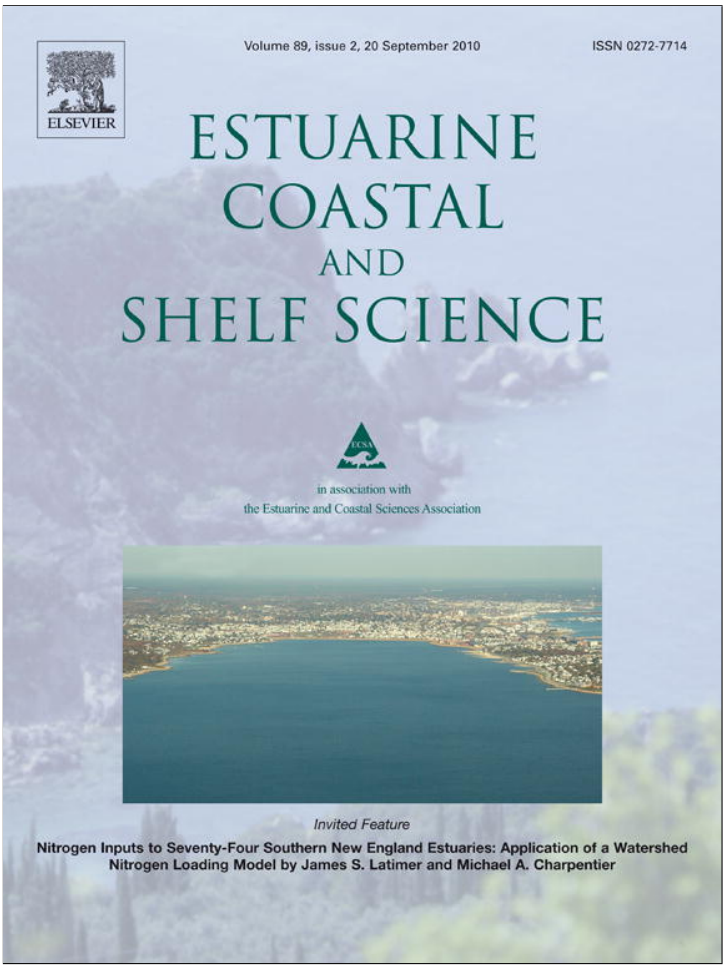
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Impact of hydrographic parameters and seasonal variation in sediment fluxes on coral status at Chumbe and Bawe reefs, Zanzibar, Tanzania

Alfred N.N. Muzuka*, Alfonse M. Dubi, Christopher A. Muhando, Yohanna W. Shaghude

Institute of Marine Sciences, University of Dar es salaam, P.O. Box 668, Zanzibar, Tanzania

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ABSTRACT

Coral reefs which are an important resource to coastal communities and nation at large are adversely affected by rate of sediment flux to the reefs. However, there is little information on seasonal trend in sediment flux and its impact at the reefs off Zanzibar. Two years' monthly data on sedimentation at Chumbe and Bawe reefs were used to assess seasonal variability in sediment flux and its implication on the coral status. Sediment flux to the Bawe reefs for the duration of the study ranged from 0.2 to 41.5 mg cm^{-2} d^{-1}, while it ranged from 0.8 to 65.8 mg cm^{-2} d^{-1} at the Chumbe reefs. Sediment fluxes at Bawe reefs were highest between November and March, while they were highest between April and September at Chumbe reefs. Generally, sediment fluxes at Bawe reefs were low compared to those at Chumbe. The total sediment input to the reefs ranged from 4615 to 123,403 kg d^{-1} for Bawe reefs and 2750 to 79,636 kg d^{-1} for Chumbe reefs. High sediment fluxes at Bawe reefs between November and March; and the Chumbe reefs between April and September can be attributed to water currents and wind pattern in the east African region which are under the influence of the monsoons. The observed trend suggests that the period for coral transplant as a management option for the two sites should be different. Coral transplant can be undertaken in such a way that stress of the corals due to sedimentation can be felt after they have overcome stress from transplant process and temperature. The results from this study contribute to the much needed information for coral transplant, restoration, and management.
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1. Introduction

Coral reefs represent an important resource to coastal communities and nation at large, providing sources of food, building material, and revenue through tourism and the aquarium trade (Naim et al., 2000; Spalding et al., 2001; Rees et al., 2005). They also provide natural coastal defenses and are regions of high biodiversity (Bellwood and Hughes, 2001). Apart from the goods and services they provide to human beings, the health and survival of reefs around the world are currently under threat from point source pollution, terrestrial runoff, increased turbidity, destructive fishing practices and coral bleaching associated with increases in sea surface temperatures (Naim et al., 2000; Roberts et al., 2002; Cole, 2003; McCulloch et al., 2003; Sheppard, 2003). Deterioration of the coral reefs is projected to continue in response to increasing sediment input to the ocean owing to changes in land-use patterns such as clearing for agriculture, logging, construction and mining (McManus, 1988; Hodgson, 1990; Rogers, 1990; Brown, 1987; Fabricius, 2005; Piniak and Storlazzi, 2008). Other human activities which increase sedimentation in coastal waters are dredging (Brown, 1987; Rogers, 1990), drilling (Hatcher et al., 1989; Rogers, 1990) and dumping of liquid and solid wastes (Rogers, 1990). Apart from sediments being derived from land, sediment resuspension, caused by strong wave action, may be important where coral reefs occur on or near sandy habitats, as in most shallow water reefs in Tanzania.

Coral reef ecosystems are very sensitive to ecological change owing to the fact that corals have a narrow physiological tolerance against stressors (Pastorock and Bilyard, 1985). One of the stressors that affect a coral reef ecosystem is sediments (McClanahan and Obura, 1997; Gleason, 1998). Corals differ greatly in their ability to resist sedimentation, with most species being highly intolerant of even small amounts; while a minority are able to tolerate extremely muddy conditions, and a few are even able to live directly in muddy bottoms (Gleason, 1998; Fabricius, 2005; Victor et al., 2006; Sofonia and Anthony, 2008). Sediment tolerant corals are able to push sediment off their surface through a variety of mechanisms, but all of these require expenditure of metabolic energy and when sedimentation is excessive they eventually reach the point where they can no longer spare the energy to keep

* Corresponding author.
E-mail address: muzuka@ims.udsm.ac.tz (A.N.N. Muzuka).

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themselves clean, and the affected tissue dies (Gleason, 1998; Fabricius, 2005).

Various studies have shown that changes in coral reef communities depend on the responses to siltation of the individual component species (Gleason, 1998; Golbuu et al., 2008). Excessive sedimentation smothers and kills coral tissue and reduces light levels and food supplied to the coral by symbiotic algae (Woolfe and Larcombe, 1999). Owing to these sedimentation effects, total coral cover and diversity are generally reduced near the source of terrigenous sediment, which indicates that a plume of sediments onto coral reefs is an important factor contributing to the deterioration of corals (Acevedo et al., 1989; Gleason, 1998; Fabricius, 2005; Victor et al., 2006; Sofonia and Anthony, 2008). According to Golbuu et al. (2008) areas with high accumulation of sediments are characterized by low coral cover and low coral diversity. Although studies on impact of sedimentation on coral cover and diversity have been carried out globally, few studies have been carried out to relate sedimentation and coral cover/diversity in the reefs around Zanzibar and Tanzania in general.

There are many parameters influencing settlement, survival and growth of corals such as predators, substrate type, seawater temperature, turbidity, salinity and algal cover. However, sedimentation (Yap and Gomez, 1985; McManus, 1988; Rogers, 1990; Hodgson, 1990; Wesseling et al., 1999), seawater temperature (Yap and Gomez, 1984; Goreau and Hayes, 1994; Winter et al., 1998), substrate type (Carleton and Sammarco, 1987), algal cover and competition (Pearson, 1981; Done, 1992; Tanner, 1995) have been shown to be important. Although reef restoration efforts have been undertaken for some time in the Tanzanian coastal waters information on the history of sedimentation in reefs within the Tanzanian coastal waters is lacking. Furthermore, there are no records on long-term trends in sediment input on monthly basis covering an annual cycle.

Nearshore currents patterns and their strength play a critical role in sediment transport, deposition and resuspension. In order to know the effect of sedimentation on coral reefs one needs to get information on how long sediment particles remain on top of coral polyp before being removed by currents, the type of sediment, particle size, current strength and direction. Critical current strength is required to move particles of certain grain size. Knowledge of current strength is required for better understanding the dynamics in a reef system. However, there is no comprehensive information on currents in and around the Zanzibar reefs. Thus, the present study intended to determine seasonal patterns of various hydrographic parameters (sedimentation, currents, and waves) and their impact on coral health status so as to understand the impact and effect of sedimentation on coral cover and health.

2. Methodology

This study was undertaken in Chumbe and Bawe reefs, which are located on the western side of Unguja Island, Zanzibar (Fig. 1). Sediment traps and Acoustic and Wave Current (AWAC) profiler were deployed within the reef benthos assessment sites.

2.1. Sedimentation rates and current measurements

Twenty sediment traps with an internal diameter of 7.62 cm and length of 38.1 cm (diameter: length ratio of 1:5) were made from PVC pipes and fixed on flowerpots using concrete. The mouth of the traps was at least 40 cm from seafloor thereby allowing trapping of vertical flux particles (English et al., 1994). However, this has been contended and indicated that sediment traps of this type trap horizontally transported materials (Bale, 1998). The traps were deployed at Bawe and Chumbe reefs (Fig. 1). They were deployed at

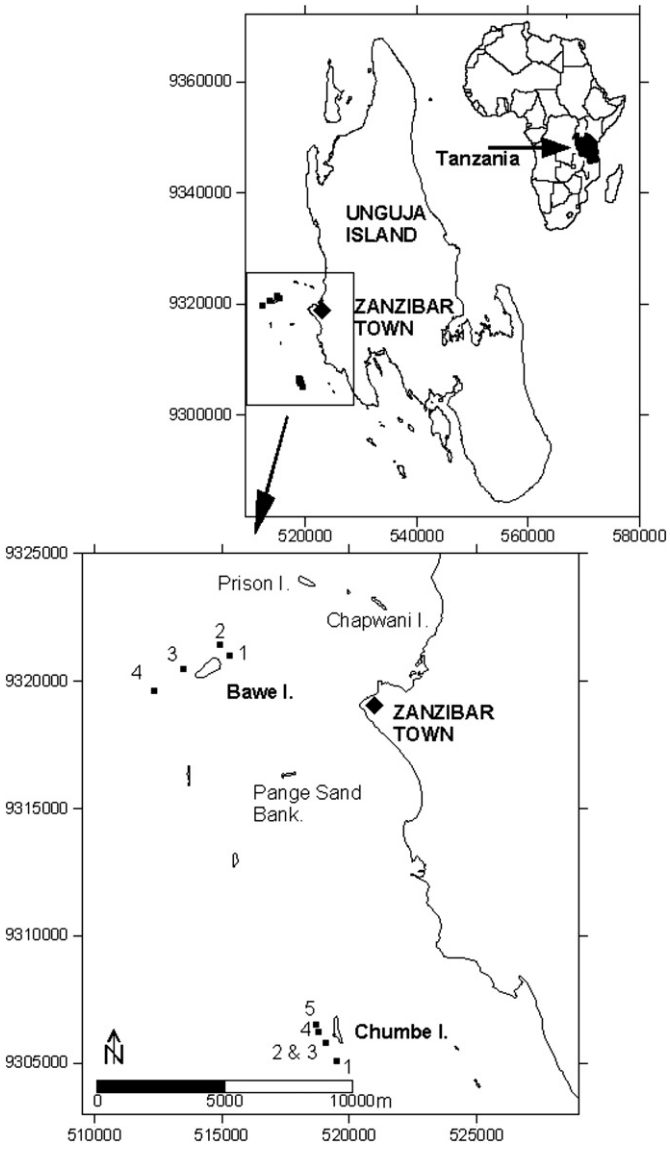


Fig. 1. Location map of the study sites.

Bawe reefs from 24th July 2006 to March 2009 and Chumbe reefs from 31 of August 2006 to March 2009. At Bawe reefs, four permanent stations were established and at each station two traps were deployed. At Chumbe reefs, 5 permanent stations were established and two stations (1 & 3) had 3 sediment traps deployed, while two traps were deployed at the remaining stations. At one of the stations (3) at Chumbe, a Nortek's AWAC (www.nortek-as.com) profiler was deployed in approximately 10 m of water depth during spring low tide. Beginning May 2007 to March 2009 sediment traps were retrieved on a monthly basis. Similarly, AWAC profiler was retrieved and redeployed once every month. Data download was done at the Institute of Marine Sciences.

2.2. Assessment of reef benthos

The percent cover of reef benthos was evaluated using Line–Intercept Transects method (English et al., 1994). At least six 20m transects were randomly set in a permanent reef plot of about 75m long. Chumbe had five permanent plots while Bawe had four permanent plots, which were at least 150 m apart. Collected information included: live coral cover at genera level, coralline

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algae, soft corals, sponges, fleshy algae, other living benthos, dead coral (recent), dead coral covered with filamentous algae (old), empty rocky surfaces, rubbles and sand. The total number of indicator categories used in this study was 72 and corals were assessed at genera level to enhance biodiversity change detection (Muhando, 2008).

2.3. Data analysis

ANOVA statistical analysis was performed to find out inter-site and inter-reefs relationship in sedimentation rates. The percent cover of the 72 categories measured were summarized into eight main categories (Acropora, non-Acropora, coralline algae, Soft corals, Sponges, Fleshy algae, other living substrate, and substrate (which include dead coral (recent and old), rocky, rubbles and sand). In order to reveal representation in terms of growth forms, all live coral genera were assigned one growth form category (i.e. branching, massive, sub-massive, encrusting, foliose and solitary). Furthermore, the Reef habitat complexity as well as the coral genera diversity was estimated using Shannon diversity index (H′) taking into consideration the relative benthic cover of all the categories encountered.

3. Results

3.1. Sediment fluxes

Sediment flux at Bawe reefs for the duration of the study ranged from 0.2 to 41.5 mg cm^{-2} d^{-1} (Fig. 2). Highest sediment fluxes at the reefs occurred at station 4 where it averaged 3.9 mg cm^{-2} d^{-1}. Stations 1 and 2 had relatively the lowest sediment fluxes while Station 3 had high sediment fluxes relative to Station 1 and 2 (Fig. 3). Sediment flux rates between the months of January and March were higher relative to other months (Fig. 2). ANOVA without replicate analysis showed a significant seasonal difference in sediment fluxes at Bawe reef ($F = 10.03$, $p = 9.48 \times 10^{-16}$, $F_{critical} = 1.66$) at 95% confidence level, however there was a lack of inter-site differences at the 95% confidence level.

Sediment fluxes at Chumbe reefs ranged from 0.8 to 65.8 mg cm^{-2} d^{-1}, and sediment fluxes were highest (about 4 times the mean value) in September 2007 than in other months (Fig. 2). Highest sediment fluxes at the Chumbe reefs occurred at station 1 and 5 where it averaged 10.9 and 10.5 mg cm^{-2} d^{-1} respectively Fig. 3). Station 3 had relatively the lowest sediment fluxes which averaged 2.6 mg cm^{-2} d^{-1} (Fig. 3). Sediment fluxes at the Chumbe reefs were highest between April and September and were lowest between November and March (Fig. 2). ANOVA without replicate analysis showed a significant seasonal variation ($F = 9.38$, $p = 9.73 \times 10^{-14}$, $F_{critical} = 1.70$) and inter-sites ($F = 5.25$, $p = 0.035$, $F_{critical} = 4.46$) differences in sediment fluxes at Chumbe reef at 95% confidence level.

Inter-reef comparison showed that sediment fluxes at the Bawe reefs were low relative to that of Chumbe (Figs. 2 and 3). ANOVA single Factor analysis for Chumbe and Bawe reefs showed significant differences ($F = 7.21$, $p = 0.010$, $F_{critical} = 4.06$) in sediment fluxes at 95% confidence level for the two reefs. Highest sediment fluxes at Bawe reefs occurred between the months of January and March, while it occurred between the months of April and September at Chumbe reefs (Fig. 2).

3.2. Ocean currents

Data from the AWAC showed that the maximum current speeds (January–December 2008) at the Chumbe reefs were of the order of 0.38–0.94 m s^{-1} (Fig. 5). The maximum currents strengths greater than 0.8 m s^{-1} in each case occurred within 4–7 m water depths (Fig. 5) and during mid-tidal phases of the tidal cycle, while minimum currents were characteristic of the bottom and surface water layers. The analyses of current roses indicated that the currents in Chumbe area are dominantly northwards almost throughout the year, except in December–February where it is impeded by the southward flowing currents due to the influence of the NE trade winds (Fig. 4).

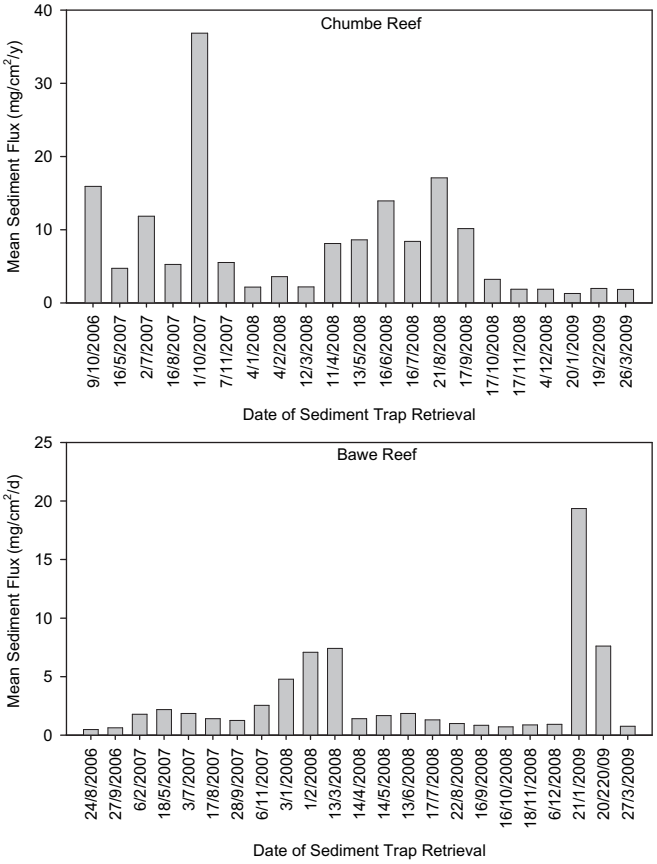


Fig. 2. Variation in mean sedimentation rate at Chumbe (top) and Bawe (bottom) reefs.

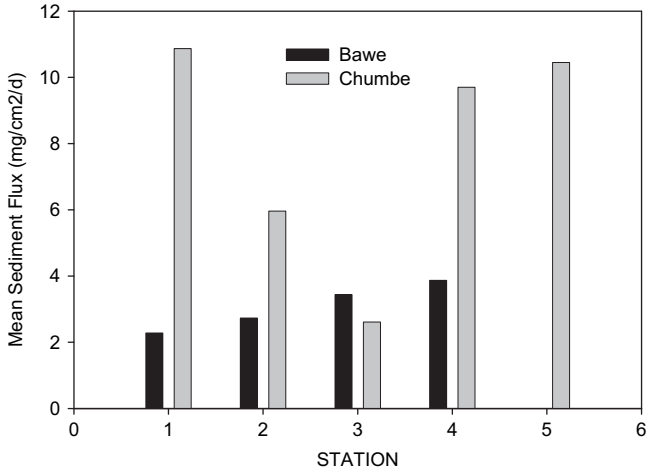


Fig. 3. Mean sediment flux at various sediment deployment trap sites for Bawe and Chumbe.

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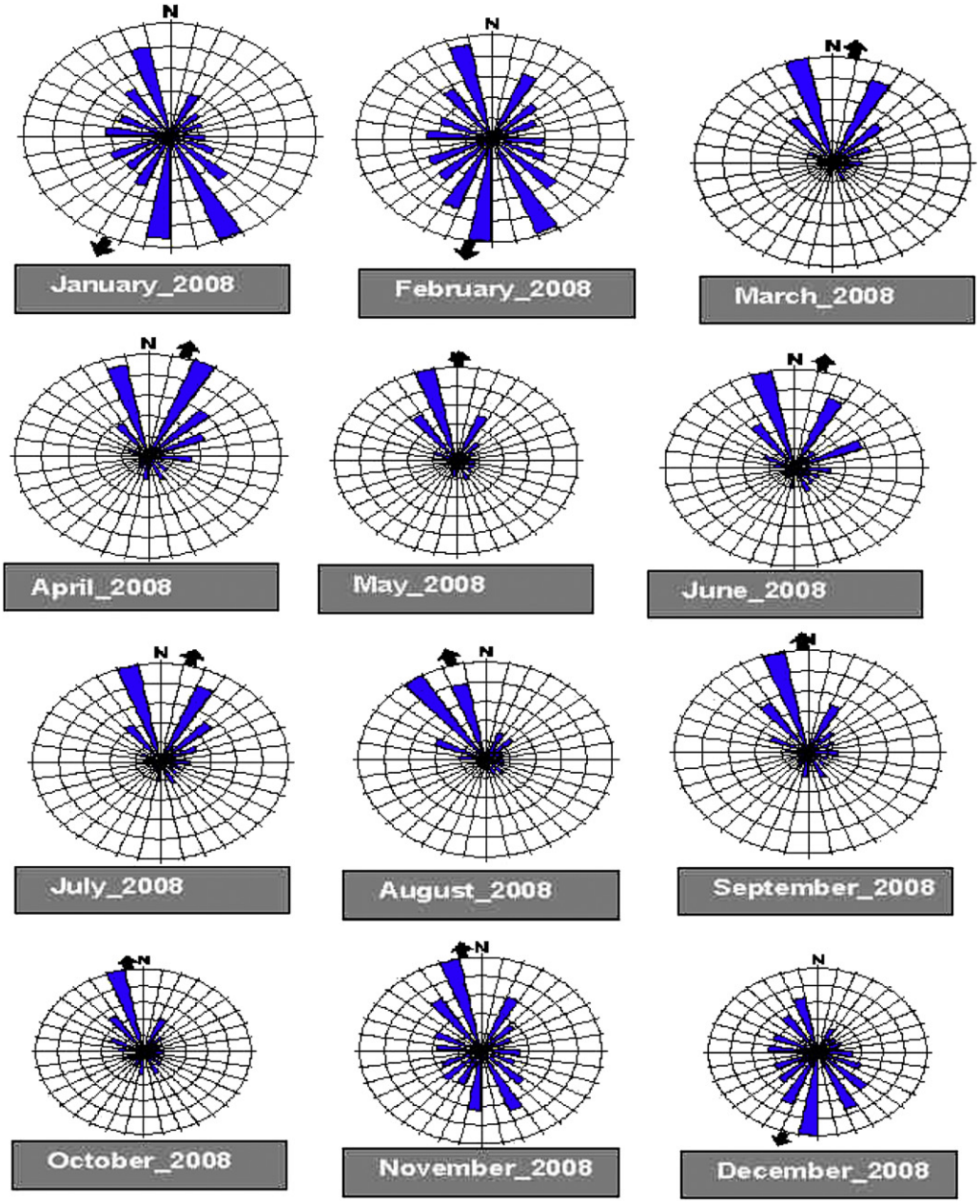


Fig. 4. Monthly current roses for Chumbe for the year 2008.

3.3. Coral health

3.3.1. Habitat complexity – based on all categories measured in 2008

Only 54 of the 72 indicator categories were encountered, with 47 in Chumbe and 36 in Bawe. Shannon diversity index indicated higher complexity at Chumbe ($H'' = 2.739$) than at Bawe ($H'' = 2.343$). *Synarea* (or *Porites rus*), dead coral covered with filamentous algae and Galaxea, were the dominant categories in Bawe, while *Acropora*, *Synarea* and dead coral with algae were abundant in Chumbe (Table 1a)

3.3.2. Coral genera diversity – based on coral cover

Coral genera richness was higher in Chumbe (**37**) than in Bawe (**23**). Similarly, Shannon diversity index was higher in Chumbe ($H' = 2.404$) than in Bawe ($H' = 1.502$) (Table 1b). The most dominant genera in terms of coral cover in Chumbe were *Acropora* (24%), *Synarea* (13%), massive *Porites* (7%), *Echinopora* (6%) and branching *Porites* (4%). In Bawe the dominant genera in terms of coral cover were *Synarea* (22%), *Galaxea* (17%), branching *Porites* (8%) and massive *Porites* (4%).

Based on coral genera frequency of occurrence, *Acropora* was the most frequently encountered genera in Chumbe followed by branching *Porites*, *Fungia*, *Pocillopora*, *Synarea*, *Goniastrea* and *Astreopora*. In Bawe the most frequent genera was branching *Porites* followed by *Synarea*, *Fungia*, *Acropora*, *Galaxea*, *Pocillopora*, *Stylophora* and *Coscinarea*. Shannon diversity based on frequency of occurrence was higher in Chumbe ($S = 41$; $H' = 2.642$) than in Bawe ($S = 34$; $H' = 2.255$) (Table 1c).

3.3.3. Comparison of coral growth form abundance between Bawe and Chumbe

There was more live coral cover in Chumbe (75%) than in Bawe (54%). The Bawe reefs were dominated by sub-massive type of coral

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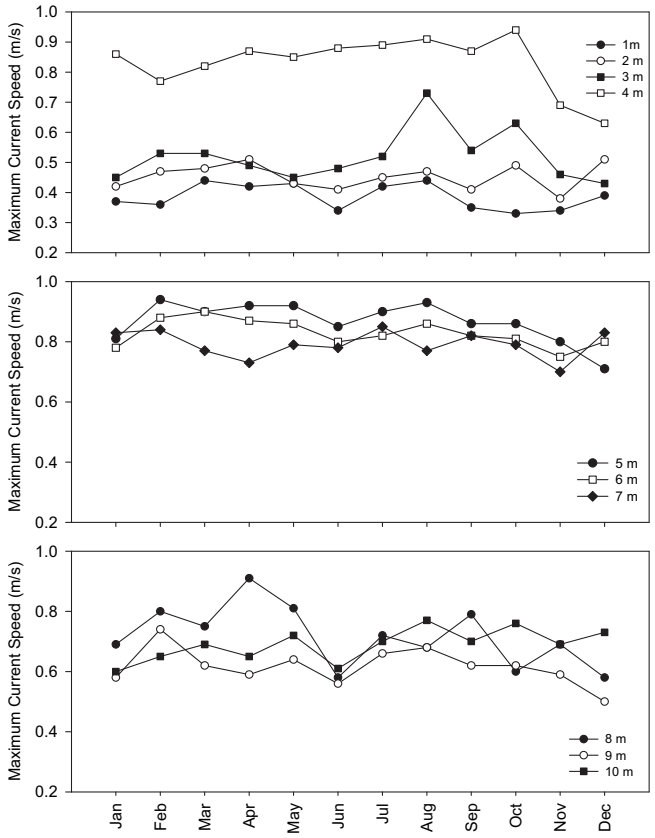


Fig. 5. Maximum current speeds at Chumbe reefs as recorded by the AWAC from January to December 2008. Depth profiles are from bottom (1 m) to the surface (10 m). Note that highest values of maximum current speeds are observable between 4 and 7 m from the sediment–water interface.

(38%) followed by dead coral with algae (20.7%) and branching coral (9.9%). In contrast, the Chumbe reefs were dominated by branching corals (37.0%) followed by sub-massive (15.6%) and massive (13.21%) (Table 2). Massive and sub-massive corals at the Chumbe reefs accounted for more than 28% while it accounted for 43% at the Bawe reefs (Table 2). Furthermore, there were more encrusting corals on Chumbe than on Bawe.

4. Discussion

Tanzania is subjected annually to two types of seasonal wind patterns namely the southeasterly monsoons that are prominent between April and October, and northeasterly monsoons that are prominent during November through March. The southeasterly monsoons are generally stronger and less variable in direction than the northeasterly monsoons (Bargman, 1970). The observed trend of high sediment fluxes at the Bawe reefs between January and March and at the Chumbe reefs between April and September can be partly attributed to these seasonal changes in wind pattern. Seasonal wind reversals due to the monsoon winds appear to influence the general water currents' flow direction in the study areas. Current pattern in Chumbe area as depicted by current roses (Fig. 5) showed a general northward flow for the large part of the year beginning from March to October, a time of high sedimentation at the Chumbe reefs. The current roses also showed that the northward flow current reverses between December and February (Fig. 5), a period with elevated sedimentation rates in the Bawe reefs. The current pattern in the area is in phase with the monsoon winds pattern.

A question which arises from the sedimentation results is what are the sources of sediments deposited in these reefs. Annual rainfall between 1950 and 1996 averaged 1629.7 ± 398 mm y with most of it falling between April and May (Fig. 6). Since there are no major reservoirs (lakes) on the island that can reduce amount of runoff reaching the sea, most of the runoff associated with this amount of rainfall reaches the sea carrying with it a lot of suspended materials. The stable isotope composition of organic carbon showed an offshore decrease in the transport of terrestrially derived organic matter with values of −17‰ close to the reef (Muzuka, 1999). Thus part of the material particularly fine grained particles could originate from the Unguja Island. Terrestrial derived materials are transported offshore and southward by tidal currents. The tidal flood/ebb streams enter/exist the Zanzibar channel at both the north and south channel entrances (Shaghude et al., 2002). The north and south components of flooding tides converge in the vicinity of the Zanzibar town (Shaghude et al., 2002). During ebb the tidal currents diverge in the vicinity of the Zanzibar town (Shaghude et al., 2002), and thus transporting material offshore and in the southern direction.

Sediment traps were located on the western side of the Chumbe Island, which is about 5 km from the shore and oriented in a northwest–southeast direction parallel to the main Island of Unguja. The channel between the Main Island and Chumbe Island has a maximum water depth of 20 m. The channel may act as a sediment trap as there is no sandy beach on the eastern side of the Chumbe Island. Thus, the sediment input at the Chumbe reefs could have originated from the sandbanks located in the southern part of

Table 1
Univariate (a) Diversity indices based on all categories measured in 2008, (b) Coral genera Diversity indices based on coral cover, and (c) Diversity indices based on frequency of general occurrence.

Sample	Category Richness	N	d	J′	H′(loge)	1-Lambda'
(*a*)						
Bawe_08	36	100	7.6	0.6538	2.343	0.8715
Chumbe_08	47	100	9.989	0.7115	2.739	0.901
(*b*)						
Sample	S	N	d	J′	H′(loge)	1-Lambda'
Bawe_08	23	54	5.515	0.4789	1.502	0.7202
Chumbe_08	37	75	8.333	0.6657	2.404	0.8541
(*c*)						
Chumbe	41	130	8.22	0.7114	2.642	0.8732
Bawe	34	158	6.519	0.6396	2.255	0.8483

Table 2
Comparison of dominance of coral forms at Bawe and Chumbe reefs.

	Bawe		Chumbe
Sub-massive	38.827	Branching	37.02
Dead coral with algae	20.713	Sub-massive	15.628
Branching	9.90	Massive	13.214
Coralline algae	5.548	Dead coral with algae	11.958
Massive	4.533	Sand	5.917
Rubble	4.317	Foliose	5.656
Sand	3.229	Rock	2.681
Corallimorpharia	3.158	Encrusting	2.281
Soft corals	2.738	Rubble	1.744
Dead coral	2.348	Solitary	1.417
Rock	1.988	Coralline algae	1.019
Others	1.281	Algae	0.694
Sponges	0.613	Corallimorpharia	0.469
Foliose	0.504	Sponges	0.264
Solitary	0.200	Others	0.036
Algae	0.067	Soft corals	0.000
Encrusting	0.035	Dead coral	0.000

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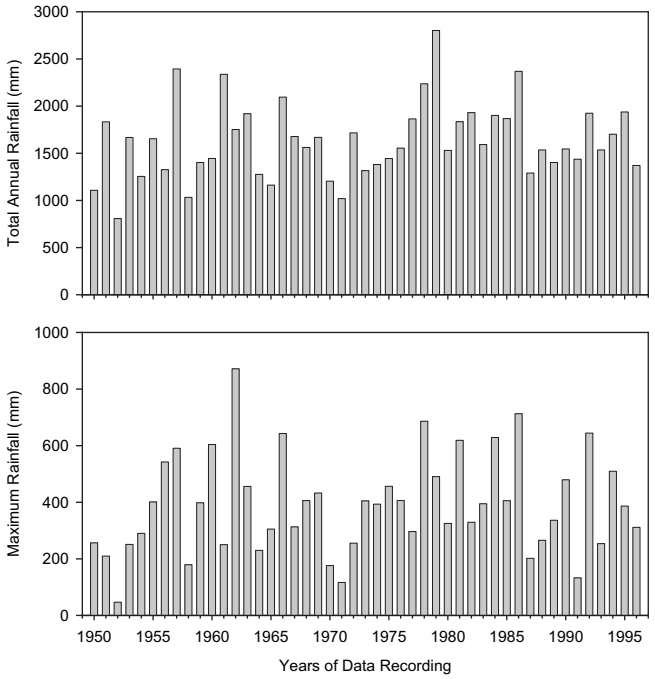


Fig. 6. Annual rainfall (top panel) and maximum monthly rainfall (April) for a period between 1950 and 1996. Amount of annual rainfall is generally above 1000 mm with most of it being realized in April.

the Island. Bathymetry of the southern part of Chumbe Island is shallow with a maximum depth of 10 m. Strong currents which are up to 0.9 cm s^{-1} could be responsible for reworking sandbank's material. Part of the sediments at Bawe reefs are also most likely derived from the sand banks located north of the reef.

Sediment input at Bawe is low making this site a potential area for high diversity of corals. However, the reefs are routinely disturbed by fishermen and uncontrolled anchoring by tourists boats. This is supported by high dominance of coral fragment in the area as shown in Table 2.

High sediment fluxes at the Chumbe reef in September 2007 could be related to unusual high wave activity probably resulting from an earthquake that took place in the Indian Ocean and produced a tsunami or meteorological factors. On 12 September 2007, an earthquake with a magnitude of 8.4 on the Richter scale occurred in the Indian Ocean with its epicenter located at latitude 4.52°N and longitude 101.37°E (Srivastava et al., 2007). Because of relatively long distance between earthquake epicenter and the tsunami propagation to the coast of East Africa no significant tsunami impact was felt. However, during this period the tsunami wave height was likely superimposed to the locally generated wind waves leading to an above-normal wave height. This is evident from the wave height record for the Current and Wave profiler installed at the study site (Fig. 7). Spectral analysis showed that the peak frequency of the waves was 0.1 Hz (equivalent to significant waves with a peak period of 10 s) with a direction of 220° (Fig. 8). Waves with a peak period of 10 s are normally swells and not locally generated by prevailing wind (Gilhousen and Hervey, 2001, http://www.ndbc.noaa.gov/windsea.shtml). This confirms that the swell waves were directly responsible for the unusual sediment flux at Chumbe reef. For this episode, Bawe reef was spared because of the leeward (protected) position of the reef.

However, this could have been a result of meteorological factors. On 26 September, wind speed was generally normal except in the afternoon at 2 pm where wind speed peaked to about 20 m s^{-1} and

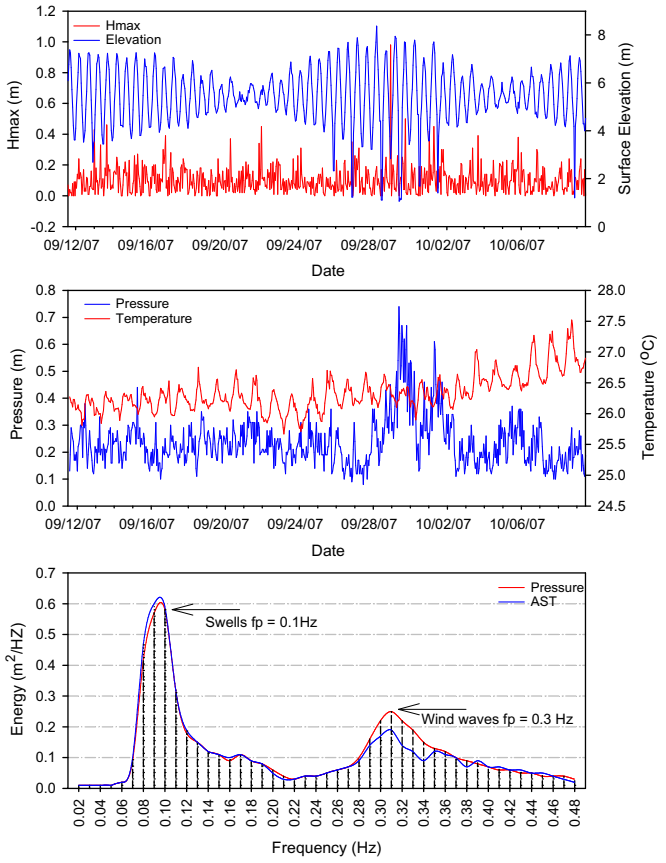


Fig. 7. Variation in (1) surface elevation and maximum wave height (top panel), (2) pressure and water temperature (central panel), and (3) energy spectrum (bottom panel) for the month of September 2007.

lasted for less than 1 h (http://www.wunderground.com/history/airport/HTZA/2007/9/27/MonthlyHistory.html). This wind speed could have generated waves with height of at most 1.4 m. Since the height of wind-driven waves depends on the wind speed, duration,

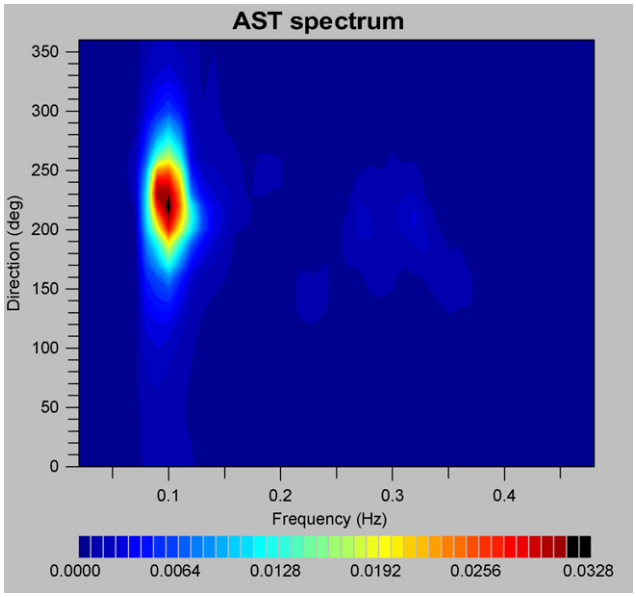


Fig. 8. Wave direction Spectrum 29 Sept 2007 Note that AST means acoustic surface tracking.

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fetch length and water depth it is unlikely that it was able to stir or resuspend a lot of sediments from greater water depth. This is because according to the sediment transport theory, a wave touches the sediment boundary layer when water depth is 0.5 of the wavelength.

4.1. Impact of sedimentation on corals

In both sites the sedimentation rates fluctuated below and above the lethal limit of 10 mg cm^{-2} d^{-1} suggested by Rogers (1990), implying that sedimentation is stressful to corals at some times of the year at both sites. Stressful duration and season differed between these sites. Despite higher sedimentation rates, Chumbe reef had higher coral cover and higher habitat and coral genera diversity. This is contrary to findings by other researchers who reported that areas with high accumulation of sediments were characterized by low coral cover and low coral diversity (Golbuu et al., 2008). The results of the present study demand another explanation for the observed, where corals are able to cope with high levels of sedimentation. These results suggests that corals at Chumbe are probably adapted to the sedimentation situation and thus the sediment lethal limit for Chumbe is much higher than 10 mg cm^{-2} d^{-1} suggested by Rogers (1990). This study therefore does not provide direct evidence that the observed sedimentation rates have a direct negative influence on coral species richness and diversity. Three processes: 1) the clear reef slopes 2) reef oriented in relation to main ocean currents, and 3) protection from destructive fishing and tourism may have concealed the impacts of sedimentation in Chumbe. The relatively strong tidal currents clean off sediment particles on coral tissues (Rogers, 1983; Larcombe et al., 1995), more efficiently on the reef slope than on the reef flat. However, this could be a result of type of sediments settling on the corals. It has been noted the carbonate rich sediments do not impact corals in the same way as the riverine sediments (Fabricius, 2005; Piniak 2007). According to Muzuka (1999) and Shaghude et al. (2002) the carbonate content in sediments around the reefs is as high as 99%. Result of total carbon content in sediment traps collected over a period of 2 years in the study area show that total carbon is high (close to 12) with sediments collected close to the study sites having carbonate content of more than 90%. Moreover, sediments collected from the eastern margin of the Zanzibar channel, which include the present study area, are coarse to medium grained (Shaghude et al., 2002). Unguja Island being separated from the mainland by a channel with a maximum depth of 60 m it is unlikely that continental siliciclastic material from the Mainland Tanzania reaches the study site.

Impacts and response to sedimentation stress differ between species and depends on the relative position of corals (Gleason, 1998; Torres, 2001; Torres and Morelock, 2002; Torres et al., 2001; Fabricius, 2005; Victor et al., 2006; Sofonia and Anthony, 2008). Colonies on the reef flat and encrusting (polyps in contact with surface) colonies are likely to suffer more than those on the reef slope and those standing above the substrate. The Chumbe reefs were dominated by Acropora branching corals accounting for more than 37% while it accounted only 15% at the Bawe reefs. Furthermore, the Bawe reefs had high percentage cover of submassive to massive corals compared to the Chumbe reefs. This could be related to differences in the relative position of corals as well as levels of sediment fluxes at these two sites. Branching corals have been observed to be more tolerant to sedimentation than submassive to massive type of corals (Rogers, 1990; Rachello-Dolmen and Cleary, 2007). However, low coral cover of branching Acropora coral at Bawe reefs could also be a result of disintegration by humans during fishing and anchoring as the reefs are not protected, while the Chumbe reefs are well protected.

4.2. Implication to reef management

Coral settlement, growth and recovery after disturbances are influenced by many factors such as sedimentation, sea surface temperature, cyclones, volcanic activity, catastrophic low tides, man-made disturbances and *Acanthaster planci* infestations (Pearson, 1981). Knowledge of sedimentation is an added advantage to the manager, who must take into consideration all factors influencing coral health. This study has demonstrated seasonality in sedimentation rates. Severity of sediment stress on coral reefs depends on occurrence of synergistic or diluting factors such as reef topography, ocean currents as well as the presence of coral competitors, predators, diseases like ocean ally with other physical and biological factors, such as substrate suitability, sea water temperature, algal and corallimorpharia competition, and predation. Temperature is stressful, and elevated water temperatures in Zanzibar occur in March–April. This time interval is also closely associated with higher algal abundance which peak in April–May. Synergistic influence of these is likely to weaken resilience of corals. Management could intensify enforcement of regulations in Chumbe during March–May to avoid synergistic impacts added from destructive anthropogenic activities. Managers involved in coral reef restoration using coral fragment transplantation should understand sedimentation patterns, since young corals, being near the bottom, are highly sensitive to sedimentation.

The observed sedimentation trend suggests that the suitable period for coral transplant is from September to October at Chumbe and from May to October at Bawe. At least two months of good weather are required to build resilience. Recovery of bleached coral will be high if coral bleaching will be followed by period of low sedimentation. Elevated sea surface temperature above normal normally occurs between January and March. Thus, the Bawe reef is heavily impacted by sediment fluxes and elevated sea surface temperature that may cause coral bleaching.

4.3. Northward flow and coral larval dispersal and connectivity

The distance and the patterns of larval dispersal are influenced by several factors which act synergistically over the pelagic larval duration including: (1) larval behavior: swimming speed and directional capabilities of larvae are considered to be highly species-specific, (2) larval duration: amount of time larvae spend in the open ocean is also species-specific; ranging from hours to months, and typical pelagic duration is 28–35 days, (3) food resources: amount of available food during the pelagic duration, (4) predators encountered: predators affect survival, condition and growth rates, and (5) influences of currents or other oceanographic factors. The current's flow patter is generally considered to play a major role in larval dispersal (Cowen and Sponaugle, 2009). Thus, larval dispersal route in the Zanzibar waters may be northwards and Chumbe could be a source of larvae to northern reefs. However, this needs more research particularly involving DNA studies.

5. Conclusion

Sedimentation rate at Chumbe reefs is highest by several orders of magnitude relative to Bawe reefs. At Chumbe, the highest sediment fluxes were observed between April and September, while it was highest between December and February at Bawe. The observed sedimentation trend implies that any management effort such as coral transplant should be carried out between September and October at Chumbe; and between May and October at Bawe. Live coral cover as well as coral diversity and complexity were observed to be highest at Chumbe than at Bawe. Furthermore, submassive type of coral was the most dominant form at Bawe while

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branching corals were the most dominant form at Chumbe reefs. Although the level of sedimentation at these two reefs was above lethal level of 10 mg cm^{-2} d^{-1} there was no apparent impact to coral status. This could be a result of the northward strong currents which flush sediment away from the coral polyp during the southeast monsoon winds and types of sediment which are generally coarse to medium grained carbonate sand.

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