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MONITORING PROGRAMME FOR RESOURCE CONDITION, ENVIRONMENTAL AND BIOLOGICAL PARAMETERS FOR MNAZI BAY RUVUMA ESTUARY MARINE PARK (MBREMP) TANZANIA

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ABSTRACT

This study aims to improve the existing monitoring programme for the coastal environment and resources of Tanzania and develop guideline strategies to be used during monitoring. An environmental and biological monitoring study of Eyjafjordur fjord located north of Iceland was carried out in December 2005 to become familiar with Icelandic monitoring programmes. CTD data, benthic communities and zooplankton were studied along the fjord. Surfer 8 and grapher 6 graphical softwares were used in the presentation of the CTD data obtained from the fieldwork as well as data and information from previous monitoring. This was used to develop a monitoring programme for Mnazi Bay Ruvuma Estuary Marine Park (MBREMP). Variables to be monitored for resource condition, environmental and biological parameters are proposed together with the monitoring sites and sampling frequency. Good understanding of monitored information on environment and resource condition over time will help to set the level of protection as well as identify problem areas that need additional management. Skill in handling and managing the monitored information is required for Tanzanian MPAs. The use of information technology and communication skills is very important for communicating the monitored information and data. The CTD data results obtained in Eyjafjordur fjord were found to be similar to those obtained from the previous monitoring studies. Six groups of macrofauna were identified in the sediment samples. Few zooplankton organisms were found in the water samples during the study period as it was winter and most of the activities in the water column in temperate regions are minimal.

LIST OF ABREVIATIONS

ICM	Integrated Coastal Management
MPAs	Marine Protected Areas
MBREMP	Mnazi Bay Ruvuma Estuary Marine Park
DMRs	Dar es Salaam Marine Reserve Systems
TCZCDP	Tanga Coastal Zone Conservation and Development Programme
TCMP	Tanzania Coastal Management Partnership
SEC	South Equatorial Current
UNEP	United Nations Environmental Programme
MPRU	Marine Parks and Reserves Unit
ITCZ	Inter-Tropical Convergence Zone
NE	Northern Monsoon
SE	Southern Monsoon
EACC	East African Coastal Current
MC	Mozambique Current
CTD	Conductivity Temperature Depth
EIA	Environmental Impact Assessment
CZM	Coastal Zone Management
WWF	World Wide Foundation
MIMCA	Misali Island Conservation Area
ZPAP	Zanzibar Protected Areas Project

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1 INTRODUCTION

Coastal zones extending from coastal plains across the continental shelves are regions where the landmasses, oceans and atmosphere interact. They are characterised by strong gradients in environmental and ecological properties and provide valuable living and non-living resources which are presently often being exploited by humans on a non-sustainable basis (Holligan 1995). This zone has the highest biological diversity and productivity compared to any part of the sea and it is estimated to contribute 25% of the global biological production and support most of the world's fisheries (Norse 1993). Environmental changes have been driven directly and indirectly by human activities in the coastal areas. However, many of its ecosystems worldwide are now facing major environmental problems that ultimately threaten the sustainability of the goods and services they provide to human beings. Such problems are often particularly acute within developing countries where demographic trends, coupled with requirements of economic growth, suggest that pressures on coastal areas and their associated resources will continue to increase (Tsontos *et al*. 1998). Therefore, appropriate management and use of coastal zones is needed both regionally and globally.

Awareness of the quality of global coastal ecosystems being adversely impacted by multiple driving forces has accelerated efforts to assess, monitor and mitigate coastal stressors. In the 1980s many coastal states and nations established national programmes for assessing and monitoring marine ecosystems to try to minimise the degradation on the coastal ecosystems. The main aims of the programmes were to prevent, reduce, and control the rate of degradation of the marine environment and to improve, maintain and support its life-supporting and productive capacities. An essential component of an ecosystem regime is the inclusion of a science-based strategy that monitors and assesses the changing state and health of the ecosystem by tracking key biological and environmental parameters. Sherman (1998) defined marine ecosystem assessment and monitoring as a component of a management system that includes regulatory, institutional and decision-making aspects relating to marine ecosystems to include a range of activities needed to provide management information about ecosystem conditions, contaminants and resources at risk.

The coastal resources of Tanzania, as elsewhere in the world, are under increasing pressure from the people that depend on them for food and income (Tanzania ICM 2003). The demand for fisheries resources has been gradually increasing with the increase in population and tourism. This has caused an increase in fishing pressure and the use of gears and techniques that are destructive and cause damage to marine habitats and ecosystems, especially coral reefs and sea grass beds. Much of the degradation of the inshore marine environment has been caused by destructive fishing methods and over-fishing. The inshore fishery shows signs of overexploitation and in the vicinity of high population areas shallow reefs are highly degraded (Jiddawi 2003 and Guard *et al*. 2000).

The government of Tanzania has responded to these problems by introducing a range of management and conservation initiatives to address the declining trend in fisheries resources and habitat destruction to safeguard the future of the country's marine resources. Marine Protected Areas (MPAs) are particularly important tools (Francis and Bryceson 2001). Other methods include mangrove forest inventories, zoning and management plans. National guidance for sustainable development of coastal aquaculture has also been adopted as well as a National Coastal Management Strategy under which Integrated Coastal Management (ICM) is practiced. Several MPAs and coastal management efforts have been operational since the middle of the last decade. The MPAs provide a means of managing coastal and marine resources to achieve objectives of sustainable development and conservation of marine biodiversity. The purpose of MPAs, as described by Kelleher and Kenchington (1991), are wide-ranging, including protection of marine species and their habitats, conserving marine biodiversity, restoring fish stocks, managing tourism activities and minimising conflicts among the diverse resource users.

Despite substantial efforts including MPAs and other coastal management initiatives, monitoring of environmental parameters and natural resource condition is not sufficient. Appropriately designed, management, focused on resource and environmental monitoring is essential for effective management of the coastal zone of Tanzania. Sustainable use and development of the coastal zone requires effective monitoring and assessment of changes which occur in the coastal zone through identification of priority problems requiring urgent attention. The key coastal issues to be monitored have been identified to include the anthropogenic impacts due to increasing population pressure and development of the coastal zone, the quality of coastal waters and loss of coastal habitat (Bennet *et al*. 2004). The effectiveness management of Tanzanian MPAs and coastal zone as a whole will occur when there are effective management plans that include adequate ecological and socio-economic monitoring as well as tools to ensure that the plans are enforced. Without planning, monitoring and enforcement most costal management efforts will not achieve their objectives of conserving the resources. Appropriate resource and environmental monitoring will provide the information needed for effective science-based managerial decision-making on resource protection and conservation of the environment.

1.1 Significance of the study

Currently there is no effective monitoring programme in place for the coastal environment and marine resources in Tanzania. The present monitoring programmes are incomplete and lack consistence and focus on issues concerning global environmental changes e.g. rising sea levels and pollution. The programmes in place are also characterised by fragmentation of responsibilities. Often the monitored data and information are inaccessible and no clear documented monitoring guidelines are used. The monitoring is carried out for short periods of time to address the need of problems encountered at that particular time, which leads to results that lack integration. In MPAs, the present monitoring programme focuses more on the ecological processes in respect to an increase in biodiversity rather than environmental parameters which also play a significant role in the ecosystem structuring. Collected information and data from monitoring programmes are not properly stored, analysed or represented due to inadequate knowledge of the field. Insufficient resources and funds hinder comprehensive monitoring of the coastal resources and environment.

MBREMP has no monitoring programme in place yet. Therefore, there is a need to develop comprehensive monitoring guideline strategies, which will track changes in resource conditions, and biological and environmental parameters on the coastal ecosystems around the park. The knowledge gained from this study will be used to facilitate, support and coordinate the monitoring programmes in MPAs and Tanzanian coastal waters as a whole. Knowing the condition of natural resources and environmental parameters is crucial to the services ability to protect and manage the coastal resources of Tanzania since a lot of destruction has already been done on the coastal ecosystems. The capacity to measure and assess variations in biophysical processes and coastal uses can contribute to reports on the state of the marine environment and provide a significant contribution to the national strategy for coastal and marine sustainable development.

1.2 Objective of the study

This study is aimed at learning various strategies used in monitoring the environmental and biological parameters in the coastal water of Iceland. Various methods of analysing and representing the monitored information and data were also adopted during the study. Through the experience from Icelandic monitoring, an environmental and biological monitoring programme for MBREMP was developed. Generally the objectives of the study were:

1. To become familiar with Icelandic monitoring programmes for coastal resources and the marine environment together with various ways used the interpretation and presentation of monitored information.
2. To develop a monitoring programme for the environmental and biological parameters for MBREMP.

2 BACKGROUND

2.1 The Tanzanian coastal zone

Tanzania has a coastline of about 1,424 km excluding near shore islands, bays, lagoons and estuaries. The continental shelf extends to 4 km offshore, with exception of the Zanzibar and Mafia channels where the shelf extends for some 60 km. The area of the shelf to the 200 m depth contour for both mainland Tanzania and Zanzibar combined is about 30,000 km^2. The islands within the continental shelf include Unguja, Pemba and Mafia as well as numerous small islands, islets and sand dunes surrounded by reefs such as Latham, Tutia, Songosongo and Mbudya (Nyandwi and Dubi 2001). Unguja and Mafia are limestone islands on the continental shelf and were probably part of a Pleistocene inshore coral reef system now separated from the mainland by relatively shallow water channels of about 30 – 50 m in depth (Well *et al*. 2004). Important ecosystems include mangrove forests, estuaries, coral reefs, sea grass beds, inter-tidal flats, muddy and sandy beaches.

Most or nearly all inshore fishing takes place on the continental shelf where productive areas such as coral reefs, reef flats, sea grass beds, mangroves and estuaries are located. These habitats have been reported to be subjected to heavy fishing pressures from artisanal fishermen (Guard *at al*. 2000). Inshore marine fishery is extremely important to the coastal communities of Tanzania that depend on the coastal resources for food as well as income. These coastal ecosystems interact with each other and together sustain a tremendous diversity of marine life, which is an important source of sustenance for coastal communities (Jiddawi 2003). However, as elsewhere in the world, the coastal and marine environment of Tanzania is facing unprecedented threats from both anthropogenic and natural changes including:

- Over-exploitation
- Destructive fishing methods (fish dynamiting, poisoning, beach seining)
- Industrial and domestic pollution (oil spills, effluents, wastes)
- Potential unregulated tourism development
- Global climate change

All these degradations are attributed to unsustainable use of coastal resources as well as pressures from the growing coastal population (Ruitenbeen *et al*. 2005). The government responded to these problems in the 1990s by introducing a range of management and conservation initiatives. These responses include traditional management systems, enforcement of policies and laws through regulatory mechanisms and collaborative management arrangement. Under the traditional management system organisation of resource harvest is under the supervision of local experts or leadership. In Tanzania the traditional management systems have basically retained their mode of operation, which is based mainly on trust and respect for the authority of elders. Certain villages used to prohibit prawn and octopus fishing in their areas for two or three months during breeding and spawning (Tobisson *et al*. 1998). However, this has become more vulnerable and increasingly fails to survive due to the emergence of external challenges, pressures and opportunities. Collaborative management involves the sharing of the functions rights and responsibilities of resource management among stakeholders under which prime stakeholders include government authorities and resource users. MPAs are one of the co-management and other communities' initiatives e.g. Tanga Coastal Zone Management Programme. Generally all of the coastal initiatives are aimed at protecting ecosystems (habitats) and resources for maximum productivity and for protecting scenic and coastal areas against abuse (Muhando and Francis 2002). Kelleher and Kenchington (1991) identified the reasons for creating MPAs as the following:

- To maintain essential ecological processes and life support systems
- To ensure the sustainable utilisation of species and ecosystems
- To preserve biotic diversity

2.2 MPAs of Tanzania

Coastal and marine protection takes a variety of forms in Tanzania all of which provide a means for managing coastal and marine resources, which have been over-utilised and mismanaged in the past decade. The Marine Parks and Reserves Act No. 19 of 1994 provided the first guide on the establishment and the institutional mechanisms for the management of parks and reserves. The legislation for mainland Tanzania allows for the gazettement of three types of MPAs: marine parks, marine reserves and national parks containing marine habitat (Well *et al*. 2004). Marine parks are relatively large multiple use zoned areas while marine reserves are smaller areas in which the extraction of any marine resource is prohibited.

Currently there are two marine parks and five marine reserves established and gazetted under this institutional framework. The reserves include Dar es Salaam Marine Reserve systems (DMRs), which refer to a set of four islands and the adjacent sea area of Bongoyo, Pangavini, Funguyasini and Mbudya located north of Dar es Salaam harbour and Maziwi Island marine reserve located in the north of Dar es Salam at Pangani, Tanga. Mafia Island Marine Park (MIMP) was legally established in 1996 and the Mnazi Bay Ruvuma Estuary Marine Park (MBREMP) was gazetted in 2000. These two parks are relatively large, consisting of multiple use areas that are very much like small-scale models of integrated coastal management. Natural resource protection while maintaining the local community's rights to resources is the management approach which used to run the marine parks.

Marine resource management and protection under the community based approach management are practiced in Menai Bay Conservation Area located on the south coast of Zanzibar which was established in 1997, Misali Island Marine Conservation Area located 10 km off the west coast of Pemba, the Misali Island Marine Conservation Project on Pemba, the Jozani-Chwaka Bay Conservation Area located 35 km southeast of Zanzibar town as well as Tanga, Muheza, and Pangani Districts under the direction of the Tanga Coastal Zone Conservation and Development Programme (TCZCDP). Other community-based coastal and marine management initiatives include the Kinondoni Integrated Coastal Area Management Programme, the Rural Integrated Project Support, and Rufiji Environment Management Project. Community-based management is based on the idea of empowering communities to care for their own resources. The third form of marine protection is found in Zanzibar, where small protected areas are managed by private companies that have an agreement with the government. They include Chumbe Island Coral Sanctuary and Mnemba Island Marine Reserve.

The main goal of Tanzanian MPAs is to ensure sustainable conservation of coastal resources for the benefit of present and future generations with the vision of establishing well managed, integrated networks of marine and fresh water protected areas, which will ensure the sustainability of Tanzania's aquatic biological diversity and ecological processes. The general objectives of the MPAs include:

- Protection, conservation and restoration of the species and genetic diversity of living and non-living marine resources and ecosystem processes of marine and coastal areas.
- To stimulate rational development of under-utilised natural resources.
- To manage marine and coastal areas so as to promote sustainability of existing resource use, and the recovery of areas and resources.
- To ensure that communities in the vicinity of marine parks and reserves are involved in all the processes of management and share the benefit of protected areas.
- To promote community awareness on sustainable conservation of marine parks and reserves resources.
- To facilitate research and monitoring of resource conditions and uses within the marine parks and reserves

2.3 Mnazi Bay Ruvuma Estuary Marine Park (MBREMP)

The Mnazi Bay Ruvuma Estuary Marine Park, covering a total area of about 650 km^2, was established in 2000. The park area includes within its boundaries 11 villages with a population of about 30,000 and it is the first park in East Africa with a high dry land ratio (MBREMP 2005). The rationale behind incorporating such a wide area of land in the park was to constitute a buffer zone and control human activities that impact the protected marine environment. The high population in the park area is imposing significant pressures on the park and its biological resources, through fishing, coral mining and other forms of extraction of resources. Several biophysical assessments conducted on MBREMP have shown that the marine environment is highly impacted by the human activities, particularly by over-fishing, destructive fishing and coral mining (Guard *et al*. 1998, Guard 2004 and Obura 2004). The mangrove forest around the park has also been destroyed through anthropogenic use (Wagner *et al*. 2004).

The continental shelf is very narrow off Mnazi Bay, only about 1 - 3 km wide (Muhando *et al*. 1999) and extends for about 60 km from the Ruvuma estuary northward to the Mtwara port north of the park border. The shelf is composed primarily of sediment deposits from the Jurassic and Lower Cretaceous Period and sediment layers are eroded within the bay, with additional structure provided by past reef growth that forms the reefs and islands of the eastern part of the bay. The Mnazi Bay area has been recognised as an area of biodiversity value at both the national and international level (Kelleher and Bleakley 1996).

MBREMP has extensive mangrove forests, which are breeding and nursery grounds for prawns and other species of fishes. Fisheries resources in the park area include fish, lobsters, prawns, sea cucumber, bivalves and gastropods. Sea grass beds occur in shallow water areas in the bays. Coral reefs occur as patch reefs in the Mnazi Bay and continuous fringing reefs outside the bay. Coral reefs in Mnazi Bay have been described by Darwall, Guard (2000) and Muhando *et al*. (1999) to be in good condition, with 85-95% coral cover with about 36 and 42 coral genera on outer and channel reefs, respectively. However, high levels of habitat damage from dynamite and dragnet fishing was observed. On outer reefs less damage was observed due to greater inaccessibility.

The latest resource survey conducted by Obura (2004) identified a total of 258 coral species in 59 genera and 15 families as well as 369 species of fish in 146 genera and 47 families. It is believed that the combination of its geographical point of contact with the South Equatorial Current (SEC), location, close proximity of the continental slope and large size of the bay result in highly complex and diverse reef communities and abundance of benthic and fish life (Darwall and Guard 2000 and Obura 2004). Large amounts of rubbles and a highly disturbed benthic community give strong evidence of massive historical and current disturbance to coral reefs in the MBREMP through destructive and excessive fishing (Obura 2004). Currently, dragnet fishing is reported within Mnazi Bay, further contributing to destruction of habitats around the bay by preventing cementation of rubbles and recruitment of coral polyps from the past destruction. High levels of extraction of reef resources, particularly reef, pelagic fish and invertebrates (octopus and sea cucumbers), and coral and salt mining have been observed in the waters of MBREMP (Obura 2004, Guard *et al*. 2000 & Muhando *et al*. 1999).

Coral mining was considered one of the major contributors of reef and forest degradation along the Tanzanian coast during the 1990s (Guard *et al*. 2000). This impacted much of the reef habitats in Mafia Island (Darwall and Guard 2000) and spread to the Mtwara area where life coral rock of massive *Porite lutea* were found piled on the seashore of the Mtwara and Mnazi Bay coastline (Obura 2004). It is estimated that currently 4,800 tonnes of live coral and 3,000 tonnes of fuel wood are used in the coral mining industry in Mtwara per year (Guard *et al*. 2000 and Guard 2004). However, the practice of mining of live coral particularly for lime production in Mtwara is at an alarming stage and poses threats to the conservation of the biodiversity of the park. Deliberate efforts are being made by MBREMP in collaboration with the Mtwara District Council to develop alternatives to live coral as a source of lime for local and urban building (MBREMP 2005). Use of fossilised coral mining for cement and lime on land has been recommended as a suitable alternative. Mangrove forests around the park are also impacted by coral mining through cutting for fuel (Wagner *et al*. 2004).

Obura (2004) identified various threats to the resources and environment around the park including coral bleaching and mining, the location of the park near the Mtwara port as well as the existence of natural gas in the sedimentary of the park. Following the national coral reef monitoring network to assess the impact of 1989 El-Nino it was shown that the reefs of Mnazi Bay were significantly impacted by bleaching with declines in coral cover from 30-50% to 25-30% (Mohammed *et al*. 2000). Although the coral reefs were highly impacted it was noted that there was good potential for coral recruitment around the Mnazi Bay waters. Another threat to the park resources and environment in general is the Mtwara town port located on the north just adjacent to the park area. The increasing population and expansion of Mtwara urban centre can have significant impact through shipping activities and the development on marine environments and organisms around the park. The existence of natural gas in the sedimentary sands beneath Mnazi Bay and the focus on an initiative to extract the gas is a potential future threat to the marine environment in the bay if environmental assessment measures are not considered.

2.4 Research and monitoring

Research and monitoring of the environmental processes and resources is an essential part of the management mechanism of any coastal zone. Most of the coastal management initiatives for managing the coastal zone of Tanzania, including the MPAs, were established after several studies of the existing resources during the 1990s, which revealed the need for action on the resource management. For example, Frontier Tanzania Association in collaboration with the University of Dar es Salaam, conducted ecological studies in the southern part of Tanzania's coastline covering Mafia, Lindi, Mtwara, Kilwa, Songosongo and Rufiji. The main focus was to establish the status of the coastal resource base on which fisheries depend, including coral reef, sea grass beds, fish abundance, invertebrate of commercial importance and benthic communities. The Institute of Marine Science in Zanzibar carried out a number of research projects during this period especially in the coastal waters around Unguja, Pemba, Tanga, Dar es Salaam and some parts along the southern coastline. Human activities along the coastal zone of Tanzania were found to have significant impact on coastal habitats and hence the declining fisheries products (Mohammed *et al*. 2000). Coral mining, despite being part of the local culture of coastal people, was highly destructive to the marine environment and the whole ecosystem (Ruitenbeen *et al*. 2005).

The declaration of MPAs in the Islands of Zanzibar including Misale, Mnemba and Chumbe were based on surveys carried out by Ngoile (1990), Jiddawi and Muhando (1990), UNEP (1989), Horill (1992), Horill *et al*. (1994), Muhando and Mohammed (1996) and other studies by Zanzibar government officials. Frontier activities in southern Tanzania e.g. Gaudian and Richmond (1990) described and assessed the marine environment in the area where (MIMP) is now located. MBREMP was declared based on an assessment carried out by Guard et al. (1998), Muhando et al (1999) and Mwaipopo and Ngazy (1998). The Dar es Salaam Marine Reserve system (DMRs) was gazetted in June 1975 by the Minister of Natural Resources and Tourism following scientific recommendations by Ray (1968) and Hamilton (1975) who showed that the resources where abundant and protection measures were needed. The law that made the DMRs did not provide for an authority to guide conservation measures. Thus resources in the reserves continued to be depleted through poaching and unsustainable use. Surveys in the 1980s and 1990s by Bryceson (1981), UNEP (1989), Kamukuru (1998), McClanahan *et al*. (1999) and Wagner (2000) revealed the effects of fishing on the environment and the possibilities that the resources were overexploited and recommended immediate action to rescue the environment and its resources. With the passing of the Marine Parks and Reserves Act no. 29 of 1994, the responsibility of management of the DMRs was placed under the Marine Parks and Reserves Unit (MPRU) and effective management started in 1998. The biophysical assessment of DMRs by Muhando (2004) provided information, which was used to develop the General Management Plan for the reserves.

These studies provided guidance for the establishment of the MPAs, which later developed their management plans with objectives of conservation of biodiversity, abundance and functions of all physical and biological resources within the gazetted areas. However, the intention of the studies was to make available adequate scientific information to allow the management to define and monitor the conservation goals for sustainable levels of resources and track changes in the prevailing socio-economic situation of the coastal communities. The research and monitoring provide knowledge and understanding of natural resources and ecological processes, especially of sustainable levels of utilisation, and help to establish and adopt a participatory monitoring system of ecological and social indicators.

2.4.1 Ensuring research and monitoring

Effective management of a complex ecosystem under human pressure like the MPAs is not possible without science. The natural sciences are needed to understand the functioning of the ecosystem and the social sciences to understand human-induced problems and how they can be solved. The science done for an MPA must be driven by management needs. According to Parker (2002), the best monitoring programmes are designed to assess resource condition while minimising available management resources and should include the following:

- Detecting and characterising the ambient condition of existing resources.
- Describing whether resource condition is improving, degrading or staying the same
- Defining seasonal patterns in resource condition.
- Identifying thresholds for system stressors i.e. how much the system can be disturbed without causing unacceptable changes in resource quality or degradation of beneficial use.

2.4.2 Objectives of research and monitoring programmes

Research is about understanding the functioning of a system and monitoring is the repeated observation of a phenomenon over time. The goal of research and monitoring is to enable management to meet the purposes set for the MPA (Kelleher 1999) and this determines the objectives of the research and monitoring. Research and monitoring programmes should provide answers to many questions such as how, when, where, and at what levels do unacceptable resource conditions occur (Parker 2002). For MPAs, or any other coastal and marine management, questions to be answered include:

- What are, or have been, the pressures on the system, whether natural, e.g. severe storms, tectonic events or El Niño, or human-induced, such as pollution, habitat destruction or over-exploitation?
- What are the states of the managed ecosystems, in particular of their dominant biota, rare endangered or threatened species, ecological processes e.g. sedimentation, absorption of nutrients and toxic elements, ecological states e.g. water quality, temperature, suspended sediment levels and nutrient levels?
- What are or have been the effects of the management response?
- Are the measures specified in the management or zoning plan being implemented?
- Are people complying with the conditions in the plan?
- Is management meeting its objectives?

Monitoring programmes should be implemented to test whether resource conditions are improving, through monitoring changes in resources such as fish stocks, environmental parameters, biological processes and measuring the level of impact from different activities, e.g. tourists as visitor numbers grow (Kelleher 1999). It must also include the geographic coverage, the time-scale to be covered and related socio-economic factors. For the good coverage of the monitoring parameters to be measured it is advisable to focus on the ecosystem as the unit of study rather than be limited by the boundaries of the MPA itself. This is because of the high connectivity in marine systems, there is little value in research and monitoring that is limited to small or medium-sized MPAs. Moreover, the research and monitoring should include terrestrial and marine areas that significantly affect the MPA.

Socio-economic factors, such as the economic benefits brought by the MPA, can be just as important as biological ones. Natural and social scientists should contribute at every stage and the approach should be inter-disciplinary. The resulting analysis should consider all relevant practices in a given location typically including fisheries, aquaculture, agriculture, forestry, industry, waste disposal and tourism in the context of the conservation objectives of the coastal zone with the needs and aspirations of the communities affected (Pomeroy *et al*. 2004). It should distinguish between issues that are important over the long term such as climate change, population growth and the consumption habits of society and more immediate concerns associated with conflicts among user groups.

3 ENVIRONMENTAL AND BIOCHEMICAL PARAMETERS

3.1 Important parameters to be monitored in an ecosystem

Environmental and biochemical parameters are the key determinants of overall aquatic community health and viability. These are the components of water quality and include temperature, salinity, oxygen content, turbidity, sedimentation rate, nutrient loading, pollutants, bacteria and other particulate matter (IOC-UNEP-FAO 1994). However, water quality is an important indicator to measure because it is necessary for the maintenance of respectable levels of coastal waters. Human activities which negatively influence water quality include point and non-point discharge of human and other solid and liquid wastes, dumping of trash and refuse into the sea, oil and toxic spills within coastal waters, water run-off from urban areas, upland erosion of sediment transport and deposition on a downstream coastal environment, fertilizer presence from agriculture run-off and bilge water discharge (Pomeroy *et al.* 2004).

Changes in environmental and biological parameters in coastal and marine ecosystems have an influence on organisms and plants living there. Changes in temperature have been found to influence the metabolism and can alter ecological processes such as productivity and species interactions (Kennedy *et al*. 2002). Species are adapted to specific ranges of temperature and salinity and are therefore sensitive to just a few degrees higher or lower than those they usually experience. Muthiah (2005) found that larvae of sea cucumbers have the highest survivorship and growth rate at specific water temperature, salinity and pH of 28 – 32 °C, 35 psu and 7.8, respectively. Temperature influences organism biology including mortality, reproduction, growth and behaviour. Development of egg and gonads in most of the fish species are influenced by temperature and salinity (Lin *et al*. 2005 and Vicent *et al*. 2004). Marine organisms and plants like coral reefs and sea grasses are sensitive to changes in the environmental parameters around them. Coral reefs are said to be affected by changes in temperature and pH by decreasing its calcification necessary for building coral reef material (Kennedy *et al*. 2002). Bleaching of corals is found to occur when water temperatures around the coral reefs are too high or low and present an excellent example of the effects of increasing temperature on tropical marine ecosystems (Mgaya 2004). The majority of marine species have optimal physical environmental parameter ranges e.g. temperature ranges for respiration and growth for animals and plant photosynthesis for primary producers (Hansen 2003). Therefore, monitoring of such environmental parameters is important especially in the breeding and spawning areas where there is a high diversity of plants and animals.

River discharges into the estuaries and coastal waters usually contribute loads of sediments, nutrients and pollutants to the inshore waters (IOC-UNEP-FAO 1994). Increased loads of sediments, nutrients and other pollutants flowing into coastal waters and oceans can reduce the water clarity and block light for underwater plants and organisms like coral reefs, sea grasses, algae and other organisms, hence inhibiting photosynthesis and growth of plants and organisms on the sea bottom. Increased sediment loading to marine habitats may cause stress to the system as individuals, such as corals, will need to use extra energy to clear the sediments (Hansen 2003). However, nutrients encourage the growth of algae and plankton leading to blooms, which are sometimes harmful to the fishery and humans as well. The massive blooms of plankton can cause deoxygenated water when the plants die and accumulate on the bottom. Fresh water runoff can also carry pollutants from the agriculture and wastewater, which may affect the organisms and coastal habitats (IOC-UNEP-FAO, 1994). Pollutants from agriculture and industry can kill marine habitats and associated organisms in the coastal zones when released in high quantities. Therefore it is important for the MBREMP to monitor and control activities along the rivers around the park area.

Fresh water runoff has also been found to influence other environmental parameters like temperature and salinity. It lowers the salinity and thus causes increased stratification, which may affect the primary production. Nyandwi and Dubi (2001) found a significant decrease in salinity and temperature of inshore waters due to fresh water runoff during the 1998 El-Nino rains on the East African coast. Such environmental changes could have negative effects on the biodiversity of the coastal zone if they persist for a long time. Changes in rainfall regimes, which are now experienced by Tanzania as well as many tropical countries may have a significant impact on the coastal and marine environment especially the recovery of coral reefs, sea grass beds and benthic communities, which are taking place along the coastal waters. Prolonged rain seasons have been found to increase the volume and strength of the Ruvuma River and all its tributaries, which in turn increases erosion and washing of sediments into the sea (Francis *at al.* 2000). Sediments in water and nutrients carried with rivers are important for productivity, especially of plankton and seaweed but excessive amounts can have effect on the coastal ecosystems like coral reef and sea grass beds (Moberg and Folke 1999). Fresh water run off, sedimentation and nutrients around MBREMP are important variables to be monitored.

Hydrological information related to the coastal waters should be considered. Relevant data to be monitored include current movement, speed and direction. The currents and winds are important for the dispersal of eggs and larvae of different marine organisms and plants. The waters around MBREMP are brought across the Indian Ocean, a long way by the SEC carrying eggs and juvenile stages of thousands of marine animals and plants that were produced among the mangroves, sea grass beds, rocky shores and coral reefs of Indonesia and Australia (Obura 2004). The variability of ocean currents and circulations has also been found to be one of the contributors to the sea level rises. Sea level rises on Tanzania’s coastline were found to be influenced more by ocean currents than fresh water runoff (Ragoonaden 1998). Therefore it is important to monitor the changes of currents and winds in the park area to be able to understand and correlate their effect to the biodiversity and other ecological processes.

The rapid increase in population and industrialisation of coastal towns and cities coupled with poor and inadequate management led to the generation of more solid wastes which make their way to the coastal waters especially during the rainy season (Bryceson 1982 and Salim 2003). During the wet season rainwater drain through the dumps and as a consequence a high amount of nutrients, organic and turbidity loadings end up in coastal water, further reducing the water quality and oxygen concentration. Good water quality is an important prerequisite for all social and economic activities that occur in or around the aquatic environment including both marine and freshwater ecosystems. Similarly, tourism and other leisure activities are especially sensitive to an aquatic environment that is deemed to be of poor quality.

Protected areas located around the large cities like DMRs and MBREMP should take into consideration parameters like fecal coliforms especially around the swimming and diving sites. Fecal coliforms are indicators of pathogens and their presence in bathing waters can have an effect on the people bathing in the areas. Although seawater is said to be a good buffer to pollutants dumped in the sea, it is important to monitor bacterial contamination in the coastal waters especially in the recreation areas including swimming areas. Monitoring of bacterial contamination is important in the MPAs' waters especially MBREMP since the population around Mtwara and its suburban areas is increasing. However, this will also reduce the risk of infection in the recreational waters by controlling the source of pollution and communicate the results for scientific advances. Fresh water runoff from upstream can contribute to the water quality by bringing polluted waters with pathogens to the coastal waters.

Monitoring and measurements of these parameters requires trained staff and knowledge of physical oceanography and a good understanding of the currents, tides and water dynamics of the local coastal areas. In addition, advanced and specialised equipment is required to be able to monitor variables like heavy metals and toxic compounds such as pesticides, PCBs hydrocarbons etc. Monitoring of such parameters is not always easy and requires networking and collaboration with universities, research institutions, environmental quality organisations and agencies. More complex parameters like productivity, nutrients, pollutants including heavy metals and bacterial contaminations, need more specialised technology and significant amounts of funding. However, it is important to include such parameters in the monitoring plans of the parks and reserves. Simple variables to measure like salinity, temperature and water turbidity should be included in the current monitoring programmes in MIMP and DMRs.

The use of maps and questionnaires will help in locating and determining the sampling stations. Available facilities and resources in individual MPAs will limit the frequency of sampling. Depending on the variable to be measured daily, weekly, monthly, semi-annual and/or annual intervals are recommended to ensure sustainability and good representation of the individual variables.

Table 1: Summary of variables to be measured during the monitoring of the MPAs.

Component	Possible variables	Method
Physical parameters	• Seawater temperature, salinity and pH levels, light intensity/water transparency, water turbidity/ sedimentation rate	CTD instruments, thermometer, refractometer, light meter, secchi disc and sediment traps are among the instruments to be used to measure these parameters
	• Ocean currents	Current meter
	• Fresh water runoff; rivers and streams flow rates	Flow meter, tidal gauge
Biochemical parameters	• Chlorophyll-a content, (phytoplankton and zooplankton) and primary productivity	Water quality assessment standard methods according to Kirk (1994), Sournia (1978), Jeffery et al. (1997) and SCOR-UNESCO (1966 & 1973)
	• Dissolved oxygen content	Water quality assessment standard method according to Winkler's method as described by Parsons *et al*. (1984)
	• Fecal coliform	Water quality assessment standard methods according to APHA (1970 & 1992)
	• Nutrient concentrations (nitrogen and phosphorus)	Water quality assessment standard methods according to Strickland and Parsons (1972) and Parsons *et al*. (1984)

3.2 Storage and presentation of monitored information and data

3.2.1 Data and information storage

An operational data documentation, treatment, storage and retrieval system is a prerequisite for efficient monitoring programmes. How the data and information are managed, communicated, archived and made available largely determines a programme's efficacy (Davis 2005). Each MPA where monitoring is operational should install a database where data and information will be stored (see Annex 1). The use of database software developed by Microsoft Access gives access to all types of data and is more than just a tool to manage the data. The enables the use of more than one database table at a time to reduce the complexity of the data and make it easier to manipulate the information and data stored. Although data and information obtained from the monitoring of the Eyjafjordur fjord (Annex 1) were stored in the database since 1994, the quality was still good and it was easy to access and select the range of data one preferred. Developed queries over the database when it was developed, make selections of information from the database quicker and easier.

3.2.2 Presentation of information and data

The level of information technology (IT) knowledge within the CZM is as diverse as the disciplines. In general, however, most coastal mangers are computer literate and can adapt to the use of computer software. Many scientists also have specialist knowledge of hardware/software that is specific to their precise requirements. Accordingly, data visualisation is an important area of information provision, particularly where the results of data analysis are required on a routine basis for management purposes. Graphical data and animations are more useful for decision-making and other resource users including fishermen and communities around the parks. Tabulated numbers may be suitable for scientific research.

Monitored data and information from MPAs including MBREMP are for communication to different stakeholders ranging from resource users e.g. fishermen, decision-makers, government authorities, scientists as well as international communities. Knowing this, it is very important to develop logical presentation according to the targeted group. However, for scientific and international communities computer knowledge and use of software have made the presentation easier and simpler. For example, use of the software Surfer and Grapher (www.goldensoftware.com) ensures representation of both 2D and 3D data and allows the users to generate and produce maps and figures that are representative of the data and information in use (see Annex 1). These types of software are also relatively cheap and easy to use. Skill and knowledge of park managers in using software is important for better presentation of the information and data monitored within the MPAs of Tanzania.

4 RESOURCE CONDITION, ENVIRONMENTAL AND BIOCHEMICAL PARAMETERS MONITORING FOR MNAZI BAY RUVUMA ESTUARY MARINE PARK (MBREMP)

4.1 Physical characteristics of Tanzanian coastal waters and MBREMP

MBREMP is located in the southern coast of Tanzania close to the Tanzania-Mozambique border at Ruvuma estuary in the Mtwara region. The park covers an area of about 650 km^2 of which 220 km^2 is land and the remaining 430 km^2 is water (Figure 1). The park extends from Ras Msangamkuu at the entrance of Mtwara Port in the north for 45 km along the coastline to the Ruvuma River where it extends inland along the river to Mahurunga village. Other features found within the park are the inhabited islands of Namponda, Mmongo and Kisiwa Kidogo. Two of these islands (Namponda and Mongo) are surrounded by mangrove forests. The park area also includes Msimbati channel, Mnazi bay, Ruvula peninsula and Ruvuma Estuary. MBREMP comprises marine, coastal and terrestrial habitats that include large tracts of mangrove forests around the Ruvuma river delta, highly productive and undisturbed ecosystems such as estuary, coral reefs and sea grass beds. North of the Ruvuma estuary there is a development of sand dunes of the highest quality on the East Africa Sea board with plants species not found anywhere else in continental Africa. A large population of crab plovers has led to the area being designated as an important bird area. The Ruvuma River forms the international boarder with neighbouring Mozambique.

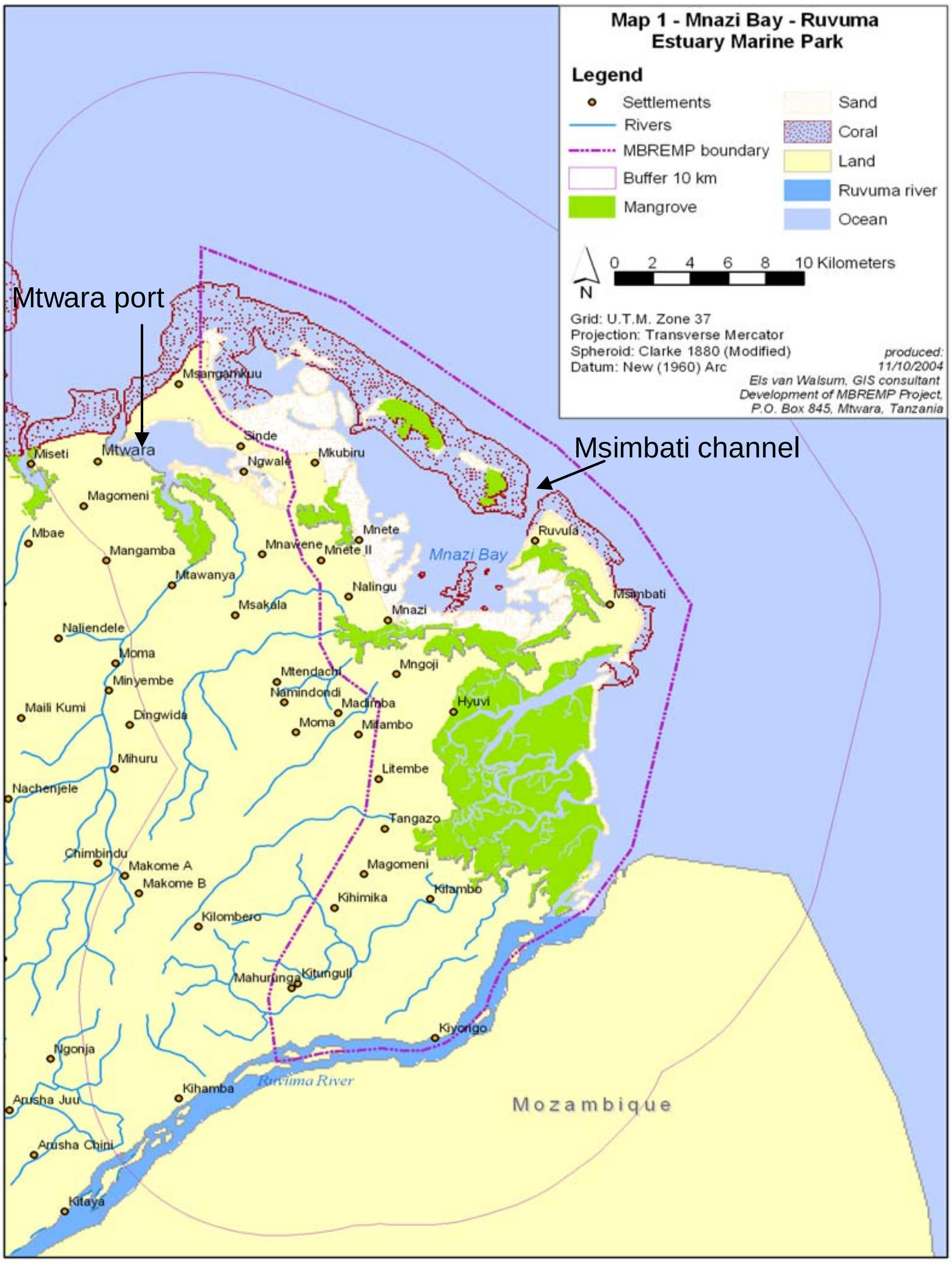

Figure 1: Mnazi Bay Estuary Marine Park (MBREMP 2005).

4.1.1 Climate

The climatic conditions of Tanzania are controlled by two factors including its geographical location in the equatorial region and its position on the eastern edge of Africa, which exposes the coastal zone to large seasonal changes brought about by the circulation of air over the Indian Ocean (Guard *et al*. 2000 and McClanahan 1988). Like other countries bordering the Indian Ocean, Tanzania is affected by the monsoon trade winds, which control atmosphere-ocean dynamics in the region. Seasonal patterns in the East Africa coastal zone are dictated by the behaviour of the Inter-tropical Convergence Zone (ITCZ), which creates two distinct seasons, the northeast and southeast monsoons (McClanahan 1988). The monsoons influence wind direction and speed, temperature, rainfall etc. There are two monsoon seasons prevailing in Tanzanian waters. The northeast monsoon (NE) which prevails from November to March and is characterised by weaker winds and higher air temperatures (> 30°C) than the southern monsoon (SE) that prevails from June to September and is marked by lower air temperatures (approximately 25°C) as well as strong winds and is occasionally associated with horrific events such as cyclones and storms (Guard *et al*. 2000, McClanahan 1988 and Ruitenbeen *et al*. 2005). McClanahan (1988) described the SE monsoon's meteorological parameters to be characterised by high cloud cover, rainfall, river discharge, terrestrial runoff and wind energy while solar insulation and temperatures are low and oceanographic conditions are characterised by cool waters, a deep thermocline, high water-column mixing and wave energy, fast currents, low salinity and high phosphorus. These parameters are reversed during the NE monsoon. The inter-monsoon periods occur in the months of March/April and October/November and are the calmest. June and July are the windiest months while March, April and November experience the lowest and most variable wind speeds.

4.1.2 Bathymetry

The inner parts of the bay are sandy environments, while the outer coastline has a fringe of rocky cliffs and reef platforms, extending 62 km from the Ruvuma estuary to Msangamkuu (Muhando *et al* 1999). The bay is enclosed by sandy shores to the west and the Ruvula-Msimbati spit and string of rock islands and reefs to the east. Connections to the sea are maintained primarily through the deep Ruvula channel in the south, a smaller reef gap in the northern part of Mnazi Bay, and at high tide by water spilling over the reefs of the island complex and northern Mnazi Bay. Together with the large inter-tidal parts of the bay, this produces a change in area of the bay from 67 to 150 km^2 at low and high tides, respectively (Obura 2004).

The bathymetry of the bay is complex, with a deeper basin (up to 25 m) in the south with complex patch reef systems reaching to the surface, a shallow basin (<3 m) in the north, a deep channel (up to 60 m at the mouth) and extensive (over 80 km^2) inter-tidal flats. As a result of this complexity, the range of habitats is diverse and patchy, and tidal currents in the main passes and shallow reefs are reported to exceed 6 knots. Marine habitats in the Mnazi Bay area include mangroves, algal mats and open sand on rocky/sandy tidal flats, and deeper sand, sea grass, and coral reefs (see Figure 2).

Figure 2: Biological and physical characteristics of the MBREMP area (MBREMP 2005).

4.1.3 Currents and tides

The major currents prevailing in the waters off Tanzania are the South Equatorial Current (SEC), which flows westwards permanently around 12°S and the northward flowing East African Coastal Current (EACC) (Francis *et al*. 2000). Southern Tanzania and northern Mozambique are located in the centre of the East Africa Marine Eco-region where the South Equatorial Current meets the mainland after crossing the Indian Ocean from the east (Figure 3). Here the main current splits north and south, forming the EACC and the Mozambique Current (MC), respectively. These currents flow in one direction throughout the year, though with seasonal variation in speed, forming a one-way conveyor for marine larvae dispersed by the currents. Southern Tanzania and northern Mozambique are the first arrival points for marine species carried across the Indian Ocean. The Mnazi Bay – Ruvuma Estuary is therefore located at the source point for the EACC, and forms a critical node for the accumulation. The EACC is strongest in the southern monsoon season (April – October) and can reach a velocity of up to 2 m/s but is weaker during the northern monsoon (November – March) with an average of less than 0.2 m/s (Dubi 2000).

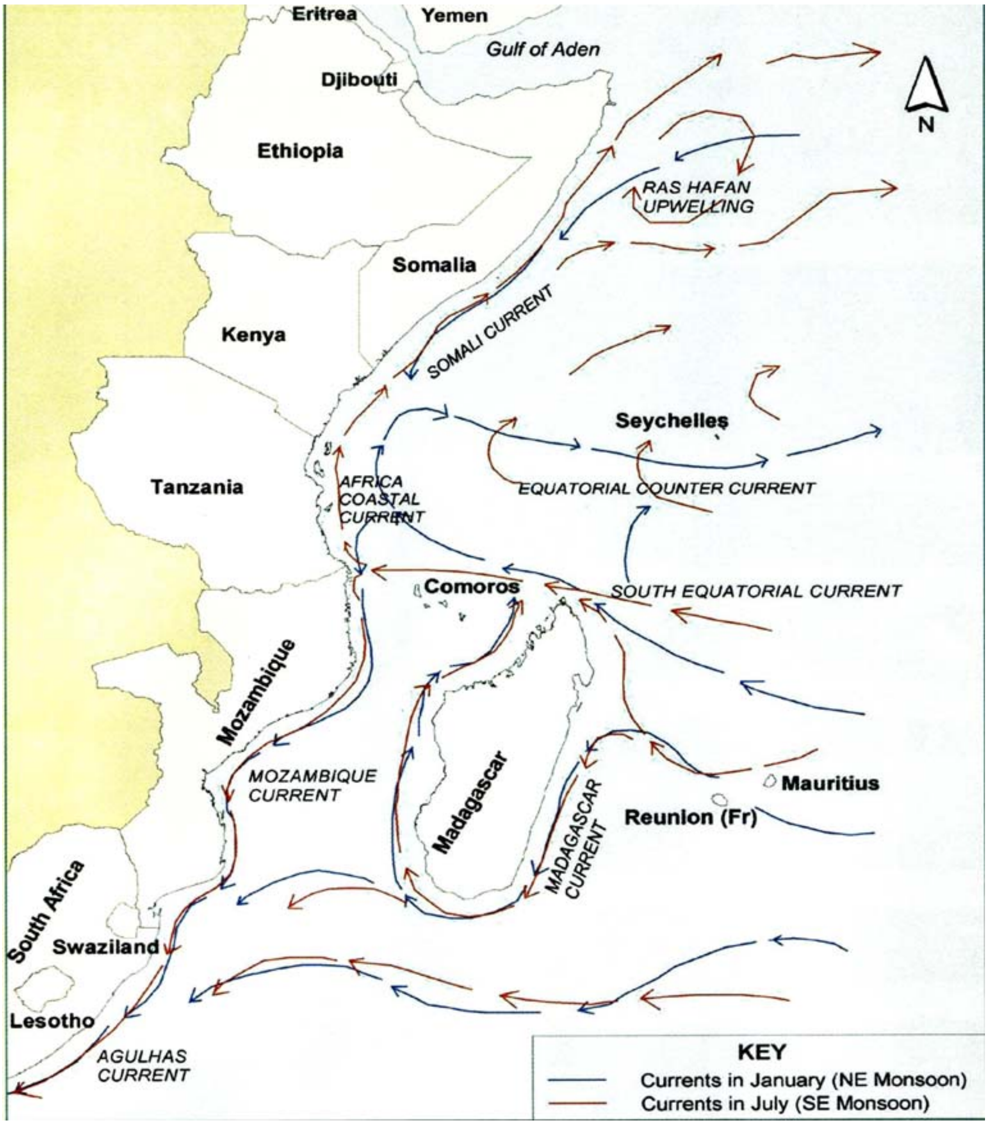

Figure 3: Ocean currents in Tanzanian coastal waters : (Ruitenbeen *et al*. 2005).

Hamilton and Brakel (1984) described the tidal range of Tanzania as one of the highest in the Indian Ocean with an average of 3.3 m amplitude during spring tides and 1.1 m during neap tides. These cause strong localised currents around islands and reefs, which are superimposed on the overall along shore current. On the East African coast, the tidal range increases from South Africa (1.5–2 m) to Mozambique (up to 5.5 m), then decreases to 3–3.5 m in Kenya, and to 1.5 m in Somalia, at 11°N (Carbone and Accordi 2000). During the high spring tides the sea enters Mnazi, Mtwara and Mikindani bays and covers 80 km^2 of inter-tidal areas. The tidal range experienced in the bays is about 4.5 m during spring tides. Seawater flows from the Indian Ocean into the bays through the 50 m deep channel of Msimbati.

4.1.4 Temperature and salinity

Sea surface temperature exhibits seasonality that is influenced by changes in the water masses of the Indian Ocean and by climate factors. During the southeast monsoon, the South Equatorial Current brings water of relatively low temperature from the Pacific Ocean, while during the northeast monsoon it draws in waters of high temperature (Francis *et al.* 2000). The surface temperature in the coastal waters of East Africa within the latitudes 0 – 10° S band, including Tanzanian waters, are highest during March and April ranging from 28 – 30°C and lowest from June to September with an average of 24 °C (Newell 1959). The thermocline depth ranges between 50 and 120 m depending on season, and oxygen concentrations are generally close to saturation in the upper surface water throughout the year. Warm El Nino events in the Western Indian Ocean generate high surface water temperatures, sea levels and low salinities due to high rainfall, the impacts of which vary from place to place and generally increase offshore (Francis *et et al*. 2000). However, global warming is expected to contribute to increased storminess and shoreline recession, which will have an impact on the coastal resources and environment. Salinity values around Tanzanian waters are relatively low during April and May, following the peak freshwater outflow, and highest in November. The salinity values start to decrease in February before the beginning of the rains (Nyandwi and Dubi 2001). This is attributed to the flow of lower salinity water from the south. In the open ocean, salinity ranges from 34 – 35 psu and lower salinities are measured closer to the coast due to freshwater runoff.

4.1.5 Oxygen concentration and nutrients

According to Wagner (2002), oxygen concentration approaches saturation throughout the year in the surface water, but with some reduction in O_2 tension before the thermocline is reached. The dissolved oxygen concentration in the coastal waters of Tanzania has been found to range from 2 – 7 ml/l (Bryceson 1982). McClanahan (1988) and Bryceson (1982) reported that, the main sources of nitrogen and phosphorus in near shore waters of Dar es Salaam are attributed to the discharge and runoff occurring during the rainy season and found the concentration to be high in June soon after the onset of the southeast monsoon. 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 of 4.0 µ-at N/l (Anderson 1994) have been reported.

The amount of the pesticide concentration found in Tanzanian coastal waters range from 6.6 - 53 µg/kg, which is significantly below the FAO/WHO maximum acceptable limits of 200 µg/kg in fish and seafood (Salim 2003).

4.1.6 Fresh water runoff

The coast of Tanzania is strongly influenced by rivers that bring to it waters, sediments, nutrients and pollutants. About 10 rivers drain into the Indian Ocean, of which Pangani in the north, Rufiji in the middle and Ruvuma in the south are the main rivers. The smaller rivers include Zigi, Wami, Ruvu, Matandu, Mavuji, Mbwemkuru and Lukuledi. These rivers flow to the ocean influencing the coastal environment through the creation of productive brackish water environments in estuaries, maintenance of deltas, tidal flats and shorelines, as well as nourishment for mangroves and sea grass beds. The Indian Ocean drainage system is the largest, which constitutes about 50% of the surface runoff of Tanzania (Francis *et al*. 2000). The Rufiji River is one of the largest rivers in Africa, which contributes much of the Indian Ocean drainage by discharging an average range of about 2000 – 3000 m^3/s runoff (Shaghude 2003 and Dubi 2000). River outflow peaks in the rainy season increasing the amount of suspended sediments in the coastal waters.

The main rainy seasons coincide with the end of the southern monsoon in March – May, with a shorter period of rainfall known as the short rains in November to December (Francis *et al*. 2000). The dry season that prevails in the northern coastal areas during the period of January to February arises from the effect of the northern monsoons. Freshwater and sediment influences of the MREMP bays are relatively high. A small river and some seasonal streams drain upland areas to the west into the Mnazi bay around the village of Mnazi. In addition, during floods, fresh or brackish water from the Ruvuma Estuary spills over the low causeway linking the Ruvula/Msimbati spit to the mainland (Muhando *et al*. 1999). Kazinja (2001) reported the flow rate of the Rufiji River to be 285.39 m^3/s. The prolonged rainy season swells the volume and strength of the Ruvuma River causing erosion and washing sediment into the rivers, which are finally flushed into the sea.

4.1.7 Plankton

Due to its remoteness there have been limited numbers of scientific surveys of resources around the southern part of Tanzania including Mnazi Bay. No studies have been carried out around the waters of MBREMP for plankton and primary productivity of the area. Generally the primary productivity of Tanzanian coastal waters is very low when compared to other areas of the tropics. The biomass in terms of chlorophyll 'a' was found to range from 0.04 – 1.4 mg/m^3 and the concentrations are generally higher during the northern monsoon and lower during the southern monsoon (Francis *et al*. 2000). High biomasses of nitrogen fixing phytoplankton *Trichodesimium* spp are found to form blooms during the northern monsoon (Lugomela *et al*. 2002). Phytoplankton biomass, fish catch and production are also highest during this period. However, more than 20 species of potentially harmful microalgae have been identified in the Tanzanian coastal waters around Dar es Salaam and Zanzibar (Kyewalyanga and Lugomela 1999). Most of the species identified were diatoms and dianoflagelates of genus *Pseudonitzchia* and *Gambiaediscus,* which are responsible for most of cases of ciguatera.

Very few studies have been conducted concerning the zooplankton in Tanzanian coastal waters. Higher abundance of zooplankton was found to occur during the rainy season when there is a lot of runoff from streams (TCMP 2000). The coastal waters around Dar es Salaam city were found to contain *Calanoida* spp of zooplankton in higher abundance during the northern monsoon seasons.

4.2 Proposed coastal resource condition, environmental and biochemical parameters to be monitored

4.2.1 Resource condition and use

MBREMP contains complex and unique marine ecosystems and habitats. Surveys carried out in MBREMP confirm that the waters of the park are home to a great diversity of marine life, with features unique in Tanzania and the region. Mangrove forests of the Ruvuma River provide reproductive and nursery facilities to many fish and crustaceans. Open sand habitat is extensive and sea grass beds are variable, diverse, and dense in some places. Over 250 species of hard coral reefs supporting more than 400 species of fish and other organisms are found in MBREMP waters particularly in Mnazi Bay. Although the inter-tidal and sub-tidal habitats are in relatively good condition, species diversity and abundance is lower due to over-exploitation. Use of destructive gears has caused damage in some parts of the habitats including mangroves, coral reefs and sea grass beds. According to Wagner et al. (2004) mangrove harvesting appears to be sustainable in most part but other species are being over utilised and are hence less abundant in all areas of the park.

Since MBREMP is implementing the conservation measures for resources and environment around the area, monitoring of the resource condition and recovering is important to be able to put in place the right measures for management. The trend of the resource uses and identified impacts will help in decision-making regarding the management conservation measures in place and if necessary reorient the management. Table 2 below summarises the variables for resource condition to be monitored.

The monitoring of the resources should be on a long-term basis and resources to be monitored will include mangroves, coral reef, sea grass bed, benthic organisms as well as endangered and vulnerable species. Resource use patterns should include the monitoring of the visitors visiting the park area as well as the social economics of the community living around the park area. Representative sites should be selected to cover the whole part of the management area. Sampling sites should include intact, less to highly damaged areas. One area in the core zones should be taken as a reference area. The reference areas are those parts of ecosystems which are least impaired by anthropogenic effects. For comparison with non-managed areas, one site outside the park should be monitored. Selection of the sites can be made by using the zoning plan and reports of resource surveys carried out recently. Monitoring of the shell and fish catches will indicate the benefits obtained from the park area as well as trends of fishery stocks recovery.

Sampling frequency for resource conditions should be annually and periodically after every 1 – 2 years for coral reefs, mangroves and sea grasses except areas, which need special attention e.g. area with gas wells. At Ruvula area southern part of the park where the gas wells are located monthly monitoring of the resources around is proposed especially when the implementation of the project and drilling processes will start. New sites found to have specific problem should be incorporated in the plan for management to respond to the issues or problems encountered. Daily monitoring should be carried out for visitors visiting the park area as well as shell and finfish catches.

Sampling for social economics monitoring should be periodically, 3 -5 years. The assessment and monitoring framework for social economics, if applied, are expected to produce the essential information required for ecosystem management for the coastal zone ecosystems management as well as MPAs (Pomeroy *et al*. 2004 and Christensen *et al*. 1996). Monitoring of the variables under social economics will be easy after a comprehensive research to get baseline information.

Table 2: Proposed coastal resource condition variables to be measured and included in the MBREMP monitoring programme.

Component	Method	Variables
Coral reef condition	**Coral diversity** • Line transect method can be used • Coral species counts, coral species can be identified by observers during snorkelling and diving over the reef area	Coral species; hard corals, soft corals and dead corals
	Benthic cover • Line Transect Method (Pomeroy *et al.* 2004) • Organisms on the coral reef area recorded along 20 m long transects	Coralline algae, turf algae, macro algae, sponges, sand, rubbles and rock, sea grasses, and other organisms including sea anemones
	Macro-invertebrates • Belt transect method can be used by establishing transects along the reef, observers describe and count the invertebrates in a belt of 2 m width from the edge of the tape.	Sea urchins, starfishes, giant clam, gastropods, lobsters
	Coral recruits • Belt transect method can be used by establishing transects along the reef and coral recruits counted along the belt of 2 m width from the edge of the tape.	All coral recruits species along the line e.g. Acropora, Montipora, Pocillopora and others
	Fish populations • Belt transect method can be used by establishing transects along the reef areas and members of families forming the larger part of reef fishes recorded at species level where possible	Possible species belong to the reef fish includes the families of Acanthuridae, Balistidae, Chaetodontidae, Haemulidae, Kyphosidae, Labridae, Lethrinidae, Lutjanidae, Mulidae, Nemipteridae, Pomacanthidae, Pomacentridae Scaridae, Serranidae, Siganidae, Zanclidae.
	Coral bleaching and diseases • Use of standard monitoring protocols to monitor the extent, severity and recovery from coral bleaching i.e. ReefBase method at www.reefbase.org	Percentage of coral recovery from bleaching

	• Assessment of bleaching can be carried out after the occurrence of significant storms especially after the southern monsoon which is sometimes associated with storms and cyclones • Coral diseases are very special and can require specialised monitoring methods - This can be a long term research rather than just monitoring **Coral predators population** • Predators like the crown-of-thorns starfish (COTs) *Acanthaster planci* and coral-eating snails (*Drupella* sp) need to be monitored. • The outbreaks of COTs over the reef have been found to have significant impacts on the coral communities hence need for immediate clean-up programmes • Cleaning guide as described by Fraser *et al*. (2000) can be used	Number of COTs, size (diameter in cm), depth found, associated substrate (type of coral, sand, rubble etc.) and associated in groups or single organisms
Sea grass condition	**Percentage cover** • Circular plot or quadrants can be used over the sea grass areas at random and percent cover estimate; if possible estimation for each species can be done according to the Provancha and Hall (1991) method • Observer divers can measure a range of blade heights within the plot frame and then estimate an average height for each species • Water depths at the centre of each circular plot during sampling recorded • Extent of destruction if any recorded	• Percentage cover area • Species of sea grasses • Status of the sea grass beds
Fish and octopus catches	**Observation on the landing sites** • Catch records taken on the landing sites • In collaboration with stakeholders like fish traders and fishers daily record of catch can be recorded • Simple questionnaire forms can be designed and introduced to the observers • The records can include all information needed to understand the catch • Training for recorders is important to obtain realistic information	Date, number of fishers, number and type of fishing gears, fishing grounds, fishing time, weight and number of fish species or the groups.
Fishing activities	**Field observation and use of questionnaires and survey sheets** • Records of all fishing vessels and movements of fishermen while fishing in the different zones can be collected to estimate the intensity of resource utilisation • This kind of information can be done once or twice a month during the lowest tides when most of the fishermen go out	Date, type of boat, village of origin, number of fishers in a boat, fishing gear size and numbers of gears used and fishing grounds

	fishing	
Mangrove	**Random quadrants method** • Measurements of defined variables are taken on a circular quadrants randomly located within mangrove vegetation zone (see Wagner *et al*. 2004)	Variables include species name, diameter at breast height (DBH), number of mature trees, seedlings and stumps and height of the trees located in the quadrant
Endangered species sea turtles **Dugongs, dolphins, sharks and whales**	**Questionnaires and survey of the nesting beaches by fishers, divers and other marine and coastal resource users** • Successful monitoring of turtle involves the communities around the coastal areas through training and awareness • The observers and monitors through number of trainings, report on number of nests and successful nesting turtles • Fishermen report on incidental catch and submit the tags from dead turtles • Divers report on the turtle sightings in the snorkelling and the diving sites **Report of visual sightings** • Communities and the users of the coastal resources especially fishermen can be used to collect the reports and information of dugong, dolphin and whale sightings, entanglement in fishing nets and accidentally caught • By shore and boat based observations can be done	Number of nesting areas or beaches, number of nests, name of turtle species, numbers of eggs, numbers of hatchlings, number of rotten eggs, number of dead hatchlings, number and species of turtle sighted on the snorkelling and diving sites, number and name of dead turtles on the sea and beaches, number of turtles caught in the fishing nets and name, number of released turtles from the fishing nets and name and number of tags submitted Number and time of sightings and name of species if possible, names and number of entangled and released animals
Visitation	**Assessment of the visitors through hoteliers and visitor centres** • Number of people visiting the MBREMP recorded in the visitor books • Records of number of people in diving and snorkelling areas • Visitors comments on the facilities and their level of satisfaction Additional forms should be included to get visitors willingness to contribute to the conservation effort of the area and their comments on the user fee paid. This is important and will be the base during the reviewing of the user fees	Number and name of the visitors, nationalities, comments on the status of the area and the user fees
Social economic and coastal communities	**Assessment of marine resource use patterns and users** Use of primary and secondary data • Secondary data are from government sources including villages, town offices, national agency reports, maps, statistical reports and official regulations • Primary data can be collected from focus groups through interviews, structured surveys and observations	• Activities on which people depend for food and income particularly those associated with marine resources and their location, timing and seasonality, user rights • Stakeholder characteristic e.g. householder characteristic (age, gender, education level, religion, literacy, food consumption, income), migration and

		immigration patterns • Gender issues • Stakeholders perceptions (perceptions and level of understanding of MPA management and of their impact on the environment, perceptions of other stakeholders, cultural and religious beliefs, willingness to cooperate) • Traditional knowledge • Community services and facilities e.g. medical, education, transport, communication, public utilities • Market attributes for extractive uses e.g. supply, prices and market structure such as fishing or mangrove harvest • Market attributes for non-extractive uses e.g. tourism or aquaculture

4.2.2 Environmental and biochemical parameters

Five main areas within the park area are selected to be monitored for environmental and biochemical parameters together with the sampling frequencies (Table 3). These areas are representative of the management area. Properties of the variables within these areas are thought to have significant influence and impact on the health and variability of the park ecosystems. Proposed sampling frequencies for environmental and biochemical focus on three seasons which prevail in Tanzanian coastal waters. The variations have been found to occur within the three monsoon seasons around the Tanzanian coastal waters. Therefore it is important have an understanding of the variation in environmental and biochemical parameters within the park areas.

4.2.2.1 Five selected stations, variables and sampling frequency

1- River Ruvuma flow rate:

Flow rates, height of the river water, and sedimentation/water turbidity are important parameters to be monitored. Measurements can be taken upstream before the river enters the sea. A continuous permanent monitoring of Ruvuma River by establishing a gauge and current meter stations for measuring the height of the water and flow rate will give a good understanding of the river flow. The current meter can be fixed on a permanent buoy on the selected area along the river to obtain the flow rate. The river should be monitored continuously.

2- Area from the southern boarder, from the Ruvuma River to the northern boarder near Mtwara port:

Since the oceanic influences affect the ecosystems and resources along the park area, it is important to monitor the gradient of properties, which probably vary mostly perpendicular to the coast. The coriolis forces, which deflect the water to the right of the wind direction north of the equator and to the left south of the equator (Mann and Lazier 1991 and Tait 1980), will probably tend to pile the water along the coast causing much of the fresh water to spread on the Mnazi bay. Stations should be established running perpendicular to the coastline including waters out of the continental shelf into the deep sea. This will enable an understanding of how the water properties of the deep seas and continental shelf are related. Such monitoring will also reveal the influence of the fresh water runoff from the Ruvuma River to the park resources and environment. Three sections will be established with sampling stations running toward the ocean. One section will have the stations extended to incorporate the oceanic part (Figure 4). Environmental and biological parameters including salinity, temperature, nutrients (nitrates and phosphates), oxygen, chlorophyll concentration, phytoplankton and zooplankton should be monitored in each station. The distances between the stations should increase toward the deep sea and the distance near the coast should be smaller.

Sampling will be done to include all the three seasons of northern, inter- and southern monsoons. Reduction or increase of sampling frequencies and stations will be determined by the trends of data and information obtained after a certain period of monitoring. A maximum of six samplings per year i.e. two samplings in each monsoon will give precise results while a minimum of three samplings per year i.e. one sampling in each monsoon might also be practical and reasonable. Due to complexity in measuring currents, the tidal gauge at Mtwara port may be used to obtain data on sea level for comparison with current measurements. Measurements from the tidal gauge can be used to understand how the sea level is changing around the park area. The meteorological station at Mtwara can be used to obtain useful information like wind, air temperature and rainfall.

Measuring current is complex and difficult to maintain due to the nature of the oceans and seas. For successful measurements of the current on the waters of MBREMP, stations should be located in the areas where fishing is not taking place to avoid the risk of losing the current meters. The current meters can be placed at stations along the section that is closer to Mtwara port in order to avoid illegal trawling, which sometimes takes place in the southern area of the park. Due to strong currents and waves along this area the current meters can be retrieved after one or two months depending on the weather. The current measurements should cover all three monsoon seasons.

3- Mnazi bay:

One or two representative site(s) should be selected within the bay for monitoring both environmental and biological parameters. Since the bay is enclosed by the rocky cliff it is assumed that there will not be much variation in the environmental and biological parameters. Temperature, salinity, dissolved oxygen and turbidity/sedimentation as well as biological; chlorophyll concentration, nutrients (nitrates and phosphates), zooplankton and phytoplankton should be monitored in the bay. The monitoring should be carried out during the three monsoons. Reduction or increase of sampling frequencies and stations will be determined by the trends of data and information obtained after a certain period of monitoring sampling frequency.

4- Recreation areas and beaches along Msimbati/Ruvula coastline:

Monitoring of fecal coliforms, pH, salinity and temperature should be carried out in the recreation areas. Waters around the swimming, snorkelling and diving sites should be monitored and sampling should cover the three monsoon periods. When there is a need for increasing or decreasing the sampling frequency, the plan should accommodate the plan for the management to respond to the issues or problems encountered.

5- Southern part of Mnazi bay at Ruvula channel:

This is the area where the gas wells are located. Although the investor is supposed to undergo EIA and monitor the area, MBREMP is supposed to make a close follow up of the investor's monitoring programme and reports. Environmental parameters including temperature, salinity, pH and turbidity/sedimentation should be monitored around the area as well as biological parameters like chlorophyll concentration. It is important to participate in the monitoring of the area to make sure that enough representative data and information about the area are gathered. Monitoring the ecological processes is also important as proposed in section 2.4 above. The drilling processes and pipeline route along the Mnazi Bay will have an impact on the ecology and environment around the park and therefore it is important to monitor the effects and take measures when needed. Sampling frequency of this area will depend on the stage of the project's implementation; monthly sampling will be reasonable when development of the project begins by drilling and installation of pipes and other structures.

Table 3: Summary of monitoring stations, variables and sampling frequency for MBREMP.

Monitoring station	Variables	Sampling frequency
1. Ruvuma River	Physical parameters • Flow rate • Height of the water • Sedimentation / turbidity • Salinity • Temperature)	Continuously monitoring
2. Area from southern boarder with Ruvuma River to the northern boarder near Mtwara port	Physical parameters • Currents • Wind speed • Salinity • Temperature Biochemical parameters • Chlorophyll a concentration • Nutrients (Nitrate and phosphates) • Phytoplankton • Zooplankton	Three times a year Northern monsoon Inter-monsoon Southern monsoon • Six samplings per year - maximum • Three samplings per year minimum
3. Mnazi bay	Physical parameters salinity • Temperature • Dissolved oxygen • Turbidity/sedimentation Biochemical parameters • Chlorophyll a concentration • Nutrients (Nitrate and phosphates) • Phytoplankton • Zooplankton	Cover all three seasons as in two above
4. Southern part of Mnazi bay area where the gas wells are located	Physical parameters • Temperature • Salinity • pH • Turbidity/sedimentation Biological parameter • Chlorophyll concentration	Monthly interval sampling depending on the prevailing condition
5. Snorkelling and diving sites along Msimbati and Ruvula coastline	• Fecal coliforms • pH • Salinity • Temperature	Monthly interval / seasonal

Figure 4: MBREMP proposed monitoring stations for environmental and biological parameters.

5 DISCUSSION AND CONCLUSIONS

Well-designed and targeted research and monitoring programmes are essential components of tropical marine ecosystem management to maintain biological diversity, natural resource ecosystem condition, services values of marine habitats and ecosystems. The place-based conservation effort requires the understanding and knowledge of the ecosystems and habitats they conserve (Davis 2005). Long term monitoring of the dynamics of critical ecosystem elements is a direct way to learn how ecosystems behave and how the various elements interact and influence one another hence increasing understanding of the ecosystem functioning. However, the management also needs to protect and put in place the mitigation to the threats identified within the managed areas as well as restoration of the impaired elements in the ecosystem. Monitoring of the environment and resource condition around MBREMP will contribute to proper conservation and management of the park. The trend of the resource uses and identified impacts will help in the decision-making regarding the management and conservation measures in place and if necessary reorient the management. Good understanding of monitored information on environment and resource condition and changes over time will help to set levels of protection and also identify problem areas that need additional management decisions. However, the information can also be used to inform the public and other stakeholders on the progress made in protecting the environment.

The proposed monitoring programme for MBREMP has taken into consideration its objective to facilitate research and monitoring of resource conditions and uses within the park area. Through this objective, ecological and environmental monitoring should be linked into parallel monitoring programmes on the benefit obtained from the park area such as fish catches and general socio-economic benefits of user communities. The presence of the qualified staff with various specialties in marine environment within the MPAs of Tanzania indicates the practicability of the proposed monitoring programme. The resources available in MBREMP including boats, motor cycles and vehicles can be used to facilitate the proposed monitoring programme. Two to three days will be enough to measure almost all of the parameters proposed in the area. Two to three scientists or staff that have received training in the sampling methods will be needed to complete the monitoring of the proposed parameters in Table 3.

In 2004, the use of these facilities enabled the monitoring activities, which were carried out for coral reefs, sea grass beds and mangrove by Obura (2004) and Wagner *et al*. (2004), respectively and contributed to the development of the General Management Plan (GMP) for MBREMP. However, the present collaboration and memorandum of understanding (MoU) between the University of Dar es Salaam and Tanzanian MPAs will ensure the use of university expertise and facilities to carry out the proposed monitoring programme for MBREMP.

Generally monitoring activities are expensive and time consuming. This was also observed in the monitoring of Eyjafjordur fjord, which was only carried out for two years. However, this is not a serious problem for Iceland since there are different institutions involved in the daily monitoring of coastal and marine environment parameters including the river runoff, sea surface temperature, wind, contaminants, etc. For the MPAs in developing countries like Tanzania, dependence on local and foreign expert scientists and consultants can delay or prevent the establishment of viable MPAs or coastal conservation initiatives (Kelleher 1999). This is due to high costs of consultation and sometimes the results from their work are lacking integration and assimilation. High costs in monitoring Tanzanian MPAs can be reduced through the following measures:

- Develop an indigenous cadre of scientists within MPAs staff and communities around the MPAs. This capacity building can be done by bringing in experienced scientists to provide training for a short time, which will cost less. Involvement and collaboration with local communities around the park areas in resource monitoring will not only reduce the monitoring costs but will also give the communities ownership over the resources around them. This will strengthen community collaboration and understanding in environment and resource conservation and hence contribute to the management measures.
- Encourage volunteer individuals or organisation to work with MPAs especially in monitoring activities. Tanzanian MPAs should put in place a programme or guide which will identify and detail volunteer participation in the park's activities and advise it to create awareness within the local and international community
- Networking and collaboration with universities, research institutions, environmental quality organisations and agencies is very important especially for the purposes of research and monitoring. This will help in monitoring complex parameters, which need more specialised technology, expertise and significant funding.

An operational data documentation, treatment, storage and retrieval system is a prerequisite for efficient monitoring programmes. MBREMP and all MPAs should develop databases for easier management of the monitored data and information. However, management and handling of the database requires knowledge in computer programmes related to database management and therefore these types of computer skills are important to MPA managers. Data and information from MPA monitoring including MBREMP also need to be communicated to stakeholders using a logical way of presentation according to targeted groups. The use of information technology and communication skills is very important for communicating the monitored information and data. Skills in using different and relevant graphical software like Surfer 8 and Grapher 6 are important for scientific presentation of monitored data and information for Tanzanian MPA managers and monitoring officers.

Effective management of Tanzanian MPAs and the coastal zone as whole will occur when there are effective management plans that include adequate ecological and socio-economic monitoring. Without planning, monitoring and enforcement most coastal management efforts will not achieve their objectives of conserving the resources. Effective resource and environmental monitoring will provide the information needed for effective management and decision-making on resource protection. The study proposed the monitoring programme for MBREM to include the following:

- The resource condition monitoring should be carried out together with other environmental and biochemical parameters, which are also important to the ecosystem's health and variability. The changes, which occur in resource condition might be influenced by both the environmental and biochemical parameters within an ecosystem and therefore it is important to include all the parameters in the programme.

- Resource condition, environmental and biochemical parameters to be monitored and sampling frequency are also proposed.

- The use of databases and different types of computer software for managing and presenting the monitored information and data are proposed for effective management of the monitored information.

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ANNEX 1: MONITORING CASE STUDY OF EYJAFJORDUR FJORD

INTRODUCTION

There are 21 major fjords in Iceland including Eyjafjordur fjord. A field trip was carried out in Eyjafjordur fjord which is located on the central north coast of Iceland near Akureyri town on December 13, 2005. The fjord is 60 km long and 15 km wide at the mouth with a surface area of about 440 km^2 (Jonsson and Gudmundsson 1994). Like many other Icelandic fjords, Eyjafjordur has steep sides down to 40 m which then gradually flatten out. The depth of the fjord increases gradually from a shallow (about 40 m) inner basin at Akureyri town at the head to 200 m depth at the mouth. The bottom of the fjord is covered by thick layers of sediments. There are several aquaculture activities in the fjord and also most of the fish processing plants in Akureyri and other towns are discharging their waste water to the fjord. Several parameters were measured on different stations along the fjord during the field trip including temperature, salinity, benthic macrofauna and zooplankton communities.

METHODS

Sampling

One day sampling was conducted with the aim of learning how the sampling is carried out during the monitoring of the fjord. Usually monitoring is expensive and normally during the monitoring of Eyjafjordur fjord all parameters are measured at the same time involving a team of scientists working in all fields of biological, chemical and physical oceanography. This helps to reduce the costs of carrying out individual sampling and also to get integrated results as the data and information are collected simultaneously. Samples were taken from the inner part of the fjord at the stations already established during the previous monitoring of the fjord. During the field work environmental parameters i.e. CTD data and biological parameters were measured. For biological parameters, water and sediment samples were taken for zooplankton and benthic macrofauna analysis, respectively.

Bad weather which was encountered during this period of the year limited the sampled stations to be on the inner part of the fjord (Figure 1). However, problem of electricity in the boat during sampling also affected the sampling of more stations within the inner part of the fjord.

CTD Data

CTD data were collected by using a SBE 19 SEACAT Profiler from Sea-Bird Electronics at six stations; station 7, 8, 9, 10, 13 and 14 (Figure 1). Before lowering the CTD instrument to the seafloor, it is held submerged in surface waters for 40 sec to make flow of water inside and outside reach equilibrium. The instrument was then lowered to the sea bottom. Two to five minutes were required for the instrument to collect a set of data required depending on the depth of water. Data were downloaded and processed at the end of the cruise by using software provided by the manufacturer (SEASOFT-Win32 software). The accuracy given by the manufacturer is 0.01°C and 0.001 S/m for temperature and conductivity, respectively. The data were processed and provided at 1m depth interval.

CTD Data Processing

SBE Data Processing a Windows 95/98/NT/2000/XP program is part of SEASOFT-Win32 software used in the processing of the CTD data. The software consists of modular, menu driven routines to convert, edit, process, and plot oceanographic data acquired with Sea-Bird instruments (CTD data as well as auxiliary sensor data). SBE Data Processing software was developed to enable oceanographers, incorporating input and applying fundamental principles of oceanography to data analysis. Each module is designed to perform the necessary data manipulation based on understanding of the real oceanographic features involved, and with sound physical reasons for applying specific corrections to individual types of errors. However, the software is continuously refined to reflect the latest oceanographic research, as well as to incorporate new auxiliary sensors that can interface with CTDs.

The processing module is divided into five main categories including raw data conversion, data processing, file manipulation, data plotting and seawater calculator. Data conversion uses the instrument configuration file which defines sensors, sensor channels, and calibration coefficients, to convert the raw data to engineering units. Data conversion outputs separate blocks of data associated with water bottle closures, for easy comparison of separation of sampled stations. To ensure that subsequently derived parameters are calculated based on matching temperature and conductivity SBE Data Processing apply (Filter) to temperature and conductivity data to make their time constants match and then align (Align CTD) data relative to pressure to ensure the calculations of salinity are made using measurements from the same parcel of water and also align data from auxiliary instruments. Derive uses the pressure, temperature, conductivity, and auxiliary sensor data to calculate a large number of parameters, including salinity, density, depth, dynamic meters, sound velocity, average sound velocity, descent rate and acceleration, potential temperature and potential temperature anomaly, geo-potential anomaly and specific volume anomaly. The last step in processing data is to average the data, to reduce the data set to a usable size by using Bin Average which makes a statistical estimate of data values at user-defined intervals based on pressure range, depth range, scan number range, or time range. File manipulation modules can be used to add descriptive information to a file or easily extract the desired information from the data. SeaPlot plots up to 5 variables, with 1 X axis and up to 4 Y axes or 1 Y axis and up to 4 X axes, using linear and/or logarithmic scales to create contour plots, generating density or thermostatic anomaly contours on temperature-salinity (TS) plots.

Sea Water Calculator SeacalcW is a seawater calculator that computes depth (salt and fresh water), density (sigma-t, sigma-theta, sigma-ref), potential temperature, sound velocity, specific volume anomaly, and oxygen saturation from one user-input scan of temperature, pressure, conductivity or salinity, reference pressure, and latitude. It is used as a quick check on the expected range of derived data, as well as evaluation of the sensitivity of the derived parameters to small changes in the basic measurements.

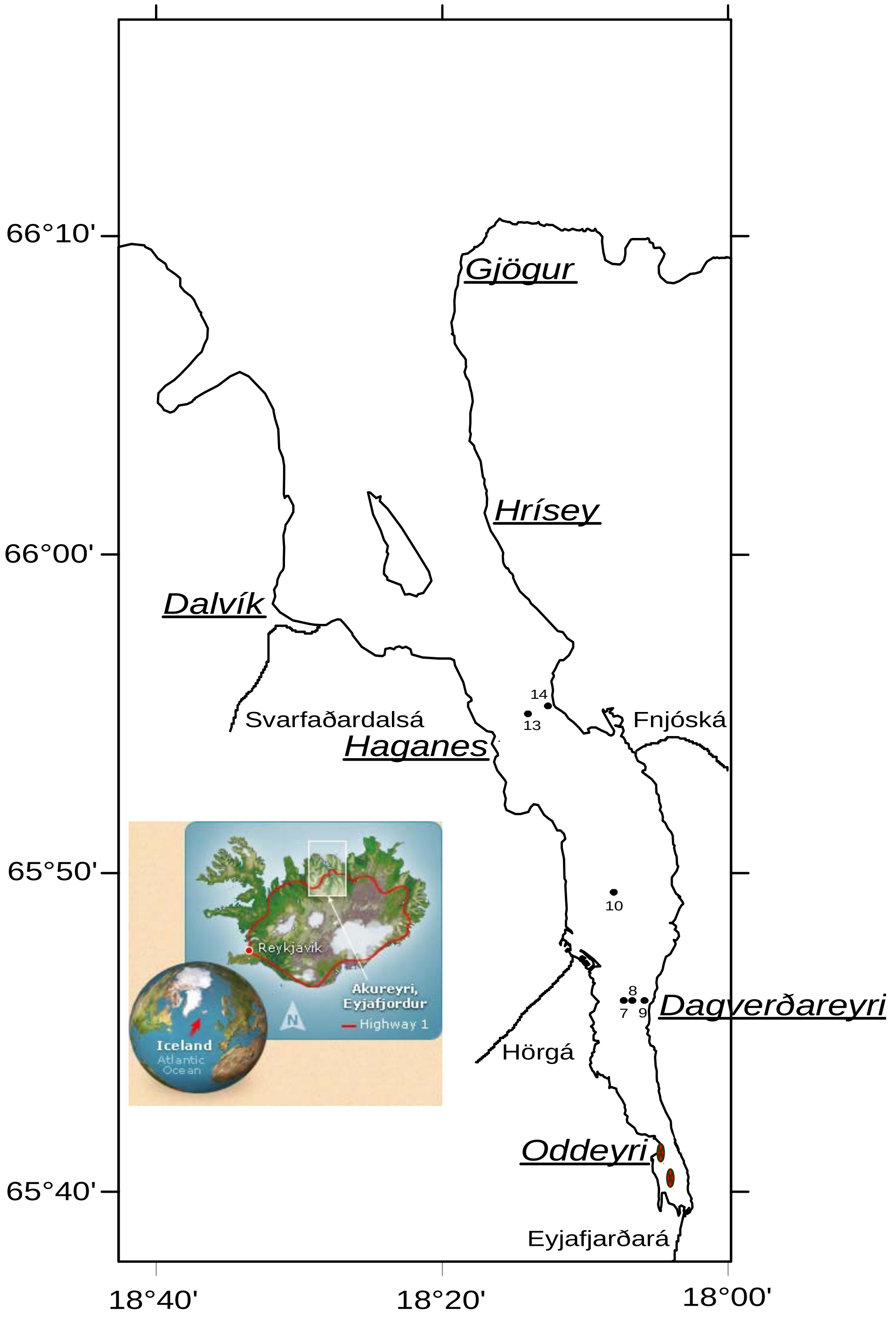
Data Analysis and Representations

Data sets collected from the field work together with those from the previous monitoring program were used to carry out different presentations and then interpreted. It is very important that the information is analyzed and presented by using appropriate statistical methods to avoid accumulation of bulks of information. Data from Eyjafjordur fjord monitoring are stored in a database in different queries developed during the development of the database. Microsoft access program was used to create this database. During the study period, basic principles on database creation were learned to be able to understand and retrieve data from the database and use them for making graphics by using graphical surfer 8 software. Two graphics softwares, surfer 8 and grapher 6 were used for presentation of the obtained monitored data. Grapher creates 2D or 3D graph types including linear, bar, polar and other graph types. In addition, grapher can be used to draw extra variable on 3D XYZ graphs, the contour maps or surface maps. Surfer is a full-function 3D surface modeling package and it can transform scattered X, Y, Z data into publication quality maps. Surfer can easily convert the data into outstanding contour, wireframe, vector, shaded relief, image and post maps. It is also used extensively for terrain modeling, landscape visualization and surface analysis. Analyzing the resulting information and data from monitoring programs is important to detect or predict changes that may require management intervention, and provide reference points for comparison with other environments and time frame.

RESULTS AND DISCUSSION

CTD data

CTD data were collected at six (6) stations along the Eyjafjordur fjord during the field trip (Figure 1). The station names and position are listed in Table 1.



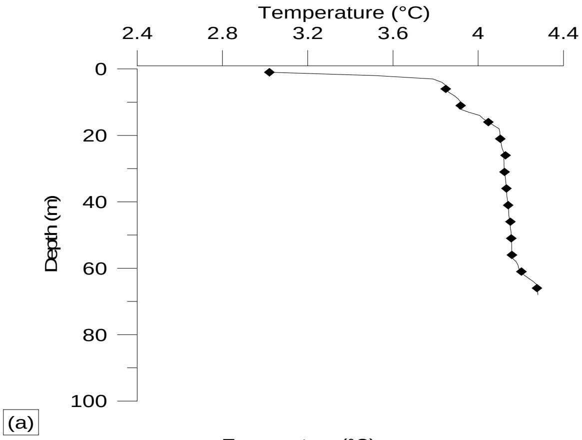
Benthic Organism Stations

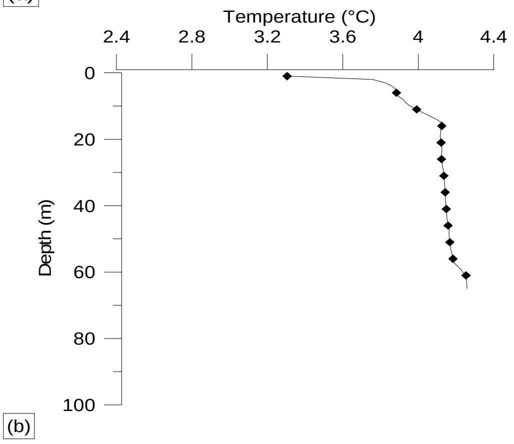
Figure 5: Sampling stations along the Eyjafjordur fjord for CTD data, zooplankton and benthos

Table 4 : List of CTD Stations

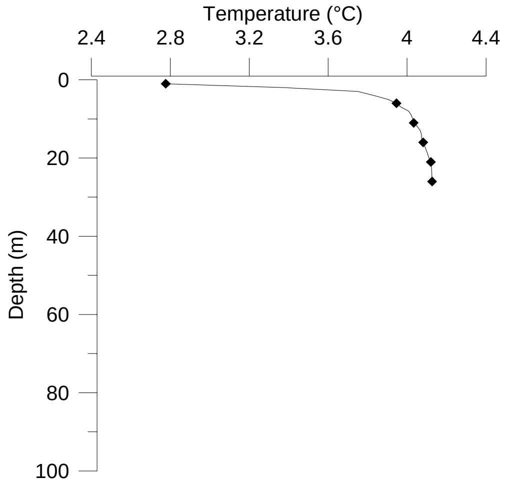
Station Name	Station Number	Latitude (°N)	Longitude (°W)	Bottom depth (m)
Dagverdareyri	7	65°45.97'	18°07.31'	70.2 (68)
	8	65°45.95'	18°06.71'	67.0 (65)
	9	65°46.00'	18°05.81'	29.0 (26)
Hjalteyri	10	65°49.44'	18°08.09'	87.4 (85)
Haganes	13	65°55.28'	18°13.81'	95.0 (88)
	14	65°54.96'	18°12.81'	65.0 (51)

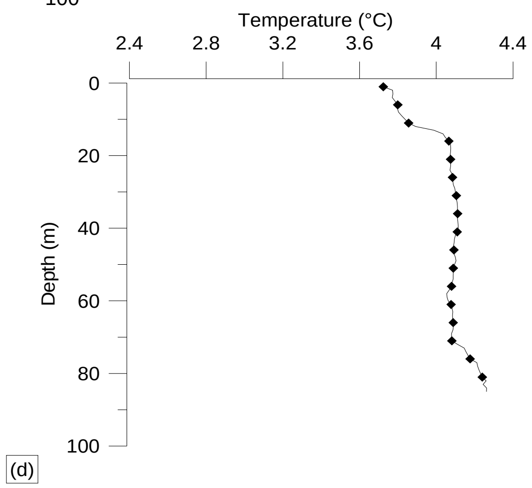
Average temperature of the water column measured during the sampling time was found to range from 3.0°C to 4.3°C along the fjord. The surface water column, from 0 – 13 m deep was found with temperatures ranging from 3.0 – 3.9°C except for station 13 where this zone extended to the depth of 23 m deep (Figure 2 a, b, c, d, e, & f). There was a very thin thermocline layer below the upper cold water layer at stations 7, 8 and 9 but such a layer was missing in the other stations. The surface water temperatures at stations 7, 8 and 9 which are located closer to the Horga river mouth were found to be much lower than other stations with values of 3.0 °C, 3.3°C and 2.7°C, respectively (Figures 1 and 2 a, b & c). Water column temperature at stations 10, 13 and 14 located much more toward the mouth of the fjord and more influenced by oceanic properties was found to be more stable (Figure 2d, e and f). However, water column temperature at station 13 was found to fluctuate with a layer of cold water below the surface layer at depth of 40 – 70 m.





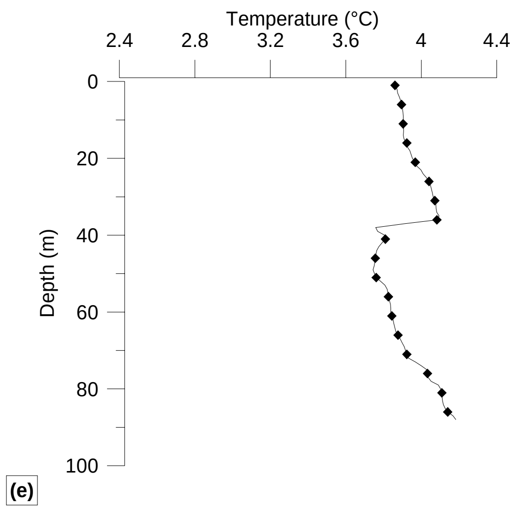
Station 7 **Station** 8

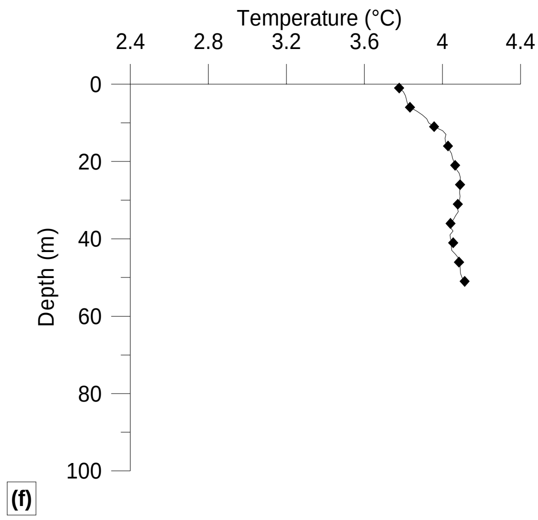




Station 9

Station 10





Station 13

Station 14

Figure 6: Temperature profiles at 6 stations sampled, Dagverdareyri (a, b and c), Hjalteyri (10) and Haganes (e and f).

The salinity of the water column was found to range from 30.1 - 35.0 psu at the sampled stations. Generally salinity was found to be evenly distributed at all the stations during this period of time where not much fresh water runoff is coming into the fjord. Lower salinities were measured at the surface waters layer to I m depth at stations 7, 8 and 9 with values of 31.6, 32.9 and 30.1 psu, respectively (Figures 3 a, b and c). The halocline layer was observed below the lower salinity waters at stations 7, 8, 9 and 10 but absent in stations 10, 13 and 14. Density (sigma-t) which is dominated by variations in salinity was found to vary in the same manner as the salinity variations.

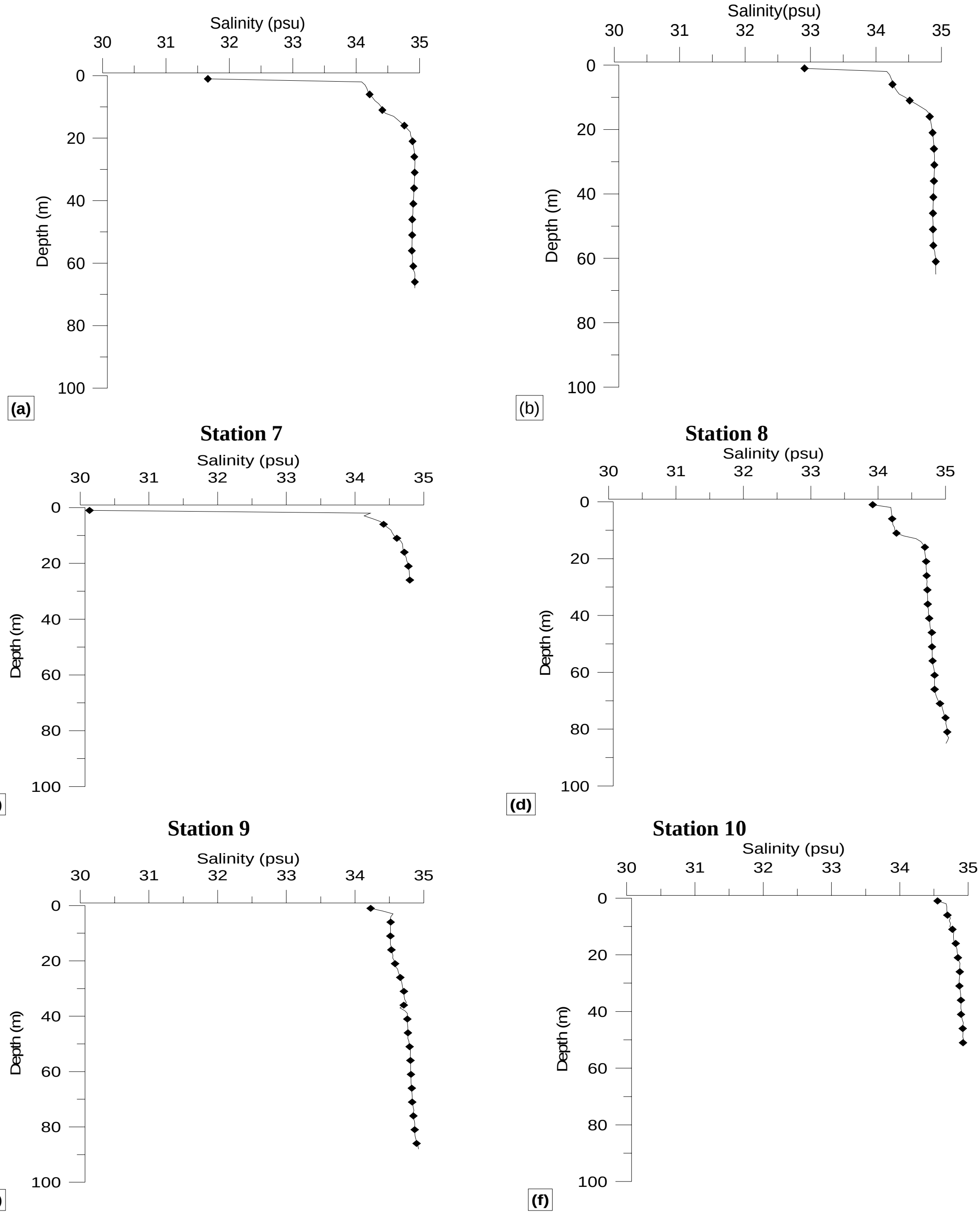


Figure 7: Salinity profiles at 6 stations sampled, Dagverdareyri (a, b and c), Hjalteyri (10) and Haganes (e and f).

Generally the results for CTD data measured show the same pattern as those measured during monitoring of the fjord although few stations were covered in this study. The upper layer of the water column (0 – 15 m) was found to be cooler at all stations sampled. Currents and wind which cause mixing of deep and upper waters might have brought the exception which was found in station 13 with layers of cold water at

40 – 70 m depth (Figure 2e). The thin layer of thermocline was found to occur below the surface cold water layer at stations 7, 8, and 9 but was absent in other stations. This usually occurs in temperate region oceans, where during winter, strong winds mix the upper ocean layers down to 100 m or more, but then in spring when winds are moderate and heating increases a thin warm layer develops at the surface with a sharp seasonal thermocline beneath.

During the previous monitoring of CTD data along the fjord, water temperature was found to start to be homogeneous at the end of September and stay steadily with decrease in temperature until April when stratification starts Jonsson and Gudmundsson 1994 and Jonsson 1994. Lower water temperatures measured at stations 7, 8 and 9 were probably due these stations being near River Horga which brings in cold waters from the upstream although there is less runoff from the rivers during this time of the year. Jonsson and Gudmundsson (1994) observed that most of the fresh water enters the fjord at the inner part through rivers Horga, Eyjafjordara, Fnjoska and Svarfadardalsa and there is a low runoff during winter while much more fresh water enters the inner fjord during the spring months when floods occur.

Salinity was found to have much less variation at all stations with upper layer at 1 m depth with lower salinity values (Figure 3). Much well mixing and low fresh water runoff into the fjord during this period of the year cause less variation in salinity which was observed within the water column although a thin halocline layer was observed at stations located on the inner part of the fjord and totally absent at the stations located seaward. Much lower salinities were measured at the surface water layer of stations 7, 8, and 9 probably due to fresh waters from river Horga which is near these stations. Monitoring data from the fjord showed that surface water salinity can drop to very low values to 18 psu especially for the inner part of the fjord during summer and spring when the river floods bring in more fresh waters (Jonsson and Gudmundsson 1994). Below the surface water layer the salinity was found to be stable with values ranging from 34.0 – 34.8 psu. The coastal river discharge can influence the temperature and salinity patterns in estuaries and near coastal waters. However, values for sigma-t or water density where also found to vary in the same way since water density is controlled by salinity variations.

CDT data Storage

CTD instruments record data at an interval of 0.5 seconds, so this make the quantity of data derived from the instrument large. However, the use of bin average makes estimate of data value at a user’s defined intervals. The bulkiness of the data to be handled increases when the stations to be monitored increases. Handling and management of such an amount of data and information is usually problematic and complicated. Therefore a need for proper storage and management is important. Environmental and biological parameters were monitored at 36 stations during the monitoring of the Eyjafjordur fjord where about 44,000 data points/values were recorded from CTD data. Additionally, more than 5 different variables were also derived from the CTD instrument including temperature, salinity, depth, sigma–t, conductivity etc.

Data values and variables obtained were stored in a database and for easy management and access of the data different queries were developed. Microsoft access program is one of the programs which are able to handle and manage large amount of data and information was used to develop the database. Through developed queries, information and data are reduced to a much smaller size quantity and hence easier handling. The whole process involved creation of tables and forms in which different variables are filled and defined. However, creation and development of database like this requires technical knowledge on computer especially the Microsoft Access program. There is a linkage between Microsoft Access and Microsoft Excel which makes data and information to be easily imported and exported from each other. The importation and exportation of data and information were frequently carried out when handling data in a database. The basic knowledge on the database development including creation of tables, forms and queries was learnt. This makes it easy to use the database with Eyjafjordur monitoring information when learning different presentation of the data.

Presentation of CTD Data

Grapher and surfer softwares were used for presentation of the data from the monitoring of Eyjafjordur fjord. Profiles for variables like salinity, temperature, density etc were developed by using Grapher 6. The program plots 2D line/scatter with X and Y values. The program allow the selection of data from excel and access files. Grapher automatically selects reasonable default settings on the created graphs and by using graph settings modifies the graphs and changes can be made on tick marks, spacing, tick labels, axis length, grid lines, line colors, symbols styles etc. Using grapher software in plotting graphs allows the selection of the variable at ones preferences.

Horizontal and vertical contour maps were plotted by surfer which interpolates irregularly spaced XYZ data into regularly spaced grids. Surfer accesses the selected data from the database after exporting them to excel and creates grid maps. The program adds boundary information, posting data points to the grid maps by overlying them and produces different maps including contour, vector, wireframe, image, relief and surface maps. The formatting of post and contour maps through properties enhance the displayed quality maps. Drawings and annotating texts can also be added to the developed maps through formatting of the post maps, contours or base maps. The use of both surfer and grapher allows the users to choose ranges of variables as preferred and also produce the maps that best represents your data.

Benthic Macrofauna and Zooplankton

Study on benthic macrofauna was carried out at two stations along the Eyjafjordur fjord. Station one was a hill which was recently discovered along the fjord where two samples were taken, on the top and side of the hill. The second station was located near the small fish landing harbour. The samples from station one were characterized as mud soil with black colour while in station two the sediment sample was muddy sand with large gravel particles with a lot of fish scales and other debris materials.

Shipek sediment sampler (0.038 m^2) was used to take the sediment samples. The sediment samples were sieved through a series of sieves (4.0, 1.0 and 0.5 mm) and material preserved in 4% neutralized formaldehyde seawater solution. In the laboratory macrofauna were sorted, counted and identified to genera and where possible to species name. Identification guide books by Hayward *et al*. (1996), Moen and Svensen (2004) and Hayward and Ryland (2002) were used.

Total of six groups of macrofauna were identified in the sediment samples including Molluscs, Gastropods, Annelids, Foraminifera, Crustaceans and Echinoderms. Number of total organisms counted per grab in stations 1 and 2 were 1,485 and 1,057, respectively. Molluscs, Annelids and Foraminifera were identified in all stations with individuals from groups of bivalves, gastropods and polychaeta worms. No effort was made to identify groups in Foraminifera. Numbers of both tube and free living polychaeta worms were found to be relatively high in both station 1 and 2 with an average number of 691and 567, respectively. Members of crustacean and echinoderms were only identified in the sediment sample from station 1. Few individuals in the groups were identified to species name as shown in table 2. Identification of the species in the groups is very difficult and requires specialists or trained personnel in marine benthos taxonomy.

Table 5 : Numbers of Organism and Species Identified at Station 1a&b and 2

Name of Station	**Phylum**	**Group**	**Number of individual**	**Species**
Station 1a (top of the hill)	Mollusca	Bivalvia Gastropoda	111 140	*Cochlodesma practenus* *Paphia sp* *Nuculana minuta* *Littorina obtusata*
	Echinodermata	Ophiolepidae (Brittle stars)	2	*Ophiura sp*
	Annelida	Polychaeta Tube worms Free living worms	 153 580	*Polychaeta spp*
Station 1b (slope of the hill)	Foraminifera	Foraminifera	800	
	Mollusca	Bivalvia Gastropoda	294 240	*Cochlodesma practenus* *Nuculana minuta* *Tellimya ferruginosa* *Macoma sp*
	Crustacea	Cumacea	2	*Cumacea sp*
	Annelida	Polychatae Tube worms Free living worms	 248 440	 *Pectinaria sp* *Nephyt caeca* *Melinna sp*
Station 2	Ferominifera	Foraminifera	240	
	Mollusca	Bivalvia Gastropoda Gastropods	10 240	*Gari costulata* *Modiola modiolus* *Macoma calcarea* *Macoma sp* *Montocuta ferruginosa*
	Annelida	Polychatae Tube worms Free living worms	 27 540	 *Pectinaria sp* *Nephyt caeca* *Melinna sp*

Water samples for zooplankton were collected by using 200 µm mesh WP-2 net with 0.25 m^2 opening. The net was towed for 5 minutes at a speed of 1 m/s in the surface water to 3 m deep at the middle of the fjord at station 10 where CTD data was also sampled (Figure 1). Collected water samples were preserved in 4% neutralized seawater solution. Identification of the zooplankton from the water samples was done in the laboratory under the light microscope. The guide manual by Todd and Laverack (1991) and Newell and Newell (1977) were used in identifying the organisms in the water sample. Very few organisms were found in the water samples collected. Only one water sample was collected at station 10. One individual species S*agitta* sp of the family Chaetognata and two fish post larvae of *Clupea harengus* were identified. There was not much activity during this time of year due to winter period. Six groups of macrofauna identified in the sediment samples from two stations sampled in the fjord were members of Molluscs, Gastropods, Annelids, Foraminifera, Crustaceans and Echinoderm. Foraminifera, Molluscs and Annelids were found in the sediment samples from all stations. Higher numbers of Polychaeta worms and Foraminifera were found at all stations (Table 2). Studies carried out in the fjord to investigate the seasonal composition of macrofauna by Gudmundsson and Gislason (1994) identified 10 phylum including Foreminifera, Polychaeta, Nematoda, Mollusca, Crustacea, Echinodermata, Nemertinea, Bryozoa, Hydrozoa and Porinfera to predominate the sediment along the fjord throughout the year. The study also reveled that Foraminifera and Polychaeta worms were the most abundant component of the macrofauna along the Eyjafjordur fjord throughout the year. Low diversity was measured during the winter months and peaks diversity on summer and spring months (Gudmundsson and Gislason 1994).

More groups and number of individuals in the groups were found at station 1a & b when compared to station 2 (Table 2). This can probably be due to soft mud sediment observed at station 1 with high organic matter which allows more individuals to colonize it. General, sediment type (clays, silts, sands, etc.), organic content, dissolved oxygen, salinity and temperature are most important in determining abundances and types of animals in bottom communities (Posey and Alphin 2002). Clay fine sediment has been found to support diverse benthic communities due to its high abundance of organic matter (Thrush and Dayton 2002). Station 2 located near the small harbour for fish landing was found to have muddy sand sediment with large gravel particles with a lot of fish scales and other debris materials with less organisms. Key physical processes controlling the distributions of benthic populations in estuaries and fjords have been found to include salinity, wave action, and sediment grain size (Dethier and Schoch 2005). Other factors which influence the distribution and diversity of macrofauna are water depth, biological geological structure on the bottom, temperature, salinity, dissolve oxygen concentration in the water as well as levels of bottom trawling fishing activity in the area. Few zooplankton organisms were found in the water samples collected during the study period. Two groups, Chaetognata (S*agitta* sp) and fish larvae (*Clupea harengus)* were identified in the water sample. The study on the zooplankton composition, abundance and seasonal variation by Gudmundsson and Gislason (1993) identified a total of 48 species in13 taxonomic groups. The zooplankton population was found to have maximum numbers in autumn while low numbers were recorded in winter months. Chaetognaths mainly *Sagitta* sp was found to have highest densities during spring and early summer in all two years of the study. Kaasa and Gudmundsson (1994) observed besides Cirripedia larvae, decapod and fish larvae to be abundant along the fjord with maximum density in May and April. Few individuals in the water sample during the study period are probably due to the winter season which started in later October. However the zooplankton net used was modified after it was broken during the previous sampling. There was also problem of electricity in the boat leading to power cut in the whole boat hence limit sampling of more water samples.