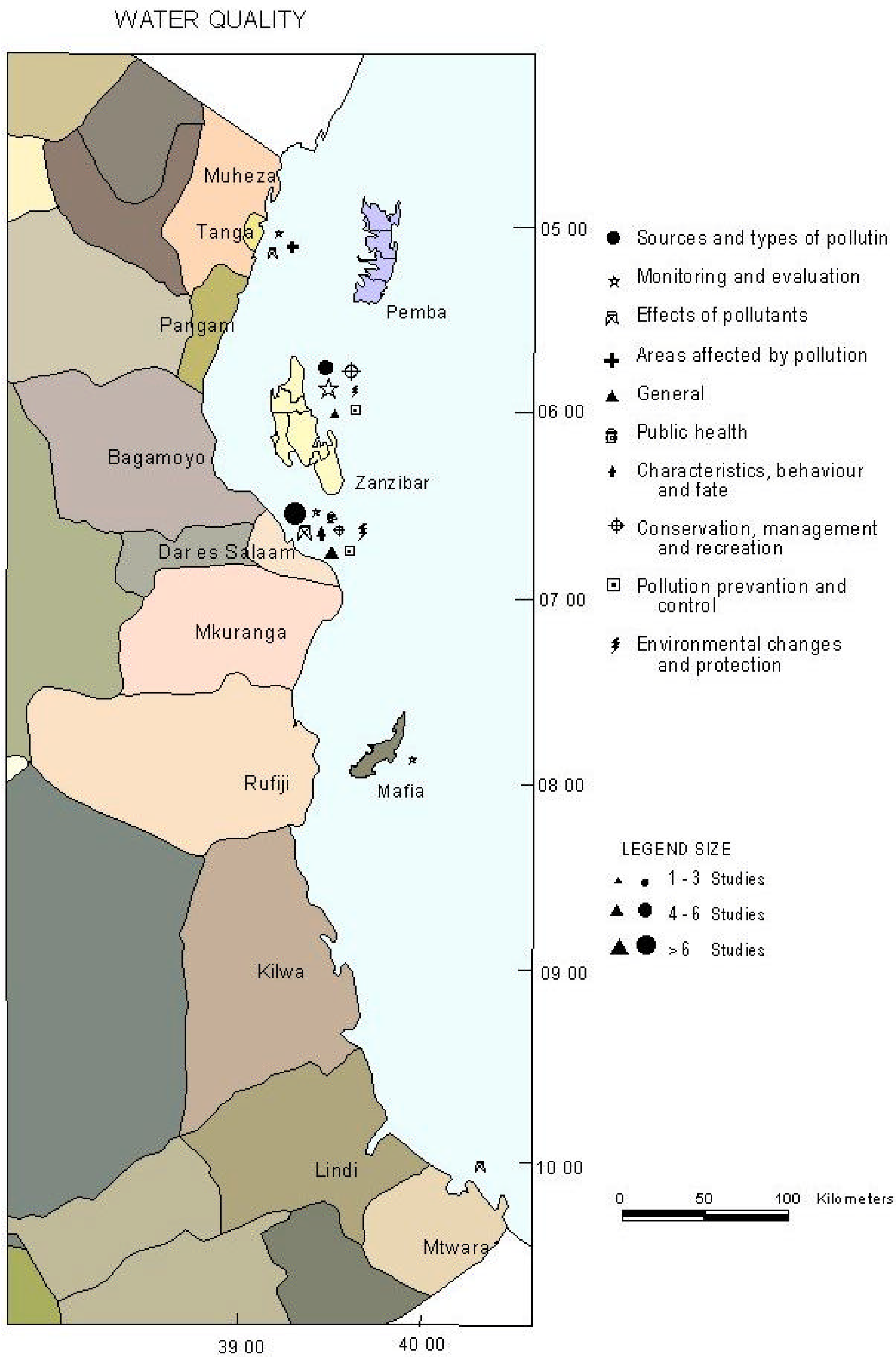

Figure 2.1. Tanzania coastal base map showing the distribution of research works that has been conducted in relation to coastal erosion. This includes all the available literature that was used in the preparation of the water quality and pollution synthesis.

Chapter 3

MARINE FISHERIES

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3.0 Background information

3.1 General description of the fisheries in Tanzania

Worldwide fishery is of immense importance and most of the coastal people depend on fisheries for their livelihood. Because of this, fishing methods have been improved and modernized in order to maximize yields per unit effort especially with the increase in demand due to the rapid rise in world population. The world fish landings currently are over 100 million tons per annum (FAO, 1997) and this does not include the over 10 million tons that are discarded every year. The current trend in the world fishery is a shift from large sized species to smaller size as a result of moving to lower trophic levels (Froese and Pauly, 1998). About 95% of the fishery in Tanzania is artisanal using traditional boats and gears. These are boats, dhows, outrigger canoes and canoes. The gears include nets, moveable traps (dema), hook and lines, fixed traps (uzio). Total catches range from 48,300mt to 56779mt for the for the Tanzania mainland (Figure 1) and 21,632mt in 1984-10062mt in 1998 in Zanzibar (Fig.2) (Jiddawi and Ngoile, 1999).

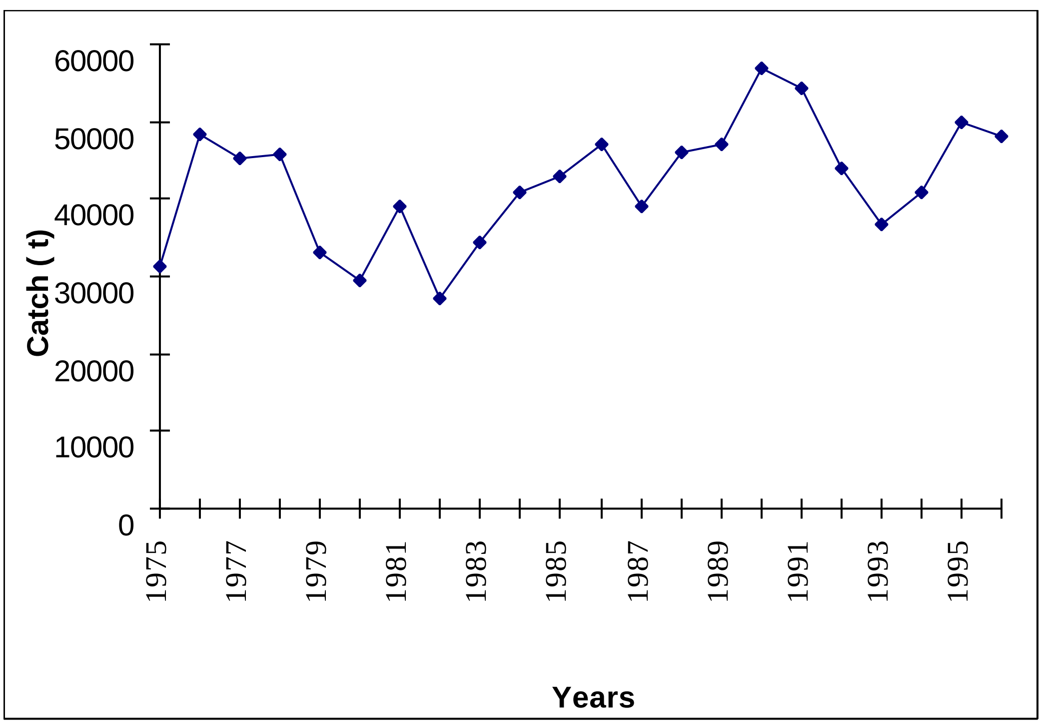

Figure 3.1: Annual fish landings Tanzania mainland 1975-1995.

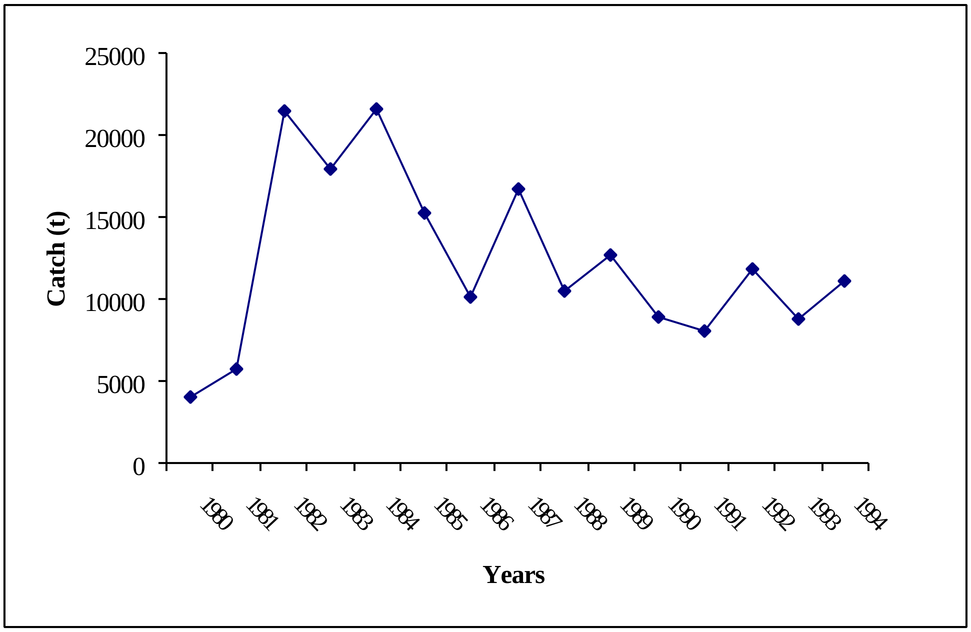

Figure 3.2: Annual fish landings Zanzibar. 1987-1996.

The continental shelf is narrow, about 4km offshore with the exception of the Zanzibar and Mafia channels where the shelf extends for approximately 60km. According to FAO (1988) the area of the shelf to the 200m depth contour for both the mainland and Zanzibar combined is 30000 $km^{2.}$ This is the area most commonly used by the artisanal fishermen. The inshore fishery recently has been showing signs of being overexploited. This can be seen especially in Zanzibar where the trend in annual catch is showing a decline trend. The same can also be heard from the elder fishermen who claim that in the past they used to catch much more and bigger fish in near shore waters than is currently the case and they have to travel further to obtain these catches. The high seas within the Exclusive economic zone continue to be unexploited and the resource potential is still not known. However, the area is rich in migratory species such as tuna, sailfish and marlin.

Most of the fish caught in inshore waters by artisanal fishermen are mostly demersal species (Lethrinidae, Serranidae, Siganidae, Mullidae, Lutjanidae) followed by large and small pelagic species (Carangidae, Scombridae, Cluepidae, Engraulidae), Others include sharks and rays, crustacea and octopus and squids. Most of the fishing practices are still destructive and have caused significant damage to the reefs. The most common destructive methods are dynamite fishing, dragged nets *(juya la kigumi)* and spears. Also, collection of marine products such as bech de mer is conducted without size limitations. The problem still persists due to lack of control, monitoring and Surveillance.

Fisheries research in Tanzania has been conducted since the beginning of the century, however at a slow pace. Research increased in the early 1940s with the establishment of the EAMFRO Organisation. Subsequently FAO played a key role in conducting research directed towards the development of fisheries in Tanzania. However most of the research in the country currently is conducted by the Tanzania Fisheries Research Institute (TAFIRI), the Zoology and Marine Biology Department, and the Institute of Marine Sciences (IMS) of the University of Dar es salaam. Recently the International Union for Conservation of Nature (IUCN) in Tanga and the Frontier Organisation in the Southern part of Tanzania has also played an active role in marine research. The main industrial fisheries in Tanzania are conducted by Tanzania Fisheries Cooperation based in Dar es salaam mainly fishing for prawns and the African fishing company based in Zanzibar mainly fishing pelagic fish in the deep sea.

3.2 Importance of the resource

Tanzania, with its 850-km stretch of coastline and numerous smaller islands including Zanzibar, is rich in fishery resources along its banks and coral reefs. Fishing plays an important role as a source of cheap protein and employment. The number of full time fishermen operating in Zanzibar is 23,000 fishermen (Lymo *et al*., 1997) and there are about 15,00 fishermen along the coast of Tanzania (Haule and Kiwia, 1999). The per capita consumption is 25-30kg/person (Jiddawi and Stanley, 1999). The contribution of fishery to the GDP varies between 2.1-5.0% in Tanzania mainland and 2.2-10.4% in Zanzibar mostly form export of fishery products (Jiddawi and Ngoile, 1999). Tanzania exports marine fishery products amounting to around US$ 7652,700 for the mainland part and US$598,203 for Zanzibar (Jiddawi and Ngoile 1999). These products are shrimp, beche demer, shells, lobster, crabs, squids, octopus, sardines, fish offal and aquarium fish. The fishery also supports a large infrastructure of supporting staff who make and repair boats and gears as well as marketing the fishery products.

3.3 Type of data and information gathered

A survey of the existing research publications reveals that there is a lot of work that has been conducted in Tanzania on fisheries covering a range of subjects from general fisheries information based on fishery constraints, development and management issues. Fisheries survey using SCUBA and snorkeling techniques have been conducted mainly in coral reef areas along the coast of Tanzania and Zanzibar. Fisheries statistics data collected from landing sites through monitoring programmes exist in areas such as Matemwe and Mkokotoni in Zanzibar, other areas includes Tanga and Begamoyo in the Coast region. The other type of data that exists is on resource utilization and socio-economic information.

In general the type of data collected is in the from research reports (both long and short term) reviews, published journal papers and unpublished reports. Most of the studies are of short term and only provides baseline information on the areas where the research was conducted. The majority of the studies are review studies.

3.3.1 Baseline studies

Out of 334 references on marine fisheries in Tanzania that were examined, 40% are baseline studies. Most of which were conducted in the 1990s and are mainly on monitoring of the fisheries resources, for example fisheries resource of Matemwe and Mkokotoni (Jiddawi and Stanley, 1997, 1999). This monitoring coved a number of aspects such as establishment of baseline information on the species diversity and abundance from the artisanal fisheries. Others are the type and number of gear used, areas fished and catch composition in relation to tides, lunar periodicity and monsoons. The importance of specific species such as octopus fishery from Matemwe and Mkokotoni has been reported in the same study (Mhitu and Jiddawi, 1999).

In Tanga, fish monitoring has been conducted through the IUCN, Tanga coastal zone conservation project and development programme, and resulted in several reports (Makoloweka *et al.*, 1996. 1997, Horill *et al.*, 1997). One aspect of the study was aimed at obtaining baseline information on the state of the environment and the starting point for the development and analysis of management strategies (Kalombo, 199). The study was initiated in 1994 and is still ongoing.

Baseline and resource use studies have also been conducted in Bagamoyo. These studies were conducted in early 1997 and the results have been documented by several authors (Mgaya *et al.*, 1999; Semesi and Howell, 1999; Semesi *et al*., 1998. and Msumi *et al.,* 1999). The main objective of these studies was to understand the extent of the use of the resources and to generate baseline data on the resources for planning and future monitoring (Semesi and Howell, 1999). The work in Bagamoyo included directed work on the sea cucumber and mollusc fishery (Mgaya *et al*., 1999). Other, short-term baseline studies have been conducted by students. These studies cover a variety of topics such as the Dema trap fishery of Tumbatu which examined the effect of habitat on trap catches (Horst, 1999), the fence trap fishery of Kisakasaka (Myers, 1999) which also provide a list of species caught in this fishery. Other topics include the large pelagic fishery of Nungwi (Smith, 1994, Knox, 1999) and the participation of women in fishery activities in Nungwi village in Zanzibar (Coleman, 1998). Richmond and Mganwa (1994) conducted a study on large pelagics at Matemwe. The study is based on the outcome of the donation of two engine powered sailing dhows by the Netherlands Embassy to two fishing cooperatives in the village. Prior to this the fishermen were using sail-powered outrigger canoes and simple fishing equipment. The most interesting aspect of this study was that, the fishermen themselves conducted the monitoring exercise by completing a daily log book provided by the scientists daily on their catches. The project is still continuing and several reports have been written (Richmond and Mganwa, 1994, 1995, Richmond, 1999).

Fewer than10 MSc and Phd studies have been conducted. The studies focussed on providing information on specific fishery topics. For example, the biological aspects of Siganids and their mariculture potential in Tanzania (Mziray, 1983); the food and feeding habits of Indian mackerel from Zanzibar, (Ndawula, 1985); the reproductive biology of the squid in the coastal waters of Zanzibar (Mhitu, 1997); the dynamics of the trap fishery in the coastal waters of Zanzibar (Mgimwa, 1998); and the population dynamics of the small pelagic fishery in the Zanzibar channel (Jiddawi, 1999). In Southern Tanzania several studies have been conducted on fisheries resources in the area by FRONTIER. These studies provide information on fish species diversity in relation to the density and diversity of coral cover as well as providing a description of the main fishery activities in the area *(*Darwall *et al.,* 1995, 1996a, 1996b; Guard, 1999).

Frame surveys on fishing units and fishermen have been conducted mainly in Zanzibar by Ngoile (1982), Carrara (1985), Hoekstra *et al.*, (1989) and Lyimo *et al*. (1997). The surveys establish the status of fishing effort in terms of number and type of gears, number and type of vessels, fishermen on foot and those operating using vessels. The surveys thus establish the geographical concentration of the gears and vessels and also set up baseline information that could be used to compare current fishing effort with the past. This information is very useful in planning and setting up fisheries development and management strategies. Muhando and Ngoile (1995) conducted a study on the nursery potential of mangrove ecosystems in Zanzibar. Amir (1997) and Ongera (1997) have conducted similar studies. In addition to providing a list of fish species found in these areas, they have also conducted length-weight relationships of some of the most common commercial species.

3.3.2 Observational studies

Only 0.9 % of the examined literature were of observational nature. These included under water visual surveys in Fumba Peninsula (Horrill, *et al.*, 1994). Observational studies also were conducted in seaweed growing sites on the East coast of Zanzibar to observe the distribution and abundance of inshore fish assemblages (Svanson and Bergman, 1998). Other studies in Zanzibar included observing fish population structure with special reference to algal farms, (Nilsen and Patterson, 1996) and a study of dema traps at Tumbatu. This study examined the placement of these traps on the different habitats and their impact on the environment. This study, however, was only of a short duration but it provided an insight on how the traps are used and what species of fish are caught, where and at which depth (Horst, 1999).

3.3.3 Experimental studies

Experimental studies are more related to gear development and usage (Losse, 1966, Mahika, 1992), and experiments related to aquaculture such as preferential settlement of oyster spat settlement on different substrates in Zanzibar (Jiddawi, 1989, 1997). Another important aquaculture study is the integrated fish-farming model that was developed in Israel and tried at Makoba in Unguja Island by the Institute of Marine Sciences in collaboration with the Prison department. The model includes effluent treatment in order to minimise downstream effects. The study also included local fish feed formulation and trying this feed on fish in the laboratory (Mmochi *et al.*, 1996, 1999). Also, an experimental culture of rabbit fish in cages was attempted in the habour area of Zanzibar town (Bwathondi, 1981a, 1981b). Experiments however, were very few and comprised only 2.4% of all the studies.

3.3.4 Applied studies

Applied studies are related to the experimental studies and these were also very few accounting for 2.7% of all the studies. Mostly they were related to aquaculture experiments such as the cage culture of *Siganus* spp. (Bwathondi, 1981a), the aquaculture of rabbit fish and milkfish in ponds at Makoba (Mmochi *et al.*, 1996, 1999) and the experimental culture of oysters, *Saccostrea cucccullata,* in the habour area of Zanzibar *(*Jiddawi, 1989). Talbot and Newell (1957) attempted the first study on fish aquaculture in marine ponds in Zanzibar. The fish cultured in the experiment was Tilapia, although *Chanos chanos* later invaded the ponds and became very successful as well. These studies have started to have a positive implication among the people in some areas of Tanzania that have shown great interest of establishing mariculture ponds.

3.3.5 Review studies

Most of the fisheries reports that were examined (41%) are of review nature. These studies presented the general information on fisheries in different parts of the country and the West Indian ocean region, for example Cushing, 1985, Maembe, 1988; Jiddawi *et al.*, 1992, 1994, Mhando and Jiddawi, 1998). Several reports discuss fisheries development in the country and priorities for fisheries management (Boerema, 1981, FAO, 1982, Ardill, *et al*., 1991). The reviews also provide information on the status and trends of exploitation of marine fisheries in Tanzania (Bwathondi and Ngoile, 1982; Nhwani, 1983, Bryceson, 1985; Ngoile, 1988,). The reports also review specific fisheries such as the pelagic fisheries (Nhwani, 1983,1988) and the demersal fisheries (Ngoile, 1982, Pratap, 1982, Bensted-Smith, 1987, Jiddawi, 1997a. Mhitu and Jiddawi, 1999). Environmental conservation in the artisanal fisheries sector has also been reviewed for the Tanzania mainland (Mwamsojo, 1999) and in Zanzibar (Jabir *et al.,* 1999).

3.3.6 Other type of studies

Fishery resource surveys have been grouped in other type of studies and forms 12% of all the studies. All the fish resource surveys conducted by Research Vessels in Tanzania waters and the region fall under this category. These surveys include the surveys conducted by Dr Fidjitof Nansen in the 19980s (Anon, 1982a; Iversen *et al*., 1985), the survey by R.V Prof Mestyasev (Birkett, 1978, Venema, 1984) and the surveys conducted by Mbegani fisheries Institute through its research vessel MV Mafunzo (Van Nierop, 1987b, Msumi, 1986, 1987, 1988). These surveys provided an insight on the fishery potential and stock abundance in the Tanzanian waters. The Fishery acts and policies also belong to this category *(*Anon, 1993; Maembe, 1984) as well as sociological and economical studies on fisheries (Mapunda1983, Chachage, 1988, Saleh, 1992, Nasser, 1995, Soley, 1997). Studies on shark trade and fish export (Ameir, 1995, Barnett, 1997) and legal aspects of fishing in Tanzania (Christy, 1981; Lamwai, 1988, Anon, 1999) have been included in this list.

3.4 Research methodology

This section refers to baseline, observational experimental and applied studies where samples were collected for detailed studies.

3.4.1 Sampling aspects and parameters

Sampling aspects varied according to the studies conducted. In the case of fish resources surveys the parameters measured were temperature, depth, salinity in order to determine the relationship between fish abundance and availability, size and species distribution with the physical parameters (Iversen *et al*., 1985). For biological studies such as length weight relationship and morphometric studies of fish the parameters measured on the fish were total length, standard length, fork length, eye diameter, body depth, snout length, and other parts of the body (Rubindamayugi, 1983; Mhitu, 1997; Jiddawi, 1999). Other common parameters measured in reproductive studies include individual weight of fish and visual observation of sex and gonad maturation (Mgimwa, 1998, Jiddawi, 1999).

Some important parameters collected during the different studies were catch and effort data of the fish during landings in studies related to estimation of fish biomass (Jiddawi, 1999). Others were areas fished, weather conditions, the fishing duration and any other factors that could have an impact on the days fishing such as festival and cultural taboos in fishery descriptive studies (Jiddawi and Stanley, 1999).

3.4.2 Instrumentation and techniques of data collection

Sampling techniques varied in the different studies. Whereas in the case of Jiddawi and Stanley (1999), the study involved standing at the landing site and recording details of each, Horst (1999) actually followed the fishermen as an observer in their fishing boats to assess the performance of the dema trap fishery. In some instances specimen were bought from the fishermen for detailed studies of specific fish. These include the biological and age and growth studies of the Indian mackerel *Rastrelliger kanagurta*, (Jiddawi, 1999), the biological study of squid (Mhitu, 1997) and during the study of the biology of the blue speckled parrotfish *Leptoscarus vaigiensis* along the coast of Tanzania, (Rubindamayungi, 1983).

Few instruments were employed in fishery studies apart from standard equipment such as the measuring board, the Vernier calipers, weighing scales and portable spring balance. In some several instances the fishing gears were checked on their efficiency. For example the beach seine net was used as an equipment for catching fish in intertidal areas during the study of the nursery potential of the mangrove ecosystem (Muhando and Ngoile, 1995), Mahika (1992) used grid separators to reduce by catch in the Panaeid fishery. Hydrographical data, such as temperature, salinity and oxygen content were collected using reversible Nankeen water bottles which were applied in different depths during fish resource surveys. Also, samples from the surface were collected by a buckets *(*Iversen *et al*., 1985). Fish abundance was investigated acoustically using scientific sounders, integrators and sonar equipment (Iversen *et al*., 1985). Pelagic trawl hauls were carried out either to identify scattering layers or to investigate the surface layer for fish. Demersal trawl hauls were placed at random in trawlable areas and fish biomass estimations were made according to the swept area method (Anon, 1982, Iversen at al., 1985; 1983; Msumi, 1988).

3.4.3 Sampling frequency and time of collection

Sampling frequency and time of collection varied depending on the study. Data collection in most of the fisheries studies requiring landings data was done normally during the rising tide when the fishermen are returning from their days fishing. During the monitoring study of the artisanal fisheries of Matemwe and Mkokotoni for example the sampling was done routinely twice during the neap tides and twice during the spring tides in a month due to the differences in fishing effort and landings during the two tides. Also, monitoring was conducted throughout the year so as to get variations within the months. Within the same study detailed sampling was also done daily to study fishing performance of selected individual fishermen over the different seasons.

In the case of the nursery potential of mangrove ecosystems study, sampling was conducted during spring tides when the water was low enough to use the beach seine and to be able to get some fish *(*Muhando and Ngoile, 1994). During underwater visual surveys of the fish distribution in algal farms observations and sampling was done during high tides to ensure good visibility and easy observation (Svanson and Bergman, 1998). Sampling was done during the day in case of daytime fishery, when the fishermen normally return from their fishing activities (Coleman, 1998. Mgimwa, 1998) and at night in case of night fishing such as for the purse seine fishery (Jiddawi, 1999) and in the Wenge light attracted fishery at Kisakasaka (Meyers, 1999).

3.4.4 Data analysis methods and procedure

In most of the studies, data was analysed using standard procedures for fisheries studies. This ofcourse depended on the aspects that were being examined. For example, Length weight relationship of fish were examined following Le Cren (1951), e.g. Rubindamayugi, 1983,; Mhitu, 1987; Mgimwa, 1988 and Jiddawi, 1999. Statistical tests were analysed as elaborated in Zar (1984), e.g. Mhitu, 1987, Mgimwa 1988. Growth and Mortality estimates were done using the Fish Stock assessment programme of FAO, e.g. Jiddawi, 1999.

3.5 Quality, usefulness and reliability of data and information

3.5.1 Duration of studies

The duration of the studies varied according to the nature of study and whether it was pure research or research leading to an academic degree. Some were of long term lasting up to several years (Jiddawi, and Stanley, 1999) whereas others lasted for a few days only (Meyers, 1999). Phd and MSc thesis related data collection was generally of about 1-2 years and thus took longer periods (Mziray, 1983, Rubindamayugi, 1983, Mhitu, 1997, Mgimwa, 1998, Jiddawi, 1999). Undergraduate projects normally lasted for about 2 to 3 months (Amir, 1997, Ongera, 1997). These were aimed at giving baseline information on some fisheries aspects. Some rapid assessment surveys lasted a few days. These were only aimed at determining where the fishermen fished and to provide baseline information on the fisheries (Horst, 1999, Gaudian and Richmond, 1990).

3.5.2 Capability of scientists and researchers

Capable renowned local and overseas scientists with high academic qualifications did most of the work on fisheries. Some were conducted by junior scientists such as undergraduate students who worked under supervision of experienced scientists. Their work provided a platform for other people to pursue indepth studies. Consultancy research work has also been conducted by experienced personnel from FAO and World Bank, for example Tiffney, 1984; Wiljikstrom, 1988, Hoekstra, 1990, Ardill, 1991. The available information is therefore quite reliable.

3.5.3 Comparability of methods

The methods used on the discussions on fishery profiles are comparable as they were mostly conducted by FAO and they involved summaries of analysis of statistical data available in the fisheries departments using the same format (FAO, 1982, Sanders, 1999, Ardill, 1984). The methods on the surveys on resources varied. Some used interviews (Carrarra, 1985; Anderson *et al.*, 1997; Nasser, 1995) others did actual observations through diving (Darwall *et al.*, 1996) and observations at the landing markets *(*Jiddawi and Stanley, 1999) and through actual surveys using research vessels (Merret, 1968, Birkett, 1978; Anon, 1983; Msumi, 1988)**.** The methods used in the studies on the biology of fish species were somehow comparable as they all observed similar aspects and followed similar methodologies. Monitoring of the fish resources in the different areas differed depending on the interest of the scientists.

3.5.4 Publications/grey literature

Out of 331 references listed about 70% are grey literature. About, 52 of these reports were published in international journals (Hatchell, 1938; Morgan, 1959, Losse, 1964; Merret, 1968; Bwathondi and Ngoile, 1982, Ngoile, 1982, Gaudian *et al*., 1995). The rest of the reports appear as seminar and proceedings, for example; Ardill and Sanders, 1991; Muhando and Jiddawi, 1998, Jiddawi and Stanley, 1999; Mgaya *et al.,* 1999. Some are

Institutes annual reports, for example; Darwall, 1995, Mmochi, *et al.*, 1997, Jiddawi *et al.*, 1994. Others are consultancy reports, for example; Horrill, 1992, Killango, 1984, Barnett, 1997, student reports *(*Knox, 1999, Meyers, 1999). Graduate thesis *(*Mhitu, 1997, Mgimwa, 1997, Jiddawi, 1999). Most of the above publications can be obtained from Universities. FAO reports with limited publications can be obtained from the FAO headquarters in Rome. The abstracts of these reports can also be found in ASFA. Some of the fisheries information has been documented as videos and are available through the Marine extension development unit of the Institute of Marine Sciences.

3.5.6 Age of information (old/recent)

About 45% of the references were written in 1990s especially the project reports such as those from Tanga *(*Makoloweka *et al.*, 1997a, from Mafia *(*Darwall *et al.*, 1996a*)*, from Mtwara (Guard, 1998), from Bagamoyo (Semesi and Howell, 1999) and Matemwe/Mkokotoni area in Zanzibar (Jiddawi and Stanley, 1999). About 36% of the reports have been written in 1980s and the rest between 1920 and 1970s. The earliest reference which was located dated back to 1929 on the survey of marine fisheries of Zanzibar Protectorate (Bonde, 1929). The earlier research papers particularly aimed at looking on how fisheries could be developed in the country. These were followed by research on gear technology and species availability. Although, the rate of publications has been increasing (Figure 3), most of the studies seem to be of short term and aimed at providing baseline information. However, the reports have greatly assisted in one way or another in adressing scientific and management issues.

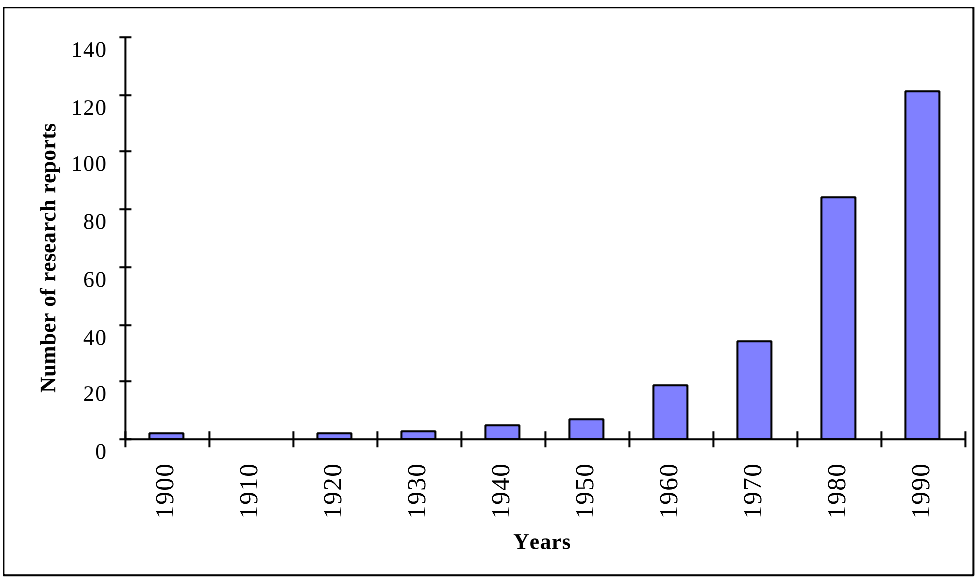

Figure 3.3: Trend in fisheries research in Tanzania

3.6 Main findings and observation

3.6.1 Types of resource use

Fisheries resources are very important to Tanzania and fish contributes over 70% of the protein intake of the coastal population. Almost all people along the coast involve themselves in fishing activities. Whereas men go out to fish in boats, women mostly glean the intertidal areas for gastropods, bivalves and sea cucumbers (Coleman, 1998). The edible portion is consumed as food and the shells are sold to tourists. Coastal communities depend on fishing as their main income activity and 95% of the fish landings in Tanzania is from these fishermen (Haule and Kiwia, 1999). Some of these resources such as shark fins and sea cucumbers are exported to the Far

East (Barbett, 1997). The trade for these resources has been present in Tanzania for centuries, Shark meat is widely consumed although it is not very popular in comparison to other species of fish. Shark jaws and teeth are sold to tourists. Some fish is exported fresh overseas and foreign exchange is available through the export of these products. Most of the export revenue comes from shrimps. The two main fishing grounds for shrimp are around Bagamoyo/ Sadani and the Rufuji Delta in South of Tanzania where about five species of shrimps are caught (Semesi and Ngoile, 1993)

3.6.2 Condition of the resource

The fishery resources have reached the upper level of exploitation. This is believed to be due fishermen fishing in the same areas since time immemorial due to the limitation of the range of their fishing vessels which are not powered by motor engines and due to lack of proper management strategies. Interviews with fishermen also confirm that catches are declining. Increase in fishing effort will not increase catch rates. The total annual catch in Zanzibar was about 20, 000t in 1988 but currently it has dropped to less than 13000t. This reduction in fish catch can also be observed in some localised areas such as in Chwaka bay (Jiddawi, 1999b) and for specific fish such as the reef fisheries of Zanzibar (Jiddawi, 1998).

There are some resources, which have been affected more than others. For example in the Zanzibar the small pelagic fisheries, the catch has drastically decline from 600t in 1986 by the Zanzibar fisheries cooperation boats to 91t in 1997 (Jiddawi, 1999a). The history of the purse seine fishery has been documented in a video produced by Jiddawi (1996) under the Marine Education and Extension Development Unit at the Institute of Marine Sciences, Zanzibar. Fish resource assessment surveys conducted in the 1970s (Birkett, 1978) and in the 1980s (Iversen, *et al*., 1985) gave estimates of the standing stocks for coastal water ranging from 94,000t to 174,000t. Annual yield estimates for demersal species was 38,000t/year and about 23,000t for pelagic species (Ardill and Sanders, 1991). Seashells and sea cucumbers are overexploited along the whole coast due to rampant collection. There have been no population studies of any of the commercially exploited species (Horrill and Ngoile, 1991). However, the traders claim that the sizes of some of the sea cucumbers have decreased, but they still continue to buy due to competition among traders. The catch rate of the long line fisheries in most parts of the region including Tanzania, the catch rate, in numbers and weight, has declined drastically (Ardill, 1984). Shark fin trade has also declined and some fish species are rarely seen now in Tanzania waters (Barnett, 1997; Jiddawi and Shehe, 1999)

3.6.3 Human impacts

The demand for fishery resources has been gradually increasing with the increase in population and tourism development. This has caused an increase in fishing pressure and the use of gears that are efficient but destructive. Most of these gears are prohibited by law (Anon, 1988, 1993) but due to lack of monitoring and surveillance they continue to be used. Some of the destructive gears commonly used are dynamites, which has been documented by several authors (Chachage, 1988, Chande, 1994, Guard and Masaiganah, 1997). The use of the beach seine *(*Benno, 1991, Linden and Lundin, 1996), sticks, spears and *juya la kigumi (*dragged net) which smashes reefs (Muhando and Jiddawi, 1998) has also been reported. This fishery is one of the most difficult to control because the net used is not illegal, however, it is the action involved in the technique of using the net which is a problem. That is the breaking of coral reefs associated with the use of sticks to chase away hiding fish. Some fishermen also use poison in fishing (Muhando and Jiddawi, 1998). The use of such gears leads to indiscriminate destruction of the breeding and nursery grounds of fish and has seriously affected the fisheries. The fish larvae and juveniles are killed before they grow and recruit into the fishery.

Destruction of habitats by human through indiscriminate mangrove cutting have also a negative influence on fisheries as mangrove are nursery and breeding grounds of fish. This is very common in many parts of Tanzania as mangroves have many uses. Also, human impact is caused through building of dams. One report summaries the impact of the Stiegler's Gorge multipurpose project on fisheries in Rufiji delta and Mafia Channel under the Rufiji Basin Study Programme *(*Atkins, 1981)

3.6.4 Natural impacts

There is no report that describes natural calamities. However, storms and strong waves are known to damage coral reefs and indirectly could affect fish populations. Other impacts could be caused by river runoffs, which could create siltation effects especially around river mouths. A recent event, has been that of coral bleaching caused as a result of the increase in water temperatures in 1998 due to El Nino effect. This is believed to have caused an impact on coral reefs in several parts of Tanzania and is hypothesised to have caused a change in fish species composition (Muhando pers comm., 1999). In Some areas where bleaching has occurred, Marcus (1999 observed a shift in species composition with herbivorous fish dominating these areas (Ohman per comm, 1999). A study has now been initiated to look at the impact of bleaching and other factors affecting coral reefs on fisheries and tourism in Tanzania and the whole region in general.

3.7 Scientific and management recommendations

3.7.1 Scientific recommendations

Several recommendations have been proposed in the different reports. Some of them are listed below:

- A comprehensive research programme on marine resources is required to determine the distribution, abundance, biology and value of the resources.
- Stock assessments as well as surveys need to be conducted in the traditional fishing grounds.
- Monitoring of the resources in order to obtain baseline information for comparison with future studies have been recommended as well as determining the extent and usage of destructive fishing gears.
- Growth studies of fish through the use of length frequency information and through culturing in ponds have also been suggested.
- The value of Underwater Visual Census surveys should be recognised especially for indicating effectiveness of fishing gears and revealing fishing effects on fishing community structure.

3.7.2 Control over the use of destructive fishing practices

- Resource users need to be involved in making management plans because they have better knowledge of the resources.
- The use of destructive gears such as beach seine and the use of poison should be banned in order to protect juvenile fish and other resources.
- Small sized shells, gastropods need to be returned to where they were collected to enable them to grow
- Existing laws on fishery need to be advertised to the general public.
- Fisheries regulations need to be strengthened and enforcement should be improved by providing facilities such as patrol boats and armed officers in order to reduce illegal fishing practices.
- There is a need to establish reserve areas that can serve as gene pools.

3.7.3 Conservation/protection/restricted use

Management of the coastal and marine environment is essential and various management options have been suggested on how best to manage the environment from all these studies for example:

- Involving the community in control and monitoring of their resources and establishment of marine reserves as a means of ensuring sustain ability of the resources.

- Establishing of marine and protected areas which could serve as a source of funds through tourism and as a source of awareness and the need for conservation among children
- Traditional management to be encouraged such as the seasonal octopus closures in the Southern Unguja villages and restrictions of visiting fishermen in restricted areas

3.7.4 Local awareness/participation/training

Conservation of the marine systems should be geared towards benefit to the community and they should be educated to appreciate the role of conservation. This should start at the lowest level, from school children by including conservation studies in their curriculum (Muhando and Jiddawi, 1995). The Institute of Marine sciences in collaboration with Memorial University of Newfoundland has produced several books and videos in an attempt to assist in education and awareness *(*Dickson and Ngoile, 1995). This process needs to be promoted further. Fishermen should form fishermen's associations that can assist them in solving their problems. It has also been proposed that there should be improved data collection systems, the current system seems to be inadequate and need to be improved. One suggestion is to inrtroduce a system of providing local fishermen with logbooks to record daily catches. Fishermen and the general public need to be sensitised on the risks and consequences of mismanaging the fish resources and their habitats. Lastly, encourage alternative fishing practices and the use of under-utilised resources such as deep-sea fishing and aquaculture.

3.8 Information gaps

3.8.1 Geographic coverage

Although fisheries seem to be widely studied, yet several gaps exist. Most of the studies are conducted in areas where the research institutions exist or where there are projects. A majority of the reports come from Zanzibar, Mafia, Mtwara, Tanga, Dar es Salaam and Songosongo. A few are from Rufiji, one from Pemba and one from Ruvu. Many areas are still not studied due to lack of any institution in those areas or lack of existing donor-assisted projects (Figure 4).

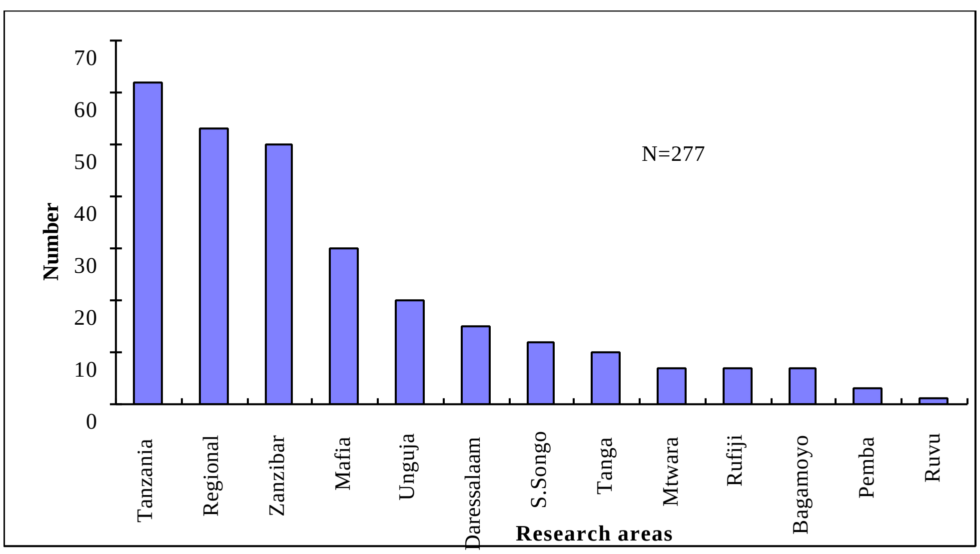

Figure 3.4: Areas in Tanzania where fisheries research has been conducted.

3.8.2 Subject coverage

Most of the reports that were examined discuss on general fisheries perspective in Tanzania (62 references). Several discuss the biological aspects of fish (28 references) and about 47 references present information on specific fisheries such as the shark fisheries or the demersal fisheries in Tanzania. About 10 references present information on socio-economic aspects of fisheries. Fisheries development is discussed in about 15 references. Conservation issues, marine parks and integrated management of fisheries is discussed in 67 references (Figure 5). It is important to note that there significant overlaping in these subjects so the large number of references should not be misleading.

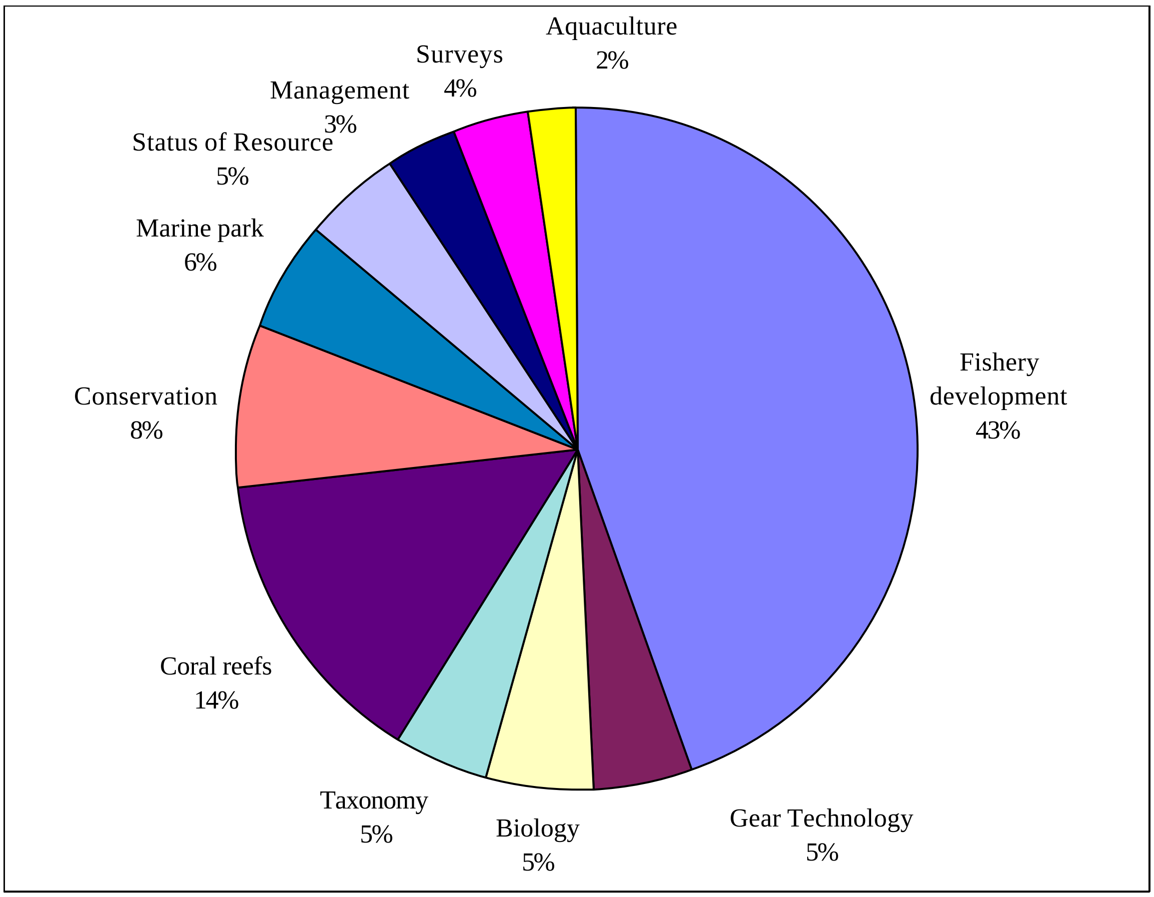

Figure 3.5: Subject categories in fisheries research.

3.8.3 Duration of studies

Most of the studies were of short term. There is therefore a need to repeat these studies over a longer duration. The only long-term study, which is still ongoing, is the Matemwe and Mkokotoni fish monitoring study.

3.8.4 Age of studies

There are several new studies, however, most of these new studies are of short term and have been conducted by students geared at giving them grades in their subjects. They are not geared at problem solving. However, a lot of surveys, which were quite useful, were conducted in the 1980s. Ever since that time no surveys have been conducted,. Also some of the useful studies have been conducted in the early 1960s and 1970s under the East Africa marine fisheries organisation.

3.8.5 Information accessibility

Almost 50% of the information is difficult to access as it is in the form of unpublished reports. In most cases only one copy of the report exists and it is based with the author. (Figure 6)

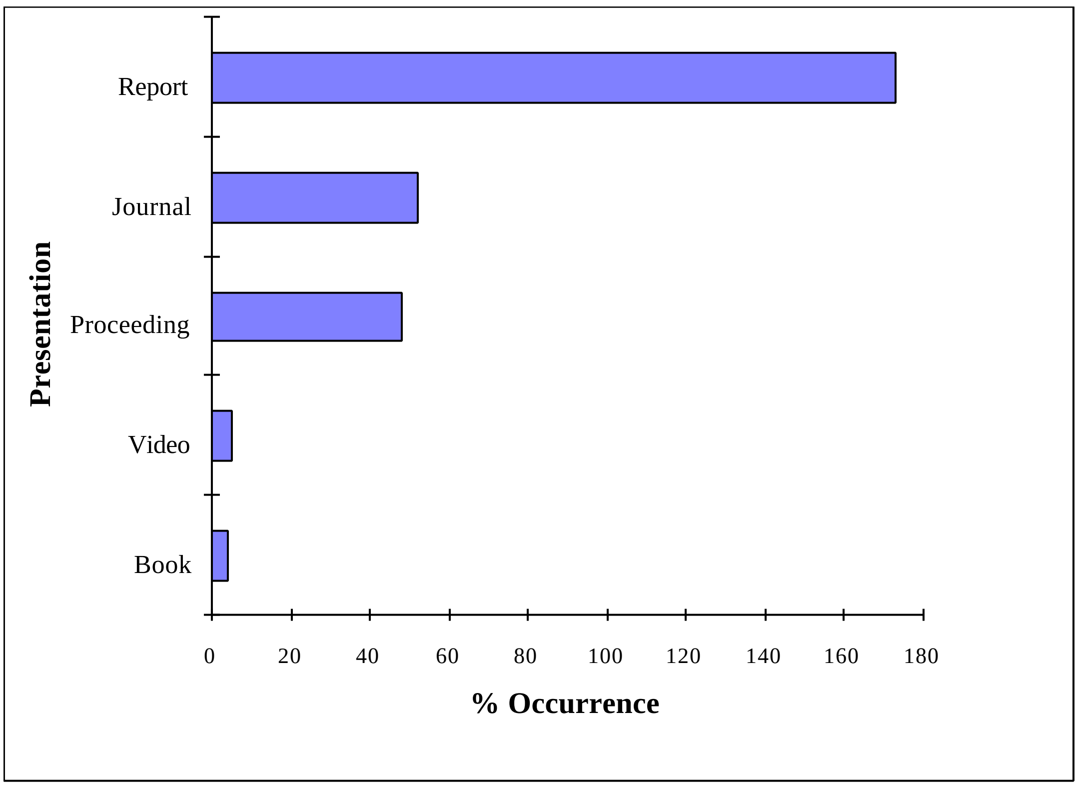

Figure 3.6: Information presentation by researchers.

3.9 Recommendations for future work

3.9.1 Methods (quality, comparability)

There must be better collection of landings and economic data from the fisheries. Without effective data collection it will be difficult to formulate better management strategies. Therefore, for the assessment of these fisheries it is important to use standardised techniques over the whole country for comparison purposes and to initiate incentive schemes for data collectors.

3.9.2 Geographic coverage

Specific reference points should be selected along the coast for monitoring purposes to ensure that at least the whole coast of Tanzania is represented. These could be in the major fish landing ports and areas where such information is required such as where there are marine protected areas.

3.9.3 Subject coverage

The areas which have been less studied such as minor fisheries such as the octopus fishery, the sea cucumber fishery, fence trap fishery need to be studied. Also more biological studies of important commercial fish species are required. Basic science studies such as looking at food and feeding habits of fish of which the results can be used in ecosystem modelling such as the ECOPATH.

3.9.4 Research

Effective management of the fish resources requires adequate research into the ecology, biology and assessment of the stocks. Therefore it is suggested that there should be continued long-term research in different aspects of fisheries, in order to get reliable information for sustainable management of the resources. Research should be geared towards problem solving and development of the fisheries. Reseasch should be multidiscilinary and integrated involving all users. Socio economist and scientists should formulate joint research proposals in determining problems facing the fisheries industry.

3.9.5 Monitoring

Monitoring is required throughout the country especially to look at the catch landings, catch rates and species diversity so as to be able to determine immediate changes. The monitoring exercise needs to be long term. The monitoring should involve the community in collaboration with scientists.

3.9.6 Training

Most of the fisheries staff in Tanzania are at a diploma and Masters level of education. There is need for capacity building in fisheries staff at a much higher level (Phd level) due to scarcity of such people in the country.

3.9.7 Other(s)

Effective communication links between relevant institutions within the country can reduce duplication efforts as well as keeping participants current with all activities. There should be a defined national policy for the protection, conservation and restoration of marine and coastal habitats. Workshops involving community need to be conducted regularly and they should be involved in all decision-making plans and resource assessments to ensure a sense of ownership. Fish farming in marine ponds need to be encouraged as a source of alternative employment to reduce pressure on the fishing grounds.

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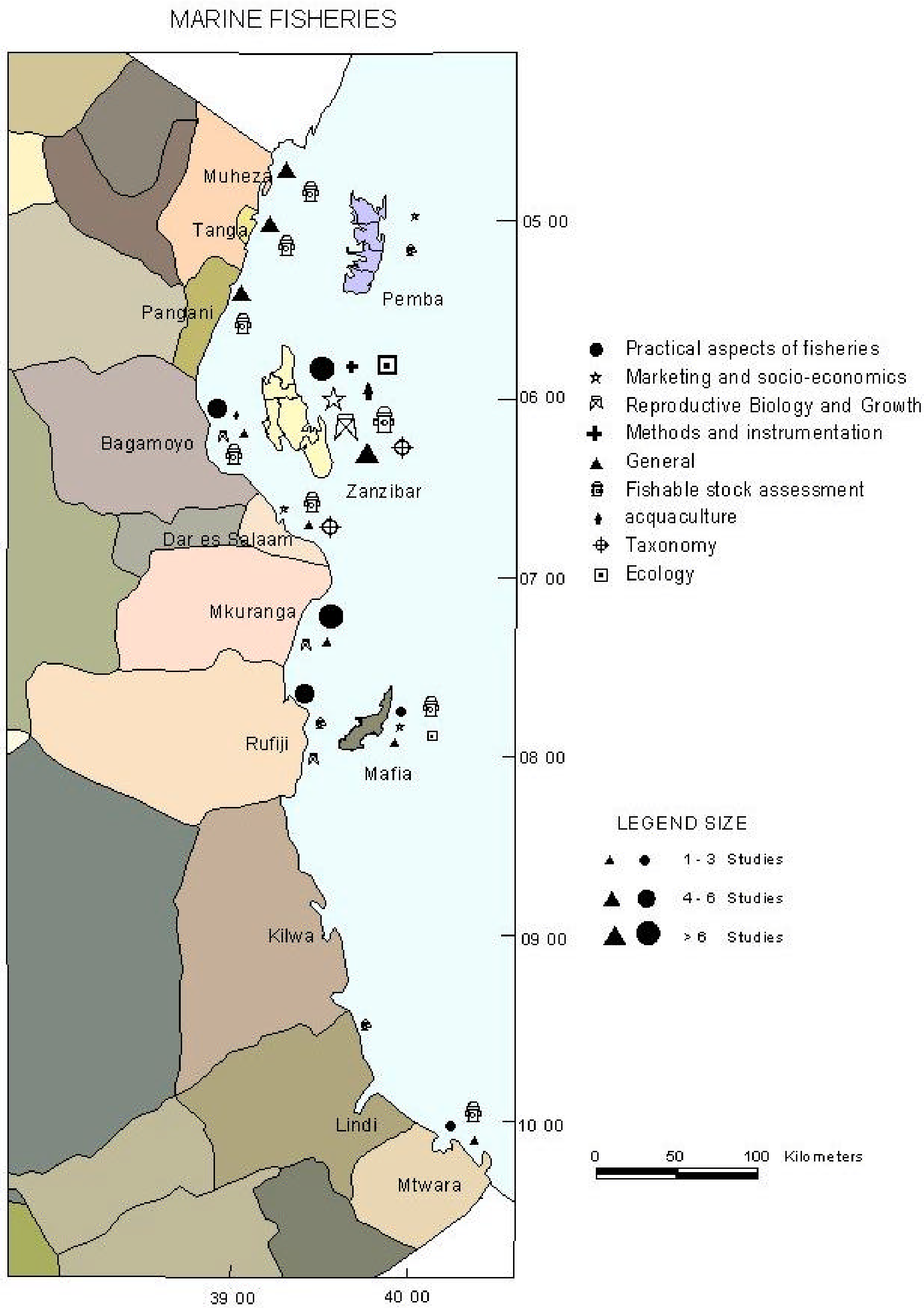

Figure 3.7. Tanzania coastal base map showing the distribution of research works that has been conducted in relation to coastal erosion. This includes all the available literature that was used in the preparation of the marine fisheries synthesis.

Chapter 4

CORAL REEFS

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4.0 Background information

4.1 General Description of Coral Reefs in Tanzania

Coral reefs are located along about two thirds (600 km) of Tanzania's continental shelf. Fringing reefs (which form margins along the edge of the mainland or islands) and patch reefs (which are often extensions of fringing reefs) predominate. However, coral reefs are mainly restricted to a narrow strip along the coast (IUCN Conservation Monitoring Centre, 1988). This is because the continental shelf is only 8-10 km wide along most of the coast, except to the portion between Mafia and Songo Songo Islands where it reaches a maximum of 35 km (Darwall *et al*., 2000). The islands of Zanzibar, Pemba and Mafia, as well as numerous small islands all along the coast, are for the most part surrounded by fringing reefs. An outer fringing reef runs along the eastern side of both the Mafia and Songo Songo Archipelagos.

The fringing reef system is broken by numerous and often-extensive mangrove stands, particularly near rivers and streams (IUCN Conservation Monitoring Centre, 1988). Especially to north of the vast Rufiji and Ruvuma rivers (since the coastal currents are predominantly northward), coral development is hindered by the very turbid waters emanating from those rivers (Darwall *et al*., 2000). The physical and chemical conditions of shallow reefs change seasonally due to heavy seasonal rains (Hamilton and Brakel, 1984), particularly those near freshwater inlets.

Fringing reefs are usually narrow and consist primarily of a reef flat, sometimes with a limited reef slope. Reefs on the landward sides of offshore islands and patch reefs are more developed with the reef slope sometimes extending below 10 m. The reefs on the seaward sides of the island have patch reefs. The continental shelf has the most extensive reef slopes (IUCN Conservation Monitoring Centre, 1988), where corals sometimes extend down to 25-30 m.

4.1.2 Importance of the Resource

Coral reefs have a number of ecologically and economically important values. Ecologically, they are important because of their great variety of microhabitats, which results in a high diversity of plant and animal life with concomitant high primary and secondary productivity. Their particularly high productivity is due to high retention of nutrients accompanied by efficient biological recycling within the coral reef ecosystem. Coral reefs also play an ecologically important role in the oceans, because they serve as breeding, nursery and feeding grounds for many marine animals. In addition, coral reefs help to prevent coastal erosion by mitigating strong wave action.

The socio-economic importance of coral reefs stems from their ecological importance. Reefs support an abundance of finfish, lobsters, prawn, crabs, octopuses, shellfish, and sea cucumbers, all of which are important in artisanal and commercial fisheries. Coral reefs support 70% of artisanal fish production in East Africa (Ngoile and Horrill, 1993). For coastal dwellers, fisheries are very important both as a source of food, supplying 90% of the animal protein they consume, and as a source of income, fishing often being their primary occupation. In addition, coral reefs are one of the major tourist attractions. Coastal tourism brings foreign currency into the country and provides a livelihood for coastal people.

4.2 Type of data/information gathered

Out of 189 references on coral reefs in Tanzania, approximately half are baseline studies which assess the condition of reefs. About one-quarter of them are review studies that give information on the importance, utilisation, threats, degradation, and management of coral reefs or review baseline studies conducted by others. Some papers report observational studies (other than baseline), e.g., concerning pollution, coral mining, or ecotourism. Very few papers are based on experimental or applied studies.

4.2.1 Baseline Studies

Many years ago, a few baseline studies were conducted in Tanzania, which had limited geographical scope. The earliest studies were primarily taxonomic (Ortmann, 1892; Werth, 1901; von Marenzeller, 1901; and Crossland 1902;1904), providing information about the presence of coral species in the area. Talbot (1965) described the coral structure and fish fauna of Tutia Reef, off Mafia Island. Hamilton (1975) and Hamilton and Brakel (1984) reported on the structure and coral species composition of four reefs near Kunduchi. i.e., Fungu Yasin (which they incorrectly called Fungu Mkadya) and the fringing reefs of Mbudya Island, Bongoyo Island and Ras Kankadya as well as the fringing reefs of Ras Mbegani and the south-east side of Mafia Island.

Thereafter, there was a lull in such studies until recently when extensive baseline studies have been conducted by different groups in several locations. For example Frontier-Tanzania in Mafia (Horrill and Ngoile, 1991, 1992; Darwall and Choiseul, 1995, 1996), the Songo Songo Archipelago (Darwall *et al*., 1994; Choiseul and Darwall, 1996; Darwall, 1996a,b; Darwall and Choiseul, 1996; Darwall *et al*., 1996a,b,c,d; Darwall *et al*., 1997; Hanaphy and Muller, 1997) and Mtwara (Guard, 1998; Guard *et al.*, 1998a,b,c). These studies have provided substantial amounts of information on biological and resource use aspects of coral reefs as well as other marine resources.

In Tanga, recent baseline studies have been conducted under the Tanga Coastal Zone Conservation and Development Programme (IUCN, 1993; Horrill and Kalombo, 1997a, b; Tanga Coastal Zone Conservation and Development Programme, 1997).

In the Dar es Salaam area, Kamukuru (1997) conducted a baseline study on the fringing reefs of Bongoyo, Mbudya and Pangavini Islands. Ngowo (1999), Sekadende (1999), Wagner *et al.* (2000a) and Wagner *et al.* (2000b) reported information on habitat type (percent cover of hard coral, soft coral, algae, seagrasses, rock, sand, etc.), the coral genera present, and the abundance of fish and invertebrates on the landward and seaward sides of Mbudya Island. In Zanzibar, baseline studies have been reported by Ngoile (1990), Horrill (1992), Horrill *et al*. (1994), Muhando (1998), Mbjije (M.Sc. thesis, in preparation) and Kuguru (M.Sc. thesis, in preparation).

4.2.2 Other Observational Studies

Observational studies on the condition, health and biological status of coral reefs (hard coral cover, live coral versus dead coral, etc.), other than baseline studies are rare. A few other types of observation studies have been conducted. Mohammed *et al.* (1993) assessed the effects of pollutants on coral reefs around Zanzibar. Johnstone and Suleiman (1998) reported on the interaction between pollution and nutrient dynamics on coral reefs around Zanzibar. Comparisons were made, with respect to ammonium and phosphate levels, between Chapwani reef, which is in the mainstream of polluted currents from Zanzibar town, and Bawe reef, which is away from the outflow of pollution. They related differences in these levels to differences in measurements on community metabolism on the two reefs.

The coral mining industry was studied in Mafia by Dulvy and Darwall (1995) and Dulvy *et al.* (1996); in Mikindani Bay, Mtwara region, by Solandt and Ball (1999); and in Kigamboni near Dar es Salaam by Jambiya *et al*.(1996).

The potential for ecotourism (in relation to coral reefs as well as other attractions) was reported by Andersson (1998) for Zanzibar and by Hansen (1999), Wagner *et al*. (2000a), and Wagner *et al.*(2000b) for Kunduchi and Mbweni, north of Dar es Salaam.

4.2.3 Experimental Studies

Most of the experimental studies have been related to the recruitment of corals, coral larval settlement and transplantation of corals.

Nzali *et al*. (1998) and Nzali (1999) studied various factors (coral cover/level of reef degradation, season, water temperature, rainfall, sedimentation, and orientation of surfaces, i.e., upward facing or downward facing) affecting hard coral recruitment on Taa Reef, a nearshore reef near the northern border of Tanzania. Clay tiles were placed on racks 20 cm above the seabed. After retrieving the tiles, they were examined for coral recruits and data were recorded on the location of recruits on the upper or lower surfaces, their identification, diameter, and their number.

Ohman *et al.* (1999) determined the effect of coral bleaching on fish populations. This study was partly experimental, in that it began with the transplantation of corals, and partly observational, in that the 1998 coral bleaching event occurred in the middle of the experiment. Before and after the bleaching event, they recorded data on live coral cover in the transplanted plots, reef structural complexity, fish abundance, and fish species composition.

Experimental studies that are still underway include a study by Muhando (Ph.D. thesis, in preparation) on techniques to enhance coral larval settlement and to transplant corals as means of promoting coral reef rehabilitation or restoration in Tanzania. Franklin *et al*. (1998) experimented on the effect of coral fragment size on the success of culturing such fragments for potential subsequent use in aquaria or for reef rehabilitation.

Kuguru (M.Sc., in preparation) examines the competitive effect of *Rhodactis* spp. (Cnidaria: Corallimorpharia) on hard corals on selected reefs of Zanzibar.

4.2.4 Applied Studies

Applied studies have mostly dealt with coral transplantation. A study by Lindahl (1998) was both experimental and applied. He attempted rehabilitating coral reefs by transplanting coral fragments using different methods of attachment, at different densities and different sites.

Wagner *et al*. (1999) conducted a trial on participatory restoration of the fringing coral reef at Mbudya Island. Fishermen were involved in transplanting corals in dynamite blasted sites. Fragments of *Galaxea* sp., *Acropora* sp., *Porites* sp., *and Montipora* sp. from nearby healthy colonies were inserted into cement-filled, disposable plastic plates placed in the damaged areas. Baseline measurements of these transplants were recorded after three months by Allen (1999) and their growth after 14-16 months was measured by Wagner *et al.* (2000b). Hansen (1999) transplanted corals in additional sites at Mbudya Island, recording baseline measurements of the transplants.

4.2.5 Review Studies

Many papers have reviewed the importance and utilisation of coral reefs, particularly in fisheries (Ali, 1998; Bwathondi *et al*., 1988; Jiddawi, 1998). Many others have discussed management issues (Horrill *et al*., 1994; Makoloweka *et al*., 1996; Horrill, 1997; Horrill and Kalombo, 1997a, b; Shah *et al.*, 1997; Horrill and Makoloweka, 1998; Kalombo and Horrill, 1998; Mambosho, 1998; Msuya, 1998; Semesi *et al.*, 1998).

Horrill *et al.* (2000) reviewed the coral reefs of northern Tanzania with respect to distribution, condition, physical and chemical characteristics as well as socio-economic and management issues; while Darwall *et al.* (2000) reviewed similar aspects for southern Tanzania.

Muhando (1999) reviewed the extent of reef damage and socio-economic impacts caused by the 1998 coral bleaching event and discussed the subsequent recovery of reefs.

Guard and Masaiganah (1997) reviewed the findings of the marine biological and resource use surveys which were conducted by Frontier-Tanzania in southern Tanzania, discussing the extent of damage by dynamite fishing, the intensity of its use, geographical variations (Kilwa, Lindi and Mtwara) and recommended possible solutions.

Wagner (1997, 1998a) reviewed impact of various types of fishing on coral reefs, while Wagner (1998b, 1999) reviewed the importance, threats, conservation and restoration of coral reefs.

4.3 Research methodology

This section pertains to baseline, observational, experimental and applied studies, but of course, not review studies.

4.3.1 Sampling Aspects/Parameters

Most of the earlier studies, such as Hamilton (1975) and Hamilton and Brakel (1984) were qualitative, only recording the presence and absence of coral species and their zonation and assemblage patterns on reefs. Little attention was paid to other biotic or abiotic aspects of the coral reef ecosystems.

More recent studies have reported quantitative, or at least quasi-quantitative data, most commonly giving percent cover of hard coral, the percentage of hard coral that is alive or dead, and sometimes the percent cover of each species. Moreover, these studies have also characterised the coral reef ecosystem by reporting percent cover of other types of biological cover (soft coral, algae, etc.), percent cover of various non-living substrate types (rock, sand, etc.), invertebrate counts, fish density, and measurements of abiotic factors such as temperature, salinity, turbidity, etc. Experimental studies have determined the growth rates of coral transplants (Franklin *et al*, 1998; Allen, 1998; Wagner *et al.*, 2000a,b) or the recruitment rates of coral larvae (Nzali *et al*., 1998; Nzali, 1999). While the Institute of Marine Sciences has not yet published it's annual monitoring report, it is important to note that permanent monitoring has started of a number of sites in Tanzania.

4.3.2 Instrumentation and Techniques of Sampling and Collecting Data

Baseline or observational studies on the condition and health of coral reef ecosystems has generally fallen into two categories: rapid assessment techniques and intensive, rigorous sampling.

Rapid assessment techniques, such as the surveys done by Frontier-Tanzania (Darwall *et al*., 1994; Choiseul and Darwall, 1996; Darwall, 1996a,b; Darwall and Choiseul, 1996; Darwall *et al*., 1996a,b,c,d; Darwall *et al*., 1997; Hanaphy and Muller, 1997; Guard, 1998; Guard *et al*., 1998a,b,c) involve swimming, while SCUBA diving or snorkelling, for a fixed time interval or an estimated distance and recording aspects such as percent biocover, percent substrate type, fish density and invertebrate density. The survey can also be done while the diver is pulled behind a boat while holding onto a manta board, i.e., the Manta Tow Survey (Horrill, 1995; Wagner *et al.*, 2000b). These techniques are very useful in that a lot of information can be gathered over a large area in a relatively short period of time. The disadvantages are that, though they are to quite an extent repeatable, they are somewhat subjective, so the reliability of repeated measurements depends largely on the uniformity of training.

Intensive, rigorous techniques include the use of line intercept transects, belt transects, point-based sampling, permanent quadrats, and permanent photoquadrats. These techniques give fairly accurate data on the percentage of each type of biocover, each species of coral and each non-living substrate type. Moreover, repeated measurements can give reasonably consistent results, even if done by different people who never trained together. The disadvantage of these methods is that they take a lot of time to cover a small area.

Generally, to get both extensive and accurate information about a system of reefs, both rapid assessment and intensive sampling techniques should be applied and the results synthesised.

Another way to cover a fairly large area and produce reasonably accurate results is by underwater photography. Lindahl (1998) took random photographs of a reef which he later analysed by point sampling on slide projections (Lindahl, 1998). Wagner *et al.* (2000b) took underwater photographs systematically and later analysed them for percent cover of life form and substrate categories by placing a mini-quadrat over them.

Photography has also often been used for descriptive and taxonomic work. Hamilton (1975) presented numerous photographs of many species of corals, providing a good record or reference for their identification.

Studies on biological aspects of coral reefs have often been accompanied by recording measurements of abiotic factors such as seawater temperature (thermometer or temperature logger), water transparency (Secchi disc), sedimentation rates (sedimentation traps tied onto fixed steel rods), reef structural complexity (Ohman *et al.*, 1999) and meteorological factors.

Socio-economic aspects of environmental issues and the utilisation of coral reefs have been studied by standardised interviews (Andersson, 1998; Wagner *et al.*, 1999), informal interviews and participatory observation (Solandt and Ball, 1999), as well as by Participatory Rural Appraisal (PRA), including transect walks, participatory resource mapping, and focus group discussions (Wagner *et al.*, 1999).

4.3.2 Sampling Frequency and Period/Time of Collection

Temporal aspects of different studies have been very variable. Nzali *et al*. (1998) examined clay tiles for coral recruits every 8 weeks for 12 months. Lindahl (1998), in his experimental study, transplanted corals in November 1995 and took measurements in October 1996 and October 1997, the entire study period being 23 months. Ohman *et al*. (1999) conducted an experiment over a period of 3 years, taking measurements after the second and third years. Many other studies, particularly baseline studies have just been conducted once, irrespective of season.

4.3.3 Data Analysis Methods and Procedures

Data analysis has varied, depending upon the number of factors involved, the number of groups compared, the nature of the data (normality, homogeneity of samples, etc.), and the hypotheses tested.

Nzali *et al*. (1998) compared coral recruits at two sites and on upper and lower sides of tiles using the non-parametric Mann-Whitney U test, while correlations between environmental factors were tested using the non-parametric Spearman rank correlation coefficient.

In the Tutia reef studies, Lindahl (1998) applied orthogonal three-way ANOVA with three fixed factors. Ohman *et al*. (1999) analysed changes in abundance and diversity of fish over time using a pairwise t test and related reef structural complexity to fish abundance using Spearman rank correlation. They applied the ANOSIM permutation test (analysis of similarities) to test for significant differences in fish community composition before and after bleaching.

Wagner *et al*. (2000a) used different tests for different aspects of their study, including the Mann-Whitney U test, two-sample t test, χ^2 test, contingency tables, and the Kruskal-Wallis test. Wagner *et al.* (2000b) used the paired-sample t test, the Wilcoxon paired-sample test (signed rank test), two-sample t test, and the Mann-Whitney U test.

4.4 Reliability, quality and usefulness of data/ information

4.4.1 Duration of Studies

Most of the studies were conducted within a very short period of time, e.g., a few months. Only a few studies lasted for one or two years. While such short studies have provided very useful information, they cannot be used for making long-term predictions.

4.4.2 Capability of Scientists/Researchers/Reporters

Most studies on coral reefs have been carried out by capable to very capable scientists. Most junior students/scientists do not have the opportunity to learn SCUBA, snorkelling or marine survey techniques that are required to conduct research on coral reefs. Therefore, most of the work has been done by senior scientist or well-trained students who are capable of good quality output. Qualified scientists have closely supervised any junior scientists involved in coral reef research.

Frontier-Tanzania has been making use of non-specialist volunteer researchers throughout Tanzania for the past 10 years. An evaluation by Darwall and Dulvy (1996) of their suitability for coral reef fish surveys showed that their loss of precision in comparison with experienced divers dropped from 13%, in their initial dive, to 0.6% after 11 additional dives. It is likely that their precision would have been similar if tested in coral reef habitat surveys. Therefore, it appears that even non-specialists can conduct quality research if they are given sufficient practice.

Most review papers and reports on experimental or applied studies have been written by experienced scientists. Thus, most publications are of high quality, standard and reliability.

4.4.3 Comparability of Methods

Some aspects of the repeatability/comparability of methods have already been discussed in Section 3.1. In addition, it can be commented that, generally, it is difficult to compare studies done in different places by different scientists since different methods or variations of methods have often been used.

4.4.4 Publications/Grey Literature

Out of 189 references on coral reefs in Tanzania, a small proportion has been published in refereed journals, either international or national. Even fewer have been published as books or book chapters. The bulk of them are papers that were presented at conferences, either published or unpublished. A large number are unpublished in-house reports to various management programmes and institutions. A few are university undergraduate research reports.

4.4.5 Age of Information (Old/Recent)

There were a few studies conducted many years ago (Ortmann, 1892; Werth, 1901; von Marenzeller, 1901; Crossland 1902;1904; Talbot, 1965; Hamilton, 1975; Hamilton and Brakel, 1984). After a long gap, there has been renewed interest in coral reef research. Numerous studies have been conducted during the 1990s.

4.5 Main findings/observations

4.5.1 Distribution of coral reefs

Hamilton (1975) collected, described and illustrated 88 species of scleractinian corals in East Africa. Hamilton and Brakel (1984) reported that the Region has 140 known species belonging to 55 genera (88 species belonging to 34 genera found in the Dar es Salaam area alone). In general, the exposed (windward) reef slopes were dominated by acroporids and pocilloporids in the turbulent upper zone and by poritids and faviids in the lower zone. *Acropora* and *Galaxea clavus* dominated sheltered reef slopes, while *Pocillopora*, *Porites, Psammocora,* and *Pavona* dominated reef flats.

More recently, distribution studies in southern Tanzania have identified 51 scleractinian coral genera (Horrill and Ngoile, 1992; Darwall *et al*., 1996; Guard *et al*., 1997, Darwall *et al*., 2000). Again, *Acropora* was found to dominate the shallow, sheltered inner reefs. In the Songo Songo Archipelago, *Galaxea* dominated many patch reefs, while two particular patch reefs, Poiasi and Pwajuu, were completely dominated by the fungiid *Halomitra pileus*. This species was also found to dominate an entire 200-m section of an outer reef adjacent to Msamgamku, Mtwara.

Muhando (1995) found the dominant coral genera on reefs off Fumba Peninsula near Menai Bay in southwestern Zanzibar to be *Acropora, Montipora, Porites, Millepora, Lobophyllia, Echinopora,* and *Favia.*

Along Tanga Region, there is 407 km of coastline, of which, 199 km are broken by bays and estuaries. Of the unbroken 208 km, 97 km (47%) is bordered by 41 distinct sections of coastal fringing reef. In addition, there are 55 patch reefs, of which, 30 are outer patch reefs (adjacent to the continental shelf) and 25 are inner patch reefs (located in near shore waters where water depth is less than 25 m). In total, there are 96 reefs in Tanga, having a total of 376 km of reef edge (Horrill *et al*., 2000).

Just north of Dar es Salaam city there is a series of reefs known as the Dar es Salaam Marine Reserves System which includes Bongoyo, Pangavini, and Mbudya Islands, which are surrounded by fringing reefs, and the patch reefs, Fungu Yasin and Fungu Mkadya (Kamukuru, 1997). There is a number of other smaller patch reefs in the vicinity.

Just south of Dar es Salaam city there are sections of fringing reef, particularly on the headlands (ras in Swahili). There are also three chartered patch reefs as well as a number of other unchartered and unnamed reefs.

Further north of Dar es Salaam, there are a number of patch reefs off the coast of Mbweni. Near Bagamoyo, there are stretches of fringing reef as well as several offshore patch reefs.

Unguja Island, one of the two main islands of Zanzibar, is surrounded by scattered coral development. Along the northern, eastern and southern sides of the Island, there is a fringing reef, which is interrupted by Chwaka Bay. In addition, there are reef formations near Mnemba, a small island to the northeast, Leven Bank to the north and Bedford Bank to the south. On the western side of Unguja, there are a number of islands and patch reefs between Ras Nungwi and Menai Bay (Horrill *et al.*, 2000).

Pemba, the second of the two main islands of Zanzibar, is estimated to have 1100 km of reef, representing 45% of the coral reefs of Tanzania. Coral growth has been observed as deep as 64 m. Misali Island, a small island on the western side of Pemba, has reefs of very high diversity of coral and fish species (Horrill *et al.*, 2000).

In southern Tanzania, there are numerous patch reefs and fringing reefs around islands in the Mafia and Songo Songo Archipelagos. There are also numerous reefs along the Mtwara coastline.

4.5.2 Coral recruitment

Nzali *et al*. (1998) found that coral recruitment is better in areas where there is higher coral cover than in degraded areas (e.g., areas where there has been dynamite fishing). Moreover, coral recruitment is highest in April, which coincides with higher temperature, higher rainfall, and lower sedimentation rates.

4.5.3 Natural impacts/threats

Natural impacts on coral reefs include storms, outbreaks of the Crown-of-Thorns starfish, and coral bleaching.

Damage due to strong wave action is common on exposed fringing reefs and on the seaward side of patch reefs and islands all along the coast of Tanzania. The Crown-of-Thorns starfish, *Acanthaster planci*, feeds on coral polyps and has, from time to time, devastated reefs in various parts of the world, such as the Great Barrier Reef of Australia. Occasional aggregations of this starfish have been sighted at Tanga, Mafia and Zanzibar (Ngusaru and Muhando, 1994), though it has not, so far, posed a serious threat. Nevertheless, vigilance is required.

The coral bleaching event (March to May 1998) coincided with higher than normal seawater temperatures and increased rainfall (lower salinity) (Muhando, 1999a). Coral bleaching was reported on all parts of the Tanzanian coast with variable severity. Bleaching was worse in shallow waters (reef flats) than in deeper waters. In Zanzibar, overall more than 60% of the scleractinian corals showed signs of bleaching, with *Acropora* being most affected; while a few corals such as *Diploastrea* and *Pachyseris* were seemingly unaffected (Muhando, 1999a). Some species of *Porites* were affected, while others were not (Wilkinson, 1998).

After the bleaching event, the dead corals were colonised by filamentous algae. By November 1998, these were replaced by macroalgae and coralline algae. By January 1999, some areas showed the recruitment of small corals, while others were colonised by corallimorpharia and soft corals. On the economic side, some dive operators reported a decline in tourist potential due to the bleaching event (Muhando, 1999a).

At Mbudya Island, the large percentage of dead hard coral (40-60%) was thought to be mainly due to coral bleaching (Wagner *et al.* , 2000a).

According to studies conducted at Tutia Reef by Ohman *et al.* (1999), following the bleaching event, 88% of the corals died. A year after the event, a large proportion of the dead corals was still standing. As surviving and dead corals were from different clones, results suggested that genetic variation might influence bleaching tolerance.

After the coral bleaching, there was a change in fish community composition and a 39% increase in fish abundance (Ohman *et al*., 1999). In particular, there was an increase in the abundance of herbivorous fish due to the growth of algae on the dead coral. Species diversity remained almost constant. There was a significant correlation between reef structural complexity and both fish abundance and the number of fish taxa. This indicates that the reef may uphold an abundant fish population as long as the architectural structure remains intact. However, if dead coral is eventually degraded and turned into rubble, with consequent loss of structural complexity, fish abundance is likely to decrease greatly.

4.5.4 Types of Resource Use

Coral reefs are utilised in a number of ways, particularly, for various types of fisheries, tourism/ecotourism, coral mining, and mariculture. Coral reefs are high density fishing grounds for a variety of finfish, octopus, sea cucumbers, lobsters, and shellfish (used both for food and curio). Since fisheries is a separate theme on its own, this use of reefs will not be discussed further here.

According to Andersson (1998), 20% of the tourists interviewed said that the main attraction for visiting Zanzibar was diving. During their visit on Unguja, 68% had dived at least once and 85% had snorkelled. Since almost all diving and snorkelling is done around coral reefs, this makes reefs an important tourist attraction.

Live coral is either used as a building aggregate or is burnt in open kilns to produce white lime which can be used as cement or to white wash houses. Live coral is whiter than fossilised coral rock and is therefore preferred. The negative impacts of coral mining include loss of reef habitat for associated fish species, loss of natural breakwaters with concomitant indirect loss of adjacent sheltered marine habitats, and loss of the aesthetic value of the reefs for tourism (Darwall *et al*., 2000). Moreover, since coral mining simplifies the surface topography of reefs, there is also a reduction in microhabitat diversity which, of course, results in a decrease in biodiversity. Solandt and Ball (1999) reported that several communities in Mikindani Bay are almost entirely dependent upon coral mining for their income. In Mitengo Village, the oldest coral mining community, out of a population of 100 people, 50-75 men, women and children are involved in various stages of the lime industry. The most commonly mined coral is *Porites lobata*. Though highly destructive, mining of live coral is, nevertheless, an all too common use of coral reefs, particularly in the south. Coral mining in Mafia, Songo Songo and Mtwara has been documented (Dulvy and Darwall, 1995; Dulvy *et al*., 1996; Darwall *et al*., 2000). In northern Tanzania, it is primarily fossilised coral rock that is mined (Horrill *et al*., 2000).

An indirect use of coral reefs is for the establishment of seaweed farms which are sometimes set up in lagoons (e.g., Paje seaweed farm, Zanzibar) between a coral reef and a sandy beach. Some are even set up over part of the reef flat. This is because the reefs shelter the lagoon from the full force of waves, but usually have openings which allow sufficient flow of water to replenish nutrients required by the seaweeds. Seaweed farming in Zanzibar has primarily been carried out by women and it has thus uplifted the status of women and, to some extent, has changed gender relations in the communities where it is practised (Horrill *et al*., 2000).

4.6 Human Impacts

4.6.1 Underlying socio-economic causes of human impacts

Socio-economic factors leading to the environmentally degrading human activities include poverty, increased human populations in coastal areas, urbanisation, greed, lack of general education and environmental awareness, and the breakdown of traditional conservation practices.

According to Guard and Masaiganah (1997), the factors that have led to the continual use of dynamite fishing are poverty, lack of law enforcement, inadequate legislation and lack of control of dynamite supplies.

4.6.2 Description of human impacts

There is a whole range of human activities that cause degradation of coral reefs, including destructive or improper fishing methods, overfishing, excessive movement of boats and people, pollution, coral mining and uncontrolled tourism. Seaweed farming may also have some detrimental effects.

The greatest human impacts on coral reefs are related to destructive or bad fishing practices (Wagner, 1998b). By far the most destructive type of fishing is dynamiting. Dynamite fishing has been practised in Tanzania since the 1960s. In the 1990s, dynamite blasts reached incredible rates. In Mnazi Bay, Mtwara, 441 blasts were recorded over a two-month period (October-November, 1996), while in the Songo Songo Archipelago, 30 blasts were heard every three hours and, at Mpovi reef (near Kilwa Kivunje), 100 blasts were recorded during one six-hour period (Darwall *et al*., 2000).

Each blast of dynamite instantly kills all fish and most other living organisms within a 15-20 m radius and completely destroys the reef habitat itself within a radius of several meters. Besides these direct impacts, there are indirect impacts due to turbidity and sedimentation, which adversely affect marine life in a much wider area. Moreover, according to Nzali *et al*. (1998), dynamite fishing appears to have a major impact on coral recruitment due to the removal of viable seed populations of corals. With numerous blasts occurring daily on reefs all over the country over a period of many years, the overall impact of dynamite fishing on coral reefs in Tanzania has been devastating. Damaged reefs take many decades to recover and some, in fact, may never recover.

While in the Kilwa/Songo Songo area, dynamite fishing is usually done by fishermen from Dar es Salaam using boats owned by Dar es Salaam businessmen and fish are taken to Dar es Salaam for sale. In Lindi and Mtwara, it is usually done by local fishermen, particularly youth (Guard and Masaiganah, 1997).

Besides dynamite fishing, the use of seine nets around coral reefs is destructive in three ways. Firstly, fishermen sometimes hit the coral heads in order to scare the fish out of hiding, known as the *Kigumi* technique, which has been particularly common on Pemba and the southwestern side of Unguja (Horrill *et al*., 2000). Secondly, the net often entangles with the corals, causing breakage. Thirdly, the small-mesh size of seine nets results in the capture of many juveniles. Horrill *et al*. (2000) reported that poison (commonly an extract from the *Euphobia* plant) was used for fishing as far back as 1900 and that its use declined during the 1960s though it is still sometimes used today.

In addition, there are several other fishing methods that may be destructive to reefs, if carried out in an improper fashion. These include octopus fishing, collection of shellfish (which entails reef walking and diving), and the use of basket traps. Other harmful activities related to fishing include the dropping of anchors and boat grounding (Wagner, 1999).

Overfishing and the catching of juvenile fish result in the depletion of fish stocks, alteration in species composition, loss of species diversity, disruption of food webs, and disturbance of the natural equilibrium of reef ecosystems (Wagner, 1999). For example, overfishing of the triggerfish, results in a proliferation of sea urchins which are known to be bioeroders of reefs (Kamukuru, 1997).

While seaweed farming is thought to be relatively environmentally friendly, it has been reported in Unguja that this activity lowers bacterial production and the abundance of small animals such as nematodes (Horrill *et al*., 2000).

Man causes many types of pollution due to industrial, institutional, and domestic discharge; agro-chemical pollutants; and sedimentation brought about by deforestation, poor agricultural practices, and construction activities; all of which can be detrimental to the health of corals when carried by seawater to the reefs (Wagner, 1999). The main centres of pollution are Dar es Salaam, Tanga, and Zanzibar and, to a lesser extent, Mtwara, Lindi and Bagamoyo. The impacts of pollution from other coastal settlements are minimal.

Solandt and Ball (1999) reported that, since coral mining has been a major industry in Mikindani Bay for the past two decades, all *Porites* above a depth of 2 m have now been gleaned from its nearby reefs. This has undoubtedly had an effect on the strength of waves impinging on the coast. This is likely leading to coastal erosion, though there is no documentation on this aspect. Miners have to go far from the Bay to get corals, sometimes as far as 15 km, and villagers estimate that all mineable coral in the area will be used up within the next 1-2 years.

While tourism is generally beneficial to the country, if uncontrolled and unmanaged, it may have negative impacts on the environment. If tourists are careless while snorkelling or SCUBA diving, they may break corals or disturb other organisms in the reef ecosystem. Others walk along reefs in search of shells, thus causing damage. Moreover, excessive movement of tourists along sandy beaches releases sediments that may be carried to adjacent coral reefs.

Another type of disturbance is the use of motorised vessels, whether by fishermen, tourists or transporters (e.g., the high speed boats that operate between Zanzibar and Dar es Salaam). This stir up sediments that can affect coral reef ecosystems by clogging the feeding apparatus of coral polyps and by blocking light, which is necessary for the symbiotic zooxanthellae as well as reef-associates such as algae and seagrass.

The consequences of human-caused degradation of reefs are a marked decrease in the diversity and abundance of fish and other commercially valuable marine animals. This also lead to habitat loss, reduction in breeding and feeding grounds for fish and other organisms, and decline in the aesthetic value of reefs which reduces their attractiveness to tourists. The end result is a decline in food supply and income for coastal communities and for the country as a whole.

4.6.3 Status and Condition of coral reefs

As far back as 25 years ago, Hamilton (1975) reported the occurrence of dynamite fishing along the Kunduchi coast and warned against its negative impacts on fishing potential. Hamilton and Brakel (1984) stated that reef growth appeared to be vigorous, but increasing degradation and overexploitation threatened the health of coral reefs. According to Guard and Masaiganah (1997), since dynamite fishing has had widespread and common use in all parts of Tanzania, virtually all coral reefs along the Tanzanian coast have been badly degraded.

The present condition of coral reefs, however, differs greatly from region to region. Moreover, the extent of degradation brought about by various impacts, both human and natural, differ from place to place. Therefore, the current status and condition of Tanzanian reefs are given below according to geographical area. Assessment of the impacts of the 1998 coral bleaching event throughout the country are given in Section 5.6.6.

Two important reef monitoring programmes have been conducted, i.e., the coral reef monitoring programme carried out by scientists at IMS (Muhando, 1999b) and the reef monitoring carried out on the Tanga coral reefs (Horrill and Kalombo, 1996). However, while the data from these programmes are available in raw form, they have not been analysed and written up in reports (Sections 7.4) and, therefore, findings from these programmes are not presented here.

Tanga

Throughout Tanga Region, the reefs have been extensively damaged by human impacts. According to a rapid survey conducted in 1987 (IUCN, 1987), most reefs, at that time had only 20% live coral cover, while some areas had less than 10%. A more extensive survey in 1995 covering 58 reefs (Horrill *et al.*, 2000) showed that 12% of the reefs were completely destroyed, 12% in poor condition, 52% in moderate condition and 24% in good condition. Most of the damage to reefs north of the Pangani River was attributed to dynamite fishing (Horrill, 1997).

Reefs that were adjacent to areas of high population density were found to have the most damage and the lowest abundance of commercially important fish species. However, the abundance of benthic target species important for commerce (crayfish and sea cucumbers), subsistence (wing shell species) and conservation (giant clams) was primarily determined by reef type or location, with the outer patch reefs having the highest abundance. The number of coral genera observed was highest on the outer patch reefs, followed by inner patch reefs and lastly by coastal fringing reefs (Horrill *et al.*, 2000).

Dar es Salaam

Kamukuru (1997) conducted a study in the Dar es Salaam Marine Reserves System at two sites each on the fringing reefs of Mbudya Island and Bongoyo Island and at one site at Pangavini Island. Using the line intercept transect method (at the reef crest only) he observed that the dominant benthic category was hard coral which ranged in area cover from 34.7% on the southwest side of Bongoyo to 81.2% on the southwest side of Mbudya. The second category in importance was algal turf which ranged from 6.5% at Mbudya southwest to 45% at Bongoyo southwest. The third was coralline algae which was highest (17.4%) at Mbudya northwest. Other benthic categories (calcareous algae, fleshy algae, sand, sea anemones, seagrass, soft coral, sponge, and clams) showed low percent cover (<10%) at all sites.

Kamukuru (1997) found that, in his five sites, the dominant hard coral taxa were *Acropora* sp. (21.3%), *Montipora* sp. (18.1%), *Galaxea clavus* (15.2%), *Galaxea fascicularis* (14.9%), and *Fungia* sp.(13.1%). There was significant positive correlation between hard coral cover and both fish biomass ($r = 0.57$, $n = 20$, $p < 0.01$) and fish density ($r = 0.64$, $n = 20$, $p < 0.002$), but significant negative correlation between hard coral cover and both sea urchin biomass ($r = -0.68$, $n = 20$, $p < 0.001$) and sea urchin density ($r = -0.56$, $n = 20$, $p < 0.01$) as well as between sea urchin biomass and fish biomass ($r = -0.62$, $n = 20$, $p < 0.005$). Sea urchins are bioeroders due to their feeding habits and the abrasive movements of their spines during locomotion; thus, where they are numerous, they can cause significant erosion of coral reefs.

Recent studies conducted on the fringing reef of Mbudya Island (Ngowo, 1999; Sekadende, 1999; Wagner *et al.* , 2000a) showed that there was significantly greater hard coral cover on the landward side (47%) than on the seaward side (12%) (Mann-Whitney $U = 61$, $0.001 < p < 0.002$), since the latter is subjected to very strong wave action which breaks the corals. Of the hard coral cover, 40-60% was dead. The live coral included 29 genera representing 11 families. There was 15-40% no biocover. A substantial area of the Mbudya Island reef (15-40%) was found to have no biocover, which was attributed to dynamite fishing and wave action. Several species of fish (the Threadfin Butterflyfish, the Goldring Bristletooth, and the Brushtail Tang) were found to be more abundant on the landward side, probably due to the higher hard coral cover found there.

Zanzibar: Unguja and Pemba Islands

Muhando (1999a) reported that, even prior to the 1998 coral bleaching event, various surveys throughout Tanzania indicated widespread degradation of coral reef environments. In Zanzibar, hard coral cover ranged from 13.9% at Mnemba on the northeastern coast to 53.1% at Bawe on the western coast.

Horrill *et al*. (2000) reported that the highest live coral cover around Unguja Island is found on the reefs near Zanzibar town on the western side, except for Chapani Island. It was found that Chapani had higher growth rates, lower coral diversity and lower coral cover than Chumbe. The higher nutrient levels at Chapani, due to its position just north of Zanzibar town, cause faster growth of a few species, but, at the same time, overall degradation of the reefs due to smothering by algae and attacks by borers.

The reefs on the southwestern side of Unguja near Menai Bay generally have lower live coral cover (12-29%), which can be attributed to the rampant use of destructive fishing methods, except for Pungume Island where it reaches 88%. Mnemba and the eastern fringing reefs were found to have 11% or less due to their exposure to strong wave action which causes physical disturbance of the corals (Horrill *et al*., 2000).

Along the western coast of Pemba Island, the fringing reef flat is extensively damaged in places; while the reef slope has few dead corals, with between 21% and 60% coral cover. The eastern fringing reef has not more than 15% coral cover due to its exposure to strong wave action. The highest live coral cover is found in Misali Island on the western side of Pemba, attaining 75% on the northern side and 53% on the eastern side. Misali has high taxonomic diversity (40 coral genera). There has been some damage of the reefs by dynamite fishing and dragging seine nets (Horrill *et al*., 2000).

Mafia Archipelago

On the fringing reef of Mafia Island, hard coral cover is diverse with good coral cover to 25-30 m. The outer fringing reef was reported to be in good health in 1995 with some damage caused by wave action. Two large, sheltered, shallow (less than 10 m) bays of Mafia Island, Chole and Jujima, have extensive growth of corals (Darwall *et al*., 2000).

Songo Songo Archipelago and Kilwa

All coral reefs throughout the Songo Songo Archipelago and most reefs in Lindi and Mtwara are extensively damaged above a depth of 10 m, primarily by dynamite fishing, though below that level, the reefs are prolific with coral growth and abundant with fish. Shallow reefs, however, are almost completely destroyed (Guard and Masaiganah, 1997). Mpovi and Amani reefs near Kilwa Kivinje, which had previously been very productive (Hasset, 1983), now have large areas of rubble, poor coral cover and low abundance and diversity of fish (Hanaphy and Muller, 1997). The reefs with the least degradation are those which are adjacent to deeper waters such as Poiasi and Pwajuu patch reefs and the outer fringing reef which has dense coral growth to 30 m. The northwestern reefs of the Songo Songo Archipelago have low coral diversity due to high sediment emanating from the Mohoro River (Darwall *et al*., 2000).

In a survey of 13 patch reefs in the Songo Songo Archipelago (Darwall *et al*., 1996a,b,c,d), average hard coral cover was found to range from 25% to 55% and the average proportion of hard coral that was alive generally ranged from 70% to 95%. Table 1 shows the percent cover of hard coral and soft coral as well as the percentage of hard coral that is alive for some of the patch reefs.

4.6.4 Assessment of damage caused by the 1998 coral-bleaching event

Before 1998, the primary threats on coral reefs were due to destructive fishing activities and storm damage. But in 1998 bleaching, damage due to bleaching in Tanzania was considerable, as indicated in Table 2 (summarised Wilkinson, 1998).

Table 1: The percent cover of hard coral and soft coral, and the percentage of the hard coral that is alive, on some of the patch reefs in the Songo Songo Archipelago (Darwall *et al*., 1996). (Values given are "unweighted" averages.)

Reef	**Reef position**	**% of Hard coral**	**% of Soft coral**	**% of Hard coral alive**
Jewe	Slope	33.8	18.8	92.5
	Subtidal flat	36.7	10	85
Luala	Slope	38.3	20	-
Pweza	Slope	47.5	25	87.5
Pwajuu	Subtidal flat	55	20	82.5
	Upper slope	31	12	85
	Lower slope	32.5	20	87.5
Poiasi	Subtidal flat & upper slope	25	7.5	88.5
	Lower slope	31	12	93.5
Machangi	Slope	35	15	70
Chocha	Upper slope	55	10	90
	Lower slope	40	20	95
Miza	Subtidal flat	50	10	80
	Slope	35	25	80
Miza Kidogo	Slope	40	25	95
Membeuso	Northern, subtidal flat & Slope	55	10	80
	Eastern, slope	55	15	90
	Southeast & northwest, slope	25	15	80
Membeuso Kidogo	Slope	40	15	95
Banda	Subtidal flat	25	5	80
	Slope	30	15	90
Songo Songo	Western, Slope	20	15	90

Table 2: Summary of information about the extent of damage due to coral bleaching event in 1998 in various areas of Tanzania (Wilkinson, 1998).

Area or reef	Estimate of coral damage
Tanga	25% of corals bleached
Zanzibar area	25-50% of corals bleached
Changuu & Chapwani, Zanzibar	less than 40% survival after bleaching
Bawe, Zanzibar	60-80% survival after bleaching
Chumbe, Zanzibar	80-95% of *Acropora* spp. bleached, 60-80% survival of corals after bleaching
Mafia Marine Park	80-100% coral death
Chole Bay, Mafia	100% *Acropora* death
Tutia Reef, Mafia	more than 95% coral death
Mnazi Bay, Mtwara	15-25% of corals bleached, with 50% survival of corals after bleaching
Kinasi Pass	80-90% *Acropora* death

4.7 Management Initiatives

4.7.1 Protection/conservation efforts

In 1968, the Tanzanian government engaged Carlton Ray as a marine consultant who proposed a management plan for the Tanzanian coast (Ray, 1968). This resulted in the Fisheries Act of 1970 which designated eight marine reserves in which reefs were to be totally protected, namely, Chole Bay and Tutia Reef, Mafia Island (Darwall *et al*., 2000); Latham Island; the Dar es Salaam Marine Reserve System; Maziwi Island; and Mwamba Wa Mbwa, Mwamba Shundo and Fungu Mnyama in the Tanga coral gardens (Kamukuru, 1997). The Act also outlawed dynamite fishing throughout the country. However, due to lack of capacity to actively manage these reserves, they became merely “paper” reserves (Bryceson, 1981).

Subsequently, the idea of multiple use areas, integrating the need for environmental conservation on the one hand and sustainable use and development on the other, was adopted as a more practical approach (UNEP, 1989) and, in 1993, a resolution was passed on Integrated Coastal Zone Management in East Africa (Darwall *et al.*, 2000).

Following preliminary investigations by Frontier-Tanzania in 1989, facilitation by the World Wide Fund for Nature (WWF) and funding by the Norwegian Agency for Development Cooperation (NORAD) commencing in 1991, the Mafia Island Marine Park (MIMP) was gazetted in 1995 (Darwall *et al.*, 2000). As a means of protecting the park, a speedboat with a water canon was acquired to patrol for dynamite fishing (Mambosho, 1998) and this has been largely successful in reducing this destructive practice in Mafia.

In 1994, the Tanga Coastal Zone Conservation and Development Program (TCZCDP) was established, funded by Irish Aid with technical support from the World Conservation Union (IUCN) (Horrill and Makoloweka, 1998). The programme is implemented by the Office of the Tanga Regional Administrative Secretary (Horrill *et al.*, 2000) and promotes the sustainable use of coastal resources in Tanga Region for the benefit of present and future generations. It operates on a collaborative, participatory approach between government agencies and local resource users such that villagers are involved in making decisions and implementing them (Horrill and Makoloweka, 1998). Key activities have been patrolling for destructive fishing practices, the closing of reefs to replenish fish stocks, the testing of mariculture options (Horrill *et al*., 2000), and mangrove planting.

In 1994, the Marine Environmental Protection Program (MEPP) was initiated for Kilwa, Lindi, and Mtwara districts, facilitated by the Rural Integrated Support Program (RIPS) and funded by FINNIDA. This programme has included seaweed farming, patrols for dynamite fishing, a village credit revolving scheme to enable fishermen to buy conventional fishing gear, and the production of media materials to enhance environmental awareness (Darwall *et al.*, 2000).

The “Songas Gas to Electricity Project” has been a good example of industry working together with conservation in that it involved the conducting of an Environmental Impact Assessment (EIA), carried out by Wagner *et al.* (1997), which assessed the potential impacts of the project on the marine environment and recommended a number of measures to mitigate negative impacts on coral reefs as well as other marine ecosystems in the area (Darwall *et al*., 2000).

Management efforts have recently been initiated in the Dar es Salaam area. The Kunduchi Fishing Village community have been involved in restoring coral reefs in the Dar es Salaam Marine Reserve System (Section 5.6.2) and efforts are being made to initiate ecotourism in the area as a means for motivating communities to protect the reefs in their area, while they, at the same time, benefit from ecotourism as an alternative income-generating activity (Allen, 1999; Wagner *et al.*, 1999; Zollet, 1999; Hansen, 1999; Wagner, 2000; Wagner *et al*., 2000a; Wagner *et al.*, 2000b).

On the islands of Zanzibar, there have been four marine management initiatives. The Chumbe Island Coral Park and Environmental Education Centre established in 1992. It is managed by a private company, Chumbe Island Coral Park Ltd., with input from an advisory committee that includes representatives from the Ministry of Agriculture and Natural Resources, the Department of Environment, the Institute of Marine Sciences of the University of Dar es Salaam, and neighbouring villages. In 1994, the Island was gazetted as a marine protected area which includes a reef sanctuary (Horrill *et al*., 2000).

The Menai Bay Conservation Area, supported by WWF, was gazetted as a conservation area in 1997 (Sichone, 1998). The main management strategies are the elimination of destructive fishing methods, such as *kigumi*, dynamite fishing and poisons, as well as the control of overfishing (Horrill *et al*., 2000).

Khatibu (1998) presented plans for integrated management and sustainable development of the Chwaka-Bay-Paje area. An Inter-agency Planning Team led by the Department of Environment (Zanzibar) began work in 1994. In addition, a Coastal Resource Management Committee has been established, which includes representatives from local and national government as well as village and private sector stakeholders.

The Misali Island Conservation Project, implemented by the Environment and Development Group (Oxford, UK) with funding from the European Union and supervision by the Commission for Natural Resources, the Department of Environment and the Commission for Tourism (Zanzibar), is aimed at establishing a financially self-sustaining marine and terrestrial protected area at Misali Island, Pemba, based on fishing and ecotourism as the main activities (Hamad, 1998). Another marine park is proposed to be established at Mnazi Bay, Mtwara, which is to cover an area of over 200 km^2. The park is, however, still in the preliminary planning stages.

Efforts have been made to stop dynamite fishing and, fortunately, it has been greatly reduced in many parts of the Tanzanian coast within the last five years or so (Horrill and Makoloweka, 1998; Wagner *et al*., 1999). In 1998, a “National Workshop to Wage War Against Dynamite Fishing” was held at Silversands Hotel, attended by representatives of key institutions all over the country, in order to assess the impact of dynamite fishing in the country, to review existing laws and regulations governing the practice, and to develop a coordinated national action plan to combat it (Anonymous, 1998). The navy has played a significant role in reducing dynamite fishing (Horrill and Kalombo, 1999). However, persistent effort will be necessary to ensure that it does not increase in the future and that it is eventually completely eliminated.

4.7.2 Restoration/rehabilitation

In contrast with efforts which are purely protective or conservational, restoration refers to human intervention whereby a degraded ecosystem is actively returned to its original state or as close as possible to it.

Lindahl (1998) found that transplanted staghorn corals (*Acropora formosa*) survived and grew well, with average cover increasing from 22% to 30% over 23 months. Both low-density transplanting and attachment by strings had significant positive impacts on the increase of coral cover, while site and interactions between factors had no significant impacts. The cover of soft corals and hard corals other than *A. formosa* also increased markedly in the experimental plots in comparison with control plots.

In 1998, Wagner *et al*. (1999), in cooperation with fishermen from Kunduchi Fishing Village, transplanted about 500 coral fragments in 2 dynamited sites on the northwestern side of Mbudya Island and 3 dynamited sites on the southwestern side. These sites were monitored by Allen (1998) and Wagner *et al.* (2000a) who, approximately 3 months after transplanting, were able to re-locate 342 coral fragments in order to record their survival rates/health status and baseline measurements. *Galaxea* sp. showed very significantly greater survival (100% complete survival) than *Porites* sp. (55.7% complete survival, 13.9% partial survival) ($\chi^2 = 37.010$, $p < 0.001$), but there was no significant difference between *Acropora* sp. and *Montipora* sp. survival ($\chi^2 = 2.200$, $0.50 > p > 0.25$). There was significantly greater survival in dynamited sites located at depths greater than 1 m (during low tide) than in shallow sites ($\chi^2 = 41.024$, $p < 0.001$). After another 5 months (i.e., 8 months after transplanting), survival rates were nearly the same. Heights of coral fragments of all species had increased significantly except for *Acropora* sp. whose slight increase was not statistically significant. Again, 14-16 months after the first baseline measurements had been taken, the heights of all species were found to have increased significantly. In many sites, heights had more than doubled (two-sample t test values were significant, with probabilities ranging from $p = 0.0242$ to $p < 0.0001$) (Wagner *et al*., 2000b).

In November 1999 (i.e., 15 months after the first transplanting session), Hansen (1999), also working with Kunduchi fishermen, transplanted an additional 587 fragments of *Acropora*, *Porites*, and *Galaxea* in 5 dynamited sites on the northwestern and southwestern sides of Mbudya. These have not yet been monitored.

4.8 Scientific and management recommendations

In the papers reviewed, there were virtually no recommendations given purely for scientific purposes, except those that recommended further research (given in Section 8). Recommendations given have generally been for management purposes, i.e., science for management. Therefore, in this section, recommendations are presented and discussed according to management issues and the various threats against coral reefs.

4.8.1 Socio-economic Issues

Unfortunately, tourism in Tanzania has almost entirely been for the benefit of a few wealthy hotel owners and dive operators. Very few residents of village communities gain any benefit from tourism. With the aim of determining how local communities could benefit by taking tourists to nearby ecosystems such as coral reefs and mangrove forests, Wagner *et al*. (2000a) conducted investigations on the potential for ecotourism in the Kunduchi and Mbweni areas. Tourists and residents of beach hotels in Kunduchi were interviewed, of whom, 92% said they would be interested in sailing to Mbudya on a traditional dhow with local fishermen and 15% would be interested in watching and/or learning coral transplantation. Of the villagers interviewed, 100% in Mbweni and most of those in Kunduchi said they were interested in participating in ecotourism. These findings indicate a good potential for community-based ecotourism in the area. Wagner *et al.* (2000b) found high interest in ecotourism amongst tourists, foreigners visiting on business, and Dar es Salaam residents who were employed at embassies.

In order to effectively and sustainably manage the marine environment, the basic underlying socio-economic issues must be addressed and addressing these will mitigate many of the threats to coral reefs at the same time. Steps to alleviate poverty could go far towards eliminating destructive fishing practices and coral mining as well as reducing pollution. Likewise, raising the level of both general education and environmental awareness would greatly facilitate conservation of the marine environment. Strengthening the enforcement of laws related to destructive fishing methods is absolutely essential.

4.8.2 Eliminating Destructive Fishing Methods and Overfishing

The problem of dynamite fishing should be given highest priority by government, law enforcers and management programmes. Otherwise, all types of restoration work will be useless. It is imperative that strong action be taken immediately to eliminate dynamite fishing as well as other destructive fishing practices. This needs the efforts and cooperation of policy makers, appropriate government departments, marine police, construction companies and industries that make use of dynamite and, most of all, the villagers themselves. Guard and Masaiganah (1997) recommended that an effective strategy be developed to confront the problem of dynamite fishing which should encompass a wide range of actions, such as continuous patrolling, police enforcement, improved legislation, increased fines, confiscation of vessels and jail sentences. In the long term, the local communities themselves must be educated and empowered to combat and stop dynamite fishing.

In addition, in order for fishermen to survive in the wake of eliminating destructive fishing practices, either they need to be empowered to engage in appropriate fishing techniques or they and their families must be directed towards alternative or supplementary income-generating activities.

Kalombo and Horrill (1998) reported recommendations, that actually came from the local fishing communities in Tanga, as follows: restrict illegal fishing techniques, close selected areas to fishing, provide appropriate gear to fishermen, and develop alternative sources of income.

McClanahan (1998) recommended the protection of important keystone species such as the red-lined triggerfish which controls sea urchin populations.

4.8.3 Managing Tourism/Ecotourism

As a priority, it can be recommended that there be a conscious and deliberate shift from the mainstream, mass tourism towards ecotourism, where there is balance and mutual benefit amongst three components: ecosystems, tourists, and the local communities.

Andersson (1998) predicted that the number of tourists visiting the country (particularly Zanzibar) is likely to increase tremendously. While this could be economically good for the country, care must be taken that this does not cause environmental degradation as has been the case in other countries such as the Maldives.

Muruke *et al*. (1999) recommended that the government should educate hotel developers on the importance of developing ecotourism so that they realise the importance of conserving ecosystems as tourist attractions. Moreover, they specifically suggested for Bagamoyo that the district government establish a special department for tourism which would assist in the formulation of partnerships between tourism developers and local communities.

Wagner *et al*. (2000a, b) recommended that restoration work should be combined with ecotourism, whereby members of the communities receive payment from tourists for guided tours to coral reef and mangrove ecosystems where, besides viewing the ecosystem, they would also watch villagers carry out restoration activities and even assist them, if they wish. The benefits of this type of ecotourism are (Wagner *et al.*, 2000b) that it provides the villagers with a source of income, thus alleviating poverty; it gives the community an alternative income-generating activity so that they do not have to engage in activities which degrade the environment and deplete resources; it motivates the villagers to restore the ecosystems in their area; and it motivates the villagers to take the responsibility of protecting the habitats in their area from the destructive activities of other people.

4.8.4 Mitigating the Effects of Boat Movement, Anchoring and Grounding

The construction of mooring buoys, in strategic positions near coral reefs and islands, which could be used by tourist and fishing boats, could be an effective way of reducing impacts of boat grounding and anchoring on reefs.

However, the target groups would have to be educated on the importance of consistently using these mooring buoys.

The movements of speedboats, both large and small, should be regulated with respect to speed as well as direction and distance from coral reefs. Though this requires further research (Section 8.4), it would seem advisable for the large speed boats that operate between Zanzibar and Dar es Salaam to pass on the outside of the reefs. If weather conditions force them to pass between the reefs and the land, they should reduce their speed and keep a good distance from the reefs. After appropriate research is done, regulations should be made (and enforced) regarding appropriate speeds and distances from reefs.

4.8.5 Control of Pollution

Johnstone and Suleiman (1998) warned that coral reefs should not be regarded as remote from land-based factors such as urban and town sewage management, but rather, they recommended that the development of sewage disposal systems must assume an integrated management approach, which includes full consideration of the sensitive character of coral reef ecosystems.

4.8.6 Alternatives to Coral Mining

With respect to the problem of coral mining, it is not recommended that this activity be immediate halted since certain communities depend upon this for either their supplementary or sole income and often there is no cheap, locally available alternative building material (Darwall *et al*., 2000). Darwall *et al*. (1995) demonstrated the feasibility of using sun-dried mud bricks as an alternative where suitable soils exist, such as on Mafia Island.

4.8.7 Mitigation of Natural Threats

One of the few natural threats for which mitigation efforts can be recommended is the Crown-of-Thorns starfish. Regular and frequent monitoring is required in order to have early warning of a possible outbreak. Where a rapid increase in its abundance is detected, the population should be controlled.

4.8.8 Recommendations on Restoration/Recruitment

Management programmes should put greater emphasis on restoration work than most of them are at the moment and consider it as a priority. For severely degraded reefs, mere protection is insufficient. Deliberate human intervention is required in order to accelerate and ensure the recovery of coral reef ecosystems. Some of the studies done have made recommendations concerning methods for restoring degraded areas of reefs.

The removal of sediments and rubble is one simple method of intervention. Another method is the transplantation of coral fragments, whereby, fragments are broken from healthy colonies and attached to a suitable substrate using cement or glue. Moreover, artificial substrates or reef structures can serve as fish sheltering devices and can also enhance coral larval settlement. Such methods can potentially greatly improve the recovery of degraded coral reef ecosystems.

Lindahl (1998) recommended that, in areas that are moderately exposed to water movement, the transplantation of staghorn coral fragments at low density by tying them with string can be an effective, low tech method of rehabilitating damaged areas of reefs. Besides increasing cover of the transplanted species, this technique also enhances the habitat, making it suitable for the establishment of other hard corals, soft corals and other organisms.

Franklin *et al*. (1998) recommended pre-culturing corals before transplanting them on damaged reefs. This could be done either by using coral larvae settled on artificial substrate or collecting fragments from natural colonies.

Wagner (2000) outlined the principles for ecosystem restoration and how these can be applied to restoring coral reefs in Tanzania. Various possible techniques for restoration were given, out of which, two methods were particularly recommended, i.e., the transplantation of coral fragments and the placement of ceramic tiles to aid coral larval settlement. Wagner *et al.* (2000a) suggested that training fishermen to transplant coral fragments using cement could be an effective way of restoring dynamited areas of coral reefs. It could, moreover, be combined with ecotourism (Section 6.3).

4.9 Management Programmes

While there are a number of marine reserves in Tanzania, these should not just be "paper" reserves, as described by Bryceson (1981), but should be properly protected and developed into natural havens of species and ecosystem biodiversity. There is still hope for most of these reserves. McClanahan *et al.* (1998) recommended that, despite the damage apparent on the reefs of the Dar es Salaam Marine Reserves System, steps should now be taken to properly protect these reefs since they still show the potential for recovery due to the persistence of species and reef structure. Thus, the recent management efforts being initiated in the Dar es Salaam Marine Reserves System (Section 5.6) need to be further pursued and perhaps developed into a comprehensive programme. At the same time, McClanahan *et al.* (1998) argued that the marine reserves in the country are inadequate and recommended increasing the number of small marine protected areas.

Ngoile (1989) recommended the establishment of a National Marine Park System in the Zanzibar Islands. The study provided information about coral reefs, fisheries and environmental aspects of various sites around Unguja and Pemba and selected seven sites to be developed into marine parks, namely, Menai Bay, Chwaka Bay, Mnemba Island, the reef complex off Zanzibar town, Misali Island, the Matumbe reef complex and the reefs off the northwest point of Ras Kiuyu. It may be noted that management programmes have already been initiated in three of these sites though none of them has as yet been developed into a marine park.

Wagner *et al.* (2000a) also recommended that future projects/programmes in the region should combine involvement of local communities in the application of already developed restoration techniques, citizen monitoring of the success of the restoration activities, and research into improving techniques.

4.9.1 Indigenous Management and Knowledge

There are recent examples of indigenous management in Zanzibar whereby the community of Ras Kisimkasi closed certain fishing areas and four communities on the Fumba peninsula combined efforts to restrict camping on Kwale Island (Horrill, 1992).

While indigenous management on mainland Tanzania has largely been forgotten, indigenous knowledge is common. Fishermen generally have good knowledge of the reefs in their area with respect to breeding sites, species of fish available in specific sites, suitable fishing gear to be used, etc. (Horrill *et al*., 2000).

4.9.2 Local awareness/participation/training

Most of he studies undertaken which address environmental management issues recognise the importance of participation of the local communities in any management programme as well as giving training and enhancing the awareness of the community. The Tanga Coastal Zone Conservation and Development Programme has been very effective in incorporating these aspects into their activities. Guard and Masaiganah (1997) felt that the long term solution to dynamite fishing is to make the local communities aware of its destructiveness and involve them in combating it.

4.10 INFORMATION GAPS

4.10.1 Geographical Coverage

Though the broad geographical coverage of coral reef studies has been quite good, there are many reefs have not yet been studied or for which there is scantly information. Even in geographical areas where many studies have been done, they have often targeted the same sites, leaving other reefs in the area undocumented.

While Pemba is estimated to have 45% of the total length of coral reefs in Tanzania, few studies have been conducted there. Therefore, this is a definite gap. Also, the reefs in the Dar es Salaam area have received very little attention until recently, despite their easy accessibility. There are still a number of reefs in this area that have never been studied. Moreover, very little has been done along the coastline between Dar es Salaam and Tanga, including Bagamoyo. And lastly, few studies have been conducted along the coast of Lindi. Though there are few patch reefs in that area the fringing reefs should be examined.

4.10.2 Subject Coverage

Since there are few experts in the country who are good at identifying all corals to species level, many studies do not fully identify all corals observed. This is definitely a weakness in much of the coral reef research undertaken. In addition, much more needs to be known about coral recruitment patterns in Tanzania. Moreover, many topics have not been covered, such as genetics, physiology, autecology of specific species and detailed taxonomic work.

4.10.3 Duration of Studies

Most studies are of very short duration or are even just a one time study. This is a limitation to thoroughly understanding complex ecosystems such as coral reefs. Usually the short duration is due to lack of funds for longer periods of research.

As mentioned earlier, there were a few old studies done more than 20 years ago and a surge of numerous studies in recent years. In between there was a long gap about which little is known. Unfortunately, it was during that period that there was great loss of coral reef habitat and, likely, a reduction in coral diversity. This gap in our knowledge presents some difficulties when planning conservation and restoration programmes.

4.10.4 Information Accessibility

Accessibility of literature on coral reefs to all scientists in the field has been a definite problem. University theses are only available at the University of Dar es Salaam. Reports of many of the studies done under specific programmes are usually kept only in their own files, with no organised system for making them available to other institutions and scientists working on coral reefs.

Information from two important reef monitoring programmes, i.e., the coral reef monitoring programme carried out by scientists at the Institute of Marine Sciences in Zanzibar (Muhando, 1999b) and the reef monitoring carried on the Tanga coral reefs (Horrill and Kalombo, 1996), is not readily available. While these programmes have, no doubt, come up with a lot of information, this information is still, for the most part, in the form of raw or semi-raw data stored in computer data bases, though bits of these findings may be presented in various publications by those involved in these monitoring programmes. In the form that this information is stored in computer data bases, it is not very useful to decision-makers, policy makers or even other scientists. Muhando (1999b) only gives the background of the coral reef monitoring programme at IMS, its objectives, and a brief description of the methods, without giving any results.

4.11 Recommendations for future work

4.11.1 Methods (quality, comparability)

There needs to be more intensive, rigorous methods conducted throughout Tanzania. While rapid assessment techniques give wide coverage, they should always be accompanied by more rigorous techniques such as the line intercept transect method in order to improve the reliability and accuracy of the information (see Section 3.1 above). Different scientists in various parts of the country have applied even the intensive, rigorous methods in slightly different forms. A consistent format would improve comparability. If possible data should be collected at regular intervals, while keeping seasonal trends in mind so that observations represent the entire range of variability in coral reef ecosystems.

4.11.2 Geographical Coverage

A coordinated effort should be made to fill in geographical gaps in coral reef research. Efforts need to be focussed on (listed in order of priority) Pemba, Dar es Salaam, the coastline between Dar es Salaam and Tanga (including Bagamoyo), and the coast of Lindi. In the areas already studied, some of the reefs, which have remained undocumented, should be examined.

4.11.3 Subject Coverage

As a priority, more detailed taxonomic work needs to be done to assist in the identification of corals to the species level. Comprehensive descriptions of all Tanzanian species and keys for their identification would greatly facilitate future studies on coral distribution and ecology.

Secondly, there is a need for various types of ecological studies, including the autecology of specific species. Muhando (1998) recommended that more ecological studies are needed in order to generate additional information and techniques to manage reefs sustainably.

It is important to know more about coral recruitment patterns in Tanzania with respect to seasons, directions of dispersion, and species. Such information would be useful for planning for the protection or restoration of reefs in certain areas.

While perhaps not a priority at this time, there are several aspects which have not been covered and which should receive some attention, including genetics, reproduction, and physiology.

4.11.4 Research

As was assessed in Section 2, most of the studies conducted to date are baseline studies or review studies. There is a great need to increase the number of experimental and applied studies and to cover a wider range of observational studies, other than just baseline studies.

In order to provide important information for management purposes, it would be advisable to conduct more studies, which examine coral reefs as integrated ecosystems, which they are, investigating as many biotic and abiotic factors as possible as well as the complex interactions between these factors. Such studies need to examine nutrient dynamics, ecological processes, biodiversity, food webs, as well as species interactions and associations.

In order to meet the urgent challenge of conserving and restoring reefs, there should be more projects, which actually apply already known techniques for restoring or protecting reefs. At the same time, such projects should have a built-in research component that evaluates the success of the applied techniques and tries to improve upon them with time. The work done in the Dar es Salaam Marine Reserves System by Wagner *et al.* (1999), Hansen (1999), Wagner *et al.* (2000a) and Wagner *et al.* (2000b) has attempted to take this approach in connection with restoration work with community involvement.

Another very important aspect, with respect to management, is to determine sustainable levels of resource use (Horrill *et al*., 1996). Management programmes always advocate sustainable utilisation of resources, since communities need to make use of their resources in order to survive, but we know very little about what the actual sustainable rates of exploitation are.

A specific problem that needs to be tackled includes the ecological impact of sedimentation. In particular, there is needs to conduct a detailed study on the impacts of speedboats, both small and large (especially the boats that goes between Zanzibar and Dar es Salaam). This is in order to obtain information on the critical speeds, orientations, and distances for travelling in the vicinity of coral reefs.

4.11.5 Monitoring

So far, monitoring has mainly just been baseline studies and if many years lapse without repetition, scientists will again have to conduct new baseline studies. What is necessary is, following baseline studies, to conduct monitoring sessions at regular intervals of a few months or, at most a year, using the same methods, the same sites and, if possible, the same transects or quadrats. Moreover, monitoring needs to be done systematically at various times of the year in order to determine seasonal patterns in reef biota and abiotic factors.

Horrill (1995) recommends that, in order to answer the information needs for management, monitoring programmes should collect the following types of information on coral reefs. Reef positions, reef names (including local names), types of human and natural impacts, management practices in place, type of use, benthic cover, counts of target, indicator and endangered species, counts of reef grazers and coral predators, description of the reef structure (framework, slope, etc.), coral growth forms and user perceptions of the current condition.

So far, monitoring has occurred somewhat haphazardly according to the availability of funds from donors. Muhando (1998) recommended that coral reef monitoring should be part and parcel of government activities. Thus, monitoring could be more systematic, both geographically and temporally.

Data from two coral reef monitoring programmes which are stored in computer data bases at IMS (Muhando, 1999b) and the Tanga Coastal Zone Conservation and Development Programme offices (Section 7.4) should be analysed, summarised and interpreted in scientific reports in order to be useful to decision-makers and other scientists.

4.11.6 Training

While some coral reef research can be done by snorkelling, much of it requires SCUBA diving. There are a limited number of trained SCUBA divers in the country since the training is expensive. Thus, there is a need to give such training to a greater number of students, researchers and community members, e.g., fishermen.

In addition, researchers need to be trained in coral reef monitoring techniques. Such training should give importance to taxonomic training so that identification can be done at the species level. Community members should also be trained in simpler monitoring techniques.

Since restoration work needs a lot of manpower, fishermen should be trained to apply various restoration techniques, such as transplanting coral fragments and placing clay tiles to aid coral recruitment (Section 6.8).

4.11.7 Other

TCMP should play an important role in a gathering information from new studies and circulating it to interested parties on a continuous basis.

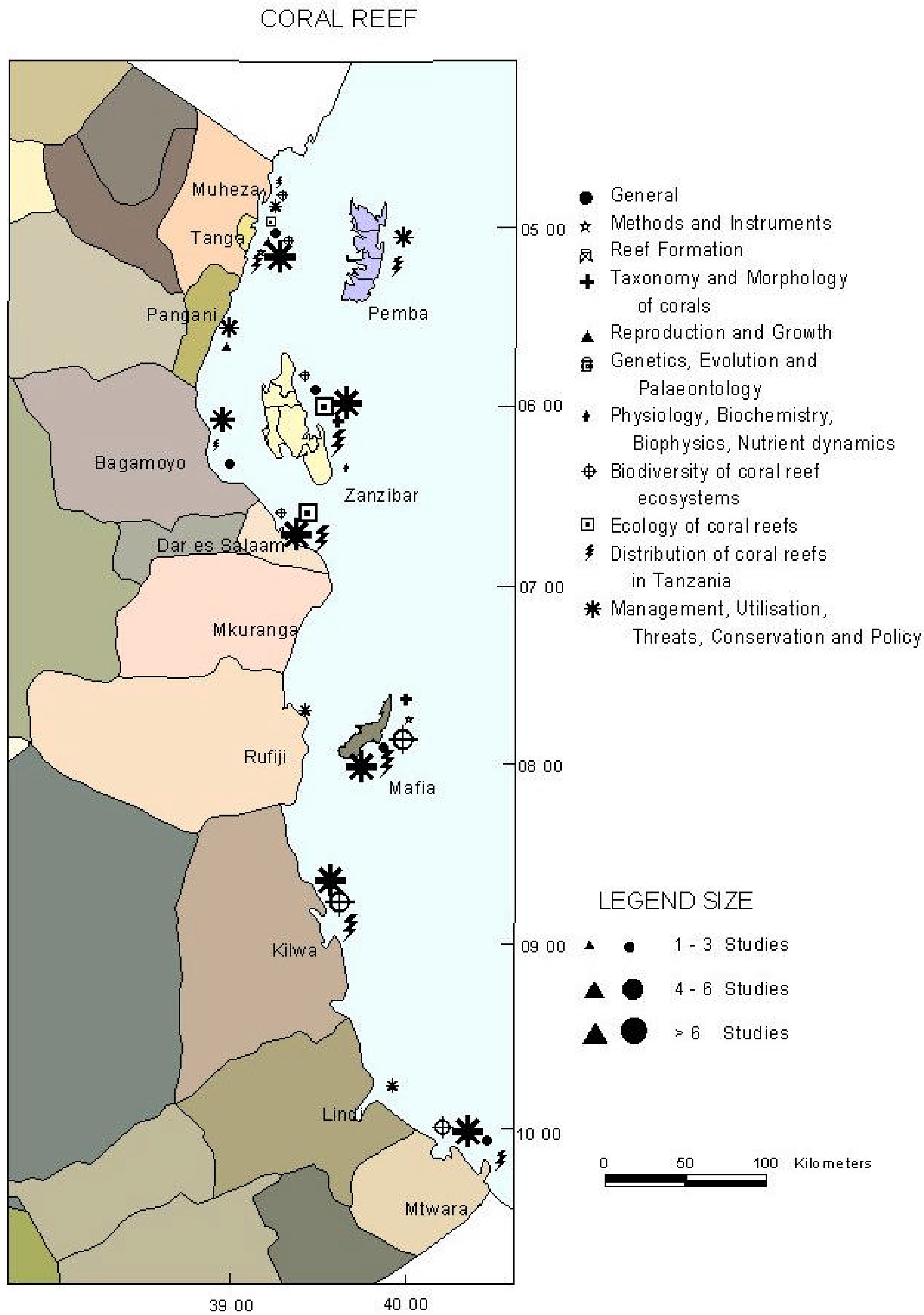

Figure 4.1. Tanzania coastal base map showing the distribution of research works that has been conducted in relation to coastal erosion. This includes all the available literature that was used in the preparation of the coral reefs synthesis.

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Chapter 5

Mangroves of Tanzania

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5.0 Background information

5.1 General description and importance of the resource

Mangroves are salt-tolerant trees or shrubs found along low-energy shorelines restricted to the area between the mean tides level and the extreme high water springs in tropical and subtropical areas (approximately 30^0N and 30^0S). About 75% of low-lying tropical coastlines with freshwater drainage support mangrove systems. In Kiswahili, the mangrove ecosystem or forest is referred to as kapa or kokoni and the mangrove trees as mikoko (Semesi 1991a). The mangrove ecosystem however, includes much more than just the trees, and encompasses terrestrial, freshwater, marine and estuarine systems. Tides are important in the mangroves as they export nutrients and protect the ecosystem from toxic accumulation of salts. Tides are also responsible for dispersal of plant propagules and of planktonic stages of animals (Grant 1938, Semesi 1986, McCusker 1971, Wolanski and Sarsenski 1997). Tidal movements also affect human activities in the mangroves. Usually mangrove cutting and collection of molluscs is carried out at low tides but the transport of poles and bulky firewood is transported from mangroves by boat during high tides (von Mitzlaff 1990, Sørensen 1997, Mgaya et. al. 1999, Semesi et al. 1998).

The mangroves are rich ecosystems that provide a variety of economic and environmental services and products (McCusker 1971, Mainoya et al. 1984, Mbwana 1986, von Mitzlaff 1990, Semesi 1991a-l, Semesi and Howell 1992, Nasser 1994, Shunula 1996, Ngoile and Shunula 1996). The full value of mangrove ecosystem is often not recognised. This is attributed to two factors: (i) many of the goods and services provided by these ecosystems are not traded on markets and thus do not have an observable value; and (ii) some of these goods and services occur off-site and are therefore not readily acknowledged as being related to mangrove ecosystems.

Most studies on mangroves of Tanzania have been on assessing area covered by mangroves, species composition, factors causing species zonation, physical and chemical composition of sediments, litter decomposition, microbial activities in sediments, and the human uses of the mangroves. Only few studies have monitored rates of growth, and none has focused on genetic diversity or the overall productivity of the mangroves. This document gives an overview of the mangrove studies in Tanzania, identifies the gaps and recommends areas where future studies should be focused so as to improve the knowledge on this resource.

5.2 Type of data/information gathered

5.2.1 Baseline studies

Since there has been relatively few studies on the mangroves of Tanzania it is therefore quite obvious that majority of these studies provide baseline information on the various aspects such as the species composition and adaptations, sediment characteristics, nutrient dynamics, people activities and uses of the mangroves. The detailed studies of

Walter and Steiner (1936), Grant (1938), McCusker (1971), Semesi (1991a-h) and Shunula (1996), Von Mitzllaf (1990) etc., are therefore quite useful. The most extensive baseline information on the distribution, coverage, uses, and status is found in the mangrove management plans of mainland Tanzania (Semesi 1991 b-l). For example the mangrove maps show the different forest vegetations, their area, stand density and stand height. Also the area covered by saltpans, water channels, clear felled and bare-saline areas are given. The status of the mangroves was assessed using aerial photographs and intensive fieldwork (Semesi 1991b-l, 1992). A socio-economic survey of the communities dependent on the mangroves was also carried out (von Mitzllaf 1990). The aerial photography included a total of 854 photos, all of which were clear and cloud-free, which reduced uncertainty in the photo interpretation process. These aerial photos (which also show the extent of the mud flats) can now be used to assess the changes that might have taken place since 1989.

The baseline information on mangroves of Kunduchi by McCusker (1971) for example has been useful in estimating the rate of loss of mangroves in the area (Banyikwa and Semesi 1986).

5.2.2 Observational studies

Observational studies are many but not all of them are found in published forms. Some can be found in the files of the Forest and Beekeeping Division on the mainland, in the Ministry of Agriculture and livestock or Natural resources commission in Zanzibar, the archives and field reports of travellers and researchers.

5.2.3 Experimental studies

Experimental studies on mangroves are rare and recent and they include both field experiments and laboratory work. Experimental studies on mangrove sediments of Mtoni, Dar es Salaam by Lyimo (1999) revealed that the rate of sulphate reduction decreases with sediment depth and was 10 to 200 times higher than the methane production rate. *In situ* values of methane production in the same sediments ranged from 0 to 2.09 ml m^{-2} day^{-1} (Julius, 1998). Higher values were measured in the middle part of the mangrove dominated with *Avicennia marina* and decreased landward and also towards the sea. It was also found that values of methane were higher during the rain periods than in the dry period. Methane production measured in the laboratory using the mangrove sediment with organic carbon of 2 % and 15 % showed that sediments with higher percentage organic carbon gave higher values of methane and that the highest peaks of methane were observed in the batch cultures with salinity of 18 $^{0}/_{00}$ (Julius 1998). Besides methanogens were found to be the most important dimethlysulphide (DMS) utilizer in mangrove sediments as compared to sulphate reducing bacteria (Lyimo et al. 2000a).

In order to assess how the mangrove sediments react when exposed to an increased nutrient load from sewage water, Hedman and Strandberg (1999) conducted a microcosm experiment using sediments at Maruhubi and Chwaka mangroves in Zanzibar. A sediment characterization was conducted which revealed that sediment show great variations in terms of physical (grain size distribution, porewater content), chemical (pH, oxygen level, organic content, ammonium, nitrate, nitrite, soluble reactive Phosphorus) and biological properties (chlorophyll a, carotenoids and phaeopigments). On the other hand Ólafsson and Ndaro (1997) designed a laboratory experiment (microcosm) to assess the impact of the mangrove crabs *Uca annulipes* and *Dotilla fenestrata* on meiobenthos. Mohamed (1998) studied nutrient dynamics and also estimated the levels of chlorophyll in sediments. He found out Chlorophyll a on sediments vary from 3.9 to 27 µg chl. a per gram of sediment in the dry season and from 2.7 to 5.6 µg chl a per gram of sediment in the wet season. Lowest levels were in sites with good mangrove trees. While Chlorophyll a in Mtoni mangrove ranged from 0.27-1.33 mg/g fresh wet of sediment (Julius 1998). Machiwa (1999) using core incubation techniques measured remineralisation rates of organic carbon in a partly polluted mangrove stand in Maruhubi mangrove stand in Zanzibar.
Other experimental studies are those on leaf litter production and litter decomposition (Shunula, 1996, Chale 1992 and Julius 1998).

5.2.4 Applied studies

Applied studies are very few. The earliest applied study was on the analysis of the tannin content in the mangrove bark so as to know which tree species can be used for tannin production (Grant 1938). Other studies are on planting mangrove trees (Grant 1938, Wagner et al 2000, Mwejudi, personal communication) to either restore degraded areas or just to replace the so called "useless" *Avicennia marina* in the Rufiji delta with the "useful species" such as *Rhizophora* and *Bruguiera*. *Avicennia marina* was considered a "useless species" because it is not a good source of either bark or poles that were important mangrove items of trade. However, species succession could not be accelerated and as such planting was restricted to the appropriate zones.

5.2.5 Review studies

Review studies are needed so as to bring together the information generated by various studies in a comprehensive manner such that the components, functions and processes in the ecosystems can be understood. They are also useful for the identifying the knowledge gabs. The first proceedings on the "Save the mangroves of Tanzania" (edited by Mainoya and Siegel, 1986) brought together for the first time various topics on the mangroves of Tanzania. The proceedings contain information on the distribution, species composition, zonation, uses and threats of the mangroves. It also identified the gaps and actions needed to be taken to save the mangroves from further depletion. As a result of this, action was taken in 1987 to survey first the mangroves of Tanga (Semesi 1989) and then all the mangroves of mainland that led to the preparation of the management plans (Semesi 1991b-l). The Management plans has stimulated more attention on the mangroves of Tanzania and as such more studies are now being carried out. For this reason majority of the publications are of the 1990s.

Among the review studies on mangroves of Tanzania are those of Williams (1948), Semesi, (1992, 1998), Semesi and Howell (1992) and Shunula and Whittick (1996). Besides all the Ph.D. and M.Sc. theses contain a section on literature review of the mangroves focusing on various aspects studied. Therefore by just compiling the literature review sections of the Ph.D. and M.Sc. theses (11 in total) we would most likely have a very good overview of the mangroves of Tanzania. Background information given on the management plans also provides an overview of the various components of the mangroves.

5.2.6 Other types of studies

Socio-economic studies have been conducted on communities living close to the mangroves. Most data was based on household surveys (von Mitzllaf, 1990, Nasser 1994, Masawe 1999, etc.). Primary data collection involved structured interviews i.e. using questionnaires, informal discussions and group discussions.

5.3 Research methodology

5.3.1 Sampling aspects/parameters

Standard research methods were used in most studies and are thus acceptable. The information gathered included tree species diversity, density, height, crown cover, diameter at breast height and the partial distribution (e.g. McCusker 1971, Mattia, 1999, Semesi 1991b, Shunula 1996). Other parameters are the area covered, wood volume, litter production, litter decomposition, microalgae, crab diversity and density. Microbial activities focusing on sulphate reducing bacteria and methanogens, meiofauna and nutrient dynamics are also some of the parameters studied. Socio-economic of the communities living close to the mangroves have also been studied.

For example, Mattia (1997) in his studies at the Rufiji delta used stratified random design, line transect method and data was collected in 41 plots. Twenty-five trees per species (for seven species) were felled at random for the volume equations. The bark volume, form factor, basal area, stem density and the importance index value were calculated from the relative frequency, relative density and relative dominance. Saplings with diameter at breast height (DBH) >5 cm and seedlings were counted from various plots to evaluate the natural regeneration status of mangroves.

Germanis (1999) conducted research on the regeneration of mangroves in selected sites in Tanga (Ulenge Island) and Pangani (estuary of river Msangazi). The number of mature trees, seedlings and stumps was recorded also the height, crown cover and the basal area. Semesi (1991b pages 29-33) attempts to give an approximate value of one average hectare of mangroves. The value were divided into three categories: local value, national value and global value and all added up to a monetary value of 1.8 million shillings /ha/year.

5.3.2 Instrumentation and techniques of sampling and data collection

The type of instrument used and technique depended on the type of study. Some of the laboratory analyses were either carried at the University of Dar es Salaam, while others were conducted at the University of Stockholm, Sweden and the University of Nijemegen, the Netherlands. For example Mattia (1997) used simple equipment, field form, clipboard, compass, Hypsometer, tape measure, calliper, diameter tape, coloured tags and matches. While Plexiglas cylinders were used to take core samples in the sediment (Mohamed 1998, Hedman and Sandberg 1999). The pore water was recovered by centrifuging and then filtering to get pure samples. Standard methods (Person et. al., 1985) were used for analysing photopigments (chlorophyll a, carotenoids and phaeopigments), ammonium, nitrate, nitrite, soluble reactive Phosphorus using Shimadzu UV-1201 or 160 spectrophotometer and the total Carbon and total Nitrogen were analysed using CHN elemental analyser (Mohamed 1998). Oxygen and temperature were measured with a WTW microprocessor, oxygen meter, OXI 196. Grain size was performed using a Retsch ISO 9001 sieve shaker. Machiwa (1998, 1999) relied on a TOC analyser.

Lyimo et. al. (2000a and b) on the other hand determined methane by flame ionisation gas chromatography using a Porpaq (80/100) mesh column. While Dimethylsulfide, Methanethiol and hydrogen sulphide were measured by flame photometric detector gas chromatography. The taxonomy of a bacterium was determined by physiological and morphological characteristics and analysing 16S rRNA sequences, which was amplified by PCR (Lyimo et. al. 2000a).

Microalgae were examined under the microscope and identified using various keys. Their biomass was estimated by the amount of chlorophyll *a* extracted by acetone from the sediment and then analysed in a spectrophotometer (Julius et. al., 1996). Litterbags as described by Cundell et al. (1979) were used to study the rate of leaf litter decomposition of mangrove species (Shunula 1996, Julius 1998). The number of heterotrophic bacteria present in the detritus was determined by using Most Probable Numbers (MPN) methods as described in APHA (1989). Rate of methane production was studied both in the field and *in vitro*. In the laboratory, batch and continuous cultures were carried out. The activity of the methanogenic bacteria in the sediments was studied under batch conditions using different substrates. Nitrogen isotope pairing techniques were used for denitrification experiments (Mohamed 1998).

The aerial photos are very useful in mapping the area and examining the status of the forests. It is possible to tell if the forest is productive or not productive from the structures of the forest and the network of water channels. A Wild APT-2 mirror stereoscope was used for photo-interpretation (Semesi 1991b). The various vegetation types were first marked as compartments on the aerial photos. Then these were taken to the field for detailed checks for the compartment classification and for finalization of boundaries between compartments. It was found that the different species of mangrove trees were easily distinguished by distinct tone, crown texture and relative location on the ground. Based on species composition the mangrove vegetation was separated into nine different categories and the density and height of trees in each compartment was established using a stereoscope.

5.3.3 Sampling frequency and time of collection

Sampling frequency has been found to vary greatly from one time observation to frequent sampling. For example sampling carried out by M.Sc. and Ph.D. students ranged from weekly to twice a month. Some studies were based on one season while others are of two years or more. Hedman and Strandberg, (1999) for example studied from June to July 1998, Masawe (199) from August to December, while Lyimo (1998) from January 1997- December 1998. Semesi (1991 a-l) from 1989 to 1991 while Shunula's Ph.D. studies were from 1993 to 1995.

5.3.4 Data analysis methods and procedure

All those who generated quantitative data analysed it statistically but some observational studies did not have any statistical treatment. The rigorous nature of the analysis depended on the type of information and also on the hypothesis being tested. Masawe (1999), Germanis (1999) and Shunula (1996) for example evaluated their data statistically using the MINTAB Statistical Software Programme. Almost all the compilation and computation work by Mattia (1997) was done using the spreadsheet software, QUATRO PRO. Also simple statistical calculations such as means and standard deviations were used to describe the structure of the forest.

Machiwa (1999) in his study in the Maruhubi mangrove forest used parametric one-way analysis of variance (ANOVA) to test the difference in his measurements in the different zones of the forest. He also used Tukey test to compare sample means. Besides using ANOVA, Germanis (1999) also used Fisher's pairwise comparisons of means. The F test was used to compare the amount of methane produced by the different types of mangrove leaves and other soluble substrate i.e. acetate, formate and trimethylamine (TMA) (Julius 1998).

5.4 Qualities, usefulness and reliability of data/information

Studies conducted by qualified researchers and M.Sc. or Ph.D. students are the most reliable. These follow research protocol very closely and for the M.Sc. and Ph.D. studies, there are various mechanisms put at the University to control the quality of the work.

Tanzania mainland has produced very comprehensive reports on mangroves, their distribution, uses and suggested management plans (Semesi 1991 b-l). This inventory of the mainland covers practically all mangrove resources, their species composition and wood quality with a separate detailed report for each region. The reports are a very useful tool for planners and decision-makers. On Zanzibar the Ministry of Agriculture and Livestock and Natural Resources Commission did a mangrove inventory.

5.4.1 Duration of studies

The duration of studies varies, from a few days, months, and years. The longest studies are those connected with the Ph.D. and M.Sc. studies by McCusker, Shunula, Mohamed, Lyimo, Machiwa, Julius, etc., those in connection with the preparation of management plans and also those done in the early 1900 in connection with mangrove planting at the Rufiji delta.

5.4.2 Capability of scientists/researchers/reporters

Most of those who were able to publish their results are capable researchers. However, a lot of some of the information in grey literature is collected by people who are not necessarily capable reporters or researchers. Some of the work is part of field reports by undergraduate students and field officers.

5.4.3 Comparability of methods

Methods used are those recommended in the literature but sometimes modifications had to be made to suit the local conditions.

5.4.4 Publications/grey literature

About 24 percent of the literature is in refereed Journals, 17 percent is in published proceedings, 28 % is in special reviews and Management plans and 19% is in grey literature (table 1).

Table 5.1: Distribution of literature on mangroves of Tanzania in various categories.

Category	Number of items
International refereed journals	32 (24%)
Published conference proceedings	23 (17%)
Special reports (UNEP and UNESCO series) and technical reports (e.g. management plans, Frontier series etc.)	37 (28%)
Books or book chapters	5 (4%)
Unpublished reports	25 (19%)
Ph.D. theses	5 (4%)
M.Sc. theses	6 (5%)
Total	133

In total there are 5 Ph.D. and 6 M.Sc. theses written on the mangroves. Four of the M.Sc. theses i.e. by Masawe, Nasser, Germanis, and Mkomwa, are not to be found in the University Libraries in the country and hence are inaccessible to readers in the country. Therefore because of the inaccessibility of information, the literature listed may have been seriously under estimated.

5.4.5 Age of information (old/recent)

Majority of the information is quite recent as 20 % is from the 80s, 65% is from the 90s to present. Among the oldest published literatures are those of Graham (1929), Grant (1938) and Walter and Steiner (1938). From the beginning of the 1900 to 1960s only 13 publications could be found that is only 10% of the total. Most of the old literature was written by foreign scientists and mostly based on short duration studies except that of mangrove planting (Grant 1938). On the other hand majority of the recent publications are produced by Tanzanian scientists or in collaboration with foreign scientists.

5.5 Main findings/observations

5.5.1 Taxonomy, morphology and adaptations

Nine true mangrove tree species are found in Tanzania (Table 2) and out of these, *Avicennia marina, Rhizophora mucronata* and *Ceriops tagal* cover larger areas but *Xylocarpus mulleccensis* is very rare (Shunula and Whittick 1996, Semesi, 1991b, 1998). Other plants that are common in mangroves but usually referred to as mangrove associates (Tomlinson 1986) are *Acrostichum aureum* (a fern), *Barrigtonia racemosa, Pemphis acidula, Hibiscus tiliaceus, Derris trifoliata, Thepseia populnea,* and *Phoenix reclinata* (a palm).

Some taxonomic treatment of mangrove trees of Tanzania can be found in Williams (1949), Shunula and Whittick (1996) and Semesi (1991b-l) but the best taxonomic work of the mangrove trees of Tanzania which also include those of other countries in eastern Africa is described in a series of publications on Flora of Tropical East Africa. The Taxonomy of *Rhizophora mucronata*, *Ceriops tagal* and *Bruguiera gymnorrihza* all belonging to the family Rhizophoraceae are described by Turrill and Milne-Redhead (1956). Verdcourt (1992) described *Avicennia marina* family Verbenaceae and Styles and White (1991) described *Xylocarpus granatum* and *Xylocarpus mulleccensis* family Meliaceae. *Sonneratia alba* (family Sonneratiaceae) has been described by Williams Sangai (1968) and that of *Lumnitzera racemosa*, family Combretaceae by Wickens (1973). Copies of these publications are found in the Herbarium of the Botany Department, University of Dar es Salaam. Shunula and Whittick (1996) and Semesi (1991b-l, 1997) provide illustrated shorter descriptions of the mangrove trees useful for rapid field identification. They used morphological characteristics of leaves, flowers, propagules, roots, etc. in classifying the species.

Mangrove plants share a number of specialised adaptations allowing them to cope with regular flooding of roots and sediments by salty waters. As an adaptation to anaerobic condition trees have developed exposed breathing roots (Walter and Steiner 1936, McCusker 1971) that absorb oxygen from the air at low tide. *Avicennia marina* and *Sonneratia alba* for example have pneumatophores (peg roots), *Bruguiera gymnorrhiza* and *Ceriops tagal* have knee roots but *Rhizophora mucronata* have prop roots that grow from the trunk and lower branches (Walter and Steiner 1936, McCusker 1971, Semesi 1991, 1997, Shunula and Whittick 1996). Mangroves cope with shallow unstable soils by having shallow widespread root systems, with support structure of buttresses and with above ground roots which do an excellent job of holding them upright. These root systems retard water flow, which leads to a number of environmental services. The quiet environment not only encourages sediment to settle but also inhibits their resuspension (Julius 1992). Mangroves thus stabilise shorelines, and reduce flood damage by dissipating the energy of floodwaters. Some other adaptation characteristics include; low water potentials and high intercellular salt concentration to maintain favourable water relations in saline environment, foliage salt-excretion to remove excesses salt from sap, Xerophytic water conserving leaves to cope with periods of high salinity stress and buoyant, viviparous propagules to promote dispersal and establishment of new and existing stand.

Table 5.2: Mangrove tree species, their local names and direct uses in Tanzania

Mangrove Tree Species		**Uses**
Scientific name	**Local name**	
Avicennia marina (Family Verbenaceae)	Mchu	Inferior firewood, but used for boiling of brine, fish smoking and production of lime, building dugout canoes and beehives; drums, carts, leaves used as goat and cattle fodder; branches support beehives, construction of beds
Bruguiera gymnorrhiza (Family: Rhizophoraceae)	Msinzi or muia	Good firewood; used for fish smoking, fishing stakes; poles for building, telephone poles.
Ceriops tagal (Family: Rhizophoraceae)	Mkandaa	Good firewood; poles; drying fish, fishing stakes; fence posts, poles for house building, timber for boat building, children use fruits to make whistle
Heritiera littoralis (Family: Sterculiaceae)	Msikundazi or mkungu	Good firewood; timber for boat-building; furniture; dhow masts
Lumnitzera racemosa (Family: Combretaceae)	Kikandaa or mkandaa dume	Good firewood, charcoal and building poles
Rhizophora mucronata (Family: Rhizophoraceae)	Mkoko	Good firewood; charcoal, poles for building; fence posts; fish traps; fishing stakes, barks used for dying nets
Sonneratia alba (Family: Sonneratiaceae)	Mililana	Good firewood; commonly used in boat-building; pneumatophores used as fish net floats
Xylocarpus granatum (Family: Meliaceae)	Mkomafi	Good firewood; used for fish smoking; boat-building; making furniture. The seeds are used to treat stomach problems and the fruit pulp to cure rashes fruit also used to induce abortion (high dosages are said to be lethal)
Xylocarpus molluccensis (Family: Meliaceae)		Good firewood

5.5.2 Reproduction and growth

Mangrove species reproduce by producing flowers and rely on pollination by bees and insects or bats (Turrill and Milne-Redhead 1956, Verdcourt 1992, Styles and White 1991, Williams Sangai 1968, Wickens 1973, Tomlinson 1986). Once pollination has occurred, the seed of *Rhizophora*, *Ceriops* and *Bruguiera* remains on the parent tree, where it germinates and produces elongated hypocotyls before being dislodged (Turrill and Milne-Redhead 1956). This unique ability is called vivipary. It gives the young tree a better chance to establish itself in the sediment before being swept away by the outgoing tides. In *Avicennia marina*, the propagule is ovoid and the dispersal part is a cotyledon in thin soft pericarp. However, *Sonneratia alba* forms a globose leathery berry with numerous small seeds which are the ones dispersed. On the other hand, *Xylocarpus granatum* form large globose woody capsule with 8-10 tetrahedral seeds and *Heritiera littoralis* forms an ellipsoid hard capsule inclosing a seed and the dispersal part is the capsule. *Lumnitzera racemosa* forms a drupe like crptoviviparous woody capsule and the dispersal part is the hypocotyls.

There is almost no information about the productivity of mangroves in Tanzania. Productivity of the mangroves is only inferred from the presence of many organisms that derive food and shelter in the mangroves. As is the case of other ecosystems, the process of photosynthesis is the cornerstone of all life in the mangroves. Therefore all those factors that limit photosynthesis and delay recycling of nutrients or limit their uptake will have an impact on productivity. Therefore water deficient, too high salinity, nutrient deficiency, particularly phosphorus and nitrogen and light will limit mangrove productivity. The mangroves in the large deltas are thus more productive than those receiving less fresh water and sediments. This is because the river brings both nutrients from the catchments area and water lowers the salinity that stimulates growth. Nitrogen fixation, as a source of allochthonous nitrogen, also sustains nitrogen input to the mangrove ecosystem. Therefore for example the Rufiji delta with the largest input of fresh water has the best mangroves and has for centuries been the source of large quantities of mangrove poles.

Grant (1938), Banyikwa and Semesi (1986), McCusker (1971, 1975), Mattia (1997), Shunula (1996) and Semesi (1991), etc has estimated natural regeneration. Most studies (McCusker 1971, Banyikwa and Semesi 1986, Semesi 1991, Shunula 1996, Mattia 1997, etc.) indicate good natural regeneration except in places where large areas of mangroves have been clear felled or in areas where strong wave action is preventing seed establishment (see Table 3 for Rufiji mangroves). The mean number of mangrove seedlings per ha for Tanga was found to be 14151 (Germanis 1999), in the heavily disturbed mangroves of Kunduchi it was 15,737 (Banyikwa and Semesi 1986) and that for Rufiji it was14950 (Mattia 1997). In less disturbed mangroves in Kipumbwi the mean number was 4926 seedlings/ ha while in disturbed area at Ulenge Island it was as high as 23376/ha (Germanis 1999). Mattia (1997) found out the stocking for the trees of diameter ≥ 5 cm at Rufiji delta was 1488 stems ha^{-1} (Table 3) and the mean basal area was $28m^2$ ha^{-1}.

Table 5.3: Stem density per ha of mangrove trees with diameters 5 cm<DBH>10 cm, 10<DBH>20 cm, DBH>20 cm, saplings (5 cm< DBH) and seedling for the various mangrove species in the Rufiji delta (Source: Mattia 1997).

Species	**Trees with diameter 5<DBH> 10 cm**	**Trees with diameter 10<DBH<20 cm**	**Trees with diameter DBH> 20 cm**	**Sapling (stems / ha)**	**Seedlings (stems / ha)**
Avicennia marina	66	60	44	156	24
Bruguiera gymnorrhiza	95	56	44	1215	3268
Ceriops tagal	185	46	39	2692	2682
Heritiera littoralis	59	32	7	360	414
Rhizophora mucronata	222	222	56	1131	1439
Sonneratia alba	10	20	5	9	0
Xylocarpus granatum	117	49	46	878	682
Total	754	493	241	6441	8509

Farmers in the Rufiji delta consider mangrove seedlings as weed in the rice farms cleared in mangrove areas (Sørensen, 1997). This indicates that natural regeneration of mangroves in the Rufiji delta is fast and very good to qualify to be referred to as a weed by farmers. When rice fields in the delta are abandoned, *Pennisetum purpureum* grass may however become too thick and prevent mangrove establishment but unaffected fields rapidly revert to mangrove forest. This observation shows that besides the physical and chemical factors such as the frequency of flooding, salinity, or tidal currents, biological factors such as the competition by ferns, the climber *Derris trifoliata* and *Pennisetum purpureum* grass (Semesi 1993, Sørensen, 1997) or seedling herbivory by sesarmid crabs and monkeys (Grant 1938) can hamper natural regeneration. Usually it is the interplay of factors and not a single factor that influence the distribution of species.

Planting of mangroves in Rufiji delta had been practiced for about 30 years during the German and British rules where active management has been in place (Tanzania archives). Grant (1938) summarized the results of this work. Plantations are successful when species are planted in the appropriate zone. Otherwise at an older stage, if species are grown at the wrong site the trees will usually die (Grant 1938). When *Rhizophora mucronata* was planted in *Avicennia marina* zone in the Rufiji delta, after 10 years the *Rhizophora* was out-competed and replaced by the natural growth of *Avicennia marina*. After seven years at an experimental plantation at Pangani, *B. gymnorrhiza* had a mean diameter of 7.5 cm and height of 3.8 m while *R. mucronata* had a mean diameter of 6.8 cm and height of 5.7 m but *Ceriops tagal* was only 2.4 m high (Germanis, 1999).

Considering the very good natural regeneration, in my opinion, only very few areas in Tanzania require mangrove planting to restore the forest. The clear felled sites documented in the maps produced in 1991 should now be used as baseline area to assess how has natural regeneration taken place and to assess if artificial planting is necessary.

The Mangrove Management plans (Semesi 1991b-l) provide the estimate of standing wood volume for the different mangroves stands of mainland Tanzania. The mangrove maps also show areas that have good mangrove growth and those that are environmentally stressed. Mattia (1997) also presents wood volume of two sites in the

Rufiji delta (table 4). He found the mean of 286 m^3 ha. For the size class 5cm<=DBH<=10 cm (diameter class 1) the volume was 15 m^3 ha^{-1} and for 10<=DBH<=20 cm (diameter class 2) it was 64 m^3 ha^{-1} and for DBH > 20 cm (diameter class 3) it was 189 m^3 ha^{-1}. *Rhizophora mucronata* contributed 42.3% of the total volume followed by *Xylocarpus granatum* with 21.1 %, *Ceriops tagal* 11.0%, *Sonneratia alba* 9.1%, *Avicennia marina*, 8.8%, *Bruguiera gymnorrhiza* 4.5%, and *Heritiera littoralis* 3.2%. *Rhizophora mucronata* and *Bruguiera gymnorrhiza* had the largest bark percent, 12 % and 11%, respectively. This is why these two species were previously exploited commercially for tannin (Grant 1938). No wonder *R. mucronata* is referred to as mkoko in Kiwahili because it was the main source of mangrove bark (barks are called makoko in Kiswahili). *Avicennia marina* has the least bark, only 3%, *Xylocarpus granatum* has 6% but *Ceriops tagal* and *Heritiera littoralis* has around 8%.

Table 5.4: Proportion of wood volume and number of trees per ha of each mangrove species in the Rufiji delta and the percentage of bark (Source: Mattia 1997) and the tannin content in the bark (Source: Grant 1938).

Species	**Proportions of wood volume (%)**	**Proportions of number of trees per ha (%)**	**Bark percent**	**Tannin content in the bark**
Avicennia marina	8.8	12.0	3.3	-
Bruguiera gymnorrhiza	4.5	13.1	11.2	35.8
Ceriops tagal	11.0	18.2	8.2	25.8
Heritiera littoralis	3.2	6.6	8.6	-
Rhizophora mucronata	42.3	33.6	12.0	36.5
Sonneratia alba	9.1	2.3	8.3	-
Xylocarpus granatum	21.1	14.3	6.0	29.8

5.5.3 Genetics, evolution and palaeontology

There are no studies on the genetics, evolution and palaeontology of mangroves of Tanzania.

5.5.4 Physiology, biochemistry, biophysics, nutrient dynamics

Physiology studies of mangroves in Tanzania are very few and these are mainly linked to salt tolerance. Walter and Steiner (1936) estimated the tolerance levels of salinity of the common mangrove tree species of Tanga and McCusker (1971) carried some work on the physiology of the mangrove trees at Kunduchi. Walter and Steiner (1936) found out that the chloride % of *Rhizophora mucronata*, *Ceriops tagal* and *Avicennia marina* seedlings still attached to the parent tree, were much lower than normal seawater. The upper limit of tolerance of mangrove trees in terms of soil osmotic potential (atm) for the Kunduchi mangroves are: *S. alba* (38.8 atm), *B. gymnorrhiza* (40.7 atm), X *granatum* (44.0 atm), *R. mucronata* (46.7 atm), *C. tagal* (50.1 atm) and *A. marina* (97.8 atm) (McCusker 1977).

Nutrient dynamic studies are linked with those done on mangrove sediments, microbial and crab activities, litter decomposition and litter movement in and out of the mangroves. The studies on sediments and nutrient dynamics are quite recent (Shunula 1996, Mohamed 1998, Julius, 1998, Lyimo 199, Lyimo et al 2000a, Machiwa 1999, Hedman and Strandberg 1999) and have mainly been part of M.Sc. and Ph.D. studies. The studies show that mangrove sediments are often waterlogged and have pH values that range from 3.5 to 8.3 (Mohamed 1998, Machiwa 1999, Lyimo 1999, Julius 1998). This is due to their limited buffer capacity and intense acidifying processes such as aerobic degradation of organic matter, oxidation of reduced components, ammonium uptake by roots and root respiration. The oxygen diffusion is greatly reduced but crab holes form interconnected tubes that help in draining and flushing salts. Near the roots there is higher level of oxygen due to aeration by the roots (Lyimo 1999, Julius 1998). Similarly benthic communities dominated by crabs and litter feeding snails effect the removal of fallen leaf litter in mangrove forests. Rates of litter decomposition vary with the season and also depend on the species. For example decomposition rates are higher for *Sonneratia alba* leaves followed by *Avicennia marina* than *R. mucronata* and least for *C. Tagal* (Chale, 1992, Shunula 1996, Julius 1998) and the rate are highest during the rainy season. Rapid weight loss occurs in the early days of incubation but slow down with time.

Nutrients and salinity in the sediments have been found to vary with season, with the location in the mangroves and tidal water movements (Mohamed, 1998, Julius 1998, Shunula, 1996, McCusker, 1971). There is thus large variation of nutrients and salinities between replicate samples. The sediments have usually high CN ratio. Mohammed (1998) in his PhD studies did measurements on nitrate, nitrite, ammonium and soluble phosphates in the water column and sediments in the Mapopwe creek and Chwaka Bay in the East Coast of Zanzibar. Investigations were also made to determine the exchange between sediments and water column in the forest as well as between mangrove and in the adjacent bay and the influence of mangrove produced nutrients on the productivity of adjacent communities in the Chwaka bay was also investigated. His conclusions were that nutrient distribution patterns in the water column and sediment as well as the exchange across sediment/water interface is regulated with sediment properties and the activities of microalgal populations present in the sediments. There is no significant flux of nutrients between sediments and the water column in mangroves of Chwaka. Similarly, there was little export of the nutrient from the system. Chwaka mangroves export particulate organic matter to the seagrass. Large variations in the data were noted because of the striking heterogeneity of mangrove sediments.

Studies done elsewhere show that ground water inflow to mangrove areas induces stratification of water column, limits salinity in dry season, supplies nutrients and is an important factor governing plant zonation. Groundwater outflow sustains the mangroves during periods of severe salinity stress and nutrients deficiency in dry seasons (Wolanski *et al.* 1992, Kitheka *et al.* 1999). The freshwater influx via rivers and direct rainfall also is responsible for lower salinities in riverine mangroves. In the mud there is little water movement except near the creeks. Therefore better growth of the mangroves takes place near the creeks.

Mangrove sediments are nitrogen-rich compared to mangrove litter, as a result of microbial nitrogen retention, uptake and fixation, and import of nitrogen-rich material (Middelburg *et al.* 1996). In mangroves at Gazi in Kenya (which is very similar to many mangroves of Tanzania), Woitchik *et al.* (1997) showed the maximum rates of nitrogen fixation in a *C. tagal* zone to be 380 nmol N_2 h^{-1} g^{-1} dw in the rainy season but 78 nmol N_2 h^{-1} g^{-1} dw in the dry season. It was estimated that biological nitrogen fixation could account for between 13 to 21% of the maximum nitrogen immobilised in the decaying mangrove leaves. Cutting mangroves on the other hand alters benthic nitrogen dynamic because the abundance of burrowing animals decreases (Stromberg *et al.* 1998).

Machiwa (1999) found in a Maruhubi mangrove in Zanzibar that there is a significant export of mangrove litter to the adjacent marine environment during spring tides. Net organic carbon export from the entire forest was 79×10^6g C y^{-1}, dissolved organic carbon accounted for about 78% of the total export. Rates of import and export of particulate matter in the forest were not statistically different. A relatively high export of macrodetritus was recorded at the marine fringe (mainly colonized by *Sonneratia alba*). There was low export of litter in the terrestrial fringe zone, a mono-specific stand occupied by *Avicennia marina*. While Machiwa (1999) showed a mangrove stand in Zanzibar was a net exporter of carbon, Middelburg, et al. (1996) on the other hand showed that mangrove sediments in Gazi Bay act as a nutrient and carbon sink rather than as a source for adjacent seagrass and reef ecosystems. Wolanski (1989) reported that the brackish and turbid water plume in the mangrove creeks is often trapped in the mangrove swamp and does not reach the coral reef. Other studies show that tidal asymmetry, characterised by stronger ebb flows than flood flows in the mangroves partly promote the net export of organic matter to the seagrass beds.

Microorganisms play important role in the carbon, sulphur and nitrogen cycles in the mangroves. These are involved in the reduction and oxidation of the carbon, nitrogen and sulphur compounds (Lyimo et al. 2000a and b, Julius, 1998). These authors have shown that in mangroves there is predominance of sulphate reducing bacteria over methanogens. Mangrove sediments have been found to produce limited quantities of methane and large amounts of hydrogen sulphide and that the production levels vary within the mangrove areas. The rate of sulphate reduction decreases with sediment depth and was 10 to 200 times higher than the methane production rate in Mtoni mangrove, Dar es Salaam (Lyimo 1999). *In situ* values of methane production were found to range from 0 to 2.09 ml m^{-2} day^{-1} (Julius 1998). During the rain periods the values of methane were found to be higher than during the dry period. Methane production measured in the laboratory using the mangrove sediment with organic carbon of 2 % and 15 % showed that sediment with higher percentage organic carbon gave higher values of methane and that the highest peaks of methane were observed in the batch cultures with salinity of 18 $^{0}/_{00}$ when leaf litter was used as substrates (Julius 1998). Besides methanogens were found to be the most important dimethlysulphide (DMS) utilizer in mangrove sediments as compared to sulphate reducing bacteria (Lyimo et al 2000a). Apparently there are no studies on the biopysics and biochemistry of the mangrove trees of Tanzania

5.5.5 Biodiversity of mangrove ecosystems

Tree biodiversity in Mangroves is low (Table2) because only few tree species can withstand the high salinity, anaerobic sediments, acidic soils and unstable substrates. However, if the total biodiversity including all groups of living organisms such as microorganisms (bacteria, fungi, cyanobacteria, microlagae, protozoa) and animals (both resident and visitors) are considered, the mangroves are found to be quite rich in biodiversity. For example the surface layer (0 - 10 cm) of the mangrove sediment contain high bacterial numbers (Lyimo *et al*., 2000b). The most probable numbers of methanogenic Archaea in mangrove sediments of Mtoni, Dar es Salaam were in the order of 10^5 - 10^6 cells/g fresh weight while those of sulphate reducing bacteria were in the order of 10^6 - 10^7 bacteria/g fresh weight. The number of bacteria on the leaf litter of *Avicennia* and *Rhizophora* when decomposition was studied below their tree stands was found to be 6.7 x 10^{10} and 1.20 x 10^{11} bacteria/g of detritus, respectively (Julius 1998). Recently a new species of an obligatory methlylotrophic methanogenic Archaea, *Metahnosarcina semesii* MDI^{T} was isolated in mangroves of Mtoni, Tanzania (Lyimo *et al.* 2000a).

Julius et. al. (1996) found a total of 23 species of benthic microalgae in Mtoni mangrove sediments. Most of the species encountered were pennate diatoms such as *Navicula* spp, *Pleurosigma* spp, *Hantzschia* spp, *Nitzschia* spp and *Amphora spp.* The mean average number of microalgae was found to be 91,856 cells per gram of soil sample while an average of 77,920 and 9,262 cells were diatoms and cyanobacteria, respectively. The biomass of these microalgae ranges from 0.27 to 1.33 mg/g of soil sample. Species in the genera *Oscillatoria*, *Spirulina*, *Lyngbya*, *Richelia*, *Nostoc*, *Pleurosigma*, *Gyrosigma*, *Hantzschia*, *Nitzschia* are found in the channels and as algal mats in the Mangroves (Lugumela et al. 1999). Cyanobacteria such as *Oscillatoria* spp, *Spirulina* spp and *Nostoc* spp were also abundant. On mangrove roots, Julius (1998) reported that the epiphytic algae *Caloglossa leprieurii* and *Bostrychia murayella* were dominant on *Avicennia marina* roots. While *Rhizoclonium grande* was dominant on the *Rhizophora mucronata* roots and *Bostrychia radicans* on the roots of *S. alba.* Mohamed (1998) found out Chlorophyll a on sediments vary from 3.9 to 27 µg chl a per gram of sediment in the dry season and for wet season in the same sites it varied from 2.7 to 5.6 µg chl a per gram of sediment

The most conspicuous animals in the mangrove are crabs and the most common crab species are *Sersama* (marsh crab) and *Uca* (fiddler crabs which have an enlarged claw) (MacNae 1968, Mgaya et al. 1999, Shunula 1996, Stromberg et al. 1998). Stromberg *et al.* (1998) found out the Ocyponinae and Serminae comprise a large component of the intertidal macrofauna in Kisakasaka mangroves, Zanzibar. These authors also showed that there is higher diversity of species in healthy mangroves than in degraded ones. These show characteristic zonation. Sersama crabs inhabit the upper zone when it is sandy. The *Uca* crabs are found mainly in areas dominated by the *Ceriops* and *Bruguiera* mangrove species. Mangrove snails like *Telebralia* spp, *Cerithidea* spp and *Nerita* spp crawl over the mud surface sometimes climbing the trees and clustering on the shaded side of trunks (Mainoya et al. 1984, MacNae 1968). Barnacles are common on stems of the mangroves especially *Sonneratia* trees. On the leaves of mangroves especially those of *Bruguiera*, *Sonneratia* and *Ceriops* species of *Littorina* are seen. Mangrove oysters (*Crassostrea cuculata*) are very prolific on pop roots and lower branches of *Rhizophora mucronata* and of *Sonneratia alba (*Mgaya et al. 1999).

A survey by Olafsson (1995) within 5 mangrove areas on the west and east coast of Zanzibar showed that Meiofauna densities in surface sediments (0-5 cm) ranged from 205 to 5263 individuals per 10 cm^2, being on average 1493 individuals per 10 cm^2. Of the 17 major taxa recorded, nematodes dominated (64-99%) in all samples while harpacticoid copepods were usually second most abundant. Within all areas the numbers of meiofauna were very variable and significant differences among areas were only detected for oligochaetes and turbellarians. Densities of nematodes, harpacticoids, polychaetes and turbellarians were, however, significantly

(P<0.001) higher at low water stations compared with mid and high water stations. Harpacticoids were negatively correlated with the numbers of fiddler crab (*Uca* spp.) burrows. Other correlation between environmental factors (grain size, temperature, salinity, oxygen tension, prop root density, fiddler crab burrows) and major meiofaunal taxa were non-significant. A total of 94 nematode genera were recorded from four mangrove areas. The most abundant and frequent genera were *Microlaimus* and *Spirinia*, followed by *Desmodora* and *Metachromadora*. In a hypersaline area diversity was much reduced and where salinity was over 100‰ the fauna was restricted to 3 nematode genera, *Microlaimus*, *Theristus* and *Bathylaimus*. Ólafsson and Ndaro (1997) found that ocypodid crabs do not regulate resident nematode assembalges, but may inhibit settlement of colonisers (e.g. harpacticoid copepods) that have not adapted to the intense surface disturbance created by these crabs.

The density of Ologochaetes in uncut mangrove area was found to be 3105 individuals m^{-2} but only 40 individuals m^{-2} in cut areas (Stromberg *et al.* 1998). In general the macrofauna decreased in the cut areas except the crab density was similar in both the cut and uncut areas because they can move around.

5.5.6 Ecology of mangroves and mangrove forest ecosystems

The occurrence of individual mangrove species within the forest is reliant on environmental factors such as salinity, nutrient availability, and oxygen level in the soil and wave energy. Normally, it is the extreme factors that limit the distribution of a species. As mangrove species differ in their tolerance of these factors, a pattern of species distribution known as zonation occurs (Walter and Steiner 1936, Chapman 1977, Semesi 1986). Commonly *Sonneratia alba* occurs in areas where the salinity is almost constant, close to that of seawater where tidal water reaches daily. Many *Sonneratia* trees in various stands are dying and little regeneration of this species is taking place.

Avicennia marina is the most widely distributed because it can tolerate high ranges of salinity, varied flooding regimes, compacted substrate, sand flats and newly deposited sediments. On the seaward side the species attains large sizes but on the landward margin is present only as bushes and it does poorly on muddy soils. When mixed with other species, it is commonly associated with *Ceriops* and *Xylocarpus*. *Xylocarpus* is most often found mixed with *Avicennia*, and it grows on raised portions where flooding takes place only for a few days a month and where there is fresh water influence. *Xylocarpus* is an important element of the riverine mangroves but does not form pure stands in Tanzania.

Ceriops is largely found on the landward side of the *Rhizophora* zone. It becomes dominant more frequently in areas where mud is thin and on relatively higher ground than the *Rhizophora* zone. Forests with mixed vegetation of *Ceriops* and *Avicennia* are found on slightly raised ground where flooding occurs only during spring tides. The substrate is usually firm during low tides. *Rhizophora mucronata* forests are dominant on muddy soils and often form extensive pure stands. On sandy soils, however, the species fails to compete with others.

Bruguiera gymnorrhiza is relatively less abundant in the mangroves of Tanzania and is often found as a narrow zone between *Rhizophora* and *Ceriops* zones or mixed with them. However, unlike most sites in the country, Mnazi Bay, Ruvura, Mana Hawanja and Mongo islands in Mtwara region are dominated by *Bruguiera gymnorrhiza* at the edge of forest followed by *Ceriops tagal*.

Heritiera littoralis, a riverine mangrove species, grows only in habitats with low salinity and thus it is restricted to areas in the vicinity of river mouths or where there is ground freshwater seepage. Such sites are usually only flooded by spring high tides, and usually the substrate is firmer compared to those on which other mangrove species are found.

Therefore different mangrove stands have varying dominant tree species and the total number also varies. This information is well documented in the 30 map sheets produced in 1991 for the mangroves of mainland Tanzania (Semesi 1991b-h). These maps are found in Catchment Forest section in the Forest and Beekeeping Division.

Mangrove leaves represent a major source of organic carbon to the mangrove sediments (Machiwa, 1998, Shunula, 1996, Julius, 1998, Rao *et al.* 1994). As mangrove leaves drop into tidal waters they are colonized within a few hours by marine fungi and bacteria that convert difficult to digest carbon compounds into nitrogen rich detritus material. The decomposing litter covered with Microorganisms become food for the smallest animals such as worms, snails, shrimp, molluscs, mussels, barnacles, clams, and oysters. These detritus eaters are food for carnivores including crabs and fish, subsequently birds and game fish follow the food chain, culminating with man. In the Rufiji delta for example, Villagers report that “Kima” monkeys eat crabs and fruits of *Avicennia marina* and *Xylocarpus granatum.* Both inshore and offshore fisheries, including the highly profitable offshore shrimp fishery, depend on inshore nursery areas, some of which are associated with mangrove.

The benefit of mangroves on marine ecology is summarised as follows. Basis of a complex marine food chain; creation of breeding habitat. Establishment of restrictive impounds that offer protection for maturing offspring; filtering and assimilating pollutants from upland run-off; stabilization of bottom sediments; water quality improvements and protection of shorelines from erosion.

5.5.7 Distribution of mangroves in Tanzania

The mangroves are distributed all along the coast in areas protected from strong waves (table 5). The total area covered by mangrove forests in Zanzibar has been reported differently. Griffith (1949) reported the area to be 15963 ha, while Mgeni (1992) and Ngoile and Shunula (1992) reported the area to be 18000 ha. The most recent inventory carried by Leskinen and Silima in 1993 revealed that the total area was 15950 ha. The large mangrove areas are to be found in Chwaka bay with 2392 ha of mangrove and the west part of Pemba Island. Pemba Island has about 69% of the total mangrove area of Zanzibar (Nasser 1994).

Mangroves cover a total area of 115, 500 ha in the mainland (Semesi 1991-l, 1992) and if water in the creeks, clear-cut areas and saltpans are included, mangrove reserve area in the mainland is 172 889 ha (Semesi 1991b-l). The largest area and the best mangroves are found in the Rufiji delta (Semesi 1991-h). Fairly large areas are also found in Tanga, Pemba, and Kilwa and at the estuaries of Ruvu, Wami, Pangani and Ruvuma rivers. The proportion of the various species is summarised in table 6.

5.5.8 Management: utilisation, threats, conservation, and policy

5.5.8.1 Utilisation

The main type of resource use is mangrove cutting for poles, firewood, charcoal and clearing for salt pans and rice farming. Fishing for prawns and fish along the water channels is also common especially in the riverine mangroves while collection of molluscs is more common on the mudflats near mangroves. There is long history of mangrove pole use and export in Tanzania. The poles were an important item of trade between east Africa and the Gulf States and Asia as early as 200 BC (Grant 1938, Semesi 1991a). About 70-80 dhows from various ports called in to load mangroves from the Rufiji Delta in the late 1980's. The mangrove barks was also a major source of Tannin used to treat leather but the bark is no longer used commercially as wattle bark is a cheaper.

TABLE 5.5: Mangrove areas in the administrative blocks in mainland Tanzania (Semesi 1991b-l) and Zanzibar islands (Ngoile and Shunula, 1992) D = District, R = Region)

BLOCK	**Forested Area (ha)**	**Non-Forested areas (creeks, salt pans, bare saline areas) (ha)**
Tanga and Muheza D.	9 403	3 528
Pangani D.	1 756	1 279
Bagamoyo D.	5 636	3 548
Dar es Salaam R.	2 168	1 045
Kisarawe D.	3 858	2 193

Mafia D.	3 473	892
Rufiji D.	53 255	14 357
Kilwa D	22 429	14 308
Lindi D.	4 547	2 754
Mtwara D.	8 942	4 408
Total area for Tanzania mainland	115 467	48 312
Pemba island	12 000	
Unguja island	6 000	
Total area for Zanzibar islands	18 000	

substitute (Mbwana 1986). Coastal communities use mangroves (table 2) to supply local needs for fuelwood, fences, and house construction, boat building, for fish traps and medicine (Mbwana 1986, Mainoya et al. 1985, Semesi 1991, von Mitzlaff 1990, Nasser 1994, Masawe 1999, Shunula 1996). Mangroves are also cut for commercial poles and for fuelwood used in the production of salt, lime and processing of fish, prawns, sea cucumbers and coconut oil. The ability to burn well and the high calorific value makes mangrove a good source of firewood. Mangrove poles are of high density, strong and durable and are resistance to termites and fungi. Fish and prawn trapping fences are made mainly of *Ceriops*, *Rhizophora* and *Avicennia* samplings. The small poles of mangroves are also used as pegs in seaweed farms.

Table 5.6: The species composition and area occupied by mangrove trees in mainland Tanzania (Semesi 1991b-l).

Classification	**Area (ha)**	**% of the total area**
Rhizophora dominant, with *Avicennia, Ceriops, Sonneratia, Bruguiera, Heritiera* and/or *Xylocarpus*	55 549.9	49
Sonneratia - almost pure stands	1 223.3	1
Sonneratia dominant, with *Avicennia, Bruguiera* and/or *Rhizophora*	6 123.2	5
Heritiera – almost pure stands	91.2	0
Heritiera dominant, with *Avicennia Bruguiera* and/or *Rhizophora*	8 188.4	7
Avicennia dominant, with *Rhizophora, Bruguiera, Heritiera*	17 141.6	15
Ceriops and/or *Xylocarpus Avicennia* – almost pure stands	1 687.4	1
Mixture of *Avicennia* and *Ceriops*	17 432.7	15
Ceriops dominant, with *Rhizophora, Avicennia* and/or *Bruguiera*	8 037.9	7
Total Mangrove	115 475.6	100
Water in creeks	24 076.0	
Clear-cut areas	4 435.0	
Bare, Saline areas	20 740.0	
Salt Pans	3 093.0	
Non-Mangrove Forest inside the reserve	5 069.3	
Total reserve area	172 888.9	

For building boats, *Xylocarpus granatum, Rhizophora mucronata* and *Heritiera littoralis* are taken for the mast and *Sonneratia alba* for the ribs. According to Nasser (1994) in 1993 the income generated from the exploitation of mangrove products at Chwaka Bay, Zanzibar was 24% of the total household income but when fishery was included in the mangrove component they made up 73% of the total income.

Orange and greenish sponges growing on the aerial roots of *Sonneratia alba* are used as fish bait (Semesi et al. 1998) and honey is collected in the mangroves (Semesi 1991a). An herb, *Sesuvium portulacastrum* (local name: Mboga Pwani), which grows on sandy portions in the mangroves, is eaten as a vegetable (Semesi 1991a, 1998). Extract from the climber *Derris trifoliata* (local name in Rufiji: Nyaganjirwa) found in the mangroves is used as fish poison. *Derris trifoliata* and *Barrigtonia racemosa* (local name in Rufiji: Mtongoto) are used as alternatives to DDT to kill sersarmid crabs that are a nuisance in the rice fields (Sørensen 1997). The stems of *Derris* are chopped and whisked through the water and the seeds of *Barrigtonia* are crushed and applied in the same way as DDT. Besides both these species are used as sources of fibre for making twine and rope for binding things. The ropes of *Derris* are used in building houses and heating over fire flame makes the rope stronger. *Derris trifoliata* and *Barrigtonia racemosa* are also used as indicator species when farmers want to identify suitable area in the mangrove for rice cultivation.

Due to large mangrove areas, the mangrove of the Rufiji delta makes its surroundings most important prawn fishing grounds in Tanzania, about 80% of the total Tanzania's commercial catch (Fisheries Division annual report). About 3 000 fishermen are involved in prawn fishing and 6 000 in other fishing. Most of the shellfishes are in the intertidal mud flats and seagrasses close to mangroves. Edible oysters, mussels, cockles, and gastropods are collected extensively for local consumption, (Kayombo and Mainoya, 1986; Ngoile and Shunula, 1992, Nasser, 1994, Masawe 1999, Semesi *et al.* 1999). In Bagamoyo, Tanga, Zanzibar and Rufiji area, the important crab species are *Scylla serrata* locally known as Kaa ungo or Mboga and *Portenus pelagicus* known as Kara Pemba (Ngoile and Shunula, 1992, Siegel, 1996, Mgaya *et al.* 1999). Women and children collect *Terebralia palustris* (locally known as Suka or Tondo) for food and men collect it mainly as fish bait or to be used as feed in the trial prawn aquaculture pond. Kombe kichaa (*Anadara* sp.), Kombe kazungu (*Anadara* sp.), Nyaluale or Nyuwali (*Strombus gibberulus*), Kinyonga (*Polinices mamilla*), Kijino (*Strombus* sp.), and Kikola or Kikopola kome (*Pleuroploca* sp.) are the common shellfishes collected in or close the mangroves of Bagamoyo (Semesi et al.1998, Kayombo and Mainoya 1986).

5.5.8.2 Conservation and Policy

All mangroves of Tanzania mainland were gazetted as Forest Reserves in 1928-1932. In the mainland legislation governing mangrove forests' reserves is included under the Forest ordinance of 1957 (Semesi 1991c). In Zanzibar, forestry legislation is covered by the Wood cutting (Amendment) Decree, 1968. Most of the mangroves are listed as protected under this decree. The Forest Reserves Principal Legislation (CAP 120), do provide for the establishment, protection and management of forest reserves (Nasser 1994).

Theoretically the legislation imposes many restrictions on access to, and utilisation of, the mangrove forests but is rarely enforced. Previous management plans emphasised on the harvesting of mangrove trees for commercial wood products that is bark for tannin, building poles, firewood, and charcoal (Grant 1938, Mbwana, 1986, Semesi, 1991). The essential role of mangroves in supplying the basic needs of coastal communities or their important value to the environment such as supporting fisheries was downplayed. Management for nonwood resources in mangroves such as for prawns, crabs, fish bait and honey is not carried out although now awareness of these issues is taking place.

Generally, no overall national authority exists that can effectively resolve conflicting issues related to conservation and development of the mangroves. Although the Forestry Division is charged with the managing of the mangroves at present, conflicts arise between those branches of government responsible for forests, fisheries, wildlife, agriculture, ports, surveying of land and issuing of titles, and mineral mining (Semesi 1991).

The mangrove forests of mainland have been divided into four management zones:
Zone I, forests which will receive total protection

Zone II, forests that are ready to be brought into production
Zone III, degraded areas that will be closed to allow recovery
Zone IV, areas that will be set-aside for different developments.

The Mangrove Management plans emphasise the need to have close coordination among the various users of the mangrove ecosystem. Although it is now 10 years since the management plans of mainland Tanzania were prepared, still it is not followed closely and community involvement is minimal (Semesi 1998). Collaborative management is being practised in three pilot villages in Tanga: Kipumbwi, Sange and Kisa (Ngunyali 1997), and 422 ha of mangroves have been allocated for trial. The mangrove management project is collaborating with the Tanga Coastal Zone Development Project and local communities. However, the government through its Forest Division still assumes the overall responsibility. The primary objective of this collaborative management is protection and wise use of mangroves for the benefit of the villagers. The main constraint identified has been limited trained personnel to carry out the implementation of the management plan and lack of experience of the foresters in involving communities. However, the mangrove management plans of Tanzania have been useful as they are used to raise awareness on the mangroves. The management plans are now used in the Kenya and Mozambique who are preparing their plans following similar approach.

5.5.9 Condition of the resource (good/ overused/ depleted/ degraded/ pristine)

The rate of cutting is high near big population centres and therefore the most degraded mangroves are those close to towns such as that at Mtoni, Kunduchi and Mjimwema in Dar es Salaam, Maruhubi close to Zanzibar town or those mangroves close to Tanga and Mtwara towns. Some mangroves found in islands in Tanga region such as Ulenge area are also quite degraded because of illegal cutting for export to Kenya and due to easy access by boat. However some parts of Rufiji and Ruvuma deltas have mangroves that are in very good condition because it is difficult to access them, there is low surrounding population and other alternative sources of firewood and timber are available to the community. We hardly have pristine mangroves in Tanzania considering the long dependency of coastal communities on the mangrove resources. Many studies (Banyikwa and Semesi 1986, Nasser 1994, Semesi et al 1999, Shunula 1996, etc.) show increasing trend in cutting and thus also the degradation of mangroves in Tanzania.

5.5.10 Human impacts

The ecological stability of the mangrove ecosystem is dependent on both upland terrestrial and the coastal estuarine ecosystems with which it is intimately and inseparably linked. Severe erosion, improper agricultural and forestry practices and pollution from pesticides and herbicides hundreds of kilometres upstream in Catchment areas can all affect mangroves and other elements of the coastal ecosystem. Petroleum prospecting, oil pollution from ships, the dumping of garbage and sewage as well as various types of industrial chemical pollution in the estuarine environment, boat traffic that increase erosive boat wakes also may have direct negative affects on mangroves.

Selective cutting is the normal practice for subsistence use and this practice usually allows profuse natural regeneration of the mangroves. However, large scale clear felling of mangroves prevent natural regeneration (Germanis 1999, Masawe 1999, Semesi 1987, Semesi et al. 1999) due to alteration of soil and microclimate and few seed bearing trees being left in the plot to act as seed source. In some stands of mangroves such as in Maruhubi and Chwaka in Zanzibar or Kunduchi and Mtoni in Dar es Salaam, the rate of annual removal of trees from the forest is higher than the mean annual increment and is thus not sustainable. Clearance of mangrove for salt production and clear cutting for charcoal are the most important in destroying the mangroves of Bagamoyo, Lindi, Zanzibar, Dar es Salaam, Mtwara and Tanga (Banyikwa and Semesi 1986, Semesi 1987, 1993, Masawe 1999, von Mitzlaff 1990, Shunula 1996, Kulindwa et al. 1998, etc.). Intensity of cutting is influenced by the ease of access and closeness to high population density.

Clearing for rice farms takes place in Ruvu and Rufiji delta in Tanzania (Semesi 1991, Semesi et. al. 1999, Sørensen 1997). In the Rufiji delta farms cleared from mangroves after approximately the 7th year (range from 4^{th} to 11^{th} year), yields fall dramatically and grasses, phragmites and sedges or *Derris* invade the farms and working the farms becomes a problem. Therefore the farms are usually abandoned after this period. Digging of polychaete worms used as fish bait in the *Sonneratia* and *Rhizophora* zones also result in ecological damage of the mangroves (Semesi et al. 1999).

5.5.11 Natural impacts

Among the natural impacts affecting the conditions of mangroves are the diversion of water due to the flood and change of river courses, strong wave action, blocking of normal tidal flow due to sand deposition, and drought which reduce the ground water seepage and create hypersaline conditions in some mangrove that are located landward. Therefore in places like the Rufiji delta there is a lot of natural changes in some mangroves because they can be killed by being flooded for too long, but also new ones are continual formed in depositional areas. Besides those mangroves close to the shore where wave action has increased due to unknown factors we see poor natural regeneration and sediments are washed away exposing some of the roots. This is quite common in Mafia Island, and some parts of Chwaka bay and Kaole mangroves for example. Mangrove die back due to unstudied courses is also common such as in the Rufiji delta and Kilwa.

5.6 Scientific and management recommendations (in the literature)

5.6.1 Scientific recommendations

Every thesis and paper published has a list of recommendations. For example Hedman and Strandberg (1999) recommends that nutrient dynamics in different mangrove sediments and the function of mangrove, as natural wastewater treating facility requires further study. They further caution that it must be kept in mind that the characteristics of a mangrove ecosystem cannot rely on generic model but must be based on local observations.

5.6.2 Conservation/protection/restricted use recommendations

Since mangrove ecosystems are interlinked with both terrestrial and marine ecosystems, any management practice aimed at handling mangrove separately would probably be ineffective. Therefore Nasser (1994) recommended that a comprehensive management plan of mangroves of Zanzibar be prepared under a broader plan of integrated coastal zone management that would cover both terrestrial and marine ecosystems. While Semesi et al. (1999) recommended that management which focuses on forest tree products should now be supplemented by considering the ecological services and the role of mangroves on capture fishery. Since assigning a direct economic value to many and complex ecological services of mangroves is difficult, precautionary approach should be used when converting mangroves for aquaculture, or salt pans. They also recommended that no more mangroves of Bagamoyo be allocated for prawn culture or salt production; already large areas have been allocated for these activities.

5.6.3 Local awareness/participation/training recommendations

According to Semesi et al. (1999) foresters that are dealing with mangrove management needs training on mangrove ecology so that they can supervise the reforestation of clear felled areas. Government needs to provide opportunities for the education of hotel developers on the importance of developing ecotourism, thus regarding and making use of mangroves as one of the tourist attractions instead of clearing them for sandy beaches (Muruke et al. 1999). In view of the present rate of exploitation and heavy dependency of the local communities for the economy on mangrove ecosystem, there should be a developed management system that would involve the local people. The mangrove management plans of 1991 should be studied more carefully and ways of involving communities should be developed.

According to Wagner et al. (2000) monitoring of plantation trials should not only be done by scientists, but should involve citizen monitoring. Scientists should work with villagers and train them to gradually take over most of the monitoring work in a simplified form, though scientists should continue to be involved as advisors and to monitor aspects that require expertise.

5.6.4 Other (if any) recommendations

The mangrove studies, preparation of management plans and their implementation rely heavily on donor support (Semesi 1998). Therefore in order to sustain these activities, mechanisms of insuring funding should be found.

5.7 INFORMATION GAPS

5.7.1 Geographic coverage

The list of references and summarised table in Appendix 1 show the geographic coverage, period and nature of study carried out. The distribution, area coverage, species composition, uses and threats of all the mangroves of mainland have been documented. Similar information on the mangroves of Unguja Island in Zanzibar has also been documented but not mapped in great detail. However no detailed information is present on most mangroves of Pemba Island except the tree species recorded.

When it comes to the detailed studies on the fauna, nutrient dynamics, hydrological parameters, microbiological process, etc. then very few sites have been studied. The most studied sites in Unguja Island are those at Chwaka bay, Maruhubi and Kisakasaka. While on the mainland those at Mtoni, Mbweni and Kunduchi, near Dar es Salaam, are the most studied. This is because of their proximity to the University of Dar es Salaam both at main campus and the institute of Marine Science Zanzibar.

5.7.2 Subject coverage (resource species/types)

Research is being undertaken, on reforestation, forest structure, nutrient dynamics, microbial processes, crabs and other fauna and ground water. Also local uses are being studied in much more detail. Information on the growth and yield of natural mangrove forests, needed to determine optimum thinning and planting strategies, is lacking. Measurement of the net flux of nutrients and organic matter are required in order to understand the role and relative importance of mangrove forests to biochemistry and productivity of coastal waters. Exploiting mangroves forest for one product or service can reduce its ability to provide others. We still do not understand all the consequences of disturbances of mangrove forests. There are also no studies on the biopysics and biochemistry of the mangrove trees of Tanzania.

There is still little information about seasonal fluctuations and zonation of benthic fauna in Tanzania. The role of some non-commercially important benthic species in materials and energy turnover and community characteristics in mangrove ecosystems also remains unclear. Insects have not attracted scientists working on mangroves in Tanzania.

Detailed ecological knowledge of the mangrove ecosystem is still limited although it is accumulating. An understanding of the food-chain relationship and specific physicochemical processes within the coastal waters is scanty. Indigenous knowledge and traditional management systems also need to be understood and evaluated.

5.7.3 Duration of studies (long/short)

Few studies are of long term mainly those connected to Ph.D. and M.Sc. studies. There is hardly any study aimed at monitoring changes with time. Majority of the studies is short term, less than 3 months.

5.7.4 Age of studies (old/New information)

As explained earlier, majority of the studies is recent this could be due to the increasing awareness, better equipments and more training scientists. The old literature focused more on the vegetation looking at the forest structure, trees diversity, Zonation and uses. While recent studies cover more topics such as sediments, Microorganisms, chemical, and fauna.

5.7.5 Information accessibility

In general it is difficult to get hold of mangrove literature in the country even those in the published forms. The observation made by Mgaya and Mohamed (when undertaking the TCMP coastal resource reviews) on information accessibility also applies to the literature on mangroves. Information inaccessibility seems to be a major constraint in Tanzania and as such research results are rarely used in planning and making decisions. Since the researchers at the University generate most of the research results, there is a need to develop better mechanisms to deliver research results to the managers and decision-makers.

5.8 Recommendations for future work

5.8.1 Methods (quality, comparability)

As pointed out earlier, standard methods have been used in most studies. Therefore the quality of research methods is similar to studies carried out elsewhere e.g. aerial photography or estimating the number of bacterial population in sediments or the levels of Phosphate or nitrates, or methane and Hydrogen sulphide. In most cases researchers just followed recommended methods rather then inventing their own. Therefore it is recommended that standard methods should continue to be used in the future but making sure to review on the most accepted methods so as to obtain comparable results.

5.8.2 Geographical coverage

Since detailed studies cover very few sites there is a need to carry out study in many more mangrove types so a obtain a more representative view of the resource. The mangrove of Pemba needs special attention as there is very little written on them.

5.8.3 Subject coverage

More research should be directed in the areas where little information is available. The recommended research topics in the mangrove management plans have only been tackled partially. Therefore more research should continue in the following:

- investigate the causes of observed deaths of some mangrove stands
- investigate contaminating effects on mangroves of agricultural practices, of human sewage from the cities and of industrial discharge and how to minimize and control the impacts of these effluents
- investigate the possibilities of seaweed/fish/ prawn aquaculture activities in saltpans
- investigate the potential for tourism in the mangroves and surrounding areas
- investigate nutrient flow and recycling
- investigate animal-plant interaction
- investigate the possible impact of global climate change.

5.8.4 Research

An ecosystem approach to the study of the mangrove resource should be adopted. Further research on ecological linkages both within mangrove ecosystems as between mangrove and other coastal ecosystems is essential. This would give the fabric of information needed for understanding the complexity of the roles of the mangrove ecosystem. Research should include both basic and applied aspects and encourage interdisciplinary teamwork. Local people know a lot of natural history of many plants and animals and they have ideas of where specific species (e.g. fish) breed and what or the way they eat. Therefore using local knowledge and people could facilitate any future research about the ecology of the mangroves.

5.8.5 Monitoring

A long-term monitoring programme should be established in selected sites along the coast of Tanzania. Monitoring of the various components of the ecosystem is essential in order to be able to assess if the changes are either due to natural or human impacts. Without monitoring it is not possible to practice adaptive management, which is necessary as the management regimes prescribed cannot be evaluated if they are effective without monitoring. Since monitoring requires carrying out observations or sampling for a long time, it is essential to train field officers and villagers to undertake monitoring. This can be complemented by remote sensing so as to get an overview of the change of coverage of the resource.

5.8.6 Training

Foresters and Fisheries officers working on mangrove areas should be trained on mangrove ecology and the interlinkages between various resources. So far fisheries officers learn mainly about fish biology and hardily on the habitat supporting the fishery. While the present foresters who work on mangroves have learned about the terrestrial forest structure and not on the mangrove ecosystems. Organising short courses focusing on specific topics of mangroves to various groups should thus be planned. In the eastern African region various short courses have been organised but these have mainly focused on Masters or Ph.D. students. In order to have a faster impact parallel course should be organised for field officers with less qualification. It is also necessary to target some training to Journalists so they can be able to report about the mangroves more accurately.

The institute of Marine Sciences, Zanzibar has got facilities for producing videos for awareness that are not fully utilized. Therefore it is recommended that this unit be more involved in producing documentation materials for public awareness and also for monitoring purposes.

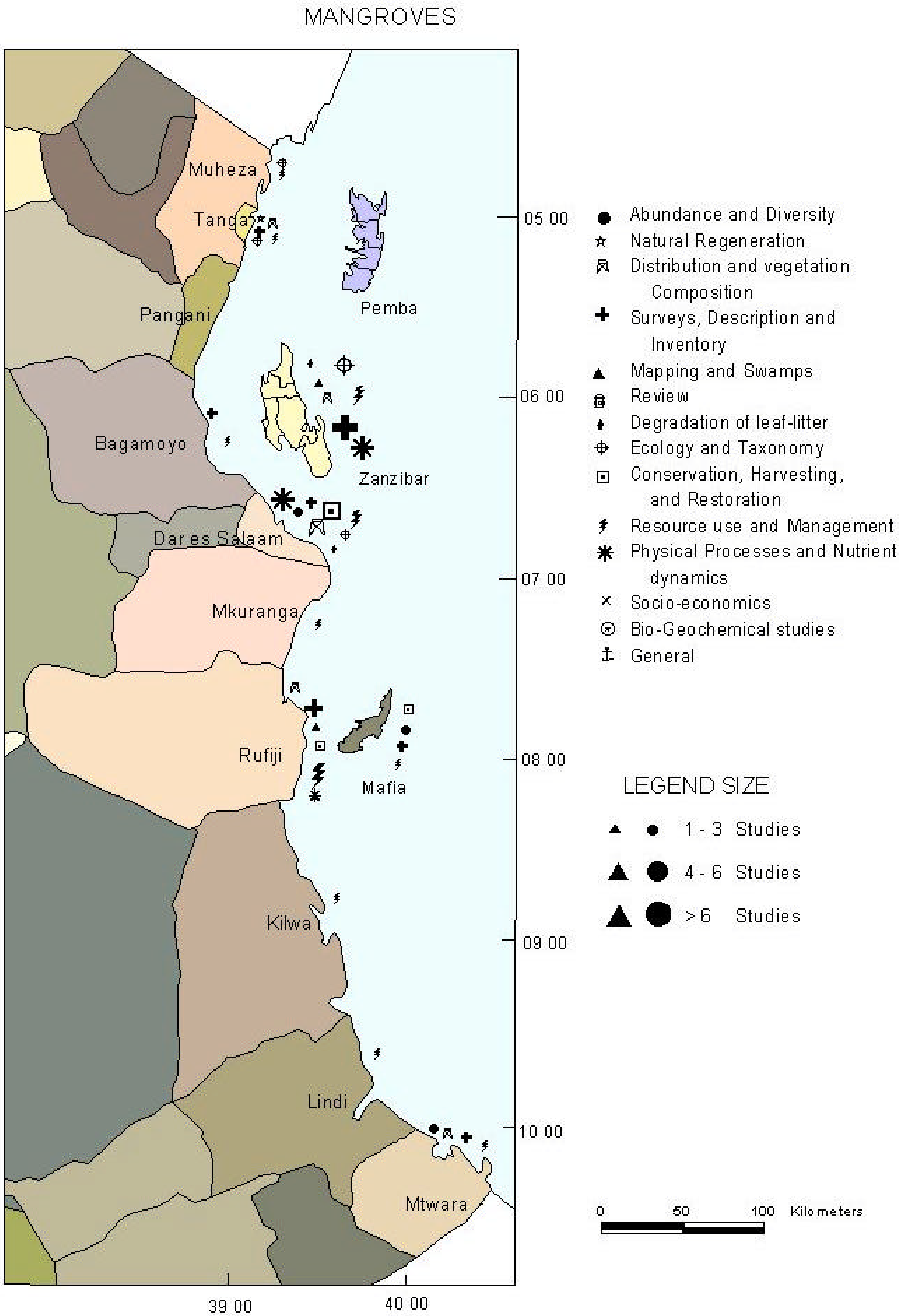

Figure 5.1. Tanzania coastal base map showing the distribution of research works that has been conducted in relation to coastal erosion. This includes all the available literature that was used in the preparation of the mangrove synthesis.

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Chapter 6

Other marine living resources

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6.0 Background information

6.1 General description and importance of the resource

Tanzania coastline is characterised by sandy/muddy tidal flats, mangroves, coral reefs, seagrass and algal beds, lagoons, and estuaries. These are ecosystems that play a major role in supporting local people as they are the source of food, cash, and energy. The category *'other living resources'* covered in this synthesis include: seaweeds, seagrasses, benthic fauna, sea turtles, marine mammals, zooplankton, phytoplankton, and marine birds.

6.1.1 Seaweeds

Seaweeds are generally large macroscopic non-vascular plants, known as the Algae. They grow attached to rocks, or to shells of marine animals, or growing as epiphytes on other marine plants (Mshigeni, 1973). The genus *Eucheuma*, occurring on the shorelines of Tanzania is one of the most favoured seaweeds as a source of carrageenans (agar-like gel). Anderson (1952) reported on the utilisation of this genus, where *Eucheuma striata* was of commercial importance in Zanzibar. *Eucheuma* prefers rocky habitats which are protected from strong waves behind coral reefs away from estuaries (Mshigeni, 1973).

In Tanzania, there are over 300 red, green and brown intertidal seaweeds (Jaasund, 1976). The species diversity of red seaweeds is higher than the other two groups but the brown algae dominate in terms of biomass (Semesi et al., 1999). Most herbivorous fish depend on seaweed resources for food. On healthy reefs, the biomass of seaweeds is kept low by grazers and thus they contribute a major proportion of the total production. Some of the current industries that use seaweeds include: cosmetics, food derivatives, healthy foods and medical uses (Semesi et al., 1999). Species of *Eucheuma* have been harvested for export trade for over four decades (Anderson, 1952; Mshigeni, 1973) due to the rich content of the phycocolloid, carrageenan in the thalli of the species (Mshigeni and Semesi, 1977). Supply from the wild stocks of *Eucheuma* could not meet the demand for the product, hence research was directed towards the culture technology for this genus (e.g. Mshigeni, 1976; 1983; 1985; Lirasan and Twide, 1993; Collén et al., 1995). Currently, seaweed farming is becoming an important economic activity in the coastal areas of the United Republic of Tanzania (MWG, 1999).

6.1.2 Seagresses

There are about 12 species of seagrasses found in Tanzanian coastal waters (Semesi and Shushu, 1988). The importance of seagrasses lies in their interactions with other ecosystems in the marine environment especially mangroves and coral reefs. They form dense beds that cover large areas of coastal waters and perform a wide range of biological and physical functions in the marine environment. Their most notable role is that they provide breeding, nursery and feeding areas for many invertebrates and vertebrate species including commercially important species of finfish and shellfish. They provide shelter and refuge for resident and transient adult animals e.g. shrimps (*Penaeus* spp.). As a result both artisanal and commercial fishery activities are carried out in these areas. Furthermore, seagrass beds support complex trophic webs both through dead and living biomass. Green turtle *Chelonia mydas* and dugongs *Dugong dugon* depend on seagrasses for food, whereas certain species of sea urchins derive their nutrition from direct consumption of detrital seagrasses.

In Tanzania, seagrasses are not utilised directly by human beings. However, they can be utilised for (1) paper making due to their high cellulose and low lignin content. (2) Making green manure and fodder, and (3) food in the form of salad (*Thalassia hemprichii* in Philippines), flour (rhizomes of *Enhalus acoroides* in the Lamu Archipelago) and seeds of *Zostera marina* in Mexico (Lugendo, 2000 and references cited therein).

Besides providing both direct and indirect food sources, seagrasses offer protection to the environment. The roots and rhizomes of a healthy seagrass bed bind the sedimentsand slow the rate of water flow over the substrate thus preventing erosion of the sediment surface from happening. So far seagrass beds are not under major threat in Tanzania except in areas where high sedimentation and prawn trawling are taking place.

6.1.3 Phytoplankton

Phytoplankton and zooplankton collectively constitute the plankton. Phytoplankton forms the first trophic level as primary producers and so they are able to sustain the productivity of the higher trophic levels. Zooplanktons are consumers of the phytoplankton, forming the next step in the food chain as secondary producers. Blooms of phytoplankton occur in tropical coastal waters, some resulting in higher productivity (e.g. *Trichodesmium* blooms during northeast monsoon, Bryceson, 1977) while others lead to contamination of shellfish or massive fish kills (e.g. *Prorocentrum* sp. and *Gonyaulax* sp., Lugomela et al., 1999). Species diversity of phytoplankton in Tanzanian coastal waters is quite high. For example, Bryceson (1977) reported a total of 265 taxa in coastal waters of Dar es Salaam and Lugomela (1996) a total of 192 species from Zanzibar coastal waters.

Okera’s (1971) nearshore zooplankton study (20 m deep, vertical tows at 0.3 m/s), completed near Bryceson’s (1977) site, indicates that zooplankton in Tanzania is most abundant during late NE and early SE monsoons and probably lags somewhat behind phytoplankton peaks. Okera (1971) revealed a very diverse composition of zooplankton species in the inshore waters of Dar es Salaam. Dominant groups included Calanoids (49%), larvaceans (12%), cyclopoid copepods (11%), ostracods (6%) and caridean larvae (4%). Oceanic species including Hydromedusae, Ctenophores, Mysidacea, fish eggs, Cumaceans, Gammarideans and Hyperrideans contributed <1%. Also present were larvae of benthic invertebrates such as carideans, brachyuran zoeae and megalopae, stomatopods, bivalves, gastropods and polychaetes.

6.1.4 Benthic fauna

Many benthic and pelagic fish and invertebrates feed on plankton. An understanding of the ecological dynamics of marine plankton may provide clues about seasonal variations in catches of various species, preferred habitats, breeding cycles, migration patterns, and may also warn of problems of toxicity.

Examples of studies on benthic fauna in Tanzanian coastal waters include those that considered molluscs (Verdcourt, 1954; Spry, 1961; 1964; Yanniek, 1978; Kayombo, 1986; 1988; Newton et al., 1993; Mgaya et al., 1999a), crustaceans (Heath, 1973; Bwathondi, 1973; Hartnoll, 1975; Bashemererwa, 1981; Chande, 1999; Kyomo, 1999; Mgaya et al., 1999b). Sea cucumbers (Horsfall, 1998; Mgaya et al., 1999a), and general aspects of benthic ecology (e.g. Mwaiseje, 1973; Hartnoll, 1976; Ndaro and Olafsson, 1995). At present there is no monitoring or control of the commercial harvesting of the majority of these invertebrate resources. This, coupled with lack of information on the stock abundance, put the resources at a very serious danger of depletion. For example, available data suggest that stocks of sea cucumbers have been drastically decreasing, as a result of intensive over-exploitation (Mgaya et al., 1999a), the same could be said for gastropods collected for the ornamental shell trade (Newton et al., 1993).

6.1.5 Marine birds

Tanzania has a variety of habitats along the coast which are attractive to seabirds in terms of feeding and nesting sites (Howell, 1988a). The associated areas of open water such as the Zanzibar and Mafia channels and the Indian Ocean itself also provide rich feeding grounds for the seabirds. The types of waterbirds that are considered here are “those which spend much of their time above, near or in coastal marine waters” (Howell, 1988a). This definition includes orders like Procellariiformes, many members of the Pelecaniformes, the family Labridae, the waders (families Scolopacidae, Charadriidae) and waterfowl (family Anatidae). There are two large categories of seabirds based on their migratory patterns: those which are resident or non-migrant and those which are migrants (Howell, 1988a). Direct exploitation of seabirds for food along theTanzania coastline is negligible, but they are important in nutrient cycling. For example, guano produced by waterbirds has been shown to critical in maintaining forests on the coral rag (Allaway and Ashford, 1984, cited in Howell, 1988a).

6.1.6 Marine Mammals

Cetaceans are a type of marine mammals which frequent our coastal waters and are divided into two groups, the Odontoceti (the toothed whales including the dolphins and porpoises) and the Mysticeti or baleen whales. These mammals spend the boreal summer feeding in the polar regions and the winter in warmer tropical waters which provide a suitable range of temperature for giving birth and suckling the young (Howell, 1988b). Some of the smaller species of Odontocetes may occasionally be killed in fishing nets, but the impact on the stocks would seem to be minimal (Howell, 1988b; Chande et al., 1994). For example, Chande et al. (1994) reported an incidental catch of rate of dolphins at 0.003 dolphins/boat-day, with the intentional catch for a period of 11 months to be only 14 dolphins for the four areas that were surveyed (Dar es Salaam, Bagamoyo, Tanga and Mtwara). Dynamite fishing could have serious effects on both adults and young cetaceans in the vicinity of a blast (Howell, 1988b).

The dugong (*Dugong dugon*) is another type of marine mammal (order Sirenia) that is found in Tanzanian coastal waters. There are two centres of dugong population in Tanzania: Pemba–Zanzibar channels and the Rufiji–Mafia area (Howell, 1988b). Dugongs feed on seagrasses, especially *Cymodocea* and *Syringodium*, and can consume up to 30 kg (wet weight) daily (Howell, 1988b). The dugong is killed for its flesh and its oil, and local populations in Tanzania have almost been decimated (Richmond, 1997). Further threats to dugong populations include, habitat degradation which might affect its food supply (e.g. pollution and siltation), dynamite fishing (kills individuals and destroys the habitat).

6.1.7 Sea turtles

There are five species of marine turtles that occur in the Tanzania coastal waters: Green turtle (*Chelonia mydas*), Hawksbill (*Eretmochelys imbricata*), Loggerhead (*Caretta caretta*), Olive Ridley (*Lepidochelys olivacea*), and Leathery turtle (*Dermochelys coriacea*) (Frazier, 1976). Sea turtles are adapted to a life in the sea and come out on land only for nesting (Frazier, 1976). Nesting period is the easiest time for predators including man to catch turtles. This results in a direct reduction of reproduction since the females are killed before nesting. The eggs and hatchlings are equally susceptible to predators. Turtles are killed for their meat, eggs and the carapace ("tortoise shell"). The Hawksbill is particularly valuable as a source of "tortoise shell" (Frazier, 1976). The author further noted that not only commercial hunting but also intense levels of non-commercial utilisation have endangered the turtle resource. Turtles are especially vulnerable to pollutants since many feed on invertebrates, which concentrate various pollutants (Howell, 1988b). Meat from such turtles could cause serious public health problems.

6.2 Type of information gathered

6.2.1 Baseline studies

Majority of the papers published during 1960s through 1980s could be categorised as baseline studies describing the distribution, species diversity, life history and aspects of resource use and conservation. For example, Spry (1961, 1964) published a survey of molluscs (gastropods and bivalves) in the Dar es Salaam area, describing various species and their habitats. Jaasund (1976) conducted an extensive baseline study on macroalgae in Tanzanian coastal waters, giving detailed species lists for the major groups of seaweeds (green, brown and red). In his thesis, Bryceson (1977) studied phytoplankton in nearshore waters of Dar es Salaam, producing plates that have proved to be very useful in the identification of the various species of phytoplankton. Kayombo (1988) published a baseline study on the gastropods, describing distribution of species their ecology in Dar es Salaam and Bagamoyo intertidal areas.

This type of information is important in that it forms a basis for applied research work in the future. For example, surveys of seaweed resources carried out by Prof. K.E. Mshigeni in the 1970s and 1980s were very instrumental during the applied research that led to the initiation of seaweed farming in Tanzania and work on phycocolloids by Prof. A.K. Semesi. Baseline studies are also important in the assessment of the status of the resources, for example, the recently published book on coastal resources of Bagamoyo district (Howell and Semesi, 1999) is an effort in this direction.

6.2.2 Observational studies

A few types of studies that are observational in nature have been published. Lawson (1969) conducted an observational study on the littoral ecology of rocky shores in Tanzania. Mshigeni (1979) made observations on the morphology and distribution ecology of the *Eucheuma* after visiting several localities along the shores of Tanzania mainland, Unguja, Pemba and Mafia islands. Frazier (1976) reported on sea turtles in Tanzania, with observations on the breeding sites and distribution of species. He observed that Maziwi Island (before it became submerged) was a very important nesting ground for Green Turtles.

6.2.3 Experimental studies

Experimental studies are generally rare. In an experimental study that investigated the growth form of *Ulva fasciata* raised from spores in two contrasting habitats, Mshigeni and Kajumulo (1979) reported that *Ulva* grown in calm water habitat exhibited erect growth habit whereas those plants from wave exposed habitats were dwarf and rosette-like.

Ólafsson and Ndaro (1997) designed a laboratory experiment (microcosm) to assess the impact of the mangrove crabs *Uca annulipes* and *Dotilla fenestrata* on meiobenthos. They concluded that these ocypodid crabs do not regulate residentnematode assembalges, but may inhibit settlement of colonisers (e.g. harpacticoid copepods) that have not adapted to the intense surface disturbance created by these crabs. In another study that involved microcosm experiments, Ólafsson et al. (1995) examined effects of intensive seaweed farming on the meiobenthos in a tropical lagoon. They reported that the algae farms accommodate different meiobenthic assemblages than closely adjacent areas, and they exhibit poorer fauna in terms of numbers and altered assemblage structure. Björk et al. (1995) carried out a laboratory experiment to examine the effect of phosphate, nitrate and ammonia levels on the growth rate and calcification of coralline algae. They found that high phospate levels negatively affected growth rates and calcification of these algae, whereas nitrate and ammonia had no effect. It must be stated that the situation regarding scarcity of experimental studies is partly attributable to inadequate research facilities to support both *in situ* and *ex situ* experiments.

6.2.4 Applied studies

Studies of applied nature are those that have mostly dealt with mariculture. Kayombo (1991) designed a system for experimental farming of the edible cockle *Anadara antiquata* and revealed that cockles stocked at lower densities exhibited faster growth rates compared to those at higher densities. In a series of trials at Kigombe near

Tanga (Tanzania mainland), Fumba Bay (Zanzibar) and Fundo Island (Pemba) Mshigeni (1983, 1987) was able to demonstrate that *Eucheuma* farming was technically and economically feasible in Tanzania. Lisaran and Twide (1993) conducted *Eucheuma* planting trials using two species *E. cottonii* and *E. spinosum* and found that the latter species performed better in terms of growth (measured as daily growth rates) and resistance to *ice-ice* disease. The authors further reported that the attempted farming trials with *E. cottonii* failed.

In an investigation on the environmental aspects of open water algal cultivation in Zanzibar Johnstone and Ólafsson (1995) found that the farming has no discernible effects on water-column microbial production, but has an effect on both benthic microbial processes and meiofauna populations. They speculate that these changes are attributable to the mechanical alteration of the sediment surface and possible enhancement of local benthic fish grazing. Collén et al. (1995) demonstrated that *Eucheuma* plants that are stressed (e.g. through high density planting, grazing, high light intensities) succumbed easily to *ice-ice* disease, and produced hydrogen peroxide and volatile halogenated compounds as part of their chemical defence.

6.2.5 Review studies

Review studies that present latest information on various aspects of the resources are a good source of information for researchers as well as students. In fact scientists, from time to time, should be encouraged to write comprehensive publishable reviews on selected topics because this type of work is has not yet been adequately done. A recent book on East African sea shores (Richmond, 1997) does a good job as a review text but also covers material from field observations in a comprehensive manner.

Several papers have reviewed various aspects of the resources and habitats. Bryceson (1981) published a review of some problems of tropical marine conservation with particular reference to the Tanzanian coast. Issues relevant to the conservation of marine mammals and turtles in Tanzania (Howell, 1988a) and waterbirds (Howell, 1988b) have been reviewed and research priorities recommended. Mgaya et al. (1999c) reviewed prawn farming issues using Bagamoyo as a case study.

6.3 Research methodology

This section covers baseline, observational, experimental and applied studies.

6.3.1 Sampling aspects/parameters

The methodology used for the various studies is scientific and acceptable. However, the methods differ among studies and resources. For example, plankton nets are used in sampling plankton, quadrats and corers for sampling macrobenthos and meiobenthos. Studies on turtles and waterbirds, were generally based on field observations. The studies done on marine mammals were mainly conducted with the aid of photographs and field observations. The objectives of these studies vary according to the type of resource being considered.

6.3.2 Instrumentation and techniques of sampling and data collection

Techniques involving ^{14}C isotope were used to measure both benthic and water column primary production. Analytical methods in chemistry (e.g. Infrared spectroscopy) were used in studies that analysed the phycocolloids of some seaweeds (e.g. Semesi and Mshigeni, 1977) and Spectrophotometer in the determination of chlorophyll concentration (Bryceson, 1977; Ólafsson et al., 1995). Basic laboratory equipment e.g. microscope has been used in the various studies. Microcosms have also been employed in laboratory studies (Ólafsson and Ndaro, 1997). Ecological studies have often been accompanied by measurements of abiotic factors e.g. salinity (refractometer), temperature (thermometer), turbidity (Secchi disc), and meteorological factors.

6.3.3 Sampling frequency and time of collection

Frequency of sampling is very variable for different studies. For example, studies on phycocolloids were based on a single field sampling of seaweeds (Mshigeni and Nzalalila, 1977; Semesi and Mshigeni, 1977). In a study by Newton et al. (1993), on the effects of shell collecting on the abundance of gastropods, field sampling lasted 32, 24, and 37 hours for Dar es Salaam, Zanzibar and Mafia respectively. Ndaro and Ólafsson (1995), in their investigation on the selection of meiobenthic prey by the fish *Gerres oyena,* sampled meiobenthos once in November 1993, and sampled fish three times (on 12 and 13 November, 1992 and 21 November, 1993). Chande et al. (1994) investigated marine mammals and fisheries interactions in a study that lasted six months (June to November). Khatib (1998) reported results from a one-year turtle nest-recording programme in Zanzibar.

The authors do not give explanations as to why a particular sampling frequency was chosen. However, where the author(s) should have increased sampling frequency (e.g. Newton et al., 1993; Ndaro and Ólafsson, 1995), it appears that the constraint has been financial and available time. The latter is partcularly relevant where a postgraduate student was involved.

6.3.4 Data analysis methods and procedure

There are variations in the data analysis, depending on the type of study and hypotheses being tested. Standard statistical techniques have been employed in some studies especially those of quantitative nature. For example, Ólafsson and Ndaro (1997) used ANOSIM randomisation test to test for differences in nematode assemblage structure and the SIMPER computer program to identify those species contributing to differences observed in the ordination analysis.

Statistical analyses were not applied to qualitative or descriptive type studies (e.g., Mshigeni, 1973; Howell, 1988a; 1988b). Analytical chemistry and stereo chemistry techniques were used in the phycocolloid studies (Semesi and Mshigeni, 1977; Mshigeni et al., 1979).

6.4 Quality, usefulness and reliability of data/information

6.4.1 Duration of studies

Duration of the studies varies from a single day sampling to a couple of days' work (Newton et al., 1993) to a year (e.g., Khatib,1998). The differences in duration is a reflection of the diversity of the studies and do not necessarily impinge on quality of the data.

6.4.2 Capability of scientists/researchers/reporters

The scientists involved in the various studies are senior scientists of high calibre, and where postgraduate students were engaged close supervision was put in place. However, this view is based on published studies and may not apply to unpublished reports.

6.4.3 Comparability of methods

Though majority of the studies made use of “low tech” methods, very useful information has been gathered. The methods are generally comparable within resources and where same authors are involved. For example, same researchers conducted all meiobenthos studies. The same could be said for phycocolloid studies. Methods were not quite comparable where different resources were involved.

6.4.4 Publications/grey literature

Majority of the studies was published in international refereed journals, some in workshop/conference proceedings and a few in grey literatures. The use of the words "grey literature" implies reports (e.g., consultancy and research reports) that are not published, and not in a retrievable form, thus not easily accessible. Postgraduate dissertations and theses are accessible only through the University Library and the authors themselves. An analysis of the various categories for the 85 references on Mgaya's list is presented in Table 1.

Table 6.1. Distribution of publications in the area of othe marine living resources.

Category	**Number of items**
International refereed journals	44
Published conference proceedings	8
Unpublished conference proceedings	2
Books or book chapters	4
Unpublished reports	17
Ph.D. theses	2
M.Sc. theses	8
Total	**85**

6.5 Age of information

A few studies were carried out a long time ago (e.g. Anderson, 1952; Verdourt, 1954; Spry, 1961; 1964). There were quite a few studies conducted in 1990s. Out of 84 references on Mgaya's list, 2 appeared in 1950s, 3 in 1960s, 21 in 1970s, 12 in 1980s and 47 appeared in 1990s. The trend in these studies has been a gradual shift from baseline studies (which dominated in 1960s through 1980s) to applied studies. For example, majority of the studies conducted in 1990s is applied in nature, as witnessed in seaweed farming research. However, baseline studies still featured in 1990s, as seen in studies on marine mammals and non-conventional resources like sea cucumbers and molluscs.

Reference can still be made to old studies, for example, in tracing changes (e.g. species distribution, abundance, etc.) over time. Generally speaking, some of the old studies, particularly those on seaweeds by Professor K.E. Mshigeni and Professor A.K. Semesi formed the basis for seaweed farming. Work by Dr. J. Frazier on sea turtles, for example, raised the awareness on the species and the information was useful in designing management strategies for the species.

6.7 Main findings/observations

6.7.1 Types of resource use

There are various resource use types depending on the species in question. For example, Seaweeds of the genus *Eucheuma* are exploited for phycocolloid (carrageenans) production and turtles are consumed by fishermen whenever they are caught, but they are not targeted. Fishermen in Mtwara were reported to kill dolphins for use as bait in the longline fishery, targeting tiger sharks *Galeocerdo cuvieri* (Chande et al., 1994). Dugongs are killed for their meat and oil, while turtles are slaughtered for their meat, eggs and tortoise shell (Howell, 1988b). Sea cucumbers are harvested and prepared as beche-de-mer which is usually exported (Mgaya et al., 1999a). Besides the foregoing consumptive uses, there are non-consumptive uses with some of the resources. For example, mollusc shells are collected for the curio trade (Newton et al., 1993), a certain type of seaweed is being harvested in Bagamoyo for use as a bait for rabbitfish (Semesi et al., 1998).

6.7.2 Condition of the resource (good/overused/depleted/degraded/pristine)

Studies leading to determination of the status of the resource are rare. Various authors give statements that point to resource depletion as a result of uncontrolled exploitation. Some examples are given hereunder. In their review paper, Stensland et al. (1998) express an urgent need for the status assessment of marine mammals. Newton et al. (1993) note that gastropods (e.g. cowries) which have commercialvalue because of the shell trade are over-exploited. The cetaceans are apparently not commercially exploited in Tanzanian coastal waters, but populations of both dugongs and marine turtles are exploited and these animals are regarded as endangered (Howell, 1988b). Based on interviews conducted in Bagamoyo, Mgaya et al. (1999a) reported that sea cucumber stocks are declining and that collectors are now employing SCUBA equipment, thus depleting the resources further.

6.7.3 Human impacts

There is some information of qualitative nature on human impacts on resources and habitats. Bryceson (1981) reviewed some anthropogenic impacts (e.g. sand mining, dynamite fishing) on marine habitats and resources and builds a rationale for their conservation. Howell (1988a) discusses human impacts, particularly habitat destruction (e.g. deforestation and dynamite fishing) and pollution (e.g. oil spills) on coastal seabirds. Chemical pollutants such as petroleum products in the water may interfere with olfaction in marine turtles, which may be used in navigation and orientation. Turtles are especially vulnerable to pollutants because many feed on invertebrates, which concentrate various pollutants (Howell, 1988b).

Stensland et al. (1998) present an argument for the need toprotect marine mammals from destruction emanating from human activities particularly fishing and marine pollution. Khatib (1998) lists several anthropogenic impacts on sea turtles around Unguja Island.

Generally, seaweed farming is considered to have mild environmental impacts, but Johnstone and Ólafsson (1995) reported that the activity has a clear effect on both benthic microbial processes and meiofauna populations. For example, they showed that attached algae vibrated in the current thus brushing against the benthos, consequently preventing consolidation of any micro-algal mats. Ólafsson et al. (1995) suggested that seaweed farming had a negative effect on the abundance of meiobenthos, mainly through increased predation by benthic feeding fish and the mechanical disturbance of the sediments. Mtolera et al. (1992) noted that unselective farm clearance ("weeding") through removal of sedentary animals, seagrasses and other seaweeds is likely to affect the benthic communities.

6.7.4 Natural impacts

Natural impacts on the resources reported here include storms and beach erosion. The latter event can lead to reduction in size or complete disappearance of an island as has been the case with Maziwi Island. The extent of the impact resulting from submergence of the island on populations of Green Turtle that were nesting at Maziwi Island has not been determined.

6.8 Scientific and management recommendations

6.8.1 Scientific recommendations

In a study on the farming and physiology of *Eucheuma*, Collén et al. (1995) recommended that

- *Eucheuma* plants be grown at medium densities,
- Extensive farms should be discouraged to avoid *Ice-Ice* disease, and the stressed condition of *Eucheuma*, and to reduce the negative impact of *Eucheuma* on other marine flora and fauna.

In order to improve our understanding of the coastal resources, Semesi et al. (1998) proposed the following recommendations:

- Government fisheries data collection should be improved, and research and monitoring be strengthened;
- Interdisciplinary research that involves government officials and local communities should be practised;
- Scientific information collected by research institutions must be transmitted to resource managers.

6.8.2 Conservation/protection/restricted use

Howell (1988b) made the following suggestions with regard to marine turtle conservation:

- Imposition of a ban on the commercial trade of "tortoiseshell";
- Introduction of awareness raising campaigns that marine turtles are endangered and must not be killed;
- Introduction of tighter enforcement of existing legislation and a ban on all individual exportation of chelonian carapaces and scales;
- Inclusion into National Nature Reserves or parks, areas of concentrated breeding.

Regarding conservation of coastal waterbirds, Howell (1988a) recommended (i) conducting biological surveys to determine the status of the resource, (ii) prevention or reduction of habitat disturbance and destruction, (iii) establishment of Nature Reserves, and (iv) education and publicity.

Since little is known of the role of sea cucumbers and molluscs in the ecosystem(s), Mgaya et al. (1999) recommended that sales of shells and beche-de-mer should be reduced until sufficient data on the ecology and population dynamics are known.

6.8.3 Local awareness/participation/training

Research that targets at among other things, educating resource users on the importance of conservation of the resource must ensure their active participation as holders of indigenous knowledge and skills. It is crucial that local knowledge is documented as soon as possible in order to build a broader base for future management.

Creation of awareness at all levels of ecosystem functioning, threats, and values, policy changes, etc. is necessary. Semesi et al. (1998) suggested that local communities should be made aware of the legislative process and opportunities for its use. Moreover, there is a need to provide translated educational materials, and to prepare films on the major habitats and resources.

6.9 Information gaps

6.9.1 Geographical coverage

In basic marine biological research, our experience so far has been confined mainly to inshore and shallow water environments. Some important areas such as deep sea ecology, offshore pelagic ecosystem etc. are still untouched. Majority of the studies have been conducted around major urban centres e.g. Dar es Salaam, Zanzibar etc., in the vicinity of research institutions and fewer studies outside these areas in remote places.

Work by Frontier-Tanzania has covered some of the remote parts along the Tanzanian coastline, for example, Darwall (1996) reported on marine resource use in the Songo Songo archipelago. Resources in the Mafia Island waters have been fairly well studied partly due to the presence of the marine park in the area (e.g. Andersson and Ngazi, 1995; Horrill et al., 1996). Mshigeni (1979) reported on observations on the morphology and distribution ecology of *Eucheuma* spp., a study that included 11 sites on the shores of mainland Tanzania stretching from Lindi in the south to Tanga in the north, 5 sites around mafia Island, 4 sites covering both the east and west coast of Unguja Island, and 9 sites around Pemba Island. Some of the sites in this study were on very remote areas.

6.9.2 Subject coverage (resource species/types)

Lack of detailed information about some of the resources like molluscs, sea cucumbers, marine birds, sea turtles, marine mammals, zooplankton and phytoplankton is identified as a major bottleneck in resource management and conservation. For example, resource abundance, distribution, trends of exploitation, biodiversity and biology of most species, and information about users are, thus, unknown.

6.9.3 Duration of studies (long/short)

With the exception of studies that led to PhD degrees (e.g. Okera, 1971; Bryceson, 1977; Semesi, 1979; Subramaniam, 1980; Chande, 1999), many studies were carried out over a relatively short time (single day to less than a year). Resources (particularly funds) permitting, long-term studies are desirable.

6.9.4 Age of studies (old/new information)

As shown earlier, majority of the studies were carried out in the last ten years. Some of the studies conducted in the 1970s and 1980s have not been followed up with recent data, especially taking into account the fact that human impact on majority of the resources has increased considerably with increase in population over time.

6.9.5 Information accessibility

As mentioned earlier, majority of the studies (44 out of 85) has been published in international refereed journals, thus should be accessible or retrievable. However, the fact of the matter is, the journals are either not available locally or where available, some volumes for certain years could be missing all together. Accessibility of University theses and in-house reports is not easy. For example, theses are only available at the University of Dar es Salaam, where restrictions on access exist. This situation may not be different from reports because usually organizations hold these reports with no organised mechanism for making them accessible to other institutions and researchers.

6.10 Recommendations for future work

6.10.1 Methods (quality, comparability)

As pointed out earlier, comparability of methods depends on the resource species or types. For instance, methods used for meiobenthos studies are generally comparable and rigorous. It is not expected to have comparable methods for the diverse groups like the ones considered in this report. However, methods are generally comparable where you have different authors studying similar aspects (e.g. analysis of phycocolloids from seaweeds).

6.10.2 Geographical coverage

Majority of the studies are localised, essentially covering a narrower geographical range. While this strategy is valid for certain types of studies, it is recommended thatcertain studies e.g. survey type, should be stretched to cover a wider coastline so that different geographical areas can be compared. Research work should also extend from inshore shallow waters to offshore deep waters, areas that are virtually untouched.

6.10.3 Subject coverage

Basic marine biological research, such as plankton and oceanographic studies and benthic ecological work should be designed to provide useful background information and ecological understanding for more applied fisheries researchand for the assessment of utilisation of resources. More research should be directed in the areas where little information is available. For the resources that are exploitable, it is recommended that biological surveys must precede any commercial exploitation. These surveys would form the basis for sound management.

6.10.4 Research

Research should include a good mix of basic and applied aspects, with an overall objective of feeding the results into resource management systems so that informed decisions can be made. Scientists should strive to publish their research findings in journals and other retrievable forms of publications for a wider circulation to a greater audience.

6.10.5 Monitoring

A long-term monitoring programme should be established in selected sites along the coast of Tanzania. Such data (from the monitoring programme) will form a backbone to development of future management plans for the resources. Furthermore, monitoring of specific issues such as over-exploitation of certain resources and loss of biodiversity is necessary to determine changes with time.

6.10.6 Training

The need to train more marine scientists can not be over-emphasised. The limited geographical coverage in the studies reported here is partly attributable to shortage of scientists in various coastal regions of Tanzania. Short courses focusing on specific topics should also be planned so as to equip scientists with state of the art methodologies.

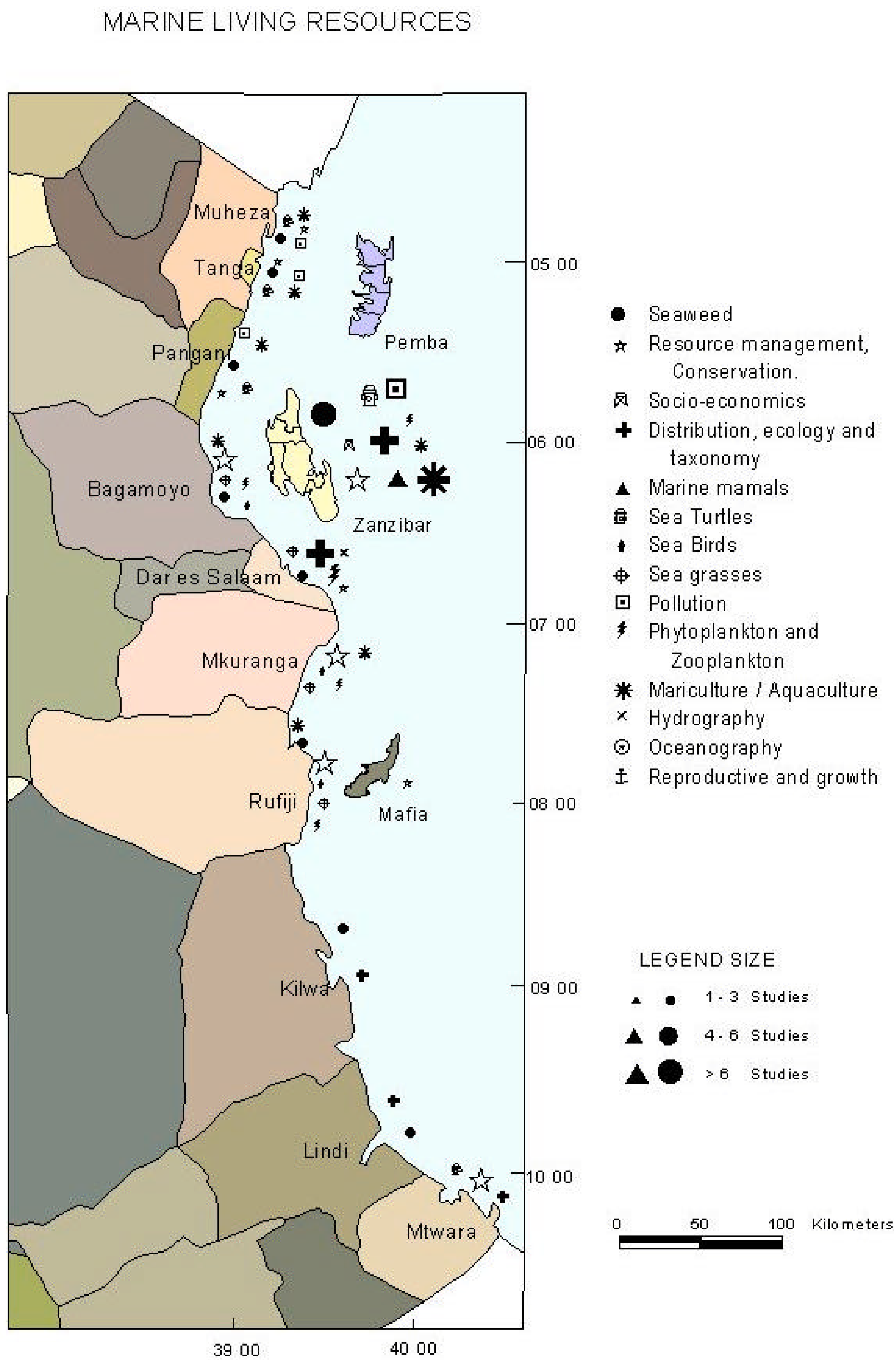

Figure 6.1. Tanzania coastal base map showing the distribution of research works that has been conducted in relation to coastal erosion. This includes all the available literature that was used in the preparation of the other marine living resources synthesis.

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