TERRESTRIAL SEDIMENT INPUTS AND BENTHIC COMMUNITY STRUCTURE OF A REEF-LAGOON ECOSYSTEM, BAY OF RANOBE, SOUTHWEST MADAGASCAR

Emma Louise Gibbons

September 2011

MANCHESTER METROPOLITAN UNIVERSITY

ACKNOWLEDGEMENT

I first wish to thank all the staff at the Manchester Metropolitan University environment department especially Chris Perry and Steve Hoon, thank you for your time and support. I would like to express my deepest gratitude to ReefDoctor, a UK N.G.O based on the Southwest coast of Madagascar, for all their support throughout the five years I have spent living and working here in this amazing country. I would also like to thank my family in Madagascar and the UK, for giving continual encouragement and support. Finally, I wish to thank the person who I aspire to be, my father, my friend who drives me to succeed.

Terrestrial sediment inputs and benthic community structure of a reef-lagoon ecosystem, Bay of Ranobe, Southwest Madagascar

Abstract

The Bay of Ranobe lagoon system is located on the Southwest coast of Madagascar, its 32km barrier reef and patch reef network form part of the '*Récif Complex de Toliara'* one of the most significant coral reef systems in the Western Indian Ocean and the third largest coral reef system in the world. Since research was first conducted in 1978 the Bay of Ranobe, episodic events and chronic stressors have instigated severe degradation of this system. Surface sediments of the Bay of Ranobe lagoon system are of two types: marine biogenic carbonates supplied by inter-reefal benthic organisms and siliciclastic (terrigenous) material deposited on the reef system through weathering, fluvial processes and coastal transportation. Sampling station 164 in the north of the lagoon system, in close proximity to the river mouth, has a terrigenous deposit composition of over 40% wt, suggesting that fluvial sediments are being transported from the river into the adjacent marine environment. Deposits of terrigenous material, located in the northern section and midpoint adjacent to the coast combined with terrestrial data (Harper 2008) imply that these areas are subject to changes in land-use practices. Benthic assessments and evaluation of sediment composition including mixing of terrigenous carbonate-siliclastic sediments provides significantly different habitat biotype profiles with seagrass meadows being the dominate feature of this grouping and are suggested to underpin the productivity of this tropical marine lagoon system.

TABLE OF CONTENTS

List of Tables

LIST OF FIGURES

1. INTRODUCTION

1.1 MADAGASCAR; A LIVING LABORATORY OF EVOLUTION

Madagascar has been described as a living laboratory of evolution in reference to its immense abundance of endemic terrestrial and marine species (Mittermeier et al 1999, McKenna and Allen 2003). As the world's fourth largest island with an extensive coastline of 4,828 km (Spalding *et al* 2001) supporting approximately 3450km of coral reefs (Webster and McMahon 2002) it is not surprising that the coral reefs are described by Cooke *et al* (2000) as one of the most significant and extensive marine habitats in the Indian Ocean.

These coral reef ecosystems have been found to be extremely rich and diverse with an estimated 752 species of fish and 380 coral species, the highest recorded coral diversity of the Western Indian Ocean and Red Sea (McKenna and Allen 2003). However, the scientific knowledge on Madagascar's marine environment is considered to be relatively poor and fragmented compared to its terrestrial counterparts (Cooke *et al* 2000, Gabrié *et al* 2000). Despite recent increases of research into Madagascar's coral reefs (McClanahan and Obura 1998, Webster and McMahon 2002, McKenna and Allen 2003, Nadon *et al* 2007, Harris *et al* 2010) there still remains considerable scope for further biological assessments of these extensive and ecologically significant habitats. In a global risk assessment of coral reefs, Madagascar’s reefs were placed at a medium to high risk (Bryant *et al* 1998). Global warming, excessive sedimentation and over-fishing are currently considered the main threats to the integrity and survival of these reefs (Cooke *et al* 2000). Extensive deforestation across the country (Inns 2010) has resulted in massive soil erosion and the subsequent increase in terrigenous sedimentation transported to coastal areas causing considerable damage to some coral reefs (Cockroft and Young 1997, Gabrié *et al* 2000).

Coral bleaching has also impacted large areas of reefs across the country; the global bleaching event of 1998 resulted in coral mortality levels of up to 80-90% in some areas (McClanahan and Obura 1998) and has been attributed to be a major cause of degradation for reefs in the southwest region (Maharavo 1997, 1999). It has also been suggested that the number of traditional fishermen has increased fivefold in the last two decades (Gabrié *et al* 2000) resulting in significant marine resource over-exploitation especially in the region surrounding the large urban centre of Toliara where around 50% of all fishermen operate (Laroche & Rarnananarivo 1995). Such rapidly growing human populations dependant on ecosystem goods and services throughout the coastal regions ensuing additional stressors to Madaascar’s coral reef systems (Hutchings *et al* 2005, Johnson and Marshall, 2007) through coastal pollution and nutrient enrichment (Hinrichsen 1998) With existing regional and global threats such as episodic events such as cyclones and subsequent bleaching of scleractinian corals together with chronic stressors such as over-harvesting of the near-shore marine environment, it is essential that the assessment of the current status these marine environments is made to enable effective future management systems to conserve this reef system in the context of global change and evaluating the potential for conservation initiatives.

Therefore, this study seeks to ascertain an evaluation of surface sediment to develop an understanding of the present distribution patterns of terrestrial sediments within near-shore settings and assess the present spatial extent of terrigenous sediment within the modern lagoon system. The environmental framework for the study area with a quantification of benthic biodiversity and distribution is to characterise the lagoon environment in terms of its physical, environmental and biological characteristics

1.2 AIMS AND OBJECTIVES OF THIS RESEARCH

The purpose and structure of this study is thus threefold.

(1) Assess data on the sediment dynamics in the shallow turbid waters of the Bay of Ranobe lagoon system. Reviewing the literature on the effects of sedimentation on coral-dominant ecosystems and present new data from the lagoon system Bay of Ranobe, Southwest Madagascar

(2) To better understand the relationship between sediment, geomorphology and biological communities

(3) Evaluate the impact of episodic and chronic stressors on the Bay of Ranobe lagoon system through the comparison of historical research data assessing the impacts of global climate change and anthropogenic disturbances.

2. Background

Coral reefs are amongst the most productive and diverse ecosystems in the world (Hoegh-Guldberg *et al* 2007, Wild *et al* 2011), with over 500 million people living within 100km of a reef system (Bryant *et al* 1998, Moberg and Folke, 1999), and a large percentage of these systems located in developing countries, climate and environmental changes that impact the productivity and diversity of these systems (Marshall and Schuttenburg 2006), will have lasting consequences on the tens of millions of people that are dependent on these reef systems for all or part of their livelihood (Moberg and Folke 1999 Le Manach *et al* 2011)

Climate change and global warming pose a sever threat to coral reefs (Buddemeier *et al* 2004) from multiple stressors such as ocean warming and acidification attributed to the increase in atmospheric carbon dioxide (Sabine *et al* 2004, Anthony *et al* 2011). Ocean warming and acidification (fig 1) is also indicated to be linked to coral disease prevalence (Williams *et al* 2010) and the reduction of calcification rates in reef building species (Kleypas and Langdon 2006).

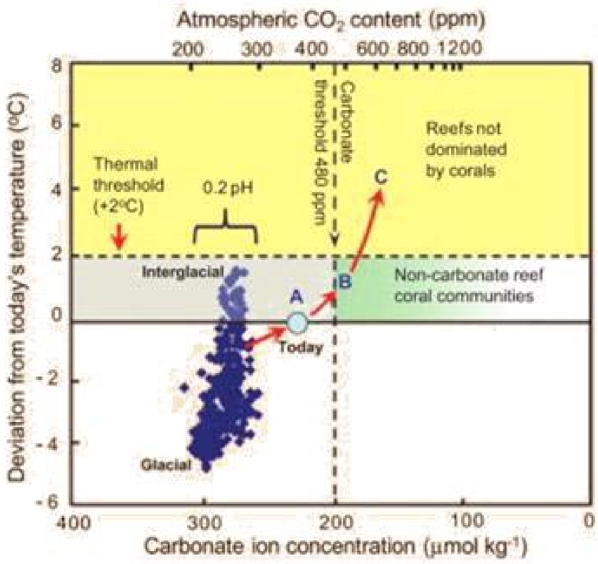

Figure 22; Temperature $[CO_2]_{atm}$, and carbonate-ion concentrations reconstructed from the past 420,000 years to show the thresholds for major change top coral communities for thermal stress and carbonate-ion concentrations that decrease the concentrations of carbonate slowing coral calcification (Hoegh-Guldberg *et al* 2007).

In the context of ecological responses of these coral-dominated systems to climate change, the escalation in the frequency and severity of episodic events (Carilli *et al* 2009, Chollett *et al* 2010) such as El Nino-Southern Oscillation (ENSO) (Wilkinson1998) and cyclonic disturbance (Turner and Klaus 2005) exerting extreme force on the reef systems (Riddle 1988) effecting framework function (Geister 1977, Blanchon 1997, Harmelin-Vivien 1994) and structure (Connell 1978, Gardner *et al* 2005) coupled with elevated and extended sea surface temperature (SST's), that have been suggested by numerous studies to inducing coral bleaching events (Quad and Bigot 1999, Hoegh-Guldberg 1999, Sheppard 2003, Donner *et al* 2005) lead to the degradation of coral-dominant systems by negatively impacting the survivorship of scleractinian corals (Hoegh-Guldberg 1999, Douglas 2003) and reductions in corallivorous fishes in the short term and fish diversity 3–4 years following a thermal stress event (Pratchett 2007, Munday *et al* 2008).

Chronic (Mora 2009) or local-scale (Anthony *et al* 2011) stressors attributed to anthropogenic impacts (Wilkinson 2002, Hughes *et al* 2003, Bellwood *et al* 2004, Underwood *et al* 2006) such as over-exploitation of the near-shore marine environment (Kendall *et al* 2003, Walker 2008) habitat modification (Smith *et al* 2011), and over-harvesting (Souter 2002 Hughes *et al* 2005) that impinge on biodiversity and productivity (Chabanet *et al* 1996) are understood to initiate ecosystem community shifts (McClanahan and Muthiga 1998, Lirman 2001, Hughes *et al* 2007) especially in areas of high human population levels (Pet-Soede *et al* 1999). Thus it can be assumed that when a coral-dominated ecosystem are subjected to episodic events coupled with chronic stressors the resistance and/or resilience of scleractinian corals to such stressors is reduced, leading to the degradation of these ecosystems. Consequential impacts on the subsequent communities that depend on these systems for all or part of their livelihood (Hoegh-Guldberg 1999, Hoegh-Guldberg *et al* 2007, McClanahan 2008) can be assumed to result in escalating poverty, which is among the major sources of human psychosocial suffering (Lund *et al* 2010) and morbidity (Acorsi *et al* 2005, Nguyen and Peschard 2003, Tucker *et al* 2011).

2.2 CORAL-DOMINATED REEF SYSTEMS

Tropical coral reef systems are physically dynamic structures comprised of a diverse matrix of calcifying sedentary organisms such as hard corals and coralline algae, as well as non-autotrophic benthic sessile organisms such as molluscs, foraminifera, echinoderms and sponges.

Hermatypic corals are the defining feature of tropical reef systems and contribute significantly to species richness and diversity as members of the phylum Cnidarian, hermatypic corals belong to the mainly colonial group Scleractinia and are characterised by the construction of a calcium carbonate ‘reef building’ skeleton and the symbiotic relationship with zooxanthellae, single-celled marine algae that colonise the endodermal tissues of corals, releasing energy through photosynthesis and providing pigmentation for the coral host.

This relationship with the coral host is termed a holobiont. Evaluation to determine the response of specific coral taxa to local and/or regional stressors that induce deleterious physiological responses or ailments (Douglas 2003) can be used to assess the potential vulnerability of reef systems. A comprehensive risk assessment of marine habitats completed by Halpern 2008 indicated that over half of the coral reef systems worldwide are under medium to high anthropogenic pressure, with over 21 percent of all coral reefs threatened by sedimentation from land based sources, primarily due to logging and poor agriculture practices (Burke *et al* 2002), with one-third of all scleractinian corals are ‘considered to be at risk of extinction’ (Carpenter *et al* 2008).

Primary controls of coral-dominated reef growth include allocyclic factors such as sea-level, salinity, temperature, acidity, currents and weather patterns (Buddemeier and Hopley 1988, Larcombe and Woolfe 1999), secondary factors include sedimentation, water quality and autocyclic direct and indirect biological interactions (Larcombe and Woolfe 1999). Whereas coral reef disturbances involve multiple anthropogenic impacts, such as destructive fishing practices, over-harvesting of marine products and eutrophication (Richmond 1993, Hughes 1994, Brown 1997, Nystrom *et al* 2000).

2.3 CLIMATE CHANGE AND CORAL REEFS

Climate change and chronic stressors that induce substantial coral mortality

(McClanahan *et al* 2007, Suggett and Smith 2011) instigating community change and/or phase shifts (Smith *et al* 1981, Hatcher *et al* 1989, Done 1992, Hughes 1994, Genin *et al* 1995, Lapointe 1997). Studies conducted by Glynn (1993), Aronson and Precht (1997), Diaz-Pulido and McCook (2002), Aronson *et al* (2004) all indicate that climate change will contribute to these phase shifts in the near-shore marine environment and may have an additional influence over the long-term through the degradation of reef framework and function (fig 2).

Phase shifts effect the framework and function of the coral reef system by shifting from a scleractinian coral-dominated system to alternative reef states such as corallimorphs (Norström *et al* 2009) gorgonians, soft corals, ascidians and sponges (Bak *et al* 1996, Maliao *et al* 2008) and/or macro-algae (Hughes 1994, McCook 1999, Diaz-Pulido and McCook 2002, Bellwood *et al* 2006, Birrell *et al* 2008).

Numerous studies have suggested that the subsequent colonisation of dead corals by a diverse macro-algae community (fig 2) (Hoegh-Guldberg *et al* 2007, Diaz-Pulido and McCook 2002) as well as the overgrowth of living scleractinian corals by invasive and damaging macro-algae (Smith *et al* 2006; Haas *et al* 2010) will, in turn reduce resistance and/or resilience of the remaining scleractinian coral community to regional and local stressors. With the loss of live coral substrate and as the coral reef community changes, topographic complexity of the reef system will be diminished through the process of bioerosion, thus, through positive feedback mechanisms

(McManus *et al* 2000) the availability of space for the settlement of new coral recruits is reduced. Diversity and density of reef fish populations are also affected as high abundances and diversity of reef fishes is associated with complex reef topography (McClanahan and Shafir 1990).

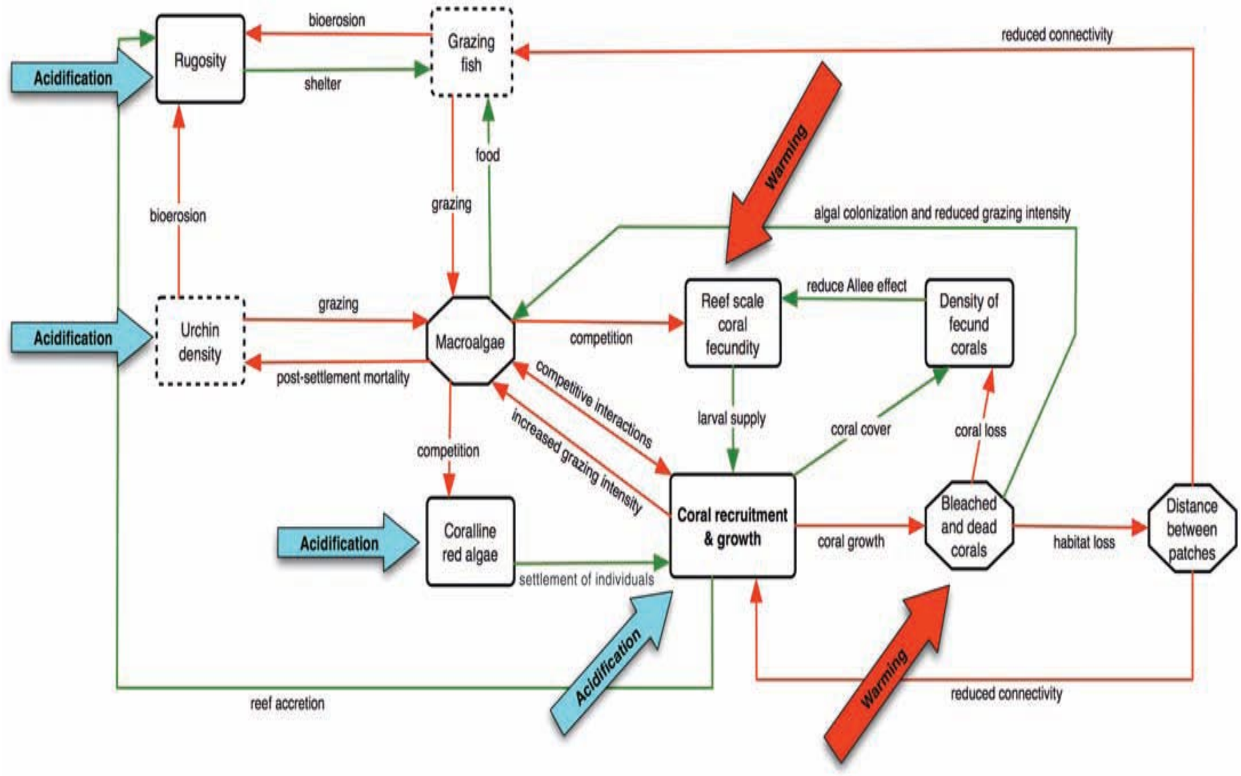

Figure 23; Ecological feedback processors on a coral reef system outlining the pathways of disturbance caused by climate change. Arrows indicate the effects of ocean acidification (blue) and global warming (red) with boxes that are joined by the red pathways implying a negative (decreasing) impact on the box. Green arrows imply a positive (increasing) relationship. Hexagonal boxes will increase, whereas rectangular boxes will decline. Boxes with a dash-line are responsive to management strategies (Hoegh-Guldberg *et al* 2007)

Rapidly declining reef health and localized phase shifts towards macro-algal dominated systems can also be symptomatic of chronic stressors inflicted by the artificially low number in herbivorous fish species (Carpenter 1986, Burkepile and Hay 2006, Williams *et al* 2001, Hughes *et al* 2007, Burkepile and Hay 2010) attributed to the over-exploitation of the near shore marine environment by coastal populations increasing the ability of macro-algae to ‘out compete’ coral for space (Carilli *et al* 2009, Anthony *et al* 2011).

The outcome of which can have significant implications for the long-term survivorship and growth of coral (Lapointe *et al* 1997, McClanahan and Muthiga 1998, Lirman 2001) affecting the productivity and diversity of the coral reef ecosystem.

2.4 EVOLUTION OF SCLERACTINIAN CORALS TO COPE WITH SEDIMENT STRESS

Sedimentation is regarded by many as a having a deleterious impact on coral reef benthic ecology (Lota 1976, Dodge and Vaisnys 1977, Cortes and Risk 1988, Vankatwijk *et al* 1998, Brown *et al* 2002). However, implications and effects of sedimentation, in terms of both near-shore (including coral reef) and benthic ecology, are complex and relatively poorly understood. In terms of the impact of sedimentation on benthic ecology, the following points are relevant.

Scleractinian corals have evolved many mechanisms to cope with sediment stress such as morphological adaptations and actively shedding sediment (Hubbard and Pocock 1972, Bak and gershuizen 1976, Lasker 1980, Stafford-Smith and Ormond 1992, Stafford-Smith 1993, Riegl 1995) such as the massive to platy morphologies of coral such as *Porites* (Sanders and Baron-Szabob 2005) possessing small-polyp’s and producing large amounts of mucus that form mucus-particle aggregations which have been observed to increase the sedimentation and recycling rates in which limited nutrients can be reutilised (Wild *et al* 2004a, 2004b, Huettel *et al* 2006, Naumann *et al* 2009). While most mendroid corals are effective at dispersing sediment (Anthony 2008) and scleractinian corals of the branching morphology such as *Acroporidae* provide a very small surface area for sediment to settle which can be dispersed by currents (Veron 2009). Thus, specific coral taxa have been found to be resilient to areas of high turbidity and/or sedimentation rates (Mayer 1918, Yonge 1930, Marshall and Orr 1931, Riegl 1995, Wesseling *et al* 1999, Sanders and 2005, Veron 2009)

As mixotrophs, scleractinian corals are supplied energy through the absorption of compounds translocated from the photoautotrophic endosymbiotic algae or zooxanthellae, dissolved organic/inorganic matter (Muscatine *et al* 1984, Wild *et al* 2011). Zooxanthellae are accountable for as much as 95% of photosynthetically fixed carbon translocated to the coral host, with the coral-zooxanthellae holobiont able to adjust the photosynthetic potential to the external environmental conditions through alterations of zooxanthellae densities in the host tissue (Goulet 2006, Osinga *et al* 2011).

Thus, scleractinian reef-building corals are dependent on light energy transferred from the photosynthetic zooxanthellae for rapid growth of an organic matrix in which calcium carbonate is deposited (Chalker 1981) reproduction and maintenance (Bythell 1988) studies have emphasised the synergies between irradiance and growth/calcification rate in scleractinian corals (Goreau 1959, Chalker 1981, Marubini *et al* 2001, Reynaund *et al* 2004, Schlacher *et al* 2007, Schutter *et al* 2008, Osinga *et al* 2011).

light limitation in zooxanthellae result in the insufficient production of energy due to reduced photosynthates (Titlyanov *et al* 2001) ineffectual translocation of photosynthates suggested by Marubini and Davis (1996) to be associated with nitrification, a reduction in internal pH from the lowered photosynthates effecting calcification rates (Schneider and Erez 2006) or photoinhibition (Iglesias-Prieto *et al* 1992) inducing photoinhibition, this can lead to bleaching defined as: the process by which the coral-algae mutualistic symbiosis (Day *et al* 2008) breaks-down leading to the expulsion of the zooxanthellae and a loss of pigmentation (Wild *et al* 2004).

Bleaching typically corresponds with extended periods of Sea Surface Temperatures (SST) (fig 2) above the suggested bleaching threshold of 27.5°C (McClanahan *et al* 2005) with the occurrence and intensity of bleaching being highly variable both within a coral colony, between coral colonies, within a reef and between reefs systems (Lough 2007). Resistance and resilience of coral to deleterious physiological responses has been linked to local stressors (Carilli *et al* 2009).

Scleractinian corals also have the ability to consume particulate organic matter through the act of macro/microphagy (Muscatine 1973, 1990, Porter 1976, Tomascik and Sander 1985, Sorokin 1990, Schlichter and

Brendelberger 1998) this provides an energy resource for the corals especially during periods of stress and/or when corals are subjected to high turbidity resulting in low light levels and/or exhibiting the bleaching response.

Heterotrophic feeding mechanisms can be utilised to provide a source of energy. Numerous species of coral including *Acropora* feeding on particulate matter suspended in the water column in near-proportion to availability Anthony (1999). Near-shore marine environments are extremely rich in nutrients in the form of planktonic organisms such as zooplankton (Porter 1974, Sebens *et al* 1996), microzooplankton (Ferrier-Pages *et al* 1998), bacteria (Bak *et al* 1998), sediment (Stafford Smith and Ormond, 1992) suspended particulate matter (Anthony 1999a, 2000, Furnas *et al* 2005, Roman *et al* 1990, Anthony 1999b, 2006) providing an energy source for heterotrophic feeders such as scleractinian corals where as oligotrophic environments maybe limited because of carbon fixation exceeds the supply of macro-nutrients such as Nitrates and Phosphates (Anthony 1999b, 2000) with research by Dubinsky and Jokiel (1994) suggesting that heterotrophic feeding maybe a way to provide the holobiont with nitrogen. However, if the expulsion of the zooxanthellae from the host occurs the act of macro/microphagy alone is unable to produce enough energy for reproduction and growth and is suggested to deplete lipid stores (Anthony 1999a) resulting in a ‘food shortage’ and starvation (Porter *et al* 1989, Fitt *et al* 1993).

2.5 SCLERACTINIAN CORALS, SEDIMENTATION AND SUSPENDED PARTICULATE MATTER

Many studies such as Roy and Smith (1971), Done (1982), Johnson and Risk (1987), Acker and Stearn (1990), Riegl (1995), Kleypas (1996), McClanahan and Obura (1997), Woolfe and Larcombe (1998), Larcombe *et al* (2001), imply that scleractinian corals that settle and grow in moderate to intermediately high turbidity are not necessarily more stressed than scleractinian corals that have settled and developed in oligotrophic waters.

Rosenfeld *et al* (1999) used fluorescently labelled sediment to demonstrate the transfer of labelled organic matter from the sediment into the cells of the solitary coral *Fungia horrid*, providing evidence for capacity of a *specific* coral species to utilize sediment in this manner. Anthony *et al* (2002), using a controlled tank experiment on *Acropora intermedia*, demonstrated that at high temperature there was an increased mortality risk at all light levels and but when corals were subjected to high sediment loads together with high temperature and/or high light conditions reduced mortality was observed, potentially due to the alleviating factor of increased turbidity reducing light penetration and by providing alternative food sources for affected corals.

Increased turbidity in the water column with consequent implications for reduced light penetration from high levels of suspended sediment can affect the photosynthetic process of reef-building coral (Birkeland 1977, Rodgers *et al* 1984). Sedimentation, turbidity, ambient suspended and settling sediments, may also instigate excessive use of energy activating sediment rejection mechanisms (Dodge 1974), such as an increase in mucus production thus inhibiting growth. Corals are subject to both passive (wave action) and active (increased muco-ciliary activity) sediment removal mechanisms (Lasker 1980) and display a range of symptoms indicative of sub-lethal stress, including sediment stress, such as the extrusion of mesenterial filaments, unusual mouth opening responses, changes in feeding behaviour, unusual polyp contraction or expansion, and excess mucus production (Brown and Howard 1985, Pastorak and Bilyard 1985; Rogers 1990, Stafford-Smith 1992, Stafford-Smith and Ormond 1992, Antony *et al* 2007).

This may lead to a decrease in zooxanthellae concentration and/or bleaching, Nemeth, Sladecemeth, and Ladeck-Nowlis (2001) found a strong positive correlation between sedimentation and bleaching. Framework-building scleractinian corals namely the genera *Acropora, Seriatopora, Pocillopora*, and *Stylopora* are examples of fast growing genera exhibiting branching and digatate morphologies that are suggested by Marshall and Baird (2000), Loya *et al* (2001) and McClanahan *et al* (2002) to be stenothermic and present a low tolerance to thermal stress, where as slow growing genera such as *Porites* that display massive and encrusting morphologies are eurythermic and present a higher tolerance to thermal stress. Furthermore, larger colonies of these stenothermic genera being more susceptible to thermal stress than small colonies (Loya *et al* 2001, Mumby *et al* 2001, Nakamura and van Woesik 2001, Bena and van Woesik 2004)

It is presented by in many studies that high sedimentation rates lead to abrasion, smothering, shading and inhibiting the settlement of coral larvae (Hubbard 1997) sediment accumulation is suggested to physically smother the coral polyps and/or damage the soft tissues of scleractinian corals through abrasion or impact by the sediment particles, especially of sandy grains (Rogers, 1990) leaving the surface of the coral susceptible to pathogens and boring organisms. Research published by Schlager (1981), Hallock and Schlager (1986) and Rogers (1983, 1990) state that corals are sensitive to the input of nutrients and sediment and these stressors have a deleterious effect on survivorship of scleractinian coral. Studies also connect coral-dominated

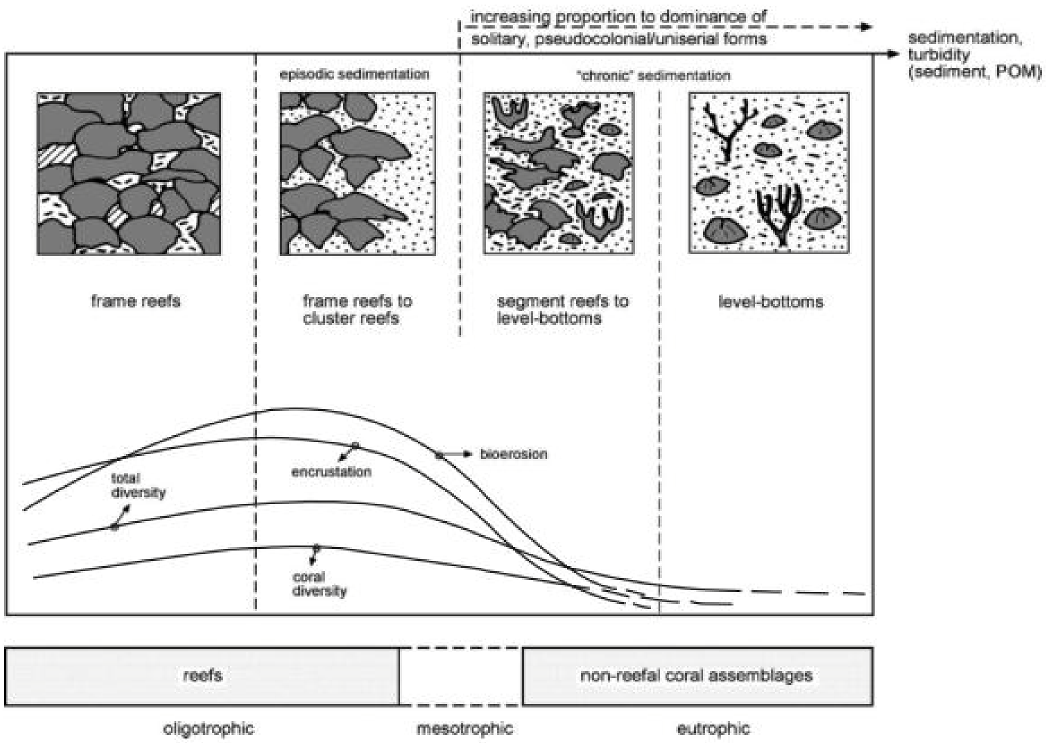

Figure 24; Scleractinian assemblages relative to sediment input, left of the diagram subjected to no or episodic sediment input with frame reefs to cluster reefs with cement-filled pores (cross-hatched). Right half of diagram shows the impact of chronic sediment/terrigenous input with segmented reefs to level-bottom assemblages forming (Sanders and Baron-Szabo 2005) reefs systems exposed to an increase in sedimentation rates (fig 3) to changes in growth (Dodge *et al* 1974, Dodge and Vaisnys 1977), skeleton morphology (Foster 1980) , coral recruitment (Gilmour 1999), and community structure (Loya 1976, Cortes and Risk 1985, Tomascik and Sanders1987)

Within the literature review by Rogers (1990), the suggested maximum sedimentation rate needed to be observed for the healthy growth and survival of a coral reef community was at 10 mg cm^{-2} day^{-1}. In this highly referenced paper Rodgers also states that elevated levels of perpetual stress cannot be tolerated and will eventually result in whole colony mortality, which leads to an enhanced possibility of later burial of the reef, even with relatively low sediment accumulation rates, because reef growth has been reduced to zero. In a similar study by Brown 1997 it is suggested that values above 50 mg cm^{-2} day^{-1} would lead to catastrophic deleterious results to the coral reef system.

However, the majority of recent literature describing the impact of stressors to reef systems are from environments affected directly or indirectly by anthropogenic disturbance (Fishelson 1973, Dodge and Vaisnys 1977, Dryer and Logan 1978, Done 1992, Bellwood *et al*1996, Bell and Elmetri 1995, Hughes *et al*.2003, Hughes *et al* 2007, Veron *et al* 2009, Harris *et al* 2010, Hughes *et al* 2011, Sanders and Baron-Szabob 2011).

Many studies (Aronson and Precht 2006, Grimsditch and Salm 2006, Hughes *et al* 2007), have shown the capacity of reef systems to recover ‘remote from additional human stresses’ and from episodic events such as storm damage or bleaching (Veron *et al* 2009).

Anthony (2006) has demonstrated that environmental conditions on inshore, high-turbidity reefs do not always exert a negative impact on the physiology of corals and may even contribute to increased lipid levels for specific scleractinian corals such as *Turbinaria mesenterina* and *Acropora valida* that displayed a 4-fold and 2-fold respectively, higher lipid content together with a low variation in reproductive fitness suggests that coral physiology in a high turbid near shore marine environment is more resilient than previously thought.

Thus, the assumption that particulate matter suspended in the water column (turbidity) has a deleterious effect on scleractinian corals needs further examination. It is frequently stated that sedimentation is a detrimental to the fitness of scleractinian corals (Lota 1976, Dodge and Vaisnys, 1977, Cortes and Risk 1985, Vankatwijk *et al* 1993, Rogers 1990, Brown 1997, Brown *et al* 2002), because of the abrasive and smothering properties and the consequential reduction in light levels light levels, essential for the translocation of energy from symbiont to host and although this is accurate for many (once oligotrophic) coral-dominant reef systems it does not take into consideration that sceleterian corals are found in a diverse range of habitats (Anthony *et al*. 2004,2006) and that thriving reefs are found in turbid conditions (Bull 1882, Babcock and Smith 2000), lower flow rates (Done 1982) and higher temperatures (Berkelmans 2002).

3. ENVIRONMENTAL SETTING

3.1 STUDY AREA

Southwest Madagascan coastline borders a unique and indigenous forest ecosystem referred to as the spiny forests containing numerous endemic species of plant, reptile and bird, many yet to be described. High rates of endemism are often treated as one of the most important criteria in the assessment and evaluation of biodiversity 'hot spots'. On comparison with the myriad of endemic terrestrial flora and fauna associated with island habitats such as Madagascar, tropical marine systems normally display considerable homogeneity primarily due to the lack of physical barriers and the abundance of small island and reef systems facilitating pelagic larva dispersal (McKenna and Allen 2003).

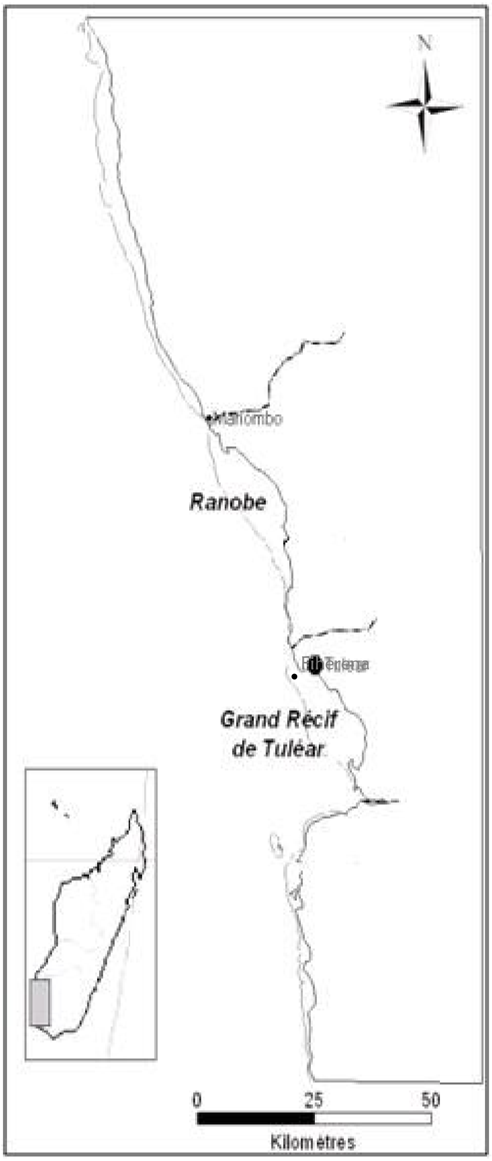

Figure 25; Study area Bay of Ranobe, Southwest Madagascar. River systems in the north (Manombo) and in the South (Fiherenana) are depicted along with the '*Grand Recif de Tulear'* south of the Ranobe system.

Madagascar is one of the largest islands in the world with an extensive coastline encompassing some of the most diverse and abundant reef systems and extensive brackish water, shallow marine, and continental shelf habitats of any Indian Ocean country apart from India (Cooke 2002). Reef systems comprised of 3,450 linear km of coral reefs of which 1,130 km is of fringing reef and 557 km of reef systems around islets, islands and patch coral reef along with 52km of true barrier reef, 1,711 km of submerged coral bank and shoals together with a continental shelf of 117,000 km^2.

Table 6 Description of the reef system from Androka to Belo-sur-Mer that that forms the '*Récif Complex de Toliara'*

LOCATION: ANDROKA TO BELO-SUR-MER	REEF DESCRIPTION
Androka	Two fringing reefs, 11 and 7 km long
Itampolo	Fringing reef, 10 km long
Lanivato to Onilahy	Long fringing reef, 100 km long by 500 m to 3.5 km width
Nosy Ve, Nosy Vorona, Nosy Manitsa	Sandy cay reefs
Bay of Ranobe (Onilahy river to the Manombo river) (fig 4)	Barrier reefs with the main coral habitats including lagoon reefs and coral banks
Manombo river to the Baie des Assassins	Fringing reefs 2 to 3.5 km wide extending for almost 80 km
Baie des Assassins to the Mangoky Delta	Fragmented reefs from barrier reefs, sandy cays reefs and coral banks to fringing reefs

(Cooke 2002)

The 32km barrier reef and patch reef network of the Bay of Ranobe (fig 4) that forms part of the '*Récif Complex de Toliara'* (table 1) stretching from Androka to Belo-sur-Mer is the most significant coral reef system in the Western Indian Ocean coupled with being the third largest coral reef system in the world, thus having an extremely significant ecological and economic value. With existing regional and global threats such as episodic events such as cyclones and subsequent bleaching of scleractinian corals together with chronic stressors such as over-harvesting of the near-shore marine environment, it is essential that the assessment of the current status these marine environments is made to enable effective future management systems to conserve this reef system in the context of global change and evaluating the potential for conservation initiatives.

3.1.1 CLIMATE

Madagascar spans almost 14° of latitude (11°47' - 25°35' S) a large area of the coast is located in the southern tropics with the study area situated just below the tropic of Capricorn. Extreme south displays an ecotone of tropical and temperate systems with two monsoon periods; South-eastern monsoon April to October producing lower air temperatures strong winds and reducing water temperature that induces low productivity and the northeast monsoon November to March that produces high air temperature and weak winds

3.1.2 CURRENTOLOGY AND TEMPERATURE

The reef complex of Toliara, (23° S, 43° E) lies off the southwest coast of Madagascar in the path of the southward flow through the Mozambique Channel. This flow is part of the warm surface flow of the global ocean circulation (DiMarco et al 2002, de Ruijter et al 2002, 2004, Schouten *et al*

2002, 2003). South-easterly trade winds dominate this system all year with evaporation exceeding precipitation in the annual mean. Precipitation only reaches significant amounts during December–March, and is associated with the SE–NW orientated cloud bands stretching from the Western Indian Ocean towards South Africa (Todd and Washington 1999). Sea Surface Temperature varies seasonally by 6 °C (Reynolds and Smith 1994) with mean sea surface temperatures range from 22 °C in the south to 28 °C in the north, with local seasonal extremes from 19 °C to 33 °C. Based on 336 yr temperature record using coral core data taken from the Bay of Ranobe when the Southern Oscillation Index (SOI) is weak and there is a strong correlation with the Pacific El Nino South (ENSO) (Zinke *et al* 2004), ENSO is also known to influence the EP balance over the Southwestern Indian Ocean and southern Africa (Tyson 1986, Reason and Mulenga 1999, Reason and Rouault 2002, Richard *et al* 2000). West coast of Madagascar has some of the largest tidal ranges of the Western Indian Ocean region due to the narrowing of the Mozambique Channel, mean spring tide of 3.8 in the north and 2.6 in the south (McClanahan 2009) The continental shelf is very narrow on the Southwest coast the 100 meter depth contour lies 5 to 8 km from shore and the Onilahy river system, north of Toliara has a sub-marine canyon drops to 1500m (Battistini *et al* 1975).

3.2 River systems

Fluvial influences are limited because of the small amount of rainfall this region and its catchment area, receiving around 300 – 800 millimetres of rain per year (Weydert 1973) as the southwest coast is not directly influenced by the monsoon of this region (Battistini *et al* 1975). The Bay of Ranobe has two fresh water systems on the peripheral boundary of the lagoon system (fig 4). In the North (Manombo) and South (Fiherenana) (fig 5) both fresh water systems have the potential to influence this study area through the deposition of terrigenous sediment and/or influx of freshwater onto the reef system. Watershed area for the Fiherenana is 6,750 km^{2}, (no information for watershed area of the North but advised around 7,500 km^{2},).

Figure 26; Dry river bed of the Fiherenana, infrequent rainfall allows growth small shrubs and bushes (visible) during peak flow the whole basin is flooded (per.obs)

3.3 MANGROVE SYSTEMS

Madagascar has with over 425,000ha of tidal marsh with an estimated 327,000 ha inhabited by extensive mangrove systems with 98% dispersed along the west coast and 95% ranging between (21˚South and 25 ˚ South) (Cooke 1999). Mangrove systems in Madagascar are described as similar as those of East Africa, diversity is limited to nine species in six families, Rhizophoracae (*Rhizophoracae mucronata, Bruguiera, Ceriops tagal*), Avicenniaceae (*Avicennia marina*), Sonneratiaceae (*Sonneratia alba*), Combretaceae (*Lumnitzera racemosa*) and Meliaceae (*Xylocarpus granatum*) (Jenkins 1987).

The bay of Ranobe is delimited by mangrove stands; however, the mangrove system in the South of the bay is under intense anthropogenic stress, mass deforestation is evident (fig 6), although recent mitigation management strategies from local environmental NGO’s have given rise to small grassroots organisations taking part in mangrove nursery and re-planting projects.

In the North of the lagoon, even with a higher population inhabiting the coastline the mangrove system is in a relatively healthy state mainly because of a local ‘fady’ or taboo surrounding the actual cutting of mangrove wood. Although, with the dilution of indigenous knowledge the adherence of local indigenous populations to the ‘fady’ is deteriorating.

Figure 27; Mangrove system in the south of the Bay of Ranobe, deforestation of these systems for fuel wood , animal feed and/or building materials has serious implication of the adjoining marine systems

3.4 SEAGRASS BEDS

Seagrasses are specialized grass-like herbaceous angiosperms and are a feature of sand flats, intertidal mud, coastal lagoons and sandy areas, closely linked to the diversity and productivity of coral reef and mangrove systems of the near-shore marine environment. Seagrass beds of the bay of Ranobe consist of a multispecies community; nine species are represented *Thalassodendron ciliatum, Thalassia hemprichii, Cymodocea rotundata, Cymodocea serrulata, Syringodium isoetifolium, Halodule uninervis, Halodule wrightii, Halophila ovalis, Halophila stipulacea* enriching the flora and fauna of the intertidal community. Limits and stressors to seagrass communities that inhabit the intertidal zones of the lagoon system such as osmotic influence from hypersalinity due to evaporation in a tropical environment and radiation impacts result from high irradiance and UV exposure at low tide.

4.1 SURFACE SEDIMENT SAMPLES

Grain size is the most fundamental property of sediment particles, effecting their entrapment, transport and deposition thus providing important information to the origin and transport history and conditions of sediment deposition (Folk and Ward 1957, Friedman 1997, Bui *et al* 1990, Blott and Pye 2001) to acquire high quality spatial data from the study area one-hundred and fifteen surface sediment samples were collected over an approximately 1 by 1 km grid system (fig 6) overlaying the lagoon system. Implementation of the grid system was accomplished using Google earth software along with Garmen etrex global positioning system (GPS) interface (longitude, latitude WGS 84). Textural analysis of samples of grain size parameters was obtained by using the method of dry sieving samples into gravel sand and mud fractions during the period of June to

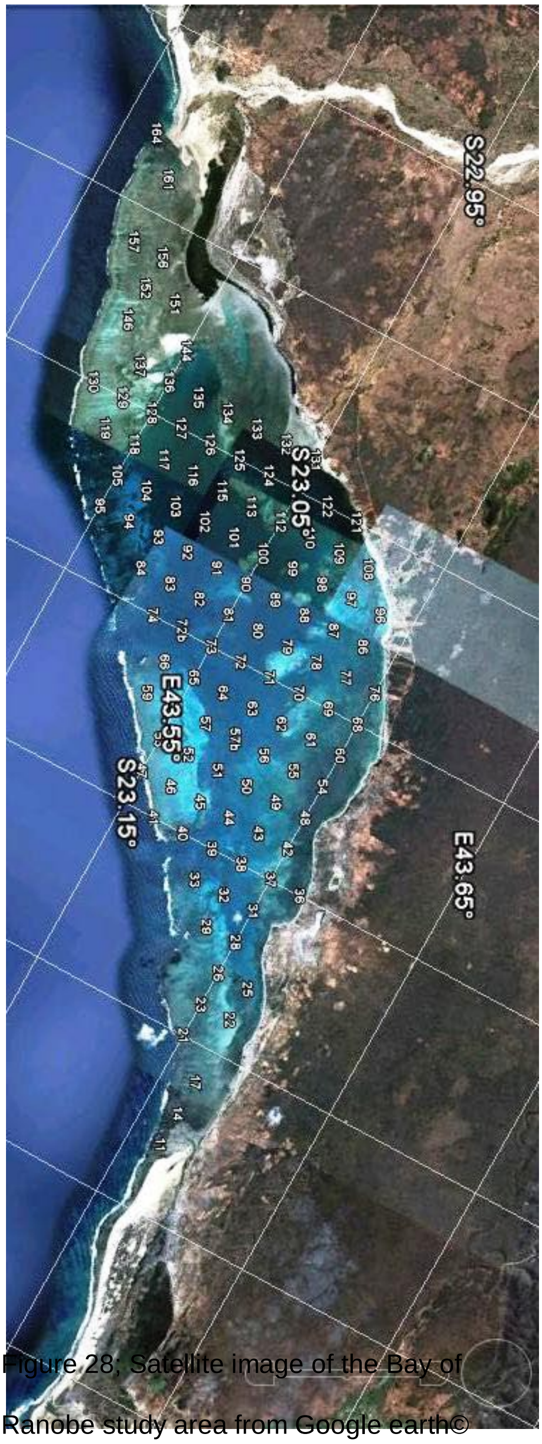

Figure 28; Satellite image of the Bay of Ranobe study area from Google earth© depicting overlying grid system used to determine sample stations throughout

September 2009. Sediment sieve size is interpreted as the diameter of the largest sphere that would pass through the retaining sieve (Roux and Rojas 2007) of which six sieves of different diameter were used in this study (2mm, 1mm, 500µm, 250 µm, 125 µm, 63 µm).

Table 7 Size scale adopted in the GRADISTAT program, compared with previously used size scales used by Udden (1994), Wentworth (1922) and Friedman and Sanders (1978)

Grain size		Descriptive terminology			
phi	mm/µm	Udden (1914) and Wentworth (1922)	Friedman and Sanders (1978)	GRADISTAT program	
			Very large boulders		
−11	2048 mm				
			Large boulders	Very large	
−10	1024				
			Medium boulders	Large	
−9	512	Cobbles			
			Small boulders	Medium	Boulders
−8	256				
			Large cobbles	Small	
−7	128				
			Small cobbles	Very small	
−6	64				
			Very coarse pebbles	Very coarse	
−5	32				
			Coarse pebbles	Coarse	
−4	16	Pebbles			
			Medium pebbles	Medium	Gravel
−3	8				
			Fine pebbles	Fine	
−2	4				
		Granules	Very fine pebbles	Very fine	
−1	2				
		Very coarse sand	Very coarse sand	Very coarse	
0	1				
		Coarse sand	Coarse sand	Coarse	
1	500 µm				
		Medium sand	Medium sand	Medium	Sand
2	250				
		Fine sand	Fine sand	Fine	
3	125				
		Very fine sand	Very fine sand	Very fine	
4	63				
			Very coarse silt	Very coarse	
5	31				
			Coarse silt	Coarse	
6	16	Silt			
			Medium silt	Medium	Silt
7	8				
			Fine silt	Fine	
8	4				
			Very fine silt	Very fine	
9	2	Clay			
			Clay	Clay	

Grain size distribution expressed in units phi (ϕ) was then plotted using an arithmetic scale to determine size class, on the ordinate to determine cumulative weight frequency to bring it to 100% with grain size parameters calculate through graphical and 'method of moments' (Krumbein and Pettijohn, 1938, Friedman and Johnson, 1982) . Moments is used to calculate statistics on a arithmetical scale; based on normal distribution with metric size values; geometrically, based on a log-normal distribution and logarithmically based on a log-normal distribution with phi values (Krumbein and Pettijohn, 1938) Grain size distribution is described by four principle groups described by Blott and Pye (2001) (a) the average size, (b) the spread (sorting) of the sizes around the average, (c) the symmetry or preferential spread (skewness) to one side of the average, and (d) the degree of concentration of the grains relative to the average (kurtosis).

Statistical parameters (mean grain size, sorting, skewness, kurtosis) were calculated using the graphical method of Folk (1968) with the Gradistat Earth Surface Processes and Landforms software (versions 9.0) developed by the Royal Holloway University of London (Blott and Pye 2001). Terminology used in this program in regards to descriptive statistical parameters uses a modified Udden-Wentworth grade scale with gravel redefined as a fraction containing five subclasses on a scale from very fine (2mm) to very coarse (64mm). Sorting, skewness and kurtosis uses the Folk and Ward (1957) methodology but are renamed to prevent confusion ranging from positive skewness termed 'fine skewed' (containing excess fines), and negative skewness termed 'coarse skewed' (table 1).

4.2 CARBONATE ANALYSIS

Relative contribution of noncarbonated (silicates, organic matter, antigenic minerals) and carbonate (skeletal) material were determined by acid digestion of bulk samples with sediment samples classified as mixed when the y contained more than 10% of terrigenous material (Mount 1985).

4.3 HIERARCHICAL CLUSTER ANALYSIS

As there is no prior knowledge of the distribution of the data set the use of cluster analysis and specifically the clustering of information from survey stations in this study can be a subjective and exploratory procedure. Cluster analysis, the generic name for a multivariate procedure of clumping similar objects into categories to enable the identification of the structure of the dataset (Wilkinson *et al* 1996) and outliers (Holden and LeDrew 1998). However, no satisfactory method has been developed for deciding the optimum number of clusters in a dataset (Jambu and Lebeaux 1983, Wilkinson *et al* 1996) thus the number of clusters is a subjective decision based on the knowledge of the dataset characteristics with Wilkinson et al 1996 stating that the main indicators of randomness in clustering is the length of branches, where the longest branches indicate random clustering. Cluster analysis is therefore used to determine which objects are similar and dissimilar and categorise them accordingly (Holden and LeDrew 1998). In this study stations were than subjected to correlation based on hierarchical cluster analysis (in R) producing families of clusters which themselves contain other clusters in order to determine if there is a distinction between carbonate, terrigenous deposits and grain size analysis at each of the sample stations.

4.4 GEOGRAPHIC INFORMATION SYSTEM (GIS)

Geographic Information System (GIS) spatial analysis software ArcView GIS 3.2 and ArcGIS 9.0 were used in order to better understand the relationship between sediment, geomorphology and biological communities in the Bay of Ranobe. These geoststistical interpolation techniques are based on statistical analysis for advanced prediction surface modelling. In this study models of sediment composition and bathymetry were obtained for the Bay of Ranobe using hierarchical cluster dendrograms and Ordanry Kriging. Kriging is a powerful statistical interpolation method used in many fields of science such as geology and assumes that the distance or direction between sample points reflects a spatial correlation that can be used to explain variations in the surface with contours or isolines used to define common characteristics. This study utilises ordinary Kriging, which assumes that there is no constant mean or trend for the data over an area (Oliver 1990) with a defined radius incorporating 4 points together with physical and biological variables to derive the spatial boundaries for mapping bathometry and to the biotope and sediment facies level of benthic habitats. Bathometry evaluation used data extrapolated from each survey station (table 4) and corrected using tidal information from Tide Master.com which was then plotted using ordinary Kriging.

4.5 BIOTOPE ASSESSMENT

Benthic community composition was assessed by the analysis of data from systematic ground surveys (Keith *et al* 2009), the objective being to critically evaluate the biotope assemblage of the reef-lagoon ecosystem (Lam *et al* 2006, Baker *et al* 2008) through the use of photographic quadrats at each of the one-hundred and fifteen stations during the period of June to September 2009. Photographic quadrats were assessed in the laboratory using Coral Point Count with excel extensions (CPCe), a Windows-based software program that provides a tool for the determination of biotope. Digital photographs were imported and cropped using Microsoft Office picture manager before analysis, this provided twelve photographic quadrats 1m^2 (a total 1,380 photographic quadrats) ready for evaluation. Edited photographs were then imported into CPCe for analysis

Table 8 Biotope categories used in conjunction with CPCe to classify benthos habitat at each survey station

OTHER LIVE (OL)	Other Live (OL)
	Gorgonians (G)
	Sponges (S)
	Zoanthids (Z)
MACROALGAE (MA)	Halimeda (HALI)
	Macroalgae (MACA)
	Sargassum (SARG)
	Seagrass (SG)
	Turbinaria (TURB)
	Turf (TURF)
CORAL (C)	Coral (general) (CORAL)
	Coral juvenile (CORJU)
	Soft coral (SC)
	Dead coral with algae (DCA)
	Old dead coral (ODC)
	Recently dead coral (RDC)
	Diseased corals (DC)
SAND, PAVEMENT, RUBBLE (SPR)	Pavement (P)
	Rubble (R)
	Sand (S)
	Silt (SI)
UNKNOWNS (U)	Unknowns (U)
	Tape, Wand, Shadow (TWS)

using random point count option. Through this program ninety-nine spatially random points (maximum level) were distributed on a transect image and the features underlying the points were user identified through biotope categorisation achieved through the adaptation of the CPCe visual basics programmed, specifically modified on site for the Bay of Ranobe, Southwest Madagascar (table 3).

In total this provided 1,188 data points per station and 136,620 data points overall for the entire lagoon system. Biotope categories were then divided into coverage statistics, calculated and the results sent to excel spreadsheets automatically (Kohler and Gill 2006, Dumas *et al* 2009) reference habitat profiles were than evaluated and calculated for each survey station from this limited set of points. Stations were than subjected to correlation based on hierarchical cluster analysis (in R) in order to assess relationships in community structure throughout the lagoon system and stations were then pooled into habitat biotopes.

4.6 PATCH CORAL REEF SYSTEMS

Additional field observations were made to identify scleractinian coral reef assemblages on patch reef systems in the north and south of the lagoon system to evaluate overall biological richness as well as ecosystem health. Assessment of scleractinian corals were quantified using the adapted rapid assessment method described in McClanahan *et al* (2001, 2004), in which observers move in a haphazardly chosen direction and distance and periodically or haphazardly select an area to survey during the summer and winter period spanning 2009.

All scleractinian coral within a two meter radius were identified to genus level with thirty replicates performed at each of the four patch coral reef stations. Estimation of absolute coral cover was also recorded for each of the haphazardly positioned circular assessment areas (CAA). The survey was replicated over the winter and summer periods to account for thermal stress that may inhibit scleractinian coral health and a mean number of individuals per genus was determined for each site

5. RESULTS

5.1 BATHYMETRY

Bathometry results extrapolated from survey stations data (table 4) highlight the differences in depth between the north and south of the lagoon system, with the average depth < 3 meters in the north (fig 8).

5.2 TEXTURAL ANALYSIS

Textural analysis of the one-hundred and fifteen surface sediment samples of the of the Bay of Ranobe Lagoon system are characterised by mixed carbonate-siliclastic deposits (table 3) Ordinary Kriging maps illustrate the areas of high gravel deposition (fig 10) with percentile range of 90-100 overlapping with the deepest areas of the lagoon system (fig 8) and areas of high sand and mud deposition (fig 11, 12) Carbonate content ranged from 60.63 to 99.73 by (wt %) (table 4) with a mean of 90.09 (wt%) (standard deviation ± 12.73 wt%). Of the one-hundred and fifteen samples twenty-six were classified as mixed (fig 8) the majority of which are concentrated in the near shore, northern section of the lagoon system, carbonate samples of (<70 wt%) were found at survey stations (60, 68, 96, 108, 115 see fig 9, 11).

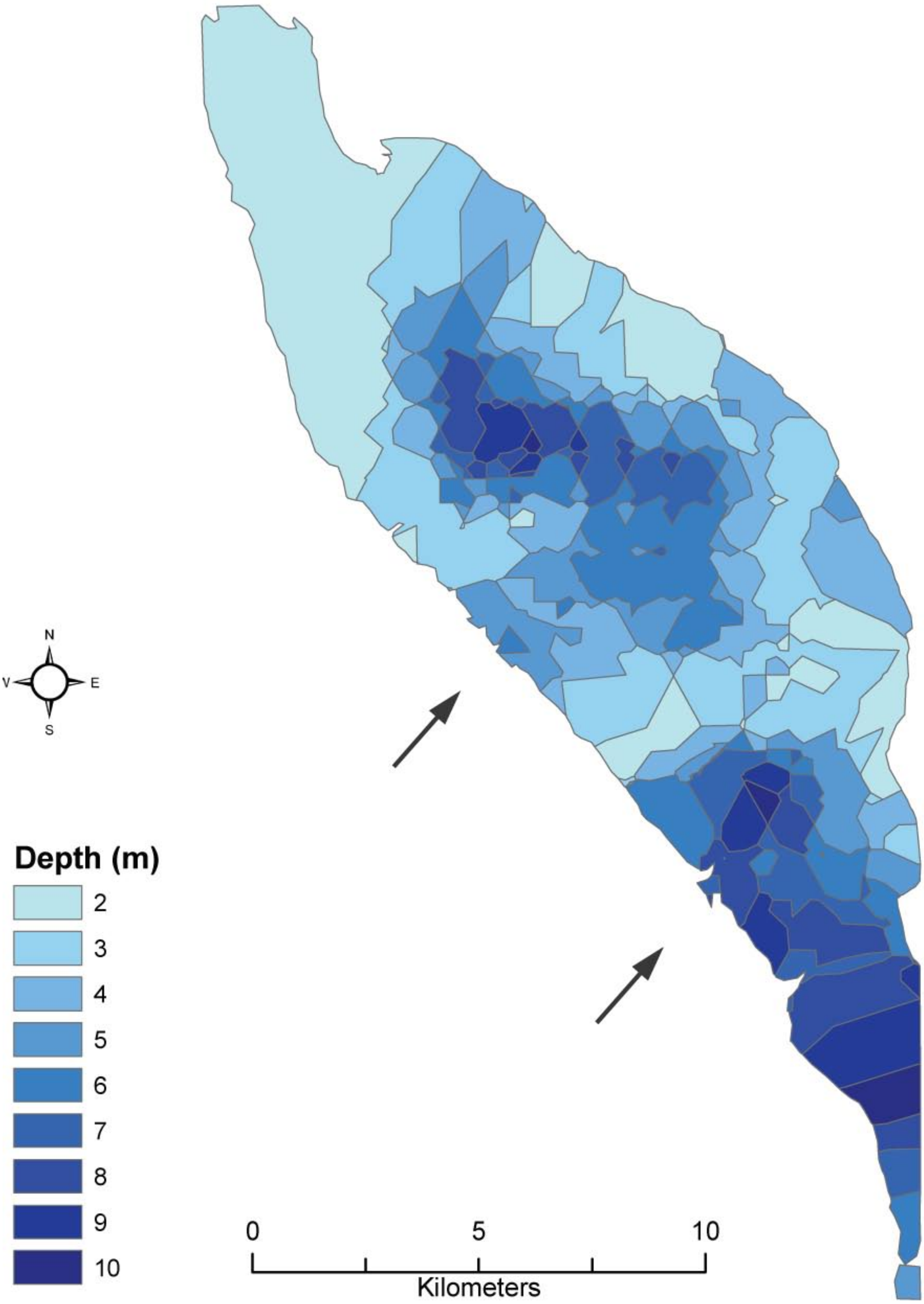

Figure 29; Bathometry extrapolated from data taken from each survey station, corrected using tidal information and plotted using ordinary Kriging to assess the depth of the lagoon system, Bay of Ranobe

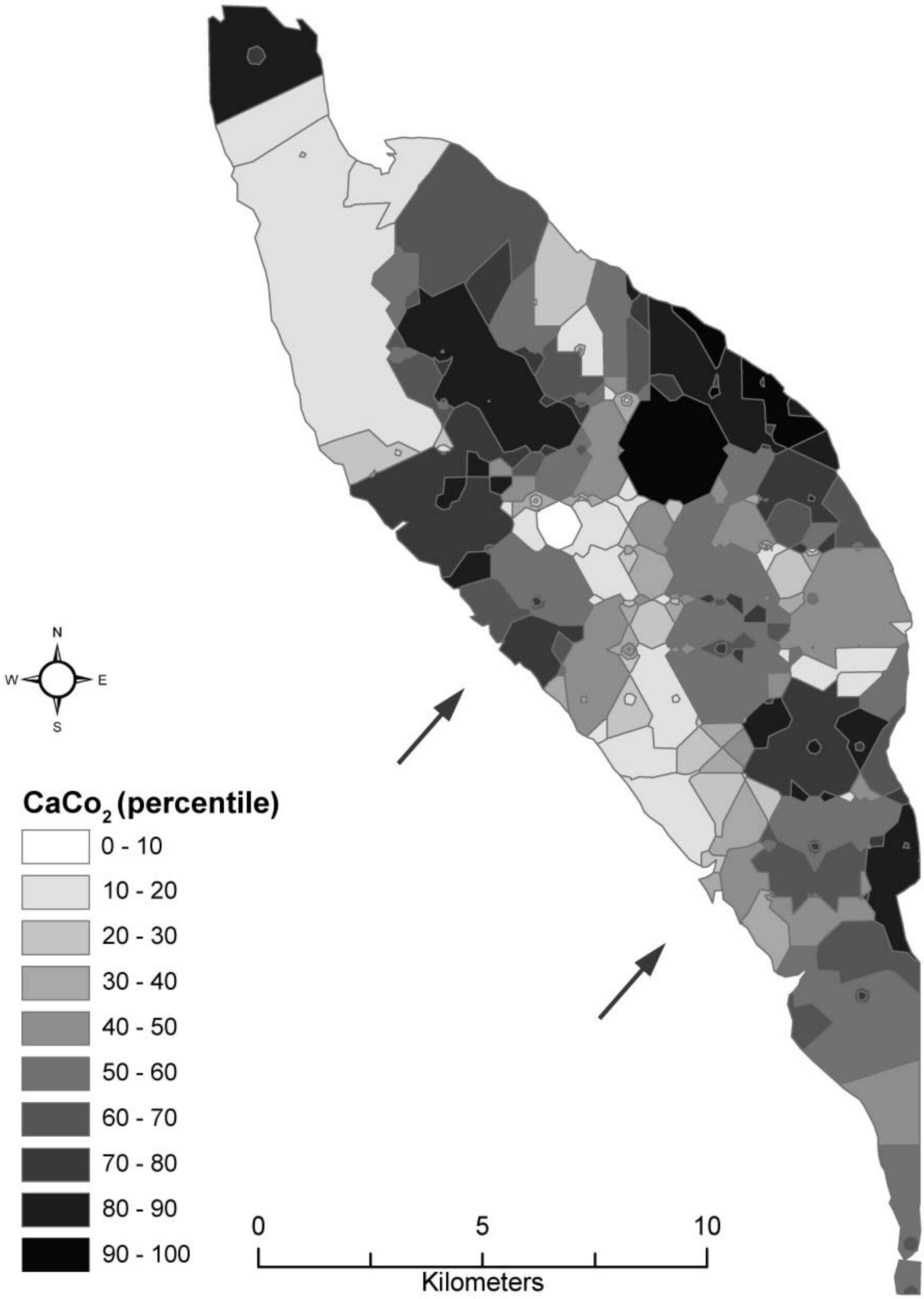

Figure 30 Carbonate percentiles illustrating the large deposits of terrigenous material in the north of the lagoon system with a concentration near the coastline across from the natural channel

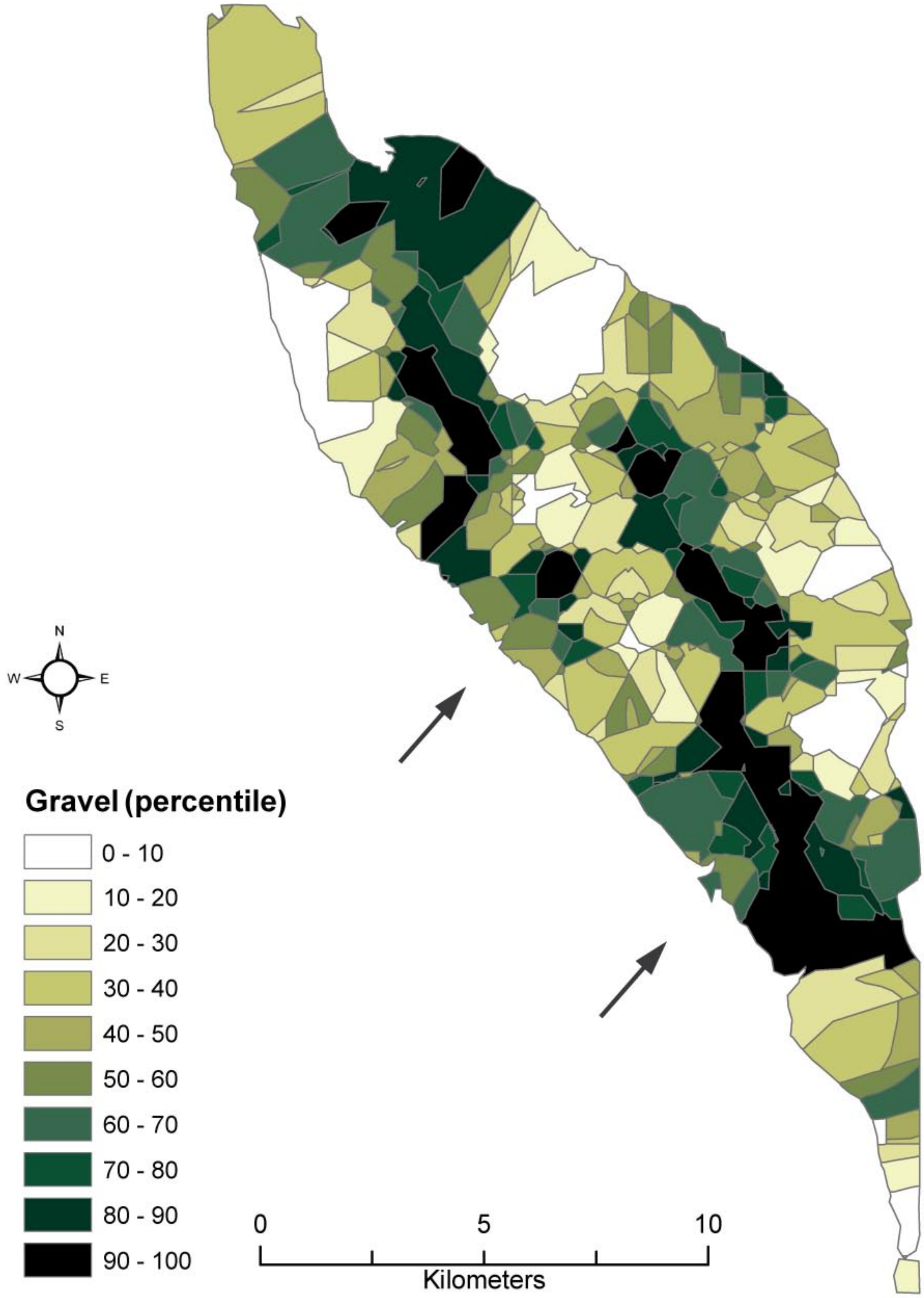

Figure 10; Gravel percentiles transformed and grouped using ordinary Kriging to evaluate and improve the understanding of the relationship between sediment sample stations and illustrating the high deposition of gravel in the deeper areas of the lagoon system

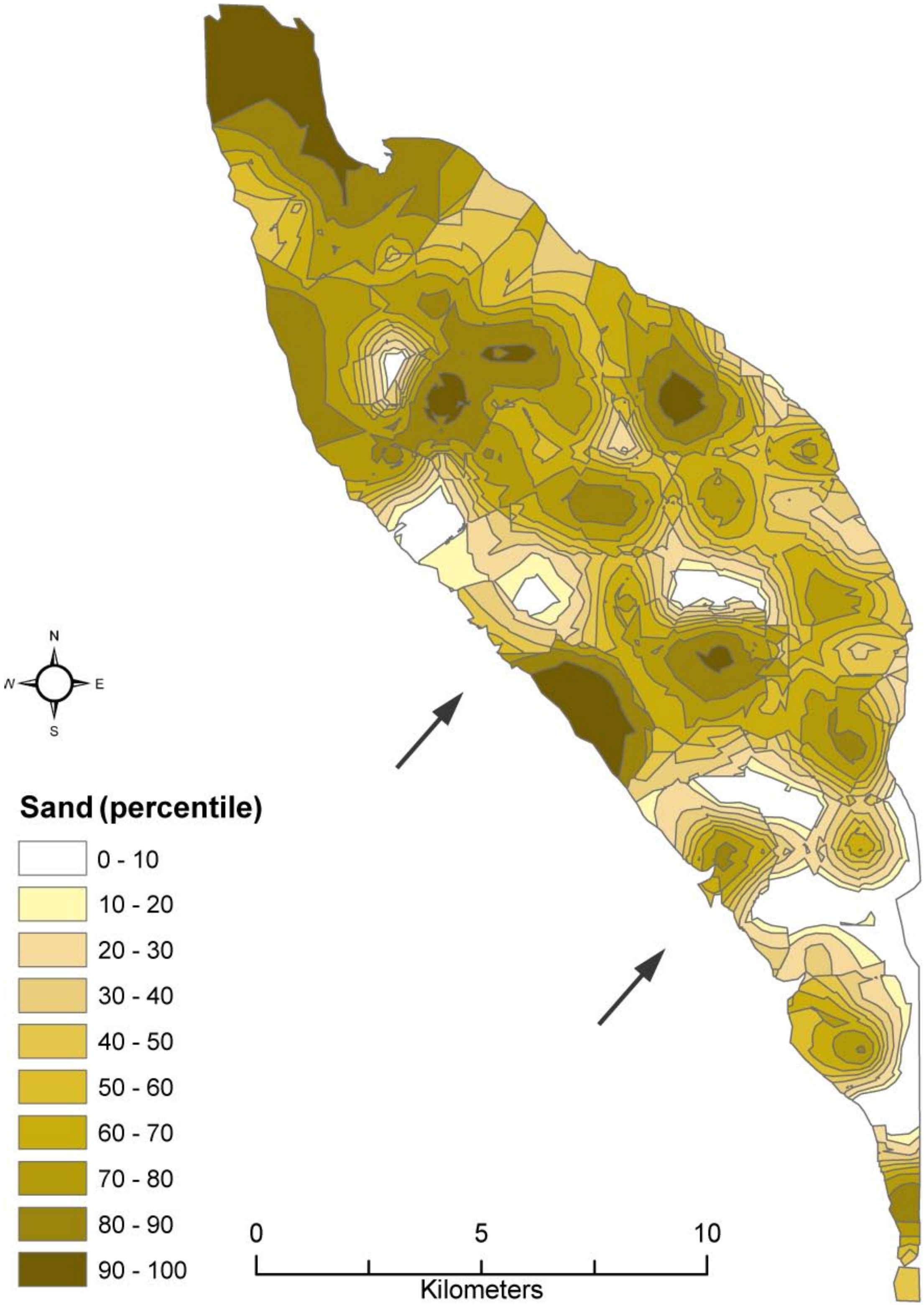

Figure 11; Sand percentiles transformed and grouped using ordinary Kriging illustrating the high deposition of sand on the reef back and near consolidated limestone areas (fig 16)

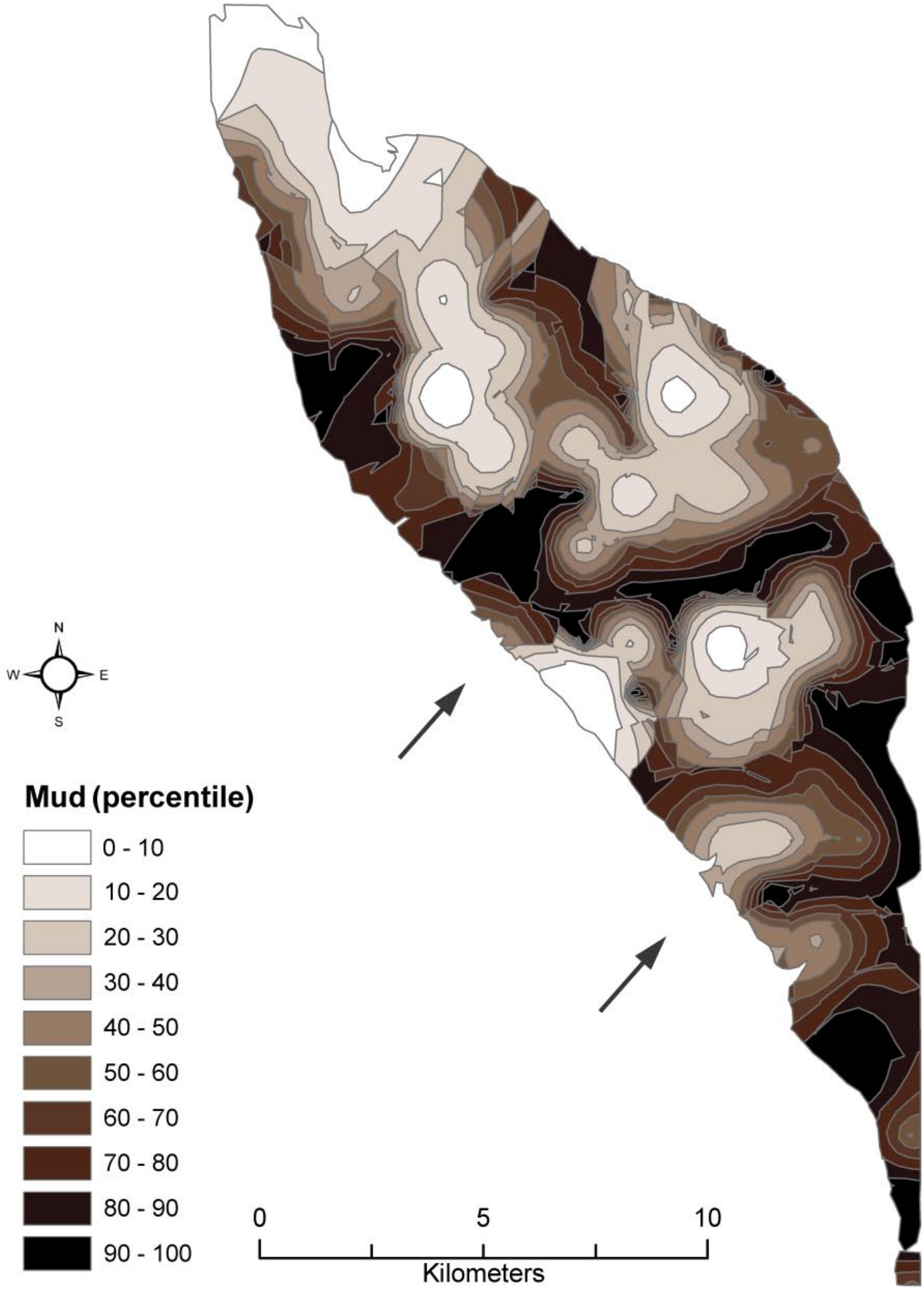

Figure12; Mud percentiles transformed and grouped using ordinary Kriging illustrating the high mud percentiles close to the coastline and within areas defined as seagrass meadows (fig 17, 19)

Figure 31 Sediment facies map of the Bay of Ranobe assembled using ERSI Arcview GIS 3.2 depicting facies 1 and 2 groupings taken from the hierarchical cluster analysis

Analysis of the textural group and mean grain size highlighted forty-six samples (40 %) of samples had a gravel content of more than 10 wt% (table 4) described as textural group ‘gravely sand’. Overall dominant modal and mean grain size was depicted as slightly gravely sand (44.3% of samples) with a sand content of over 90 wt%. Slightly gravely muddy sand and gravely muddy sand corresponds to 6.1 % and 9.6% of samples respectively. As a result, the majority of samples are therefore classified as having high gravel sand content. Paired t-test indicates a significant positive association of mean grain size, sorting coefficient and skewness correlated with carbonate content ($t = 99.9243$, $df = 114$, p-value =< 0.05, $t = 103.5296$, $df = 114$, p-value =< 0.05, $t = 104.6705$, $df = 114$, p-value = < 0.05 respectively) thus, carbonate, mean grain size, sorting coefficient and skewness are suggested to be associated with sediment composition. To facilitate in the interpretation of the sedimentation data (grain size fractions and carbonate content) a hierarchical cluster analysis was performed.

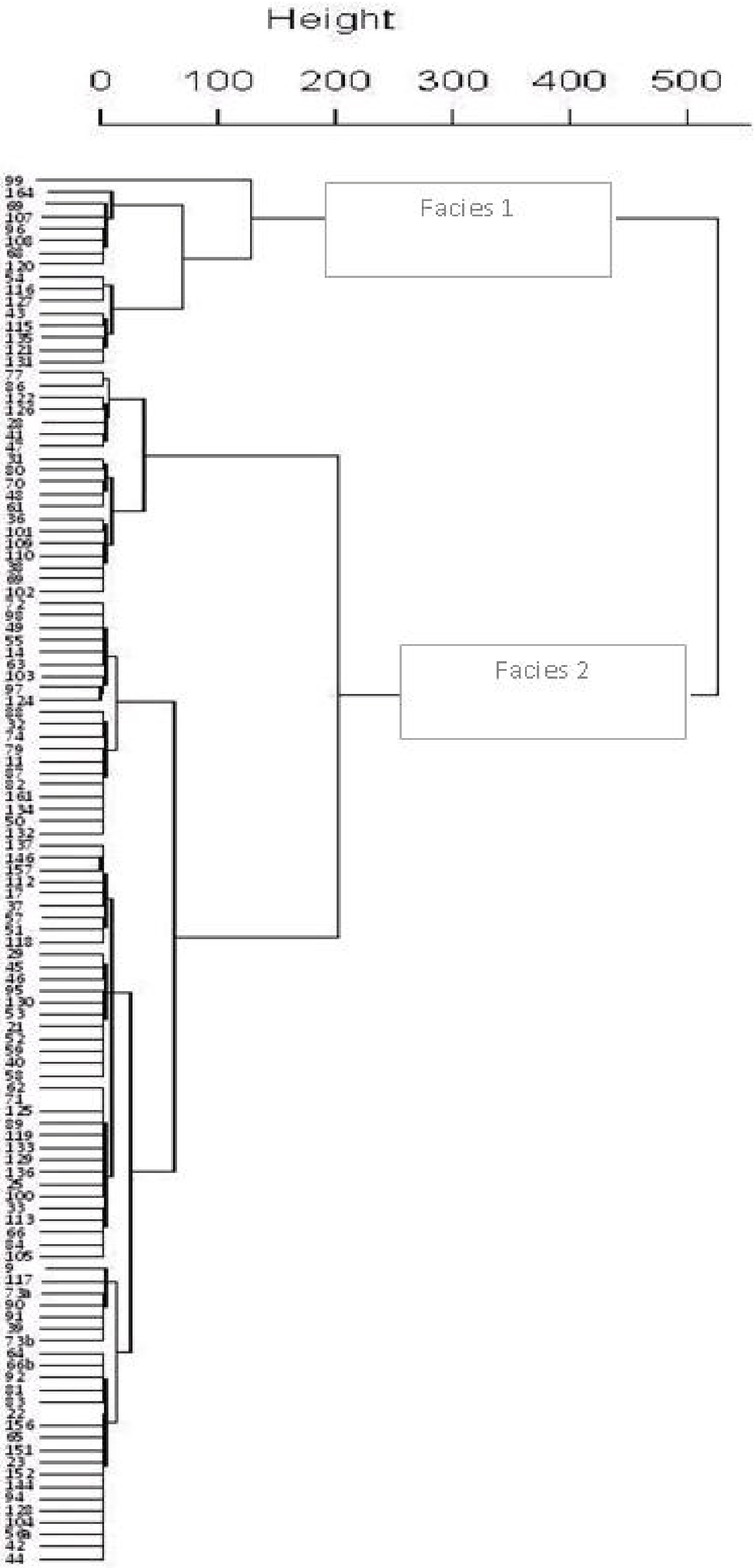

Figure 32 Hierarchal cluster dendogram of sediment samples based on grain size (several grain size classes) and carbonate content. Two sediment facies are identified (table 4)

Results are summarised in (table 4, fig13, 14) distance used for the tree diagram is a normalised Euclidean distance (root mean square discrepancy between objects and across attributes) and moving left to right signifies an increasing degree of difference, the Euclidean distance used to determine specific clusters on this hierarchical cluster analysis is represented at 100 to 200 in height denoting two distinct clusters present termed Facies one and two. Facies 1 (muddy sandy gravel mixed carbonate-siliclastic sediments) dominated by slightly gravelly, gravelly sand with a carbonate range of 60.6 - 88.8 wt% and a mean of 72.2 wt% carbonate content demonstrating a higher ratio of mixed carbonate siliclastic content than facies 2 (table 4). Facies 1 sediments are poorly sorted (93.75 wt%) indicating a weak and/or sporadic hydraulic sorting on sediment texture. Fine-grain sediments were present in a lesser extent (31.25 wt%) , which

Figure 33 Satellite image overlaid with stations in textual grouping with a gravel content of over 10 %wt

maybe either siliclastic or carbonate mud because of trapping and/or low energy environment suggested by the dominant very coarse, coarse skewed sediment distribution.

Facies 2 (medium sand, fine sandy carbonate dominant sediments) the larger of the two groups with carbonate range of 67.9 - 99.72 wt% and a mean of 94.9 wt% significantly higher than that of facies 1 and this may be sorted. Sediments are dominated by symmetrical to fine skewed distribution (table 4, fig 13) suggesting selective transport and sorting before deposition. Sediments with coarse skewed textual grouping with a gravel content of over 10 %wt in this facies grouping were found in areas where deeper waters meet consolidated limestone such as back reef and patch reef (fig 15).

5.3 CLASSIFICATION OF HABITAT BIOTOPE

Euclidean distance used to determine specific clusters on this hierarchical cluster analysis is represented at 250 to 500 in height denoting seven distinct habitat biotopes with ccontrasting differences in substrate cover and sediments were observed over the seven habitats (fig 20). Habitat 1: (fig 16) patch coral reef, dominated by scleractinian and rubble (50.2% 11.6% respectively) genera *Acroporadae* (acropora/montipora) was dominant throughout this grouping, although over 41 genera were identified (table 4).this is the only grouping with a significant hard coral substrate with all other stations within this research underrepresented in this habitat community. Habitat biotope 2: (fig 16) this grouping dominated the shallow back reef areas of the barrier reef system dominated by rubble beds covered with macro algae, large boulders and consolidated limestone classified as pavement (27.33%, 20.31%, 15.46% respectively). Habitat Biotope 3: (fig 17) displayed a 29% seagrass cover dominated by sandy sediments (63 %), this groupings had the highest diversity of seagrass with *Thalassodendron ciliatum, Thalassia hemprichii, Cymodasia rotundata, Cymodasia serrulata*, *Syringodium isoetifolium, Halodule univervis, Halodule wrightii, Holophila ovalis, Halophila stipulacea* all observed. Habitat 4: (fig 18) these grouping were situated in the deeper areas of the lagoon and characterized by soft silty substrate (96.36%) with dense cyano-bacterial mats located on the surface of sediments at a number of research stations. Habitat Biotope 5; (fig 18) this grouping exhibited extremely sparse and patchy seagrass cover (11.74%) and low biodiversity of seagrass *Thalassodendron ciliatum Thalassia hemprichii Halophila stipulacea* substrate sediments predominantly silt (72.59%). Habitat biotope 6: (fig 19) with38.86% seagrass cover of *Thalassia hemprichii, Syringodium isoetifolium, Holophila ovalis*, substrate sediments silt (58.86%) this grouping is adjacent to habitat seven and suggests a relationship between these two habitat groupings. Habitat biotope 7: (fig 19) this grouping concentrated in the north of the lagoon system displays the highest percent cover of seagrass throughout all sample stations at 50.05% with diversity lower than that of habitat grouping three with *Thalassodendron ciliatum, Thalassia hemprichii, Cymodasia rotundata, Cymodasia serrulata* and *Syringodium isoetifolium* observed. Sediment composition for this habitat had a greater percentage of sand than habitat five and six with a sand/silt composition of 23.6, 11.2 respectively.

Table 9 Sample station data and results of textural analysis of the Bay of Ranobe surface sediment samples

ample numbe	Longitude	Latitude	Depth	$CaCO_3$	GRAVEL	SAND	MUD	V FINE GRAVEL	COARSE SA	COARSE SAN	MEDIUM SAN	FINE SAND	V FINE SAN	V COARSE SI	COARSE SIL	TEXTURAL GROUP	MEAN	SORTING	SKEWNESS	KURTOSIS
9	S23.12000	E043.59000	3.2	96.79	13.9%	85.6%	0.5%	13.9%	61.9%	18.7%	0.3%	4.0%	0.7%	0.5%	0.0%	Gravelly Sand	0.015	0.874	0.484	3.984
11	S23.12000	E043.58000	1.2	95.51	0.1%	91.7%	8.2%	0.1%	1.0%	30.4%	16.5%	10.1%	33.7%	8.1%	0.1%	Slightly Gravelly Sand	2.397	1.363	-0.114	0.553
14	S23.12000	E043.57000	1.6	92.78	4.7%	84.4%	10.9%	4.7%	16.4%	25.3%	14.3%	16.6%	11.8%	10.8%	0.1%	Slightly Gravelly Muddy Sand	1.746	1.741	0.131	0.874
17	S23.12000	E043.56000	1.7	98.94	6.1%	88.8%	5.1%	6.1%	8.8%	17.6%	21.0%	28.1%	13.4%	5.0%	0.1%	Gravelly Sand	2.004	1.534	-0.046	1.000
21	S23.12000	E043.55000	1.4	98.6	11.6%	88.1%	0.3%	11.6%	23.0%	35.4%	20.8%	7.9%	0.8%	0.3%	0.0%	Gravelly Sand	0.717	1.166	0.008	0.907
22	S23.12000	E043.54000	1.8	97	5.6%	48.5%	45.9%	5.6%	9.3%	11.4%	13.2%	11.5%	3.1%	45.4%	0.5%	Gravelly Muddy Sand	2.720	1.930	-0.259	0.694
23	S23.11000	E043.60000	1.6	97.79	3.9%	93.6%	2.6%	3.9%	7.0%	10.2%	17.2%	44.9%	14.2%	2.5%	0.0%	Slightly Gravelly Sand	2.287	1.341	-0.377	1.363
25	S23.11000	E043.59000	1.8	97.62	1.8%	89.0%	9.2%	1.8%	29.4%	34.9%	15.9%	4.6%	4.1%	9.1%	0.1%	Slightly Gravelly Sand	1.072	1.479	0.410	1.068
28	S23.11000	E043.57000	6.5	85.37	0.7%	71.6%	27.8%	0.7%	2.1%	18.3%	12.9%	9.8%	28.5%	27.5%	0.3%	Slightly Gravelly Muddy Sand	2.959	1.540	-0.474	0.715
29	S23.11000	E043.56000	1.3	99.73	16.5%	82.9%	0.6%	16.5%	29.6%	25.0%	16.6%	10.0%	1.6%	0.6%	0.0%	Gravelly Sand	0.480	1.360	-0.003	0.877
31	S23.11000	E043.55000	4.3	90.88	0.2%	89.2%	10.6%	0.2%	2.6%	8.8%	15.7%	27.3%	34.8%	10.5%	0.1%	Slightly Gravelly Muddy Sand	2.819	1.162	-0.146	0.866
32	S23.11000	E043.54000	4.5	95.44	9.1%	90.5%	0.4%	9.1%	36.3%	42.6%	9.9%	1.5%	0.2%	0.4%	0.0%	Gravelly Sand	0.369	0.801	-0.276	1.125
33	S23.10000	E043.60000	2.3	96.72	14.6%	84.8%	0.5%	14.6%	14.0%	13.8%	35.0%	21.5%	0.5%	0.5%	0.0%	Gravelly Sand	1.265	1.407	-0.357	0.827
36	S23.10000	E043.59000	1.9	87.54	9.0%	84.6%	6.4%	9.0%	11.7%	21.2%	21.6%	18.8%	11.3%	6.3%	0.1%	Gravelly Sand	1.680	1.760	-0.035	1.012
37	S23.10000	E043.58000	2	98.49	2.3%	96.3%	1.4%	2.3%	9.4%	22.2%	30.2%	25.9%	8.6%	1.4%	0.0%	Slightly Gravelly Sand	1.746	1.196	-0.025	0.890
38	S23.10000	E043.57000	4.9	88.89	0.2%	99.5%	0.3%	0.2%	2.7%	20.0%	43.1%	33.3%	0.4%	0.3%	0.0%	Slightly Gravelly Sand	1.798	0.844	-0.041	0.891
39	S23.10000	E043.56000	8.9	97.18	2.7%	97.1%	0.2%	2.7%	6.0%	14.0%	58.2%	18.8%	0.1%	0.2%	0.0%	Slightly Gravelly Sand	1.684	0.931	-0.181	2.989
40	S23.10000	E043.55000	3.7	98.37	16.8%	82.6%	0.6%	16.8%	32.9%	33.8%	10.6%	4.3%	0.9%	0.6%	0.0%	Gravelly Sand	0.330	1.228	-0.069	1.299
41	S23.14000	E043.61000	0.8	84.75	1.3%	98.6%	0.1%	1.3%	3.2%	27.0%	61.0%	6.0%	1.4%	0.1%	0.0%	Slightly Gravelly Sand	1.429	0.638	-0.290	0.921
42	S23.10000	E043.54000	3.1	97.71	4.0%	94.6%	1.4%	4.0%	10.9%	20.5%	22.8%	27.5%	12.9%	1.4%	0.0%	Slightly Gravelly Sand	1.770	1.261	-0.057	0.856
43	S23.10000	E043.53000	4.4	78.26	3.0%	95.9%	1.2%	3.0%	7.4%	30.7%	22.2%	30.2%	5.4%	1.1%	0.0%	Slightly Gravelly Sand	1.707	1.165	-0.009	0.838
44	S23.09000	E043.60000	8.1	97.46	2.5%	95.4%	2.1%	2.5%	6.2%	21.0%	28.1%	33.2%	6.9%	2.1%	0.0%	Slightly Gravelly Sand	1.806	1.171	-0.065	0.896
45	S23.09000	E043.59000	2.6	99.59	15.9%	87.3%	0.0%	15.9%	15.8%	25.8%	33.7%	11.4%	0.5%	-3.2%	0.0%	Gravelly Sand	0.754	1.197	-0.112	0.831
46	S23.09000	E043.58000	2.4	99.62	10.7%	89.1%	0.2%	10.7%	14.8%	44.2%	26.2%	3.8%	0.1%	0.2%	0.0%	Gravelly Sand	0.745	1.012	-0.149	0.824
47	S23.13000	E043.61000	0.8	84.28	2.2%	97.6%	0.2%	2.2%	3.7%	19.8%	63.0%	10.0%	1.1%	0.2%	0.0%	Slightly Gravelly Sand	1.468	0.746	-0.393	1.322
48	S23.09000	E043.57000	3.4	90.82	6.4%	91.4%	2.2%	6.4%	11.9%	20.5%	25.9%	28.0%	5.1%	2.2%	0.0%	Gravelly Sand	1.487	1.462	-0.202	0.983
49	S23.09000	E043.56000	4	92.98	3.3%	93.3%	3.4%	3.3%	8.0%	19.5%	27.8%	31.9%	6.2%	3.4%	0.0%	Slightly Gravelly Sand	1.786	1.212	-0.064	0.917
50	S23.09000	E043.55000	6	94.6	6.8%	90.4%	2.7%	6.8%	8.0%	16.0%	25.4%	33.4%	7.7%	2.7%	0.0%	Gravelly Sand	1.773	1.348	-0.170	1.041
51	S23.09000	E043.54000	8.7	99.58	1.9%	90.8%	7.3%	1.9%	9.6%	17.8%	17.3%	19.4%	26.7%	7.2%	0.1%	Slightly Gravelly Sand	2.336	1.504	-0.230	0.687
52	S23.09000	E043.53000	3.4	98.44	4.4%	95.0%	0.6%	4.4%	20.2%	35.9%	29.9%	8.9%	0.2%	0.6%	0.0%	Slightly Gravelly Sand	0.846	1.012	0.084	1.064
53	S23.09000	E043.52000	1.7	98.35	7.3%	92.4%	0.3%	7.3%	24.3%	42.7%	21.6%	3.7%	0.2%	0.3%	0.0%	Gravelly Sand	0.707	0.984	-0.099	0.782
54	S23.08000	E043.59000	1.4	73.58	2.7%	94.8%	2.5%	2.7%	4.9%	16.6%	28.5%	38.8%	6.1%	2.4%	0.0%	Slightly Gravelly Sand	1.867	1.149	-0.109	1.304
55	S23.08000	E043.58000	1.9	92.59	3.7%	91.2%	5.1%	3.7%	6.8%	19.1%	27.3%	29.9%	8.1%	5.0%	0.1%	Slightly Gravelly Sand	1.822	1.246	-0.047	0.944
56a	S23.08000	E043.57000	8	97.45	9.5%	81.9%	8.6%	9.5%	18.6%	20.9%	15.6%	12.9%	13.8%	8.5%	0.1%	Gravelly Sand	1.641	1.865	0.056	0.778
56b	S23.08000	E043.56000	7.7	96.38	0.9%	93.1%	6.0%	0.9%	12.3%	22.5%	21.0%	20.3%	17.0%	5.9%	0.1%	Slightly Gravelly Sand	2.027	1.462	0.109	0.841
57	S23.08000	E043.55000	4.4	98.34	5.4%	78.5%	16.1%	5.4%	5.5%	5.2%	5.7%	17.6%	44.4%	15.9%	0.2%	Gravelly Muddy Sand	2.863	1.624	-0.672	1.780
58	S23.08000	E043.54000	1.5	98.58	18.6%	81.0%	0.4%	18.6%	29.5%	25.7%	19.8%	5.1%	0.8%	0.4%	0.0%	Gravelly Sand	0.405	1.305	-0.043	0.853
59	S23.08000	E043.53000	1	98.29	13.0%	86.6%	0.4%	13.0%	30.0%	48.4%	7.8%	0.3%	0.1%	0.4%	0.0%	Gravelly Sand	0.350	0.798	-0.355	1.107
60	S23.08000	E043.51000	2	67.9	0.7%	97.0%	2.3%	0.7%	5.3%	29.4%	26.1%	30.6%	5.7%	2.3%	0.0%	Slightly Gravelly Sand	1.770	1.130	0.007	0.833
61	S23.08000	E043.50000	2.3	90.18	1.8%	95.8%	2.4%	1.8%	6.3%	21.1%	30.5%	34.5%	3.4%	2.4%	0.0%	Slightly Gravelly Sand	1.789	1.122	-0.077	0.870
62	S23.07000	E043.59000	4.2	98.68	13.2%	83.0%	3.8%	13.2%	22.7%	25.4%	18.3%	11.8%	4.9%	3.8%	0.0%	Gravelly Sand	1.008	1.557	0.211	1.005
63	S23.11312	E043.52065	7.7	93.13	7.7%	86.3%	6.0%	7.7%	18.2%	18.3%	16.1%	18.8%	15.0%	5.9%	0.1%	Gravelly Sand	1.687	1.786	-0.030	0.751
64	S23.16298	E043.56700	9.8	96.46	5.4%	88.1%	6.5%	5.4%	16.6%	17.1%	15.2%	14.9%	24.3%	6.4%	0.1%	Gravelly Sand	1.823	1.789	-0.061	0.717
65	S23.15208	E043.55772	6.7	97.2	0.6%	97.0%	2.5%	0.6%	4.7%	15.7%	21.1%	27.9%	27.6%	2.4%	0.0%	Slightly Gravelly Sand	2.400	1.325	-0.284	0.823
66	S23.05654	E043.58033	8	97.43	5.0%	94.8%	0.2%	5.0%	28.4%	56.4%	5.4%	3.5%	1.1%	0.2%	0.0%	Gravelly Sand	0.431	0.763	-0.307	1.209
68	S23.15304	E043.61277	1.6	66.23	2.8%	96.6%	0.6%	2.8%	4.3%	32.3%	33.3%	24.0%	2.6%	0.6%	0.0%	Slightly Gravelly Sand	1.669	1.006	-0.081	0.750
69	S23.24000	E043.61000	3.1	88.88	5.5%	91.3%	3.2%	5.5%	7.2%	21.2%	25.7%	30.2%	7.0%	3.1%	0.0%	Gravelly Sand	1.760	1.324	-0.115	1.027
70	S23.23000	E043.61000	6.1	90.01	9.3%	92.3%	0.0%	9.3%	18.1%	27.2%	15.4%	16.6%	14.9%	-1.6%	0.0%	Gravelly Sand	1.174	1.561	0.192	0.758
71	S23.22000	E043.61000	1.9	98.26	24.7%	74.6%	0.7%	24.7%	15.0%	18.1%	24.1%	16.5%	0.8%	0.7%	0.0%	Gravelly Sand	0.717	1.576	-0.033	0.752
72	S23.21000	E043.61000	9.3	92.63	0.5%	95.9%	3.6%	0.5%	5.7%	11.8%	17.1%	36.4%	24.9%	3.6%	0.0%	Slightly Gravelly Sand	2.445	1.320	-0.316	0.902
73a	S23.20000	E043.60000	10.2	95.19	0.4%	99.3%	0.3%	0.4%	3.7%	18.6%	63.9%	13.0%	0.2%	0.3%	0.0%	Slightly Gravelly Sand	1.503	0.638	-0.287	2.379
73b	S23.19000	E043.61000	9.7	96.54	0.3%	98.2%	1.5%	0.3%	1.6%	13.1%	60.4%	22.9%	0.2%	1.4%	0.0%	Slightly Gravelly Sand	1.987	0.643	0.248	2.261
74	S23.19000	E043.60000	9.8	95.91	21.5%	78.1%	0.4%	21.5%	34.6%	25.9%	16.4%	1.1%	0.1%	0.4%	0.0%	Gravelly Sand	0.115	1.165	0.219	1.031
77	S23.18000	E043.60000	3.7	82.28	4.5%	94.0%	1.5%	4.5%	9.7%	28.4%	31.0%	22.5%	2.3%	1.5%	0.0%	Slightly Gravelly Sand	1.620	1.068	-0.102	0.773
79	S23.17000	E043.59000	7.3	95.51	4.6%	90.2%	5.3%	4.6%	11.5%	9.7%	8.6%	16.5%	43.8%	5.2%	0.1%	Slightly Gravelly Sand	2.276	1.651	-0.530	0.661
80	S23.16000	E043.60000	9	91.59	1.1%	97.6%	1.3%	1.1%	3.0%	6.2%	17.2%	55.9%	15.3%	1.3%	0.0%	Slightly Gravelly Sand	2.614	0.957	-0.201	1.358

81	S23.16000	E043.59000	8.3	96.92	1.2%	97.7%	1.0%	1.2%	1.7%	14.5%	32.1%	40.1%	9.3%	1.0%	0.0%	ntly Gravelly S	2.117	0.980	-0.372	1.099
82	S23.16000	E043.58000	6.9	94.89	0.3%	99.6%	0.2%	0.3%	3.2%	15.9%	47.3%	32.9%	0.3%	0.2%	0.0%	ntly Gravelly S	1.821	0.826	-0.037	0.929
83	S23.15000	E043.61000	8	96.38	4.1%	95.3%	0.6%	4.1%	1.7%	3.1%	43.0%	45.5%	1.9%	0.5%	0.0%	ntly Gravelly S	2.132	0.804	-0.006	1.247
84	S23.15000	E043.60000	1.2	96.99	12.3%	84.1%	3.6%	12.3%	33.1%	33.1%	8.7%	7.6%	1.6%	3.6%	0.0%	Gravelly Sanc	0.648	1.292	0.173	1.590
86	S23.15000	E043.59000	3	81.55	1.7%	94.6%	3.7%	1.7%	5.5%	21.8%	32.4%	28.4%	6.4%	3.7%	0.0%	ntly Gravelly S	1.804	1.167	-0.006	0.920
87	S23.15000	E043.58000	7.8	95.4	2.9%	87.9%	9.1%	2.9%	10.1%	19.4%	19.8%	22.1%	16.5%	9.0%	0.1%	ntly Gravelly S	2.095	1.536	0.092	0.739
88	S23.15000	E043.57000	4.4	95.57	13.8%	78.7%	7.5%	13.8%	20.8%	26.1%	16.1%	9.7%	6.0%	7.4%	0.1%	Gravelly Sanc	1.073	1.679	0.255	1.068
89	S23.14000	E043.60000	4.5	97.8	7.3%	91.0%	1.7%	7.3%	21.5%	36.7%	25.5%	6.1%	1.2%	1.7%	0.0%	Gravelly Sanc	0.786	1.139	0.012	0.921
90	S23.14000	E043.59000	9.5	96.71	0.1%	96.7%	3.2%	0.1%	2.5%	6.2%	11.2%	63.2%	13.6%	3.1%	0.0%	ntly Gravelly S	2.682	0.911	-0.167	3.181
91	S23.14000	E043.58000	10.1	96.42	0.1%	97.9%	1.9%	0.1%	1.7%	6.9%	10.8%	58.6%	19.9%	1.9%	0.0%	ntly Gravelly S	2.736	0.930	-0.144	2.909
92	S23.14000	E043.57000	11.1	96.26	0.6%	96.7%	2.6%	0.6%	5.1%	23.0%	24.7%	31.5%	12.5%	2.6%	0.0%	ntly Gravelly S	1.879	1.166	-0.039	0.847
94	S23.14000	E043.56000	1.5	97.66	5.8%	92.3%	1.9%	5.8%	9.2%	12.3%	17.3%	44.9%	8.5%	1.9%	0.0%	Gravelly Sanc	2.003	1.338	-0.574	1.037
95	S23.13000	E043.60000	1.5	99.21	20.4%	78.8%	0.8%	20.4%	38.2%	23.5%	13.6%	3.3%	0.1%	0.8%	0.0%	Gravelly Sanc	0.117	1.174	0.251	1.074
96	S23.13000	E043.59000	2.5	64.73	11.2%	87.3%	1.5%	11.2%	7.6%	34.8%	23.1%	18.5%	3.4%	1.5%	0.0%	Gravelly Sanc	1.150	1.361	0.086	1.267
97	S23.07000	E043.58000	1.4	93.75	7.6%	89.6%	2.8%	7.6%	12.3%	24.5%	26.6%	20.7%	5.5%	2.8%	0.0%	Gravelly Sanc	1.418	1.490	-0.152	1.027
98	S23.07000	E043.57000	4.8	92.11	3.8%	90.8%	5.3%	3.8%	8.9%	12.9%	19.6%	37.3%	12.0%	5.3%	0.1%	ntly Gravelly S	2.230	1.407	-0.320	0.958
99	S23.07000	E043.56000	7.2		5.8%	86.6%	7.6%	5.8%	12.9%	14.7%	14.8%	22.8%	21.4%	7.5%	0.1%	Gravelly Sanc	2.068	1.792	-0.335	0.775
100	S23.07000	E043.55000	8.5	98.09	1.2%	96.3%	2.5%	1.2%	16.7%	39.2%	23.2%	10.9%	6.2%	2.5%	0.0%	ntly Gravelly S	1.166	1.306	0.335	1.313
101	S23.07000	E043.54000	10.7	87.22	2.0%	89.3%	8.7%	2.0%	6.0%	9.3%	18.2%	30.1%	25.7%	8.6%	0.1%	ntly Gravelly S	2.501	1.436	-0.252	0.980
102	S23.07000	E043.53000	9.4	88.69	5.4%	90.8%	3.8%	5.4%	12.1%	13.2%	21.2%	31.6%	12.7%	3.7%	0.0%	Gravelly Sanc	1.794	1.643	-0.168	0.982
103	S23.07000	E043.52000	11.1	93.8	3.2%	79.9%	16.9%	3.2%	8.0%	8.8%	9.8%	13.2%	40.1%	16.7%	0.2%	Gravelly Muc	2.795	1.593	-0.626	0.977
104	S23.07000	E043.51000	5.6	97.99	0.1%	95.5%	4.5%	0.1%	1.0%	13.8%	44.8%	14.4%	21.5%	4.4%	0.1%	ntly Gravelly S	2.370	1.057	0.451	0.725
105	S23.07000	E043.50000	1	97.53	22.0%	76.4%	1.6%	22.0%	40.4%	21.3%	7.4%	7.3%	0.1%	1.5%	0.0%	Gravelly Sanc	0.078	1.289	0.332	1.362
107	S23.06000	E043.59000	1.7	63.07	1.8%	96.1%	2.1%	1.8%	2.1%	31.6%	37.6%	20.1%	4.8%	2.1%	0.0%	ntly Gravelly S	1.713	0.997	0.144	0.766
108	S23.06000	E043.58000	1.9	64.54	5.0%	91.4%	3.6%	5.0%	5.6%	25.6%	27.8%	24.3%	7.9%	3.6%	0.0%	ntly Gravelly S	1.749	1.240	-0.004	0.931
109	S23.06000	E043.57000	2.9	89.59	8.4%	79.5%	12.2%	8.4%	11.4%	13.6%	12.9%	22.2%	19.3%	12.0%	0.1%	velly Muddy S	2.097	1.890	-0.321	0.802
110	S23.06000	E043.56000	1.6	89.12	7.9%	68.4%	23.7%	7.9%	6.7%	12.8%	16.4%	17.4%	15.2%	23.4%	0.3%	velly Muddy S	2.515	1.849	-0.202	0.805
112	S23.06000	E043.55000	1.6	99.16	4.4%	94.3%	1.3%	4.4%	14.5%	26.3%	30.8%	19.7%	3.1%	1.3%	0.0%	ntly Gravelly S	1.389	1.219	-0.191	1.030
113	S23.06000	E043.54000	4.4	97.09	14.4%	82.3%	3.2%	14.4%	17.2%	24.4%	23.1%	13.9%	3.8%	3.2%	0.0%	Gravelly Sanc	1.031	1.543	0.143	0.990
115	S23.06000	E043.53000	7.1	79.06	8.3%	88.5%	3.1%	8.3%	14.4%	15.0%	25.0%	30.6%	3.5%	3.1%	0.0%	Gravelly Sanc	1.451	1.511	-0.240	0.952
116	S23.06000	E043.52000	7.5	74.26	2.6%	91.2%	6.3%	2.6%	7.6%	11.0%	21.8%	39.3%	11.5%	6.2%	0.1%	ntly Gravelly S	2.293	1.385	-0.287	1.408
117	S23.06000	E043.51000	6.8	96.6	0.3%	63.0%	36.7%	0.3%	0.9%	1.3%	2.6%	6.7%	51.5%	36.2%	0.4%	Gravelly Muc	3.981	0.704	0.025	1.663
118	S23.06000	E043.50000	1.7	99.52	0.2%	97.4%	2.4%	0.2%	0.5%	7.0%	19.1%	56.7%	14.1%	2.3%	0.0%	ntly Gravelly S	2.631	0.912	-0.160	1.308
119	S23.06000	E043.49000	1.6	97.81	13.8%	85.0%	1.2%	13.8%	23.8%	29.4%	18.9%	12.1%	0.8%	1.2%	0.0%	Gravelly Sanc	0.739	1.231	0.037	0.872
120	S23.05000	E043.58000	2.1	65.49	2.3%	94.1%	3.6%	2.3%	2.5%	20.2%	27.9%	33.0%	10.5%	3.6%	0.0%	ntly Gravelly S	1.898	1.067	0.042	1.054
121	S23.05000	E043.57000	1.3	76.75	4.3%	93.7%	2.0%	4.3%	3.7%	21.4%	32.8%	28.2%	7.6%	2.0%	0.0%	ntly Gravelly S	1.793	1.182	-0.040	0.942
122	S23.05000	E043.56000	1.3	83.53	7.1%	82.7%	10.2%	7.1%	4.4%	10.4%	20.4%	26.3%	21.2%	10.1%	0.1%	velly Muddy S	2.398	1.641	-0.277	1.126
124	S23.05000	E043.54000	1.8	93.75	7.0%	91.3%	1.6%	7.0%	14.4%	21.3%	27.9%	22.8%	5.0%	1.6%	0.0%	Gravelly Sanc	1.409	1.467	-0.188	0.982
125	S23.05000	E043.53000	2.6	98.03	20.4%	75.3%	4.3%	20.4%	16.9%	18.9%	16.0%	14.9%	8.6%	4.3%	0.0%	Gravelly Sanc	0.873	1.804	0.101	0.745
126	S23.05000	E043.52000	6.2	83.58	11.9%	74.8%	13.3%	11.9%	12.2%	12.8%	23.1%	16.7%	10.0%	13.2%	0.2%	velly Muddy S	1.771	1.941	-0.021	1.002
127	S23.05000	E043.51000	8.4	74.37	1.8%	88.3%	9.9%	1.8%	2.6%	8.1%	17.9%	36.4%	23.3%	9.8%	0.1%	Gravelly Muc	2.736	1.167	-0.075	0.900
128	S23.05000	E043.50000	1	97.79	0.0%	98.7%	1.3%	0.0%	5.3%	24.7%	19.9%	39.5%	9.3%	1.3%	0.0%	ntly Gravelly S	2.039	1.131	-0.453	0.817
129	S23.05000	E043.49000	1.6	97.81	12.9%	86.7%	0.4%	12.9%	22.6%	25.3%	17.1%	20.5%	1.1%	0.4%	0.0%	Gravelly Sanc	0.997	1.400	0.111	0.806
130	S23.05000	E043.47000	1.4	98.7	23.1%	76.2%	0.6%	23.1%	37.7%	26.7%	9.1%	2.6%	0.2%	0.6%	0.0%	Gravelly Sanc	-0.119	1.020	0.138	1.102
131	S23.05000	E043.57000	1.3	76.9	4.9%	91.9%	3.2%	4.9%	7.7%	21.6%	24.9%	27.7%	10.0%	3.2%	0.0%	ntly Gravelly S	1.780	1.257	-0.048	0.901
132	S23.05000	E043.56000	1.3	94.52	12.5%	83.6%	3.9%	12.5%	17.3%	18.1%	22.4%	19.8%	6.1%	3.8%	0.0%	Gravelly Sanc	1.331	1.593	-0.145	0.778
133	S23.04000	E043.53000	2.5	98.01	8.3%	89.6%	2.0%	8.3%	18.2%	22.6%	22.2%	20.6%	6.0%	2.0%	0.0%	Gravelly Sanc	1.344	1.517	-0.132	0.775
134	S23.04000	E043.52000	0.8	95.06	4.8%	93.2%	2.0%	4.8%	14.3%	22.9%	27.7%	22.9%	5.4%	1.9%	0.0%	ntly Gravelly S	1.444	1.361	-0.107	0.869
135	S23.04000	E043.51000	7.5	75.96	1.7%	79.7%	18.5%	1.7%	3.9%	8.8%	15.4%	37.4%	14.1%	18.3%	0.2%	Gravelly Muc	2.813	1.379	-0.056	1.030
136	S23.04000	E043.50000	1.2	97.9	10.6%	85.8%	3.5%	10.6%	19.7%	22.8%	19.4%	16.3%	7.7%	3.5%	0.0%	Gravelly Sanc	1.141	1.580	0.174	0.786
137	S23.04000	E043.49000	1.2	98.57	9.3%	84.4%	6.3%	9.3%	10.7%	17.3%	24.7%	23.6%	8.2%	6.2%	0.1%	Gravelly Sanc	1.513	1.609	-0.164	1.048
144	S23.03000	E043.50000	1.5	97.78	1.2%	92.9%	6.0%	1.2%	8.9%	15.5%	18.6%	36.6%	13.2%	5.9%	0.1%	ntly Gravelly S	2.280	1.401	-0.281	0.940
146	S23.03000	E043.48000	0.7	98.63	7.6%	88.5%	3.9%	7.6%	13.2%	22.3%	21.1%	25.7%	6.2%	3.9%	0.0%	Gravelly Sanc	1.456	1.532	-0.158	0.987
151	S23.02000	E043.49000	0.9	97.17	3.2%	76.0%	20.8%	3.2%	6.7%	12.3%	18.3%	25.7%	12.9%	20.6%	0.2%	Gravelly Muc	2.549	1.648	-0.141	0.930
152	S23.02000	E043.48000	1.6	97.85	1.3%	94.6%	4.1%	1.3%	6.4%	12.2%	22.3%	43.6%	10.1%	4.1%	0.0%	ntly Gravelly S	2.129	1.164	-0.476	1.349
156	S23.01000	E043.48000	1.2	97.46	9.0%	76.1%	14.9%	9.0%	7.6%	8.8%	13.1%	34.3%	12.2%	14.8%	0.2%	velly Muddy S	2.187	1.889	-0.330	0.931
157	S23.01000	E043.47000	1.4	98.74	6.3%	89.9%	3.7%	6.3%	15.4%	23.2%	23.7%	20.4%	7.3%	3.7%	0.0%	Gravelly Sanc	1.431	1.521	-0.125	0.989
161	S22.99000	E043.47000	1.2	95.08	12.3%	74.4%	13.3%	12.3%	12.6%	17.6%	24.8%	12.6%	6.8%	13.1%	0.2%	velly Muddy S	1.697	1.930	0.023	1.056
164	S22.98000	E043.46000	2.5	60.63	0.5%	19.9%	79.5%	0.5%	0.3%	0.3%	0.4%	4.2%	14.7%	78.6%	0.9%	Gravelly San	4.347	0.547	-0.265	1.313

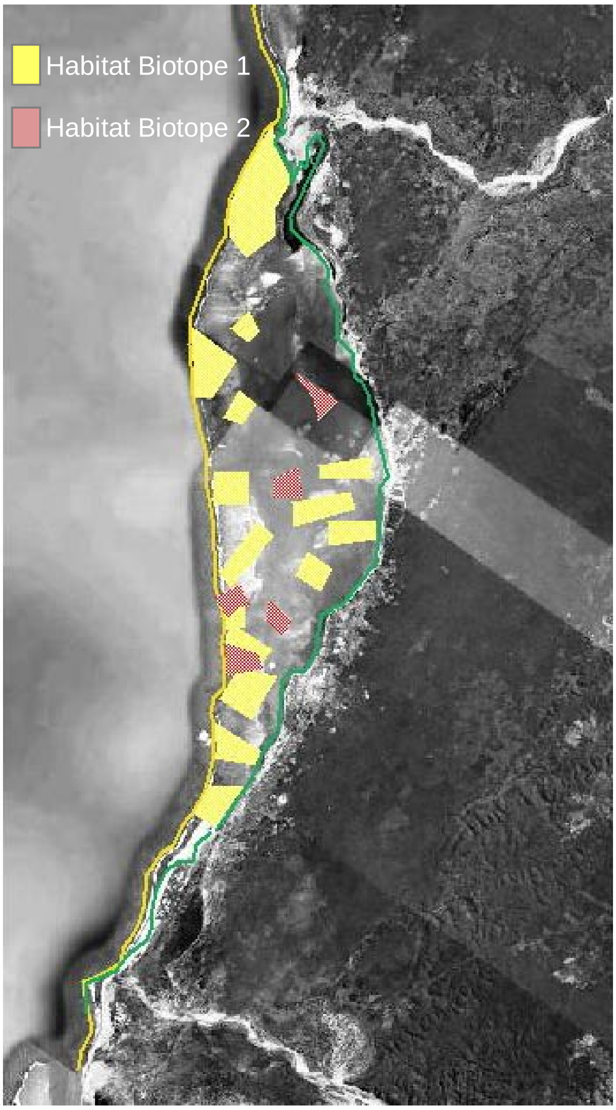

Figure 16; Habitat biotope map using ERSI Arcview GIS 3.2 to illustrate the distribution of habitat grouping one patch coral reef dominated by scleractinian corals and two back reef and consolidated limestone areas dominated by rubble and macro-algae

Figure 17; Habitat biotope map using ERSI Arcview GIS 3.2 to illustrate the distribution of habitat grouping three displaying a high diversity of seagrass on a sandy substrate

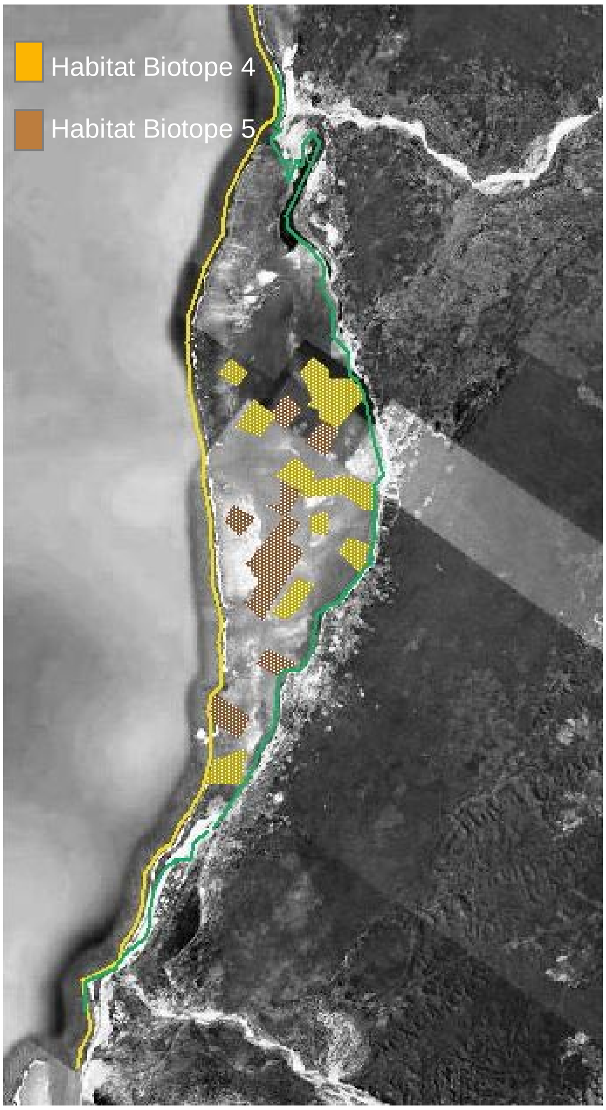

Figure 34; Habitat biotope map using ERSI Arcview GIS 3.2 to illustrate the distribution of habitat grouping four and five composed unconsolidated carbonate dominated sand with cyano-bacterial mats present

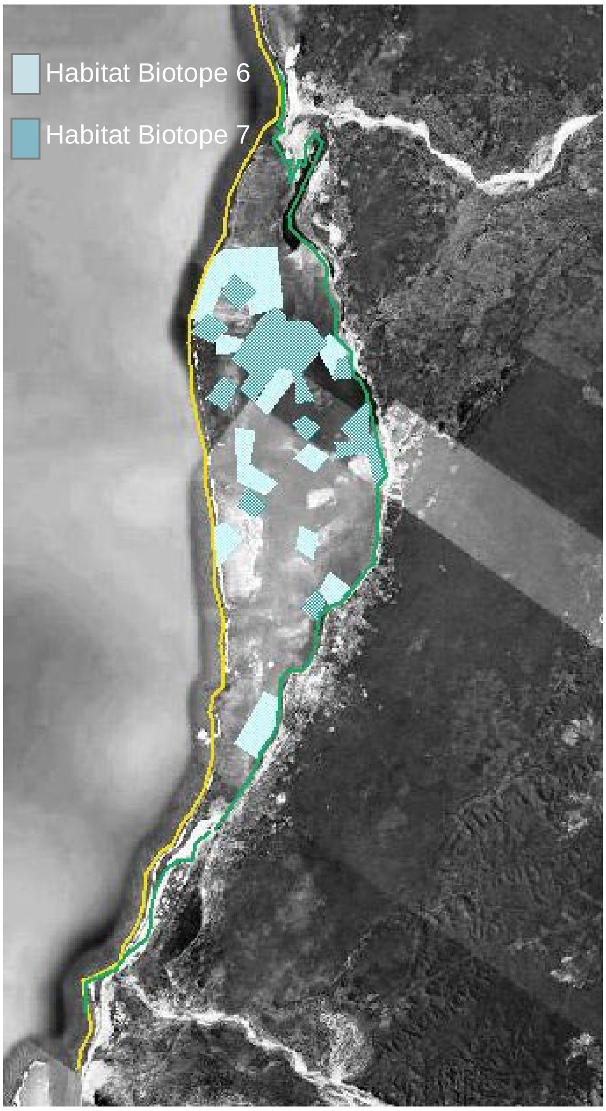

Figure 35; Habitat biotope map using ERSI Arcview GIS 3.2 to illustrate the distribution of habitat grouping six and seven dominated by sesgrass meadows sand/silt sediment composition

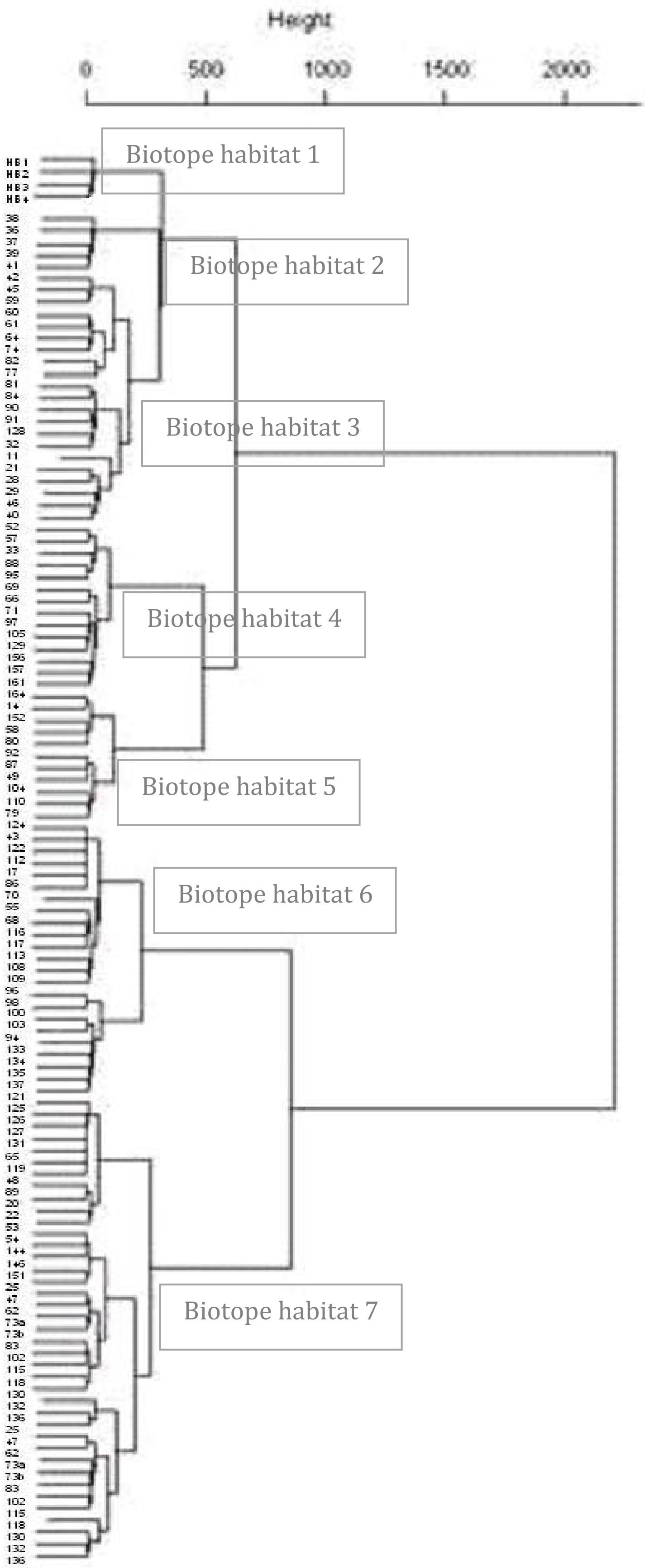

Figure 36; Hierarchal cluster dendogram of benthos communities based on CPCe. Seven habitat biotopes are identified

Table 10 colony counts from scleractinian coral survey at the four patch coral reef stations in the Bay of Ranobe

Acroporidae	Montipora	42.5	1.25	187.25	117.75
	Acropora	192.25	299.75	29.5	100.75
	Astreopora	4.25	0.25	0	7.75
Pocilloporidae	Pocillopora	325.5	101.75	39.5	120
	Seriatopora	14.5	17.25	33	76.5
	Stylophora	89.75	28	22.5	36.75
Euphyllidae	Plerogyra	1.75	1.5	0	0.5
	Physogyra	1.75	1	98	1.5
Oculinidae	Galaxea astreata	1.5	83.75	0	2.5
	Galaxea fascicularis	14.5	324	1	8.5
Siderastreidae	Psammacora	42	26.25	67.25	46
	Coscinarea	7.25	1	12.5	5.75
Agariciidae	Pavona	88.25	110.25	205.5	38.75
	Gardinoseris	8.5	1.25	10.75	1.25
Fungiidae	Fungia	48.75	151	767.25	44.25
	Herpolitha	1.25	0	2.25	0.5
	Halomitra	0	0	0	0.75
Pectiniidae	Echinophyllia	3.25	0.75	0	0
	Oxypora	2.75	2.5	0	1.25
	Mycedium	6	2.75	0	0.5
Merulinidae	Hydnophora	2.25	4.75	0	2.75
	Merulina	1.75	12.25	1	0.25
Dendrophylliidae	Turbinaria	0	0.5	0	0
Mussidae	Acanthastrea	16	3.75	0	5
	Blastomussa	0.25	0	0	1
	Lobopyllia	10.5	27.75	2.25	3.5
	Symphyllia	6.75	0.25	7.75	0
Faviidae	Favia	72.5	25.25	6.25	44.25
	Favites	41	12.5	8	31
	Goniastrea	39	26.5	6.5	21.25
	Oulophyllia	6.5	2.25	0	3.5
	Diploastrea	2.25	0	0	0
	Platygyra	24.5	12.75	0	26.75

6. Discussion

6.1 HYDRODYNAMICS AND SEDIMENTOLOGY OF THE BAY OF RANOBE

Hydrodynamic and sedimentological conditions play a large role in the productivity and biodiversity of shallow coastal environments, displacing and depositing sediments (Wild *et al* 2011). Sediments in tropical marine systems are either land-derived through riverine deposits of weathered clastic materials and soil erosion or formed by the erosion of coral reef material and/or deposition of carbonate skeletal remains of marine organisms. Surface sediments of the Bay of Ranobe lagoon system, are of two types: marine biogenic carbonates supplied by interreefal benthic organisms and siliciclastic (terrigenous material) deposited on the reef system through weathering, fluvial processes and coastal transportation. The two resulting facies are siliciclastic-carbonate sediments, but significantly differ in the degrees of mixing (fig 13).

Of the four types of mixing described by Mount (1984); source; mixed before deposited, punctuated and facies; located at a boundary layer between deposits and in-situ; where carbonate deposits are found at the same location and time as siliciclastic sediments, in-situ mixing, best describes the sediment dynamics of this study area. The well formed barrier of the lagoon system of the Bay of Ranobe provides protection from wave erosion, natural breaks in the barrier are limited to two major reef channels situated south and central. Tidal ranges of this region are subject to large fluctuations with tidal movement in the lagoon recorded at over three meters during spring tide, the affect of the exchange of interior and exterior waters being pushed and pulled through the natural channels in this lagoon system have resulted in a high velocity tidal regime. This is also supported by the overall dominance by coarse grain particles in facies 1, indicative of high wave energy and/or current velocity (Fonseca 1996) and is suggested to be the source of deposited gravel at sample stations within facies 2 where deeper tidal waters in the lagoon collide with shallow near shore and back reef platforms (fig 15). This may also increase the generation of detrital sediment on reef platforms, sediment which is subsequently: reincorporated into reef framework (Hubbard *et al* 1990); stored on reef surfaces; transported off-reef (Hughes 1999) or transferred to infill lagoons (Macintyre *et al* 1987, Kench 1998, Purdy and Gischler 2005).

Satellite images of the Bay of Ranobe implies shoaling in the northern area of the lagoon system; results from this study show an accumulation of terrigenous material in the north extremity of the lagoon in comparison with the south and depositional conditions for coral marls were met in lagoon/bay areas with siliciclastic input (Frost 1981, Bosellini and Trevisani 1992, Simo 1993, Bosellini and Stemann 1996, Sanders and Pons, 1999). This may be due to a combination of issues; (1) placement of the natural reef channels that provide high water movement in the south of the lagoon, yet in the north where there are no natural channels and depth has been reduced through shoaling, water velocity is diminished and finer sediments and mud are able to settle in the weaker currents. (2) Mangrove systems and the indigenous natural forests in the north under anthropogenic pressure through coastal community utilisation of natural resource for building material, charcoal production and agriculture causing topsoil erosion and an influx of fine terrigenous sediments into the lagoon system.

6.2 ANTHROPOGENIC IMPACTS ON TERRESTRIAL ECOSYSTEMS

Deforestation of the adjacent terrestrial ecosystem is providing a source of terrigenous material that is being deposited on the adjacent marine system. It is suggested that over 90 per cent of households dependant on fuel wood and charcoal in Madagascar (Taylor *et al* 2003), research by Sussman (1994) assessing deforestation in Madagascar by using satellite imagery and ethnographic methods suggests that over 100,000 ha of limestone forest bordering the Toliara province in which the Bay of Ranobe is included have been cleared since 1972 primarily for charcoal production. This is a huge dependency on fuel wood and charcoal in comparison with other Western Indian Ocean islands such as the Seychelles where only 8 per cent of people utilise fuel wood , even as a supplementary source of energy (Taylor *et al* 2003).

An in-depth analysis of the forest of Madagascar from 1953 to 2000 by Harpers (2007) indicate mass deforestation, degradation and changes in land use that have taken place since the beginning of the study period (fig 21). Harper stated that observed deforestation rates of the spiny forest of Southwest Madagascar were calculated at 6097 km2 during the period of 1970 to 1990 and 2817 km2 during the period of 1990-2000, averaging at a loss of 1.2% of forest per yr^{-1} (fig 21) research gauging mangrove deforestation is limited, with only partial information available for the period of

1990-2000 stating that observed deforestation rates show a 55km^2 loss of mangrove systems throughout Madagascar (fig 21).

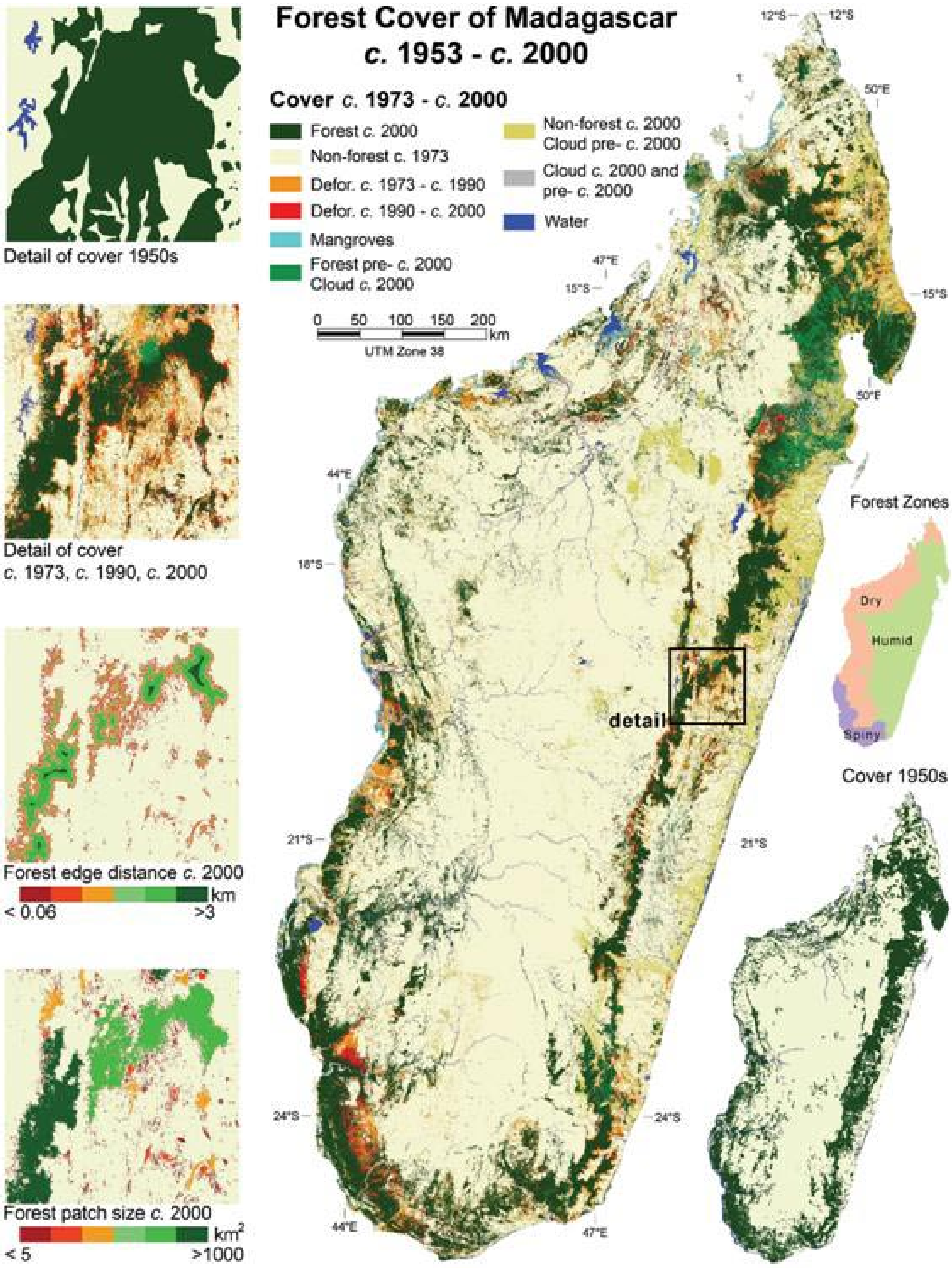

Figure 37; Depicting forest cover in Madagascar from the 1950s to *c*. 2000; changes in forest cover from the 1970s to *c*. 2000 are shown in the main figure, and forest cover in the 1950s is shown in the lower-right inset (Harper *et al* 2007), black box delineates study area, Bay of Ranobe.

6.3 RIVER SYSTEMS

River systems that may have an influence on the lagoon system due to proximity and catchment areas are the Manombo in the north and Fiherenana in the South, these fresh water systems are semi dry with flooding occurring throughout the wet season (December, January, and February). During episodic events such as cyclones that generate high rainfall, visual observations indicate significant discoloration of these fresh water systems during these increased peak flow periods suggesting considerable movement of sediment beds.

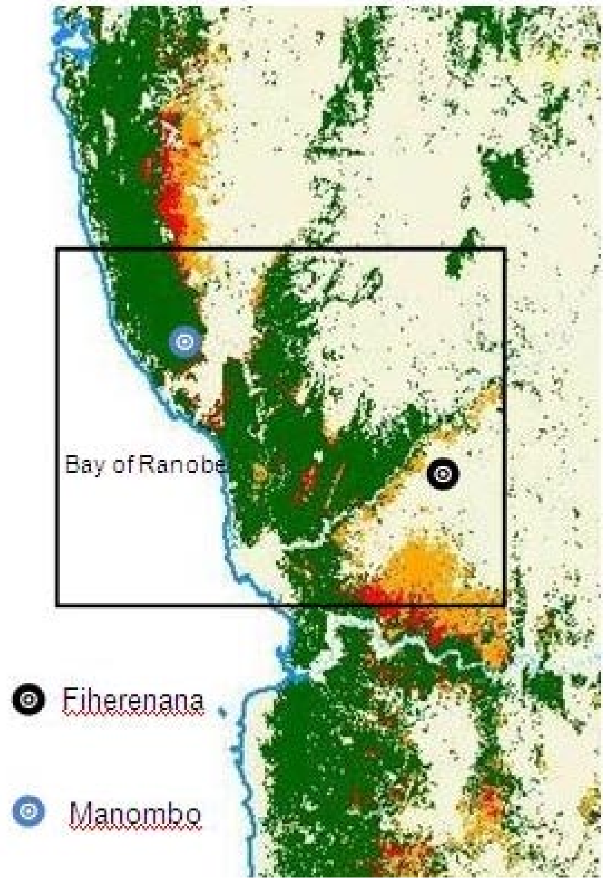

Figure 38; Forest cover of the study area Bay of Ranobe *c.* 1953 – *c*.2000; areas shaded orange depicting deforestation that has occurred 1973-1990, areas shaded red depicting deforestation rates1990-2000 (Harper *et al* 2007)

It is evident from Harper's research that major expanses of the indigenous spiny forest that delimit the southern banks of the Fiherenana river bordering the south of the lagoon system has suffered extensive deforestation (fig 22) consequential flushing and deposition of terrigenous material on the adjacent reef system is suggested by Vasseur (1997) who stated that the Fiherenana river, responsible for the transport of freshwater runoff and materials from a 6,750 km^2 catchment area was accountable for the deposition of terrigenous material on the Toliara reef system.

Although Randriamanantsoa (1997) implies that the deposition of terrigenous sediments into the Toliara lagoon system is just 1-1.5% of surface sediments. Surface sediment analysis at stations in the southern section of the lagoon system demonstrate an overwhelming carbonate dominant profile (>90%wt) (fig 9) with siliclastics deposits exhibited in very low levels. This suggests that although the fresh water system in the south of study area is showing visible signs of anthropogenic disturbance through deforestation and degradation of the adjoining terrestrial ecosystem the consequential effect on the Bay of Ranobe lagoon system is insignificant with terrigenous sedimentation derived from land clearance possibly being deposited on the Toliara reef system, south of the study area.

In the north of the lagoon system, sampling station 164 (fig7, table 4) within close proximity to the Manombo river system has a terrigenous deposit composition of over 40% wt, the highest deposit of terrigenous material in regards to all sample stations suggesting that fluvial sediments are transported from the river and deposited into the lagoon system. Deposits of terrigenous material were also located in the northern section, midpoint adjacent to the coast (fig 9) suggesting that these areas are undergoing increasing terrigenous sediment influence as a consequence of coastal land-based anthropogenic activities (Souter *et al* 2002).

Changes in land use practice are based on historical evidence from Harpers

Figure 39; accentuated map of forest cover of the area surrounding the study site Bay of Ranobe together with the satellite image of the lagoon system, areas shaded red depicting deforestation rates1990-2000

1953-2000 deforestation map of the spiny forest surrounding the Bay of Ranobe showing significant clearance of the spiny forest in the northern region of the Bay of Ranobe during 1990 to 2000 period (fig23).

This may be because the north cost of the lagoon system is more densely populated than the south and coastal villages have a larger population of Masikoro farmers; inland people (Stiles 1998) who utilise the surrounding forest (Tucker et al 2010) these migrant populations have steadily moved towards the coast for food security (Scouter *et al* 2002, Grimsditch 2009, Tucker *et al* 2010) as resources become limited inland through environment and climate change issues such as drought and changes in weather patterns. In this way the two major river systems that delimit the Bay of Ranobe lagoon system are suggested to have different levels of influence on the Bay of Ranobe lagoon system. Further research is needed to clarify if these sediments are having any secondary influence on the Bay of Ranobe marine ecosystem.

6.4 CARBONATE SYSTEMS AND ASSOCIATED HABITATS

Sedimentation evaluation indicates that the Bay of Ranobe is a dynamic system with continuous carbonate production and a suggested episodic supply of terrigenous material from land based sources. However, supply and deposition of siliciclastic sediments in this carbonate dominant system along with the capacity of this system to adjust is unknown. Carbonates are notoriously complex sedimentary systems controlled by complex biological and physiochemical processes (Hill *et al* 2009). Carbonate production is an important component of the global carbon cycle (Heart and Kench 2006) results shows a significant proportion of samples with a carbonate content of over 90%wt (fig 9) suggesting a substantial contribution to carbonate production by reef organisms in the surface sediments.

Assessment of the four patch coral reef systems surveyed in the lagoon system show an overall dominance of corals (56.4%). Habitat 1; composed of patch coral reef systems with no significant difference found in coral cover between sites (p=>0.1), 41 genera of scleractinian corals were identified, of the seven most abundant genera *Fungia Acropora, Pocillopora, Pavona Montipora Porites,* and *Favia* the family *Acroporidae* dominated the Bay of Ranobe reef system. *Acroporidae* specifically *Acropora* and *Montipora* are fast growing opportunistic species but are often more susceptible to bleaching (Hoegh-Guldberg and

Salvat 1995, Loya *et al* 2001, Obura 2001, McClanahan *et al* 2007).

Of the four sites surveyed the two shallow patch reef systems (<10 meters) displayed a monospecific dominance by *Acroporidae* with small colonies of encrusting and massive morphological forms. Coral coverage in the survey area is consistent with the rest of Madagascar such as Nosy Hara marine reserve in Northern Madagascar (Pegg *et al* 2009), Masoala national park on the Masoala peninsular northeast Madagascar (Roland and Rajaonarison 1999) Reef complex of Toliara (Clausade *et al* 1971, Thomassin 1971, Pichon 1978) and other islands of the Mascarene such as Mauritius and Rodrigues (Turner *et al* 2005). Research conducted by some of the most experienced scientists in the field of coral reef research including Veron, Turak, McKenna and Allen (2003) encompassing 30 survey stations on the north-western coast of Madagascar covering an area of 220km (linear distance) described sixty-two genera and seventeen families.

The twelve most abundant coral genera for this region in which *Acropora, Montipora, Porites, Favia, Fungia, Favites, Goniopora* and *Pavona* accounted for over half the recorded species (McKenna and Allen 2003) and reflect the dominant coral species recorded in this study. An in-depth assessment on the coral community in the northwest conducted by Veron and Turak (McKenna and Allen 2003) compiling a coral species list amalgamated earlier data from Verons research in the Toliara region in 2000 (Veron 2000). An astonishing 380 species were described providing the first complete coral species list for Madagascar, with a high diversity documented for the southwest coast of Madagascar north of the Bay of Ranobe (Clausade *et al* 1971, Thomassin 1971, Pichon 1978, Veron 2000, McKenna and Allen 2003). This can be regarded as the highest number of species recorded in the Western Indian Ocean and over the predicted total of 340 species for the entire East Africa and Western Indian Ocean region indicated by the species distribution maps in Veron (2000). Veron and Turak conclude that Madagascar is a major centre of both endemism and species diversity (Veron 2000, McKenna and Allen 2003) thus indicating the wealth of diversity of Madagascar coral reef community and the need to protect this remarkable resource.

Research from the Southwest coast of Madagascar shows an early study by Pichon (1978) who reported 130 species of scleractinian corals for the reef complex of Toliara, Pichon goes on to describe the coral community on the outer slopes of the Bay of Ranobe as being extremely lush, the outer reef slope

Figure 40; Photos taken during the study by Pichon (1978) of the back reef in the Bay of Ranobe illustrating the vast *Acropora* colonies and massive and encrusting coral morphologies that one inhabited this area and now absent characterised by spur-and-groove.

The barrier reef and fore-reef being described as being dominated by crustose coralline algae (*Porolithon onkodes* and *Lithophyllum* sp) with the inner reef flat characterised small isolated coral colonies dominated by massive growth forms but extremely high diversity. Seaward and middle zone composed of almost exclusively homogeneous branching *Acropora* species (*A. pharaonis* and *A. arbuscula*) with reef sites south of the village of Ifaty an area of 1km by 200-250m uninterrupted 100% coral cover with seagrass meadows observed on the back reef flat. Habitat two groups stations along the back reef and is dominated by rubble and consolidated lime stone blocks with macro algae coverage, according to research by Pichon (1978) this area was once *Acropora*-dominated (fig 24) with small massive and encrusting coral morphologies present and coralline/ calcareous algae. Thus, the Bay of Ranobe has undergone many changes since the study by Pichon in 1978 with episodic events and chronic stressors the source of reef degradation, particularly the 1998 episodic event that generated mass degradation to the coral reef system throughout the Indian Ocean.

An evaluation of the reef systems of the bay of Ranobe (Ifaty) was conducted as part of a large scale assessment of coral reef habitats in the Western Indian Ocean by the Coral Reef Degradation in the Indian Ocean (CORDIO) project. CORDIO was initiated to assess the impact and recovery of coral reefs from the El Nino of 1998 that caused this worldwide, mass coral bleaching event resulting in extensive full/partial coral mortality throughout all tropical marine ecosystems (fig 25) (Goreau *et al* 2000, McClanahan *et al* 2007). Results from survey in 1998, 1999, 2000, and 2002 display a 30.8%, 40.7%, 41.9%, 42% hard coral cover, respectively (Souter *et al* 2002). Since 2002 no review had been made and this study indicates an increase in coral cover of 14.2% percent since 2002. Studies by also state that as the topographical complexity of the reef system is decreased through loss of coral cover and the natural breakdown of carbonate material current occurs, water velocity will increase as water movement will not be debilitated. Thomassin *et al* (1998), Vasseur *et al* (2000) research also assessed the sedimentological and geomorphological components of the shallow reef flats of the Toliara reef complex, on comparison these study illustrate the changes to the reef system with the reef flat displaying considerable change with a reduction in width and height of the outer bolder tracts coupled with a reduction in coral cover within the lagoon system and widespread coral mortality. Increased cover of algae growth (up to 90%) with canopy algae sargassum dominant in the summer period (December, January, February) and fleshy algae dominant in the

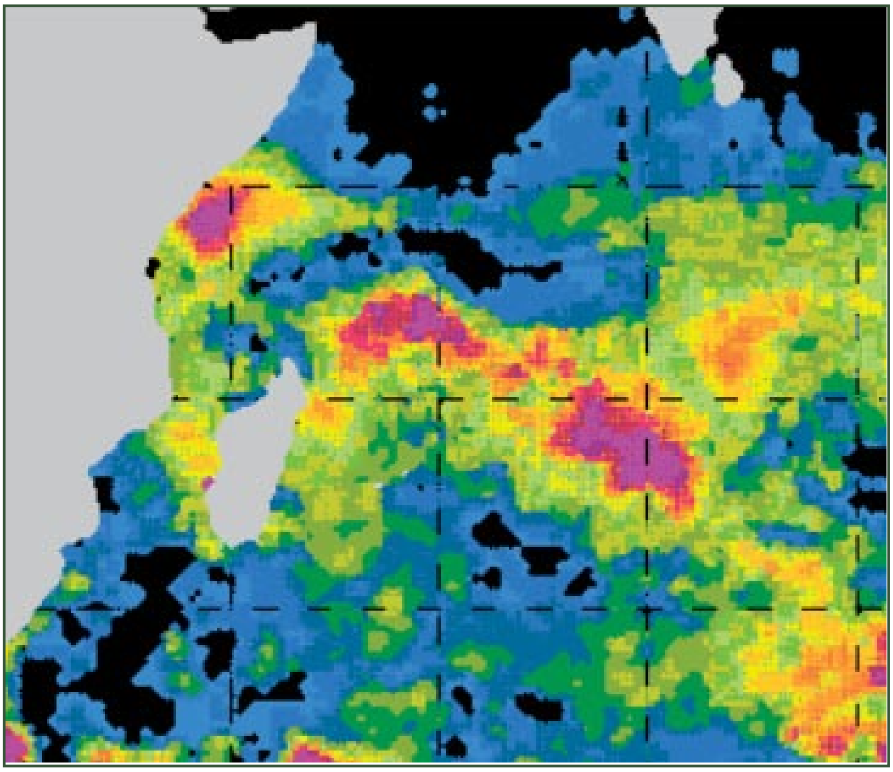

Figure 41; Degree Heating Weeks (DHW) in the Western Indian Ocean on April 30th, 1998 during the episodic bleaching event that affected the region McClanahan et al 2007).

winter period (June, July, August) seagrass meadows were heavily degraded with a loss of diversity and biomass. Large dense seagrass meadows of *Syringodium isoetifolium, Thalassodendron ciliatum* and *Thalassia hemprichii* were replaced by sparse and patchy *Halodule univervis* and *Cymodasia rotundata*.

6.5 SEAGRASS MEADOWS

Seagrasses are divided into five families *Hydrocharitaceae, Cymodoceaceae, Posidoniaceae, Zoateraceae and* Ruppiaceae with twelve genera, divided into 60 species of which about half are found in tropical habitats (Short *et al* 2007) with nine of these species identified in the Bay of Ranobe by Short (2007 per. Comm.). Seagrass meadows are the dominate feature in the survey station habitat biotope groupings. Yet each habitat differs in biodiversity, coverage, sediment grain size composition and mixing of terrigenous carbonate-siliclastic sediments providing significantly different habitat profiles provided through the use of hierarchical cluster dendograms. In the south and central areas of the lagoon system seagrasses are patchy with high seagrass diversity combined with medium to fine sandy carbonate dominant sediments and these areas are represented by habitat biotope three. Seagrass community in habitat three include nine species; *T. ciliatum, T. hemprichii, C. rotundata, C.serrulata, S. isoetifolium, H. univervis H. wrightii H. stipulate* and *H.ovalis* suggesting a highly productive biological community. Marginal seagrass meadow governing the northern section of the lagoon system exhibit a lower diversity and sediments are dominated by facies 1. Collectively these habitats are of vast ecological and social importance as these complex aggregations of flora and fauna are suggested to underpin the productivity of many tropical marine ecosystems. (Gullstrom *et al* 2002). Seagrass beds are also geologically important features, seagrass blades operate as effective "baffles," that influence sedimentation rates and, together with the rhizomes, trap and bind carbonate sediments (Ginsburg and Lowenstam 1958, Scoffin 1970) Sediment grain size is suggested to be an indicator of a variety of physical and geochemical characteristics in seagrass habitats. Except for saponaceous green algae, seagrasses are the only submerged marine macrophytes that are rooted and depend on the sediment for their nutrition (Duart and Sand-Jensen 1996) and nutrient availability in coarse sediments differ from that of finer sediments (Erftemeijer and Middelburg 1993, Idestam-Almquist and Kautsky 1995).

Habitat biotope seven seagrass community structure including *T. ciliatum, T.*

Figure 42; Seagrass beds in habitat biotope six showing *Thalassia hemprichii* with a covering of fine sediment

hemprichii, C. rotundata, C. serrulata, S. isoetifolium although diversity is lower than habitat two this grouping displays the highest mean percent cover of all seagrass habitats surveyed recorded at over 50%, this habitat grouping is dominant in the north of the lagoon system however this study suggests that these highly productive systems are to be under negatively impacting biotic/abiotic factors. Large areas of seagrass beds in habitat six with a species assemblage of *T.hemprichii, S isoetifolium, H. ovalis*, dominated by *T. hemprichii* are situated adjacent to habitat seven have a mean seagrass cover of < 40% with habitat six and seven dominated by facies 1 (fig 9) characterised by terrigenous sediment deposits and poorly sorted sediments composed of muddy sandy gravel with mixed carbonate-siliclastic material indicating a weak and/or sporadic hydraulic sorting on sediment texture. Photographic quadrats taken of these seagrass meadows from sample stations in Habitat six and seven (fig26) show the blades of the seagrass *T. hemprichii* with a substantial layer of fine sediment.

6.6 Seagrass and sediment

Tropical systems concentrations of dissolved nutrients are typically low while porewater concentrations in the sediments are substantially higher (Eritemeijer and Middelburg 1993). Studies assessing the effects of seagrass survival on terrigenous and carbonate sediments illustrate the differences in nutrient cycling between nitrogen limited terrigenous sediments and phosphorous limited carbonate sediments as phosphate ions bind differently to the carbonate matrix (Short 1987). Carpone *et al* (1992) reported significantly lower porewater NH_4 concentrations in coarse-grained sediments on comparison to fine-grained and muddy carbonate sediments and Eritemeijer and Middelburg (1993) find no evidence of p-limitation for seagrasses growing on coarse grain carbonate sediments with the capacity of carbonate sediments to adsorb phosphates directly related to grain size composition suggesting that seagrass meadows should proliferate in areas where sediment profiles exhibit carbonate-dominant systems that have a coarse skewed textual grouping such as back reef areas, consolidated limestone and patch reef in habitat one, corresponding with the earlier study undertaken Pichon (1978).

As grain size distribution becomes skewed towards silt and clay, the pourwater exchange with the overlying water column decreases (Huettel and Gust 1992, Huettel and Rusch 2000) which may result in increased nutrient concentrations (Kenworthy *et al* 1982) as well as phytotoxins such as sulfide in the marine sediments (Holmer and Nielson 1997). Seagrasses are able to switch to a fermentation pathway for short periods of time when transportation of oxygen from shoot to root is not enough to meet the demand for aerobic respiration (Smith et al 1988). thus, survive is ensured for a limited time until hypoxic stress is relieved however sustained hypoxic stress results in death (Perez *et al* 2007).

Covering of blades by fine sediments may interfere with photosynthesis as it has been estimated that seagrasses need more than 10% surface irradiance for photosynthesis (Bjork *et al* 2008) compared with algae 1% of surface light. With seasonal fluctuations and patch dynamic studies indicating that seagrass meadows are not static even under “stable” environmental conditions monthly fluctuations can be linked to wet and dry season cycles (Lanyon and Marsh 1995) tidal exposure and/or water motion (Erftemeijer and Herman 1994). In addition, settlement of carbonate-siliclastic material increasing the shoaling effect of this area may also increase light attenuation and exposure at low tide which of the seagrass meadows which in turn will also damage the photosynthetic process of seagrasses due to high irradiance process resulting in non-photochemical quenching (Bjork *et al* 2008).

The final habitat groupings three and four, are dominated by unconsolidated carbonate sand areas are either; (1) situated in relatively low hydrodynamic flow such as sheltered back-reef environments in which case dense cyano-bacterial mats have been establish, serving to bind the sand sheets. (2) Sand flats and tidal sandbanks in areas of high hydrodynamic flow that have gathered near topographic highs and occur along the base of reef slopes, beyond the framework-to-rubble interface. Sparse and/or patchy seagrass coverage was recorded in habitat biotope five only displaying n extremely low mean percent cover (<12%) with the species *T. ciliatum, T. hemprichii, H.stipulacea* observed in this grouping

Numerous studies (Orth *et al* 2006, Waycott *et al* 2009 Hilary *et al* 2011) suggest worldwide declines in seagrass caused by anthropogenic impacts including direct physical disturbance and indirect effects of watershed development and consequent water quality degradation. Thus, it is suggested that habitat six and seven situated in the north of the lagoon need further investigation to assess the impact of chronic stressors such siltation, burial and/or extended exposure during tidal fluctuations, and changes in sediment composition with the deposition of terrigenous material on these critically important and productive ecosystems.

7. Conclusion

This study indicates that episodic stressors (e.g. climate change) and chronic stressors such as the deposition of terrigenous material on the adjacent marine system, have the potential to drive major ecosystem shifts across the entire reef ecosystem and are already doing so. These fundamental shifts have the ability to cause both reversible and irreversible damage to the Bay of Ranobe ecosystem functioning with detrimental consequences for the coastal communities that depend on the productivity of these systems for survival. Episodic events inducing mass scleractinian coral bleaching and mortality are suggested to increase the production of calcareous sand through increased erosion, however this effect lasts only until the carbonate supply is exhausted at which point the biocatalytic filter system will be ineffective/inefficient at processing organic matter eventually decreasing resilience/resistance of coral-reef ecosystems.

Primary producers such as seagrass habitats serving as nursery grounds to many reef associated species are sensitive to physical, chemical and biological change (Mellors 1991, Burkepile 2006, Bjork et al 2008). This research suggests that terrigenous material deposition on seagrass beds is occurring in the lagoon system of the Bay of Ranobe through the changes in land-use by the coastal communities.

The present study has shown that the Bay of Ranobe has undergone dramatic changes since the study by Pichon in 1978. Based on the physical and biological data analysis and the integrated interpretation the following conclusions are proposed:

- Detailed analysis of grain size composition and carbonate content of surface sediment samples illustrate the high wave energy and/or current velocity in the southern and central areas of this lagoon system. Wave energy and/or current velocities in the north are less than that of the south, giving rise to deposition of terrigenous sediments transported and settling and/or transferred to infill the northern section of this lagoon system.
- There is a clear relationship between terrestrial land-use and terrigenous inputs on this carbonate-dominant system specifically in the northern section of the lagoon. This needs further investigation and implementation of agricultural management strategies.
- Altogether 41 genera of scleractinian corals were identified on the patch reef systems surveyed, with mean coral cover estimated at over 50%. Genera were dominated by *Acroporidae* specifically *Acropora* and *Montipora* species. This once coral-dominated system has suffered mass degradation evident from significant rubble fields observed in this study.
- The dataset is limited, and further research is needed to assess the:
    - Currentology of this marine lagoon system which plays a major role in the movement of sediments and
    - Near-shore fishery which will affect ecosystem function if herbivores are depleted through over-exploitation.

8. REFERENCES

Acker, K L., Stearn, C. W,. 1990. Carbonate-siliciclastic facies transition and reef growth on the north-east coast of Barbados. West Indies, J. Sediment. Petrol 60:18-25

Agardy, T., Bridgewater, P., Crosby, M. P,. Day, J,. Dayton, P. K,. Kenchington, R. Laffoley, D,. 2003. Dangerous targets? Unresolved issues and ideological clashes around marine protected areas. Aquatic Conservation-Marine and Freshwater Ecosystems 13(4): 353–367

Algeo, T.J., Wilkinson, B.H.,1988. Periodicity of Mesoscale Phanerozoic sedimentary cycles and the role of Milankovitch orbital modulation. Journal of Geology 96, 313–322.variability is recorded in a coral record off southwest Madagascar for the period 1659 to 1995. Earth and Planetary Science Letters, 228, 177 - 194. doi: 10.1016/j.epsl.2004.09.028.

Anthony, K. R. N., 1999a. Coral suspension feeding on fine particulate matter. J. Exp. Mar. Biol. Ecol. 232, 85–106.

Anthony, K. R. N., 1999b. A tank system for studying benthic aquatic organisms at predictable levels of turbidity and sedimentation: case study examining coral growth. Limnol. Oceanogr. 44, 1415–1422.

Anthony, K. R. N., 2000a. Enhanced particle-feeding capacity of corals on turbid reefs (Great Barrier Reef, Australia). Coral Reefs 19, 59–67.

Anthony, K. R. N., Fabricius, K. E., 2000b. Shifting roles of hetero- trophy and autotrophy in coral energetics under varying turbidity. J. Exp. Mar. Biol. Ecol. 252, 221–253.

Anthony, K. R. N., Connolly, S. R., Wills, B. L., 2002. Comparative analysis of tissue and skeletal growth in corals. Limnol. Oceanogr. 47:1417–1429.

Anthony K. R. N., Ridd, P. V., Orpin, A., Larcombe, P., Lough, J. M., 2004. Temporal variation in light availability in coastal benthic habitats: effects of clouds, turbidity and tides. Limnol Oceanogr 49:2201–2211

Anthony, K. R. N., Connolly, S. R., Wills, B. L., 2007. Bleaching, energetics, and coral mortality risk: Effects of temperature, light, and sediment regime. Limnol. Oceanogr. 52(2), 2007, 716–726

Anthony, K. R. N., Maynard J. A., Iaz-Pulido P. G., Mumby, J., Marshal, P. A., Hugh.-Guldberg. O., 2011. Ocean acidification and warming will lower coral reef resilience. Global Change Biology, 1798-1808. doi: 10.1111/j.1365-2486.2010.02364.x.

Acorsi, S., Fabiani, M., Nattabi, B., Corrado, B., Iriso, R., Ayella, E. O., Pido, B., Onek, P. A., Ogwang, M., Delich, S., 2005. The Disease Profiles of Poverty: Morbidity and Mortality in Northern Uganda in the Context of War, Population Dis- placement and HIV/AIDS. Transactions of the Royal Society of Tropical Medicine and Hygiene 99(3):226–233.

Aronson, R.B., Precht, W.F., 2006. Conservation, precaution, and Caribbean reefs. Coral Reefs 25, 441–450.

Bak, R. P. M., 1976 Neth J Sea Res 10 (3):285–337

Bak, R. P. M., Meesters, E. H,. 1998. Coral population structure: the hidden information of colony size-frequency distributions. Marine Ecological Progress Series, 162, 301–306

Bak, R. P. M., Elgershuizen, J. H. B. W. 1976. Patterns of oil-sediment rejection in corals. Mar. Biol., v. 37, p. 105-113,

Bak, R. P. M., Lambrechts, D. Y. M., Joenje, M., Nieuwland, G., and Van Veghel, M. L. J., 1996. Long-term changes on coral reefs in booming populations of a competitive colonial ascidian. Marine Ecology Pro- gress Series 133, 303–306. doi:10.3354/MEPS133303

Babcock, R., Smith, L. 2000. Effects of sedimentation on coral settlement and survivorship. Marine Biology, Proceedings 9th International Coral Reef Symposium, Bali, Indonesia 23-27

Baker, A. C, Glynn, P. W., Riegl, B., 2008. Climate change and coral reef bleaching: An ecological assessment of long-term impacts, recovery trends and future outlook. Estuarine, Coastal and Shelf Science 80: 435–71. doi: 10.1016/j. ecss.2008.09.003

Battistini, R., Bourrouilh, F., Chevalier, J.-P., Coudray J., Denizot M., Faure G., Fisher, J.-C., Guilcher, A., Harmelin-Vivien, M.L., Jaubert, J., Laborel, J., Montaggioni, L., Masse, J.-P., Mauge, L.-A., Peyrot-Clausade, M., Pichon, M., Plante, R., Plaziat, J.-C., Plessis, Y., Richard, G., Salvat, B., Thomassin B., Vasseur, P., Weydert, P., 1975. Eléments de terminologie récifale Indo-Pacifique. Téthys, 1, 7, 1-111

Bell, P. R. F., Elmetri, I,. 1995. Ecological indicators of large-scale eutrophication in the Great-Barrier-Reef lagoon. Ambio 24:208–215

Bellwood, D. R 1996. The Eocene fishes of Monte Bolca: the earliest coral reef fish assemblage. Coral Reefs 15:11–19

Bellwood, D. R., Hughes, T. P., Folke, C., Nyström, M., 2004. Confronting the coral reef crisis. Nature, 429, 827–833

Bellwood, D. R., Andrew, S. H., Ackerman, J. H., and Depczynski, M., 2006. Coral bleaching, reef fish community phase shifts and the resilience of coral reefs. Global Change Biology 12, 1587–1594. doi:10.1111/J.1365-2486.2006.01204.

Bena, C., van Woesik, R., 2004. The impact of two bleaching events on the survival of small coral colonies (Okinawa, Japan). Bulletin of Marine Science 75, 115–125.

Berkelmans, R., 2002. Time-integrated thermal bleaching thresholds of reefs and their variation on the Great Barrier Reef. Mar Ecol Prog Ser 229:73–82

Berkelmans, R., De'ath, G,. Kininmonth, S,. Skirving, W. J,. 2004. A Comparison of the 1998 and 2002 Coral Bleaching Events on the Great Barrier Reef: Spatial Correlation, Patterns, and Predictions. Coral Reefs 23: 74–83.

Birkeland, C,. 1977. The importance of rate of biomass accumulation in early successional stages of benthic communities to the survival of coral recruits. Proc. 3rd int. Coral Reef Congr. 1: 15-21

Birrell, C. L., McCook, L. J., Willis, B. L., Diaz-Pulido, G. A., 2008. Effects of benthic algae on the replenishment of corals and the implications for the resilience of coral reefs. Oceanogr Mar Biol 46:25–65

Björk, M., Short, F., Mcleod, E,. Beer, S,. 2008. Managing Seagrasses for Resilience to Climate Change. IUCN, Gland, Switzerland

Blanchon, P. 1997. Architectural variation in submerged shelf-edge reefs: the hurricane-control hypothesis. Pro- ceedings of the Eighth International Coral Reef Symposium 1:547–554.

Blott, S. J., Pye, K., 2001. Technical communication Gradistat: A grain size distrodution and statistical package for the analysis of unconsolidated sediments *Earth*, *1248*, 1237-1248. doi: 10.1002/esp.261

Bosellini, F., Trevisani, E., 1992. Coral facies and cyclicity in the Castelgomberto Limestone (Early Oligocene, Eastern Lessini Mountains, Northern Italy). Riv. It. Paleont. Strat. 98, 339–352.

Bosellini, F., Stemann, T.A., 1996. Autoecological significance of growth form in the scleractinian Actinacis rollei Reuss (Oligocene, Lessini Mountains, Northern Italy). In: Bruckner, A., 2007. Life Saving Products from Coral Reefs. <http://www.issues.org/ 18.3/p_bruckner.htm>

Brown, B. E,. Howard, L. S,. 1985. Assessing the effects of ‘stress' on reef corals. *Advances in Marine Biology* 22, 221–23

Brown, B.E., 1997. Disturbances to reefs in recent times. In: Birkeland, C. (Ed.), Life and Death of Coral Reefs. Chapman and Hall, New York, pp. 354–378

Brown, B.E., Downs, C.A., Dunne, R.P., Gibb, S.W., 2002. Exploring the basis of thermotolerance in the reef coral Goniastrea aspera. Marine Ecology Progress Series 242, 119–129.

Buddemeier, R. W.,, Hopley, D., 1988. Turn-ons and turn-offs: causes and mechanisms of the initiation and termination of coral reef growth. Proceedings 6th International Coral Reef Symposium, Australia, 1, 253–261.

Buddemeier, R. W., Kleypas, J. A., Aronson, R. B,. 2004. Coral reefs. Coral Reefs.

Bui EN, Mazullo J, Wilding LP. 1990. Using quartz grain size and shape analysis to distinguish between aeolian and fluvial deposits in the Dallol Bosso of Niger (West Africa). Earth Surface Processes and Landforms 14: 157–166

Bull, G. D., 1982. Scleractinian coral communities of two inshore high island fringing reefs at Magnetic Island, North Queensland. Mar Ecol Prog Ser 7: 267-272

Burke, L., Selig, E. Spalding, M,. 2002. Reefs at Risk in Southeast Asia. Washington, DC: World Resources Institute.

Burkepile, D. E., Hay, M. E., 2006. Herbivore vs. nutrient control of marine primary producers: context-dependent effects. Ecology 87:3128–3139

Bryant, D,. Burke, L,. McManus, J,. Spalding, M,. 1998. Reefs at Risk – A Map-Based Indicator of Threats to the World’s Coral Reefs. WRI, Washington (USA), p. 56,

Bythell, J. C,. 1988. Atotal nitrogen and carbon budget for the elkhorn coral Acropora palmata (Lamarck). Proceedings of the 6th International Coral Reef Symposium 6, 535–540.

Carpenter, R. C., 1986. Partitioning herbivory and its effects on coral reef algal communities. Ecol Monogr 56: 345–363.

Carpenter, K., Abrar, M., Aeby, G., 2008. One-third of reef-building corals face elevated extinction risk from climate change and local impacts. Science 321, 560–563.

Capone, D. G., Dunham, S. E., Horrigan, S. G.. Duguay, L. E., 1992. Microbial nitrogen transformations in unconsoli- dated coral reef sedunents. Mar. Ecol. Prog. Ser. 80: 75-88

Carilli, J. E., Norris, R. D., Black, B. A., Walsh, S. M., McField, M., 2009. Local stressors reduce coral resilience to bleaching. PLoS One, 4, 6324.

Chabanet, P., Ralambondrainy, H., Amanieu, M., Faure, G., Galzin, R., 1996 Relationships between coral reef substrate and fish Coral Reefs 16: 93-102

Chabanet P., Ralambondrainy H., Amanieu M., Faure G., Galzin R., 1996 Relationships between coral reef substrate and fish Coral Reefs 16: 93-102.

Cherchi, A. (Ed.), Autoecology of selected fossil organisms. Achieve- ments and problems. Boll. Soc. Paleont. It., vol. 3, pp. 31–43.

Chalker, B. E,. 1981. Simulating light-saturation curves for photosynthesis and calcification by reef-buildmg corals. Mar. Biol. 63: 135-141

Chave, K., 1964. Skeletal durability and preservation. In: Imbrie J, Newell N (eds) Approaches to palaeoecology. Wiley, Sydney, NSW, pp 377–387
Cherchi, A. (Ed.), Autoecology of selected fossil organisms. Achieve- ments and problems. Boll. Soc. Paleont. It., vol. 3, pp. 31–43.
Chollett, I., Mumby, P. J., & Cortés, J. (2010). Upwelling areas do not guarantee refuge for coral reefs in a warming ocean. Marine Ecology Progress Series, 416, 47-56. doi: 10.3354/meps08775.

Clausade, M., Gravier, N., Picard, J., Pichon, M. Thomassin, B., Vasseur, P., Vivien, M. & Weydert, P., 1971. Coral reef morphology in the vicinity of Tuléar (Madagascar); contributi

Cockroft, V., Young, D. D., 1998. An Investigation of the Status of Coastal Marine Resources along the West Coast of Madagascar. Report prepared for WWF in Madagascar. Centre for Dolphin Studies, Homewood, South Africa, 58 pp + table & map.

Connell, J., Brown, R. P. C., 2005. Remittances in the Pacific: An Overview. Manila: Asian Development Bank; The World Bank. 2008. Migration and Remittances Factbook 2008. Washington, DC: World Bank.

Cooke, B. A., 2002. Marine and coastal ecosystems of Madagascar. *Africa*

Cooke, A. J., Ratomahenina, O., Ranaivoson, E., Razafind- rainibe, H., 2000.

‘Madagascar’. In: Sheppard, C., (ed.) Seas at the Millenium: An Environmental Evaluation. Vol 2 Ch. 60 pp.113–131. Pergamon Press (Elsevier Science), Oxford

Cortes, E., 1998. Demographic analysis as an aid in shark stock assessment and management. Fish. Res. 39, 199–208

Cortes, J., Risk, M. J. A., 1985. Reef under siltation stress: Cahuita, Costa Rica. Bull. mar. Sci, v. 36, n. 2, p. 339- 356,

Day, T., Nagel, L., van Oppen, M. J. H., Caley, J. M., 2008. Factors Affecting the Evolution of Bleaching Resistance in Corals The American Naturalist vol. 171, no. 2

de la Torre-Castro, M., Rönnbäck, P., 2004. Links between humans and seagrasses – An example of tropical East Africa. Ocean & Coastal Management 47: 361-387.

de la Torre-Castro, M., 2006. Humans and seagrasses in East Africa – A social-ecological systems approach. Doctoral Dissertation. Stockholm University, Stockholm, Sweden. On-line: http:// www.diva-portal.org/diva/getDocument?urn_ nbn_se_su_diva-1061-2

De Ruijter WPM, Ridderinkhof H, Ludjeharms RE (2002) Observation of the flow in the Mozambique Channel. Geophysical Research Letters, 29, 1401-1403. 532 533 Diaz-Pulido, G., McCook, L. J., 2002. The fate of bleached corals: patterns and dynamics of algal recruitment. Marine Ecology Progress Series 232, 115–128. doi:10.3354/MEPS232115

Dodge, R. E., Aller, R. C., Thompson, J,. 1974. Coral growth related to re suspension of bottom sediments. Nature, Lond. 247: 574-577

Dodge, R. E., Vaisnys, J. R,. 1977. Coral populations and growth patterns: responses to sedimentation and turbidity associated with dredging. J. mar. Res. 35: 715-730

Done, T,. 1982. Patterns in the distribution of corals communities across the central

Great Barrier Reef. Coral Reefs 1, 95–107.

Done, T. J,. 1992. Phase shifts in coral reef communities and their ecological significance. Hydrobiologia 247, 121–132. doi:10.1007/ BF00008211

Donner, S. D., Skirving, W. J.,, Little, C., Oppenheimer, M., Hoegh-Guldberg, O., 2005. Global assessment of coral bleaching and required rates of adaptation under climate change. *Global Change Biology*, 2251-2265. doi: 10.1111/j.1365-2486.2005.01073.x.

Dorenbosch, M., Grol, M. G. G., Christianen, M. J. A., Nagelkerken, I., van der Valde, G., 2005. Indo- Pacific seagrass beds and mangroves contribute to fish density and diversity on adjacent coral reefs. Marine Ecology Progress Series 302: 63-76.

Douglas, A. E., 2003. Coral bleaching – how and why? Marine Pollution Bulletin, 46, 385–392.

Dryer, S., Logan, A., 1978. Holocene reefs and sediments of Castle Harbour, Bermuda. J. Mar. Res. 36, 399–425.

Duart, C, M., dand-Jensen K., 1996 Nutrient constraints on established from seed and on vegetative expansion of the Mediterranean seagrass *Cymodocea nodosa* Aquat. Bot. 54: 279-286

Dubinsky, Z., Jokiel, P. L., 1994. Pac Sci 48(3):313–324

Dumas, P., Kulbicki, M., Chifflet, S., Fichez, R., Ferraris, J., 2007. Environmental factors influencing urchin spatial distributions on disturbed

English S. Wilkinson C. Baker V., 2002. Survey manual for tropical marine resources 2nd ED Australian Institute of Marine Science:

Eritemeijer, P. L. A., Middelburg J J (1992). Sediment-nutrient interactions in tropical seagrass beds: a comparison between a terrigenous and a carbonate sedimentary environment in South Sulawesi (Indonesia). *Marine Ecology Progress Series*.

Erftemeijer P, L, A., Herman P, M, J 1994 Seasonal changes in environmental variables, biomass production and nutrient contents in two contrasting tropical intertidal seagrass beds in South Sulawesi, Indonesia, Oecologia 99: 45-49

Ferrier-Pages, C., Allemand, D., Gattuso, J. P., Jaubert, J., Rassoulzadegan, R., 1998. Microheterotrophy in the zoo- xanthellate coral Stylophora pistillata: effects of light and ciliate density. Limnol Oceanogr 43:1639–1648

Fishelson, L., 1973. Ecology of coral reefs in the Gulf of Aqaba (Red Sea) influenced by pollution. Oecologia 12, 55–67

Fitt, W. K., Spero, H. J., Halas, J. C., White, M. W., and Porter, J. W,. 1993. Recovery of the coral Montastrea annularis in the Florida Keys after the 1987 Caribbean ‘bleaching event’. Coral Reefs 12, 57–64. doi:10.1007/ BF00302102

Folk, R. L., Ward, W. C,. 1957. Brazos River bar: a study in the significance of grain size parameters. Journal of Sedimentary Petrology 27: 3–26.

Folk, R., Robles, P., 1964. Carbonate sands of Isla Perez, Alacran Reef Complex, Yucatan. J Geol 72:255–292

Folk, R.L., 1968. Petrology of Sedimentary Rocks. Hemphill Publishing, Austin, pp. 44e50.

Fonseca, M. S., and J. S. Fisher. 1986. A comparison of canopy friction and sediment movement between four species of seagrass with reference to their ecology and restoration. Marine Ecology Progress Series. 29:15-22.

Foster, A. B,. 1980. Environmental variation in skeletal morphology within the Canbbean reef corals Montastrea annularis and Siderastrea siderea. Bull. mar. Sci. 30: 678-709

Fourqurean J, W, Powell G, V, N., , Kenworhy W, J, Zieman, J. C., 1995 The effects of long-term manipulation of nutrient supply on competition between the seagrasses *Thalassia testudinum* and *Halodule wrightii* in Florida Bay. Oikos

72:349-358

Friedman, G. M., 1979. Differences in size distributions of populations of particles among sands of various origins. Sedimentology 26: 3–32.

Friedman, G. M., Johnson, K. G,. 1982. Exercises in Sedimentology. Wiley: New York

Frost, S.H., 1981. Oligocene reef coral biofacies of the Vicentin, northeast Italy. In: Toomey, T.F. (Ed.), European fossil reef models. Soc. Econ. Pal. Min. Spec. Publ., vol. 30, pp. 483–539.

Furnas, M., Mitchell, A., Skuza, M., Brodie, J,. 2005. In the other 90%: phytoplankton responses to enhanced nutrient availability in the Great Barrier Reef lagoon. Mar Pollut Bull 51:253–265

Gabrie, C., Vasseur, P., Randriamiarana, H., Maharavo, J., Mara, E., 2000. The coral reefs of Madagascar. In: McClanahan, T. R., Sheppard, C., Obura, D., (eds) Coral Reefs of the Indian Ocean. Oxford University Press, New York

Gardner, T, A Cote I, M., Gill J, A., Grant A., Watkinson A, R., 2005. Hurricanes and Caribbean coral reefs: impacts, recovery patterns, and role in long-term decline. *America*, *86*(1), 174-184.

Geister, J. 1977. The influence of wave exposure on the eco- logical zonation of Caribbean reefs. Proceedings of the Third International Coral Reef Symposium 1:23–39.

Gilmour, J., 1999. Experimental investigation into the effects of suspended sedimentation on fertilization, larval survival and settlement in a Scleractinian coral –Marine Biology 135: 451-462, Springer-Verlag

Genin, A., Lazar, B., Brenner, S., 1995. Nature 377, 507

Ginsburg R. N., Lowenstam H. A., 1958.The influence of marine bottom communities on depositional environment of sediments J. Geol 66: 310-318

Glynn, P. W. 1993. “Coral Reef Bleaching: Ecological Perspectives.” Coral Reefs 12: 1–17.

Goreau, T. F., 1959. Biol Bull 116:59–75

Goreau T, McClanahan T, Hayes R, Strong A. 2000. Conservation of coral reefs after the 1998 global bleaching event. Conservation Biology 14: 5–15.

Goulet, T. L., 2006. Most corals may not change their symbionts. *Marine Ecology Progress Series*, *321*(Baker 2003), 1-7.

Grimsditch, G. D., Salm, R. V., 2005. Coral Reef Resilience and Resistance to Bleaching. World.Press

Grimsditch, G., 2009. The Management of Natural Coastal Carbon Sinks. *Sciences-New York*, (November).

Gullström M, Torre Castro M, Bandeira S O. , Björk M , Dahlberg,M Kautsky N Rönnbäck P, Öhman M C. 2002 Seagrass Ecosystems in the Western Indian Ocean Vol. 31, No. 7/8, The Western Indian Ocean

Gullström, M., de la Torre-Castro, M., Bandeira, S.O., Björk, M., Dahlberg, M., Kautsky, N., Rönnbäck, P. & Öhman, M.C. (2002). Seagrass ecosystems in the Western Indian Ocean. Ambio 31(7-8): 588-596.

Haas, A. F., al-Zibdah, M., and Wild, C., 2010. Seasonal in-situ monitoring of coral–algae interaction stability in fringing reefs of the Northern Red Sea. Coral Reefs 29, 93–103. doi:10.1007/S00338-009-0556-Y

Harmelin-Vivien, M., 1994. The effects of storms and cyclones on coral reefs: a review. Journal of Coastal Research 12:211–231.

Hallock, P., Schlager, W., 1986. Nutrient excess and the demise of coral reefs and carbonate platforms. Palaios 1, 389-398

Halpern, B. S., Walbridge S., Selkoe K. A.., 2008. A global map of human impact on marine ecosystems. Science 319, 948–952

Harris, A., Manahira, G., Sheppard, A., Gough, C., Sheppard, C,. 2010. Demise of Hart, D. E., & Kench, P. S. (2006). Carbonate production of an emergent reef platform, Warraber Island, Torres Strait, Australia. *Coral Reefs*, *26*(1), 53-68. doi: 10.1007/s00338-006-0168-8.Madagascar’s once great barrier reef -

change in coral reef condition over 40 years. Atoll Research Bulletin, (574).

Hatcher, B. G., Larkum, A. W. D,. 1983. An experimental analysis of factors controlling the standing crop of the epilithic algal community on a coral reef. J Exp Mar Biol Ecol 69: 61–84.

Hill, J., Tetzlaff, D., Curtis, A., & Wood, R. (2009). Computers & Geosciences Modeling shallow marine carbonate depositional systems. *Computers and Geosciences*, *35*(9), 1862-1874. Elsevier. doi: 10.1016/j.cageo.2008.12.006.

Hinrichsen, D,. 1998. Coastal Waters of the World: Trends, Threats and Strategies. Island Press, Washington, 275 pp

Hoegh-Guldberg, O,. 1999. Climate change, coral bleaching and the future of the world's coral reefs. Mar. Freshw. Res. 50, 839–866.

Hoegh-Guldberg, O. 2007 Coral reefs under rapid climate change and ocean acidification. Science 318, 1737–1742. (doi:10.1126/science.1152509)

Hoegh-Guldberg, O, Salvat, B., 1995. Periodic mass-bleaching and elevated sea tem- peratures: bleaching of outer reef slope communities in moorea, French Polynesia. Marine Ecology Progress Series, 121, 181–190.

Holden, H., LeDrew, E., 1998. Spectral discrimination of healthy and non-healthy corals based on cluster analysis, principal components analysis, and derivative spectroscopy Remote Sens. Environ 65, 217-224.

Holmer , M., Nielsen, S. L., 1997. Sediment sulfur dynamics related to biomass-density pattern in Zostera marina (eelgrass) beds. Mar Ecol Prog Ser 146:163–171

Homer M Nielsen S L Sediment sulfur dynamics related to biomass-density patterns in *Zostera marina* (eelgrass) beds, Mar. Ecol. Progr. Ser. 146: 163-171

Huettel, M., Røy, H., Precht, E., Ehrenhauss, S., 2003. Hydrodynamical impact on biogeochemical processes in aquatic sediments. Hydrobiolo- gia 494, 231–236. doi:10.1023/A:1025426601773

Hubbard, J. A. E. B., Pocock, Y. K., 1972. Sediment rejection by recent scleractinian corals: a key to palaeo-environmental tion. Geol Rdsch 61:598-626

Hubbard, D. K,. 1997. Reefs as dynamic systems. In: BIRKELAND, C. (Ed.) Life and death of coral reefs. New York: Chapman and Hall, p. 43-67.

Huettel M, Gust G 1992 Impact of bio roughness on interfacial solute exchange in permeable sediments Mar. Ecol. Prog. Ser, 89: 253-267

Huettel, M., Wild, C., and Gonelli, S., 2006. The mucus trap in coral reefs: formation and temporal evolution of aggregates caused by coral mucus. Marine Ecology Progress Series 307, 69–84. doi:10.3354/MEPS307069Huettel M, Rusch A 2000 Transport and degradation of phytoplankton in permeable sediment Limnol. Oceanogr 45: 534-549

Hughes, T. P., 1994. Catastrophes, phase shifts, and large-scale degradation of a Caribbean coral reef. Science, 265, p. 1547-1551

Hughes, T. P, Baird, A. H., Bellwood, D, R., 2003 Climate change, human impacts, and the resilience of coral reefs. Science 301, 929–933. (doi:10.1126/science.1085046)

Hughes, T. P., Bellwood, D. R., Folke, C., Steneck, R. S., Wilson, J. 2005. New paradigms for supporting the resilience of marine ecosystems. Evolution, 20(7).

Hughes, T. P.2007. Phase shifts, herbivory and the resilience of coral reefs to climate change. Curr Biol 17:1–6 doi:10.1016/ j.cub.2006.12.049

Hughes, T. P., Graham, N. A. J., Jackson, J. B. C., Mumby, P. J., Steneck, R. S., 2010. Rising to the challenge of sustaining coral reef resilience. Trends Ecol Evol 25:633–642

Hughes, T. P., Bellwood, D. R., Baird, a H., Brodie, J., Bruno, J. F., Pandolfi, J. M. 2011. Shifting base-lines, declining coral cover, and the erosion of reef resilience: comment on Sweatman et al. (2011). Coral Reefs.

Hutchings, P., Haynes, D,. Goudkamp, K., McCook, L., 2005. Catchment to Reef: Water Quality Issues in the Great Barrier Reef Region--an Overview of

Papers. Marine Pollution Bulletin 51: 3;

Idestam-Almquist J., Kautsky L., 1995 Plastic responses in morphology of *Potamogeton pectinatus* to sediment and above-sediment conditions at two sites in the northern Baltic proper Aquat. Bot. 52: 205-216

Inns, J. L., 2010. Madagascar rosewood, illegal logging and the tropical timber trade. Madagascar Conservation and development Vol. 5

Jambu, M., Lebeaux, M., 1983. Cluster analysis and data analysis. Amsterdam: North Holland Publishing Company.

Johnson, J. E., Marshall, P. A., 2007. Climate Change and the Great Barrier Reef: A Vulnerability Assessment. Great Barrier Reef Marine Park Authority, Townsville, Australia.

Johnsond. P,. Risk, M. J,. 1987. Fringing reef growth on a terrigenous mud foundation, Fantome Island, central Great Barrier Reef, Australia. Sedimentology 34, 275–287.

Jones GP, McCormick MI, Srinivasan M, Eagle JV. 2004. Coral decline threatens fish biodiversity in marine reserves. Proceedings of the National Academy of Sciences, USA 101: 8251–8258.

Kenworthy W J Zieman J C., 1982 Evidence for the influence of seagrasses on the benthic nitrogen cycle in a coastal plain estuary near Beaufort, North Carolina (USA) Oecologia, 54: 152-158

Kench, P. S., 1997. Contemporary sedimentation in the Cocos (Keeling) Islands, Indian Ocean: interpretation using settling velocity analysis. Sediment Geol 114:109–130

Kendall, M.S., Christensen, J., Hillis-Starr, J., 2003. Multi-scale data used to analyze the spatial distribution of French grunts, Haemulon flavolineatum, relative to hard and soft bottom in a benthic landscape. Environ. Biol. Fish. 66, 19–26.1996. Coral reef development under naturally turbid conditions: fringing reefs near Broad Sound, Australia. Coral Reefs 15, 153–167.

Kirkman H., 1978 Decline of seagrass in northern areas of Moreton Bay, Queensland, Aquat. Bot. 5: 63-76

Kirkman H., 1996 Baseline and monitoring methods for seagrass meadows. J. Environ. Mgmnt 47: 191-201

Kleypas, J. A.,. Hopley, D,. 1992. Reef development across a broad continental shelf, southern Great Barrier Reef,Australia. Proceedings of the 7th International Coral Reef Symposium,Guam1, 1129–1141.

Kleypas, J.A., Langdon, C., 2006. Coral reefs and changing seawater chemistry. In: Coral Reefs and Climate Change: Science andManagement. AGU Monograph Series, Coastal and Estuarine Studies, Vol 61, (eds Phinney JT, Hoegh-Guldberg O, Kleypas J, Skirving W, Strong A), pp. 73–110. Am. Geophys. Union, Washington, DC.Knowlton N, Jackson JBC (2008) Shifting baselines, local impacts, and global change on coral reefs. PLoS Biology, 6, 215–220.

Kline, D. I., Diaz-Pulido, G., Dove, S., Hoegh-Guldberg, O., 2008. Ocean acidification causes bleaching and productivity loss in coral reef builders. Proceed- ings of the National Academy of Science, 105, 17442–17446.

Kohler, K.E., Gill, S.M., 2006. Coral Point Count With Excel Extensions (Cpce): a Visual Basic Program for the Determination of Coral and Substrate Coverage Using Random Point Count Methodology. Comput. Geosci. 32 (9), 1259–1269.

Krumbein WC, Pettijohn FJ. 1938. Manual of Sedimentary Petrography. Appleton-Century-Crofts: New York

Lam, K., Shin, P.K.S., Bradbeer, R., Randall, D., Ku, K.K.K., Hodgson, P., Cheung, S.G., 2006. A Comparison of Video and Point Intercept Transect Methods for Monitoring Subtropical Coral Communities. J. Exp. Mar. Biol. Ecol. 333 (1), 115–128.

Lanyon J, M., Marsh H., 1995 Tropical changes in the abundance of some tropical intertidal seagrasses in North Queensland Aquat. Bio. 49: 217-237

Lapointe, B. E,. 1997. Nutrient thresholds for bottom-up control of macroalgal blooms on coral reefs in Jamaica and southeast Florida. Limnology & Oceanography, 42, 1119– 1131.

Larcombe, P., Woolfe, K,. 1999. In- creased sediment supply to the Great Barrier Reef will not increase sediment accumulation at most coral reefs. Coral Reefs 18:163-169.

Larcombe, P., Costen, A., Woolfe, K.J., 2001. The hydrodynamic and sedimentary setting of nearshore coral reefs, central Great Barrier Reef shelf, Australia: Paluma shoals, a case study. Sedimentology 48, 811–835.

Laroche, J., Ramananarivo N., 1995. A preliminary survey of the artisanal fishery on coral reefs of the Tulear Region (southwest Madagascar). Coral Reefs 14, 193–200

Lasker, H. R,. 1980. Sediment rejection by reef corals: the roles of behavior and morphology in Montastrea cavernosa (Linnaeus). J. exp. mar. Biol. Ecol. 47: 77-87

Le Manach, F., Gough, C., Harris, A., Humber, F., Harper, S., Zeller, D,. 2011. Unreported fishing , hungry people and political turmoil : the recipe for a food security crisis in Madagascar ? J.Mar Pol.

Lirman, D., 2001. Competition between macroalgae and corals: effects of herbivore exclusion and increased algae biomass on coral survivorship and growth. Coral reefs 392-399

Lota, Y., 1976. Effects of water turbidity and sedimentation on the community structure of Puerto Rican Corals. Bull. Mar. Sci., v. 26, n. 4, p. 450-466,

Lough, J.M. 2001. Unprecedented thermal stress to coral reefs? Geophysical

Research Letters 27: 3901-3904.

Loya, Y., Sakai, K., Yamazato, K., Nakano, Y., Sambali, H., Van Woesik, R., 2001. Coral bleaching: the winners and the losers. Ecology Letters, 4, 122–131.

Macintyre, I. G., Graus, R. R., Reinthal, P. N., Litter, M. M., Litter, D. S., 1987. The Barrier Reef sediment apron: Tobacco Reef, Belize. Coral Reefs 6:1–12

Maharavo, J., 1997. National Centre for Oceanographic Research Mission Report. (unpub). 1997. 14 p.

Maharavo, J., 1999. Atelier de formation sur le suivi des recifs coralliens et utilisation de la base de donnee 'ARMDES'. Antalaha, 28th Novembre au 2nd Decembre 1999. (Unpub. Tech. Rep. PRE/COI)

Maliao, R. J., Turingan, R. G., and Lin, J., 2008. Phase-shift in coral reef communities in the Florida Keys National Marine Sanctuary (FKNMS), USA. Marine Biology 154, 841–853. doi:10.1007/S00227-008-0977-0

Marshall, S.M., Orr, A.P., 1931. Sedimentation on Low Isles reef and its relation to coral growth. Scientific reports of the Great Barrier Reef Expedition 1/5, 93–132.

Marshall, Schuttenberg., 2006 a reef managers guide to coral bleaching Great Barrier Reef Marine Park Authority

Marubini F, Barnett H, Langdon C, Atkinson MJ (2001) Mar Ecol Prog Ser 220:153–162

Marubini, F., Davies, P., 1996). Nitrate increases zooxanthellae population density and reduces skeletogenesis in corals. Marine Biology 127, 319–328.

Maiklem WR (1968) Some hydraulic properties of bioclastic car- bonate grains. Sedimentology 10:101–109

Mayer, A.G., 1918. Ecology of the Murray Island coral reef. Carnegie Inst. Washington publ. 213, 9, 3–48

McClanahan T. R., 2007. Achieving sustainability in East African coral reefs . Journal of Marine Science and Environment

McClanahan, T. R, Arthur, R., 2001. The effect of marine reserves and habitat on populations of East African coral reef fishes. Ecological Applications 11: 559–569.

McClanahan TR, Ateweberhan M, Sebastian CR, Graham NAJ, Wilson SK, Bruggemann H, Guillaume M. 2007. Western Indian Ocean coral communities, bleaching responses, and susceptibility to extinction. Marine Ecology Progress Series 337: 1–13.

Mcclanahan, T. R., Ateweberhan, M., Omukoto, J., & Pearson, L., 2009. Recent seawater temperature histories , status , and predictions for Madagascar ' s coral reefs. Marine Ecology Progress Series, 380, 117-128. doi: 10.3354/meps07879.

McClanahan, T. R., Cinner, J. C., Maina, J., Graham, N. A. J., Daw, T. M., Stead, S. M., Wamukota, A., Brown., Ateweberhan, M., Venus, V., Polunin, N. V. C,. 2008. Conservation action in a changing climate Conservation Letters

McClanahan, T. R., Muthiga, N. A.,1998. An ecological shift in a remote coral atoll of Belize over 25 years. Environ. Conserv. 25, 122–130

McClanahan T R, Maina J. Moothien-Pillay R. , Baker A. C., 2005. Effects of geography, taxa, water flow, and temperature variation on coral bleaching intensity in Mauritius Mar Ecol Prog Ser Vol. 298: 131–142,

McClanahan, T. R., Obura, D., 1995. 'Status of Kenyan Coral Reefs'. Coastal Management 23: 57–76.

McClanahan, T.R., Obura, D., 1997. Sedimentation effects on shallow coral communities in Kenya. J. Exp. Mar. Biol. Ecol. 209, 103–122.

McClanahan, T. R., Obura. D., 1998. Monitoring, training and assessement of the coral reefs of the Masoala Penin- sula. Wildlife Conservation Society, June 1998.

McClanahan, T. R, Shafir, S. H., 1990. Causes and consequences of sea urchin abundance and diversity in Kenyan coral reef lagoons. Oecologia 83:362–370

McManus, J. W., L. A. B. Menez, K. N. Kesner-Reyes, S. G. Vergara., M. C. Ablan., 2000. Coral reef fishing and coral- algal phase shifts: implications for global reef status. Journal of Marine Science 57:572–578.

Mellors J, E 1991 An evolution of a rapid visual technique for estimating seagrass biomass Aquat. Bot. 42: 67-73

McKenna S.A. and G.R Allen, eds. 2003. A Rapid Marine Biodiversity Assessment of Northwest Madagascar. Bulletin of the Rapid Assessment Program 31, Conservation International, Washington, DC.

Moberg, F., Folke, C., 1999. Ecological goods and services of coral reef ecosystems. Ecological Economics 29:215–233.

Mora, C., 2009. A clear human footprint in the coral reefs of the Caribbean. Society, 767-773. doi: 10.1098/rspb.2007.1472.

Mount, F., 1985. Mixed siliciclastic and car- bonate sediments: A proposed first-order textural and compositional classification. Sedimentology 32:435-442.

Mumby, P.J., 2001. Beta and Habitat Diversity in Marine Systems: a New Approach to Measurement, Scaling and Interpretation. Oecologia 128 (2), 274–280.

Munday, P. L., Jones, G. P., Pratchett, M. S. and Williams, A. J. (2008a). Climate change and the future for coral reef fishes.

Munday, P. L., Kingsford, M., O'Callaghan, M. and Donelson, J. M.., 2008b. Elevated temperature restricts growth potential of the coral reef fish 27, 927-931.

Muscatine, L., 1973. Nutrition of corals. In: Jones, O.A., Endean, R. (Eds.), The geology and biology of coral reefs, vol. 2. Academic Press, London, pp. 77–115.

Muscatine, L., 1990. The role of symbiotic algae in carbon and energy flux in reef corals. In: Dubinsky, Z. (Ed.), Ecosystems of theWorld, Coral Reefs, vol. 25. Elsevier, Amsterdam, pp. 75–879, 261-285.

Muscatine, L., Falkowski, P. G., and Porter, J., 1984. Fate of photosynthetic fixed carbon in light and shade-adapted colonies of the symbiotic coral Stylophora pistillata. Proceedings of the Royal Society of London, Series B. Biological Sciences 222, 181–202. doi:10.1098/RSPB.1984.0058

Nadon, M. O., Griffiths, D., Doherty, E., Harris A. 2007. The Status of Coral Reefs in the Remote Region of Andavadoaka, Southwest Madagascar; Western Indian Ocean J. Mar. Sci. 6: 207–218

Nagelkerken I, Dorenbosch M, Verberk WCEP, Cocheret de la Morinière E, van der Velde G (2000) Day-night shifts of fishes between shallow-water biotopes of a Caribbean bay, with emphasis on the nocturnal feeding of Haemu- lidae and Lutjanidae. Mar Ecol Prog Ser 194:55–64

Nguyen, Vinh-Kim, and Karine Peschard 2003 Anthropology, Inequality, and Disease: A Review. Annual Review of Anthropology 32:447–474.

Nakamura, T., and van Woesik, R. (2001). Water-flow rates and passive diffusion partially explain differential survival of corals during the 1998 bleaching event. Marine Ecology Progress Series 212, 301–304. doi:10.3354/MEPS212301

Naumann, M., Richter, C., el-Zibdah, M., and Wild, C., 2009.. Coral mucus as an efficient trap for picoplanktonic cyanobacteria – implications for pelagic–benthic coupling in the reef ecosystem. Marine Ecology Progress Series 385, 65–76. doi:10.3354/MEPS08073

Neckles, H. A., Kopp, B. S., Peterson, B. J., Pooler, P. S., 2011. Integrating Scales of Seagrass Monitoring to Meet Conservation Needs. Estuaries and coasts. doi: 10.1007/s12237-011-9410-x.

Nemeth, R. S,. Sladeck-Nowlis, J,. 2001. Monitoring the effects of land development on the nearshore reef environment of St. Thomas, USVI. Bull. Mar. Sci., v. 69, n. 2, p. 759-775

Norström, A. V., Nyström, M., Lokrantz, J. and Folke, C,. 2009. Alternative states on coral reefs: beyond coral macroalgal phase shifts. Mar. Ecol Prog. Ser 376 295-306

Nyström, M., Folke, C., Moberg, F., 2000. Coral reef disturbance and resilience in a human-dominated environment. Trends Ecol. Evol., v. 15, n. 10, p. 413- 417

Orth, R.J., T.J.B. Carruthers, W.C. Dennison, C.M. Duarte, J.W. Fourqurean, K.L. Heck Jr., A.R. Hughes, G.A. Kendrick, W.J. Kenworthy, S. Olyarnik, F.T. Short, M. Waycott, and S.L. Williams. 2006. A global crisis for seagrass ecosystems. Bioscience 56: 987–996.

Ochieng, C.A., Eftermeijer P. L.. A.,1999. Accumulation of seagrass beach cast along the Kenyan coast: a quantitative assessment. Aquatic Botany 65: 221-238.

Ogden, J. C., Buckman, N. S., 1973. Movements, foraging groups, and diurnal migrations of the striped parrotfish Scarus croicensis Bloch (Scaridae). Ecology 54:589–596

Osinga, R., 2008. In: Leewis RJ, Janse M (Eds.). Advances in coral husbandry in public aquariums. Public aquarium husbandry series, Vol 2, pp. 167–171

Ogden, J. C., Ehrlich, P. R., 1977. The behavior of heterotypic resting schools of juvenile grunts (Pomadasyidae). Mar Biol 42:273–280

Obura, D. O .,2001. Can differential bleaching and mortality among coral species offer useful indicators for assessment and management of reefs under stress? Bulletin of Marine Science, 69, 421–442.

Osinga, R., Schutter, M., Griffioen, B., Henard, S., Taruffi, M., 2011. The Biology and Economics of Coral Growth. *Marine Biotechnology*. doi: 10.1007/s10126-011-9382-7.

Pastorok, R. A., Bilyard, G. R,. 1985. Effects of sewage pollution on coral-reef communities. Mar. Ecol. Prog. Ser. 21: 175-189

Pet-Soede, L.H., Cesar, S.J., Pet, J.S., 1999. The economics of blast fishing on Indonesian coral reefs. Environmental Conservation 26, 83–93.

Pedersen, O., Binzer, T. and Borum, J. 2004. Sulphide intrusion in eelgrass (Zostera marina L.). Plant, Cell and Environment 27: 595-602

Pegg, J., Gordon, L., Steer, M. D., 2009. An initial rapid assessment of reefs and mangroves in Nosy Hara, Madagascar. Frontier Madagascar Environmental Research Report 23. Society for Environmental Exploration, UK; ANGAP; Conservation International

Perez, M., Invers, O., Ruiz, J.M., Fredriksen, M.S. and Holmer, M. 2007. Physiological responses of the seagrass Posidonia oceanica to elevated organic matter content in sediments: An experimental assessment. Journal of Experimental Marine Biology and Ecology 344: 149-160.

Pichon, 1972. The Coral Reefs of Madagascar. In: Richard-Vindard RBaG (ed) Biogeography and Ecology in Madagascar. Dr W. Junk B.V. Publishers, Hague, pp 367-416

Porter, J.L., 1974. Zooplankton feeding by the Caribbean reef-building coral, *Montastrea cavernosa*. In: Proc. 2nd Int. Coral Reef Symp., Brisbane 1, pp. 111–125.

Porter, J.W., 1976. Autotrophy, heterotrophy, and resource partitioning in Caribbean reef-building corals. Amer. Natur. 110, 731–742.

Purdy EG, Gischler E (2005) The transient nature of the empty bucket model of reef sedimentation. Sediment Geol 175:35–47

Porter, J. W., Fitt,W.K., Spero, H. J., Rogers, C. S., White, M. N., 1989. Bleaching in reef corals: physiological and stable isotopic responses. Proceedings of the National Academy of Sciences of the United States of America 86, 9342–9346. doi:10.1073/PNAS.86.23.9342

Pratchett, M.S., P.L. Munday, J. Wilson, N. A. J. Graham, J. E. Cinner, D. R. Bellwood, G. P. Jones, N. V. C. Polunin and T. R. McClanahan 2008. Effects of climate-induced coral bleaching on coral-reef fishes - ecological and economic consequences. Oceanography and Marine Biology: An Annual

Review 46:251–296

Pulich Jr, W. M., 1985 Seasonal growth dynamics of *Ruppia maritime* L. and *Halodule wrightii* Aschers. in southern Texas and evaluation of sediment fertility status Aquat. Bot. 23:53-66

Quod, J. P., Bigot, L., 1999. Coral bleaching in the indian ocean islands: ecological consequences and recovery in madagascar, comoros, mayotte and reunion. *Change*.

Randrianamantsoa, B. J. and J. Brand. 2000. Etude de reconnaissance et zonage des écosystèms marins. Rapport d'étude. Development Evironment Consultants. Report prepared for Projet UNESCO-MAB Mananara-Nord. Antananarivo. 66 pp.

Reason, C.J.C. Mulenga H. , Relationships between South African rainfall and SST anomalies in the southwest Indian Ocean, Int. J. Climatol. 19 (1999) 1651–1673.

Reason, C.J.C., Rouault , M., 2002. ENSO-like decadal variability and South African rainfall, Geophys. Res. Lett. 29 10.1029.

Reynaud S, Ferrier-Pagès C, Boisson F, Allemand D, Fairbanks RG (2004) Mar Ecol Prog Ser 279:105–112

Richard, Y., Trzaska , S., Roucou, P., Rouault , M., 2000. Modifica tion of the southern African rainfall variability/ENSO relationship since the late 1960's, Climate Dynamics 16 883–895.

Richmond, R. H,. Coral reefs: present problems and future concerns resulting from anthropogenic disturbance. Am. Zool., v. 33, p. 524-536, 1993.

Riddle, J., 1988. Cyclone and Bioturbation Effects on Sediments from Coral Reef Lagoons. *Science*, 687-695.

Riegl, B., 1995a. Description of four new species in the hard coral genus *Acropora Oken*, 1815 (*Scleractina: Astrocoeniina: Acroporidae*) from south-east Africa. Zoological Journal of the Linnean Society 113: 229–247.

Riegl, B., 1995b. A revision of the hard coral genus *Acropora Oken*, 1815 (*Scleractina: Astrocoeniina: Acroporidae*) in south-east Africa'. Zoological Journal of the Linnean Society 113: 249–288.

Rodgers C. S., 1990. Responses of coral reef and reef organisms to sedimentation. *Marine Ecology Progress Series, vol. 62: 185-202.,1990*

Rogers C. S,. 1983. Sub-lethal and lethal effects of sediments applied to common Caribbean reef corals in the field. Mar. Pollut. Bull. 14: 378-382

Rogers, C. S., Fitz, H. C., Gilnack, M., Beets, J., Hardin, J., 1984. Scleractinian coral recruitment patterns at Salt River submarine canyon, St. Croix, U.S.V.I. Coral Reefs 3:69-76

Roland, L. R. D., Rajaonarison, R. (1999). Status and Management of the Marine Protected Areas in Madagascar . *Network*, *70*.

Roman, M. R., Furnas, M. J., Mullin, M. M., 1990. Zooplankton abundance and grazing at Davies Reef, Great Barrier Reef, Australia. Mar. Biol. 105, 73–82.

Rooker JR, Dennis GD (1991) Diel, lunar and seasonal changes in a mangrove fish assemblage off southwestern Puerto Rico. Bull Mar Sci 49:684–698

Rosenfeld, J. K., 1979. Ammonium adsorption in nearshore anoxic sediments. Limnol. Oceanogr. 24: 356-364

Roux, J. P. L., & Rojas, E. M. (2007). Sediment transport patterns determined from grain size parameters: Overview and state of the art. *Delta*, *202*(2), 473 - 488. doi: 10.1016/j.sedgeo.2007.03.014.

Roy, K.J., Smith, S.V., 1971. Sedimentation and coral reef development in turbid water: Fanning Lagoon. Pac. Sci. 25, 234–248.

Sabine CL, Feely RA, Gruber N., 2004. The oceanic sink for anthropogenic CO2. Science, 305, 367–371.

Sammarco, P.W., 1996. Comments on coral reef regeneration, bioerosion, biogeography, and chemical ecology: future directions. J. Exp. Mar. Biol. Ecol. 200, 135–168.

Sanders, D., Pons, J.M., 1999. Rudist formations in mixed siliciclastic-carbonate depositional environments, Upper Creta- ceous, Austria: stratigraphy, sedimentology, and models of development. Palaeogeogr., Palaeoclimatol., Palaeoecol. 148,249-284

Sanders, D., Baron-Szabo, R. C,. 2005. Scleractinian assemblages under sediment input: their characteristics and relation to the nutrient input concept.

Sanders, D., Baron-Szabo, R.-C., 2011. Cretaceous bioconstruc- tions and coral-dominated assemblages in relation to deposi- tional environment, Eastern Alps. In: Hubmann, B., Piller, W. (Eds.), Fossil Reefs of Austria. O Komm., Vienna. sterr. Akad. Wiss., Erdwiss.

Palaeogeography, Palaeoclimatology, Palaeoecology, 216(1-2), 139-181.

Sandro, A., Fabiani, M., Nattabi, B., Corrado, B., Emingtone, R. I., Pido, O. A. B., Onek, P. A,. Ogwang, M., Delich, S., 2005. The Disease Profiles of Poverty: Morbidity and Mortality in Northern Uganda in the Context of War, Population Displacement and HIV/AIDS. Transactions of the Royal Society of Tropical Medicine and Hygiene 99(3):226–233.

Sano, M., Shimizu, M., Nose, Y,. 1987. Long term effects of destruction of hermatypic corals by *Acanthaster planci* infestation on reef fish communities at Iriomote Island, Japan. Mar. Ecol. Prog. Ser. 37: 191-199

Schneider, K., Erez, J., 2006) Limnol Oceanogr 51(3):1284–1293

Scoffin, T. P., 1992. Taphonomy of coral reefs: a review. Coral Reefs 11:57–77

Schlager, W., 1981. The paradox of drowned reefs and carbonate platforms. Geol. Soc. Amer. Bull. 92, 197–211.

Schlichter, D., Brendelberger, H., 1998. Plasticity of the scleractinian body plan: functional morphology and trophic specialization of *Mycedium elephantotus* (Pallas, 1766). Facies 39, 227–242.

Schlacher, T. A.,, Stark, J., Fischer, A. B. P., 2007. Aquaculture 269:278– 289

Schutter M, Van Velthoven B, Janse M, Osinga R, Janssen M,Wijffels R, Verreth J.,

2008. J Exp Mar Biol Ecol 67:75–80

Sebens, K. P., Vandersall, K. S., Savina, L. A., Graham, K. R., 1996. Zooplankton capture by two scleractinian corals, *Madracis mirabilis* and *Montastrea cavernosa*, in a field enclosure. Mar. Biol. 127, 303–317

Short, F.T., 1987. Effects of sediment nutrients on seagrasses: Literature review and mesocosm experiments. Aquatic Botany 27: 41-57.

Sheppard, C. R. C. 2003. Predicted recurrences of mass coral mortality in the Indian Ocean. Nature 425:294–297.

Simo, A., 1993. Cretaceous carbonate platforms and stratigraphic sequences, south-central Pyrenees, Spain. In: Simo, J.A.T., Scott, R.W., Masse, J.-P. (Eds.), Cretaceous carbonate platforms, Amer. Assoc. Petrol. Geol. Mem., vol. 56, pp. 325–342.

Smith, S. G., Ault, J. S., Bohnsack, J. A., Harper, D. E., Luo, J., Mcclellan, D. B,. 2011. Multi-species survey design for assessing reef-fish stocks, spatially explicit management performance, and ecosystem condition. Fisheries Research, 109 (1), 25-41. Elsevier

Smith, S. V., 1981. The Houtman Abrolhos Islands: carbon metabolism of coral reefs at high latitudes. Limnol Oceanogr 26:612–621

Smith, R.D., Pregnall, A.M. and Alberte, R.S. 1988. Effects of anaerobiosis on root metabolism of Zostera marina (eelgrass): Implications for survival in reducing sediments. Marine Biology 98: 131-141.

Sorokin Y I 1990 Aspects of tropical relations, productivity and energy balance in coral reef ecosystems. . Coral Reefs 291-327

Souter, D., Wilhelmsson, D., Obura, D., 2002. Coral Reef Degradation in the Indian Ocean. *Director*.

Sorokin, Y.I., 1990. Plankton in the reef ecosystem. In: Dubinsky, Z. (Ed.), Ecosystems of the World, Coral Reefs, vol. 25. Elsevier, Amsterdam, pp.

291–327

Souter, D., Wilhelmsson, D., Obura, D,. 2002. Coral Reef Degradation in the Indian Ocean. *Director*.

Spalding, M. D., C. Ravilious., E. P. Green., 2001. World Atlas of Coral Reefs. Prepared at the UNEP World Con- servation Monitoring Centre, University of California Press, Berkeley, U.S.A.

Stiles, D., 1998. The Mikea hunter-gatherers of South-west Madagascar: Ecologyand socioeconomic African Study Monographs, 19(3): 127-148

Stafford-Smith M. G., 1992. Mortality of the hard coral *Leptoria Phrygia* under persistent sediment influx. Pac. 7th Int. Coral. Reef. Symp. Guam 1, 289-299.

Stafford-Smith, M. G., Ormond, R. F. G,. 1995. Sediment-rejection mechanisms of 42 species of Australian *Scleractinian* corals *Australian J. Mar. Freshwater Res.,, 43, 683-705*

Stafford-Smith, M. G., 1993. Sediment-rejection efficiency of 22 species of Australian scleractinian corals. Mar. Biol. 115, 229–243.

Stafford-Smith, M. G., Ormond, R. F. G., 1992. Sediment-rejection mechanisms of 42 species of Australian scleractinian corals. Australian Journal of Marine and Freshwater Research 43, 683–705.

Suggett, D.J ., Smith, D. J., 2011. Interpreting the sign of coral bleaching as friend vs. foe. Global Change Biology, 45-55. doi: 10.1111/j.1365-2486.2009.02155.x.

Sussman, R. W., 1994. Satellite Imagery, Human Ecology, Anthropology, and Deforestation in Madagascar, *22*(3).

Taylor, M., Ravilious, C., Green, E. P,. 2003. Mangroves of East Africa of East Africa. UNEP World Conservation Monitoring Centre

Thomassin, B., 1971. Révue bibliographique des travaux de la Station Marine de Tuléar (Madagascar) 1961-1970. Téthys, Supplement 1: 3-49.

Titlyanov, E. A., Titlyanova, T. V., Yamazato, K., Van Woesik, R., 2001. J Exp Mar Biol Ecol 263:211–225

Tomascik, T., Sander, F., 1985. Effect of eutrophication on reef- building corals. I. Growth rate of the reef-building coral *Montastrea annularis*. Mar. Biol. 87, 143–155.

Tomascik, T., Sander, F,. 1987. Effects of eutrophication on reef-building corals. 111. Reproduction of the reef-building coral Porites porites. Mar. Biol. 94: 77-94

Torre-castro, M. D., Eklöf, J. S., Rönnbäck, P., & Björk, M. (2008). Seagrass Importance in Food Provisioning Services : Fish Stomach Content as a Link between Seagrass Meadows and Local Fisheries, 95-110.

Tucker, B., Humber, F., Benbow, S., Iida, T., 2010. Foraging for Development: a Comparison of Food insecurity, Production, and risk among Farmers, Forest Foragers, and marine Foragers in Southwestern madagascar. *Society*, *69*(4), 375-386.

Tucker, B., Huff, A., Tombo, J., Hajasoa, P., Nagnisaha, C. 2011. When the Wealthy Are Poor: Poverty Explanations and Local Perspectives in Southwestern Madagascar. American Anthropologist, 113(2), 291-305

Turner, J., Klaus, R., 2005. Coral reefs of the Mascarenes , Western Indian Ocean Coral reefs of the Mascarenes ,. Coral Reefs, 229-250. doi: 10.1098/rsta.2004.1489.

Uku, J. & Björk, M. (2005). Productivity aspects of three tropical seagrass species in areas of different nutrient levels in Kenya. Estuarine, Coastal and Shelf Science 63: 407–420.

Underwood, J . N., Smith, L. D., Van Oppen M. J . H. GILMOUR J . P., 2006. Multiple scales of genetic connectivity in a brooding coral on isolated reefs following catastrophic bleaching. *Molecular Ecology*. doi: 10.1111/j.1365-294X.2006.03187.x.

Vasseur, P., B. A. Thomassin, B. Randriamanantsoa and M. Pichon 2000. Main changes in the last 30-40 years on coral reefs and coastal areas induced mostly by human pressure: the Tulear region example (SW Madagascar, Indian Ocean). 9th International Coral Reef Symposium

Veron, J.E.N. 2000. Corals of the World. Vols 1-3. El Cajon, CA: Odyssey Publishing.

Veron, J. E. N., Lenton, T. M., Lough, J. M., Obura, D. O., Sheppard, C. R. C., Spalding, M., 2009. The coral reef crisis: The critical importance of<350ppm CO2. Marine Pollution Bulletin, 58(10), 1428-1436. Elsevier

Vinh-Kim, N., Peschard , K., 2003. Anthropology, Inequality, and Disease: A Review. Annual Review of Anthropology 32:447–474.

Walker, B. K., 2008. A Model Framework for Predicting Reef Fish Distributions Across the Seascape Using GIS Topographic Metrics and Benthic Habitat Associations. North, (July), 7-11

Washington, R., Todd, M., 1999. Tropical–temperate links in South- ern African and southwest Indian Ocean satellite-derived daily rainfall, Int. J. Climatol. 19 1601–1616.

Waycott, M., Duarte, C. M., Carruthers, T. J. B., Orth, R. J., Dennison, W. C., Olyarnik, S., Calladine, A., Fourqurean, J.W., Heck Jr, K. L., Hughes, A. R., Kendrick, G. A., Kenworthy, W. J,. Short, F. T., Williams, S. L., 2009. Accelerating loss of seagrasses across the globe threatens coastal ecosystems. Proceedings of the National Academy of Sciences 106: 12377–12381.

Webster, F., McMahon, K,. 2002. An assessment of coral reefs in the north west Madagascar. In Linden O., Souter D., Wilhelmsson D. & Obura D. (eds.). Coral reef degradation in the Indian ocean: Status report 2002. Cordio, pp. 190-201.

Wesseling, I., Uychiaoco, A.J., Alino, P., Aurin, T., Vermaat, J.E., 1999. Damage and recovery of four Philippine corals from short-term sediment burial. Mar. Ecol. Progr. Ser. 176, 11–15.

Weydert P., 1973. Morphologie et sédimentologie de la partie méridionale du grand récif de Tuléar (Madagascar): les ensembles sédimentaires de la pente interne. Téthys, supplément 5: 133-156.

, C., Rasheed, M., Werner, U., Franke, U., Johnstone, R., 2004b. Degradation and mineralization of coral mucus in reef envir- onments. Marine Ecology Progress Series 267, 159–171.

Wild, C., Tollrian, R., and Huettel, M., 2004c. Rapid recycling of coral mass spawning products in permeable reef sediments. Marine Ecology Progress Series 271, 159–166.

Wild, C., Hoegh-Guldberg, O., Naumann, M. S., Colombo-Pallotta, F., Ateweberhan, M., Fitt, W, K., Iglesias-Prieto, R., Palmer, C., Bythell, J. C., Ortiz, J-C., Loya, Y., van WoesikK R-A Coral Reef Ecology Group (CORE), Leibniz Center for Tropical Marin., 2011. Climate change impedes scleractinian corals as primary reef ecosystem engineers. Marine And Freshwater Research, 205-215.

Williams, I, D., Polunin, N, V, C., 2001. Large scale associations between macroalgal cover and grazer biomass on mid-depth reefs in the Caribbean. Coral Reefs 19:358–366Wild, C., Huettel, M., Klueter, A., Kremb, S. G., Rasheed, M., 2004a. Coral mucus functions as an energy carrier and particle trap in the reef ecosystem. Nature 428, 66–70.

Wilkinson, C., 1996. Global change and reefs: impacts on reefs, economies and human cultures. Global Change Biology. 2 (6): 547-58

Wilkinson, C.R. 1998. The 1997-1998 mass bleaching event around the world. In: Wilkinson C.R. (ed.) Status of coral reefs of the world, 1998. Australian Institute of Marine Science. pp 15 - 38.

Wilkinson, C., 2002. Status of Coral Reefs of the World. Australian Institute of Marine

Williams, G. J., Aeby, G. S., Cowie, R. O. M., Davy, S. K., 2010. Predictive Modeling of Coral Disease Distribution within a Reef System. PLoS ONE 5(2): e9264. doi:10.1371/journal.pone.0009264 Science, Townsville, Australia.

Woolfe, K. J., Larcombe, P., 1998. Terrigenous sediment accumulation as a regional control upon the distribution of reef carbonates. In: Camoin GF, Davies PJ (eds) Reefs and carbonate platforms in the Paci"c and Indian Oceans. IAS Spec Pub 25: 295}310

Yonge, C. M., 1930. A year on the Great Barrier Reef. Putnam, London. 246 pp.

Yamano H, Miyajima T, Koike I., 2000. Importance of foraminif- era for the formation and maintenance of a coral sand cay: Green Island, the Great Barrier Reef, Australia. Coral Reefs 19:51–58

Zinke, J., Dullo, W., Heiss, G. A., & Eisenhauer, A. (2004). ENSO and Indian Ocean subtropical dipole