# Western Indian Ocean
# JOURNAL OF
# Marine Science

Volume 15 | Issue 1 | Jan – Jun 2016 | ISSN: 0856-860X

Chief Editor José Paula

# Western Indian Ocean JOURNAL OF Marine Science

Chief Editor **José Paula** | Faculty of Sciences of University of Lisbon, Portugal

Copy Editor **Timothy Andrew**

## Published biannually

Aims and scope: The *Western Indian Ocean Journal of Marine Science* provides an avenue for the wide dissemination of high quality research generated in the Western Indian Ocean (WIO) region, in particular on the sustainable use of coastal and marine resources. This is central to the goal of supporting and promoting sustainable coastal development in the region, as well as contributing to the global base of marine science. The journal publishes original research articles dealing with all aspects of marine science and coastal management. Topics include, but are not limited to: theoretical studies, oceanography, marine biology and ecology, fisheries, recovery and restoration processes, legal and institutional frameworks, and interactions/relationships between humans and the coastal and marine environment. In addition, *Western Indian Ocean Journal of Marine Science* features state-of-the-art review articles and short communications. The journal will, from time to time, consist of special issues on major events or important thematic issues. Submitted articles are subjected to standard peer-review prior to publication.

Manuscript submissions should be preferably made via the African Journals Online (AJOL) submission platform (http://www.ajol.info/index.php/wiojms/about/submissions). Any queries and further editorial correspondence should be sent by e-mail to the Chief Editor, wiojms@fc.ul.pt. Details concerning the preparation and submission of articles can be found in each issue and at http://www.wiomsa.org/wio-journal-of-marine-science/ and AJOL site.

**ISSN 0856-860X**

Cover image: Fisherman pushes his boat along the channels around Inhaca Island, Mozambique (© José Paula)

# Western Indian Ocean
# JOURNAL OF
# Marine Science

Volume 15 | Issue 1 | Jan – Jun 2016

# Table of Contents

# Current status of sea turtle protection in Lamu Seascape, Kenya: Trends in nesting, nest predation and stranding levels

Mike Olendo[1], Cosmas N. Munga[2,*], Gladys M. Okemwa[3], Harrison Ong'anda[3], Lilian Mulupi[1], Lily Mwasi[1], Hassan Mohamed[1]

[1] WWF Coastal Kenya Programme (CKP), P.O. Box 99, 80500, Lamu, Kenya

[2] Department of Environment and Health Sciences, Marine and Fisheries Programme, Technical University of Mombasa, P.O. Box 90420, 80100, Mombasa, Kenya

[3] Kenya Marine and Fisheries Research Institute, P.O. Box 81651, 80100, Mombasa, Kenya

* Corresponding author:
cosmasnke2001@yahoo.com
ckamunga2014@tum.ac.ke

## Abstract

Globally sea turtles are threatened including in Kenya where they are legally protected. Results of sea turtle protection in Kenya are presented in this paper in reference to the WWF Lamu seascape conservation efforts. Temporal and spatial trends in sea turtle nest protection, predation and strandings based on beach monitoring efforts in five locations totaling 20.7 km of beach were investigated. A total of 2021 nests in 6,205 days (between 1997 and 2013) were recorded where 64.4% (n = 1299) were translocated to higher safer sites for successful hatching. An increasing trend in nest density was observed with highly significant difference among locations (1-way ANOVA; p = 0.001). A slight decreasing trend in monitoring effort of sea turtle strandings was observed, however, decreasing trends in predation levels were observed and this was higher in the warmer NEM season with no significant difference among locations (Kruskal-Wallis test; p = 0.085). A total of 227 sea turtle strandings were recorded in 188 days (between 2001 and 2014) and this generally showed a decreasing trend. The causes of sea turtle strandings were mostly fishery-related (53%). This was followed by unknown causes (20%), shark attacks (13%), with the tumor-causing viral disease fibropapillomatosis recorded in 11% of the strandings. Overall, the highest number of strandings was recorded for Mkokoni (35%) while the lowest was recorded for Mvundeni (4%). Green turtles with a mean size of 68.9 ± 1.9 cm CCL, comprised the bulk (79%) of the strandings recorded. Stranding incidences were observed year-round; however, this was higher during the dry NEM season (January to March) when fishing effort is highest as compared to the SEM season (April to September) when fishing effort is low. To continue the observed improving trends over time, it is vital that sea turtle conservation efforts, including a comprehensive monitoring programme, are supported.

**Keywords:** Predation, Protection, Sea turtles, Conservation, Lamu seascape, Kenya

## Introduction

Of the seven species of sea turtles, three species are documented to nest in Lamu, Kenya; these are the green, *Chelonia mydas,* hawksbill, *Eretmochelys imbricata*, and olive ridley turtle, *Lepidochelys olivacea*. Even though loggerhead, *Caretta caretta,* and leatherback turtles, *Dermochelys coriacea,* forage along the coast or migrate through Kenyan waters, they do not nest along the Kenyan coast (Frazier, 1980; Church and Palin, 2003). Sea turtles have a global distribution ranging from temperate, sub-tropical to tropical regions (Hirth, 1997; Bjorndal, 1997), however, they have very specific nesting and foraging preferences influenced by their natal homing behavior (Rees *et al*., 2012; Lohmann *et al*., 2013). For example, green turtles in the southwestern Atlantic prefer to nest in island rookeries (Domingo *et al*., 2006).

Sea turtles occupy various habitats (nesting beaches, coastal, neritic and oceanic areas) throughout their lifetime, transcending various Exclusive Economic Zones and international waters while conducting feeding and reproductive migrations (Domingo *et al*., 2006; Rees *et al*., 2012; Jensen *et al*., 2016). The migration to, and residence time of sea turtles in foraging grounds also depends on the prevailing physico-chemical water parameters such as sea temperature, upwelling as well as water depth (Rees *et al.*, 2012). Further, preference of foraging grounds and migration routes also depend on the age of individuals (Jensen *et al.*, 2016), which has been revealed through spatial and temporal genetic variation studies on the green turtle (Jensen *et al.*, 2016). Their complex life cycle exposes turtles to high risk of mortality from myriad natural and anthropogenic threats. According to the World Conservation Union Red List category, the green turtle, loggerhead and olive ridley are "Endangered" and the leatherback and hawksbill are "Critically Endangered" (Hilton-Taylor, 2000; IUCN, 2004).

Commonly reported fisheries-related sea turtle mortalities are due to entanglement in long lines, or as bycatch in trawling and gill net operations (Domingo *et al.*, 2006; FAO, 2004; Bourjea *et al.*, 2008). Other anthropogenic threats include direct hunting for meat, shell and eggs; habitat degradation from coastal developments, and pollution (Wamukoya *et al.*, 1997; Frazier, 1982; McLellan *et al.*, 2012). Sea turtles are also threatened by nest predation and pollution causing diseases such as fibropapillomatosis (Domingo *et al.*, 2006; McLellan *et al.*, 2012).

Protection of nesting beaches is one of the components of sea turtle conservation (Antworth *et al.*, 2006); however, this is considered part of a broader suit of conservation strategies that also take into consideration in-water mortality factors during other stages of a sea turtle's life cycle (Frazier, 1992). Nesting beach protection includes translocation of nests (*ex-situ*) to more suitable locations commonly employed to reduce the threats from poaching, predation, erosion or inundation due to poor placement (Beggs *et al.*, 2007). On the other hand, *In-situ* protection of nests from natural predation is also carried out (Garcia *et al.*, 2003; Antworth *et al.*, 2006) where turtle nests on safe sites are left to hatch without moving them. In Kenya, the main conservation strategies for sea turtles include a complete ban on exploitation or trade of sea turtles and sea turtle products, monitoring of nesting activities, and nest protection. Monitoring of nesting beaches occurs on the entire Kenyan coastline, well supported by community-based sea turtle conservation groups (Okemwa *et al.*, 2004). A total of 34 sea turtle nesting beaches (20.7 km of beach), covering 5 locations within the Lamu seascape have been monitored since 1997. The Lamu seascape hosts the most important nesting sites for sea turtles in Kenya with higher concentrations of nesting green turtles having been documented than elsewhere (Frazier, 1982; Church and Palin, 2003). This paper presents the spatio-temporal status of sea turtle conservation efforts in Lamu seascape through trends in nest densities, predation levels as well as trends in sea turtle strandings.

## Materials and methods

### Study area

Lamu County stretches from the Kenya-Somalia border in the north to the Tana River Delta to the south, incorporating the Dodori forest channels. The northern most part hosts the Kiunga Marine National Reserve (KMNR), a marine protected area (MPA) rich in biodiversity. The seascape comprises a series of linear islands and islets including Rubu Island, Kiwayu Island, and Kiunga which provide important sea turtle foraging habitat and nesting beaches. An estimated 20.7 km of beach has been monitored in the study and this includes five monitoring locations at Kiunga, Rubu Island, Mvundeni, Mkokoni and Kiwayu (Fig. 1). The beach stretch at these locations range from relatively long open beaches backed by vegetated dunes to small pocket beaches surrounded by cliff edge or scrub vegetation (Church and Palin, 2003), measuring between 1.1 and 7.6 km long.

The biodiversity in the MPA includes rare coral species such as *Horastrea indica* and *Siderastrea savignyana* (Obura *et al.*, 2007), extensive sea grass beds composed of eight different species (Gullstrom *et al.*, 2002), mangrove forests of about 20,000 hectares comprising 30% - 40% of the total mangrove cover in Kenya composed of the dominant *Rhizophora mucronata* and *Ceriops tagal* (Kairo *et al.*, 2002). The landscape adjacent to the MPA contains indigenous forests protected in the Dodori and Boni National Reserves covering an area of over 1,000 km$^2$ (Church and Palin, 2003). The Kiunga MPA allows for multiple subsistence uses, unlike other MPAs in Kenya which do not permit extractive resource use (McClanahan and Kaunda-Arara, 1996).

The coastal climate of Kenya, including Lamu, is influenced by an interplay of monsoon winds and ocean currents; the north flowing East Africa Coastal Current (EACC) and the southwest flowing Somali Current (SC). This interplay creates two distinct seasons, characterized by very strong winds and rough seas between April and September (southeast monsoon, SEM season) and calm seas with moderate currents between October and March (northeast

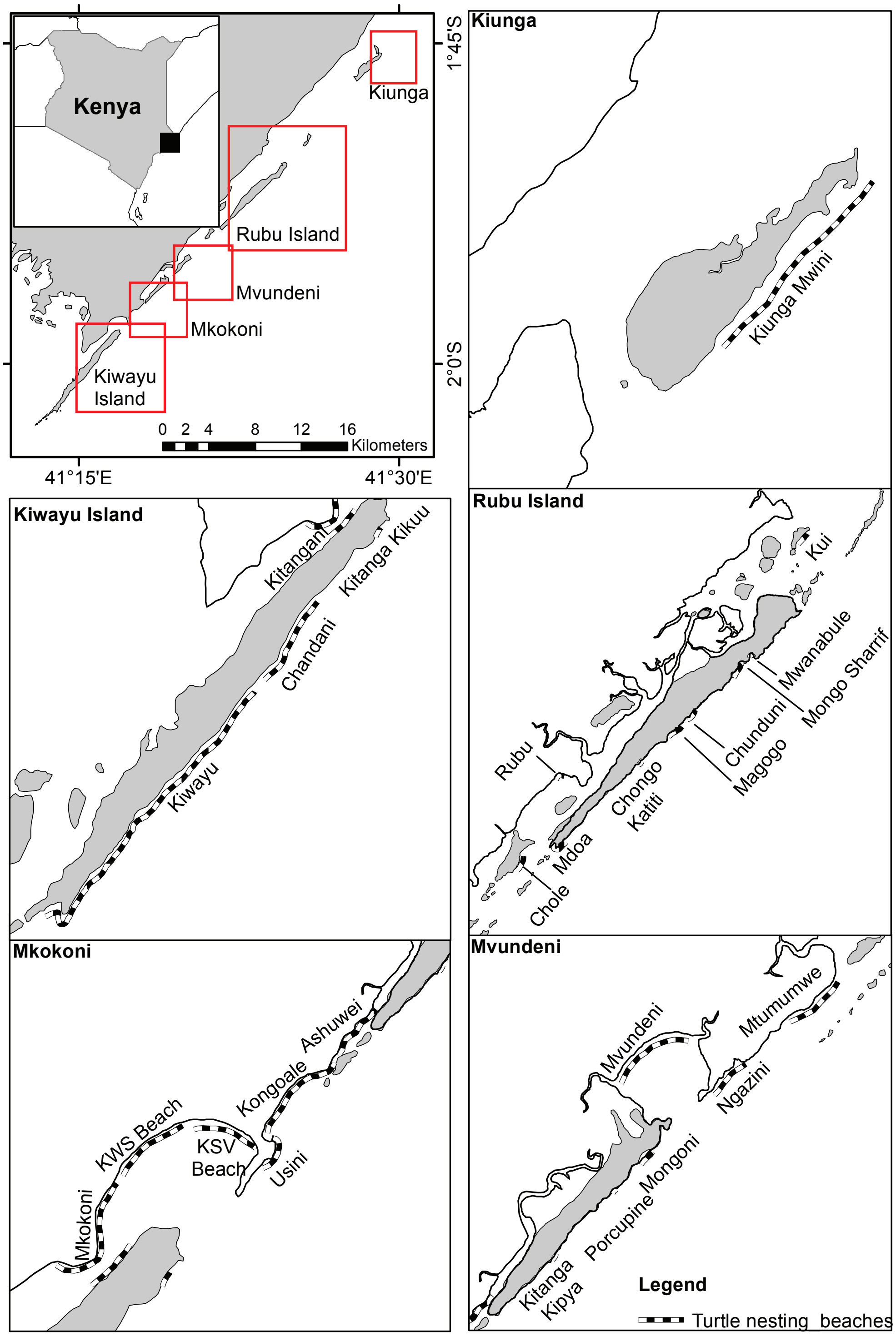

**Figure 1.** Map of the Lamu seascape, Kenya showing the different monitoring locations and beach stretches.

monsoon, NEM season; McClanahan, 1988; Benny, 2002; Spencer *et al.*, 2005). In particular, the northern area of the seascape is characterized by mild upwelling events and eutrophic conditions (Gert, 1989; Schott, 2001; Benny, 2002; Spencer *et al.*, 2005) resulting in increased algae and high fisheries productivity during the NEM season.

## Data collection

Sea turtle nesting data were collected following the WWF Lamu sea turtle nesting protocol developed for sea turtle conservation groups (TCGs) in the area (WWF Lamu, 2012). This protocol requires nesting data to be collected at night by trained data collectors. Data collectors used minimum light and observed the nesting and egg laying process in silence. After laying, the turtle was restrained to read tag information, attach a new flipper tag and record carapace length and width. Beach surveys were regularly conducted at dawn and late at night, and nesting data collected using WWF standardized beach monitoring data sheets.

Observed sea turtle tracks were examined and potential nests verified to confirm existence of an egg clutch. Once verified, nests were left in the same position (*in situ*) above the drift line of the high water mark, or translocated (*ex situ*) when below the drift line of the high water mark, to suitable sites to avoid inundation, then covered and marked, numbered and location recorded with a hand-held GPS (Taiwanese GARMIN). Turtle tracks were then smoothed over to avoid attracting attention of potential predators. Regular surveillance of both GPS marked and translocated nests were conducted and progress of incubation monitored for signs of hatchling emergence.

Hatchlings emerging during the day were released at night, and hatchlings that emerged at night were released at dawn. The released hatchlings were guided to the sea to minimize the chances of predation from land-based predators. Predation data were collected from the number of affected clutches, and from turtle strandings through beach surveys conducted during

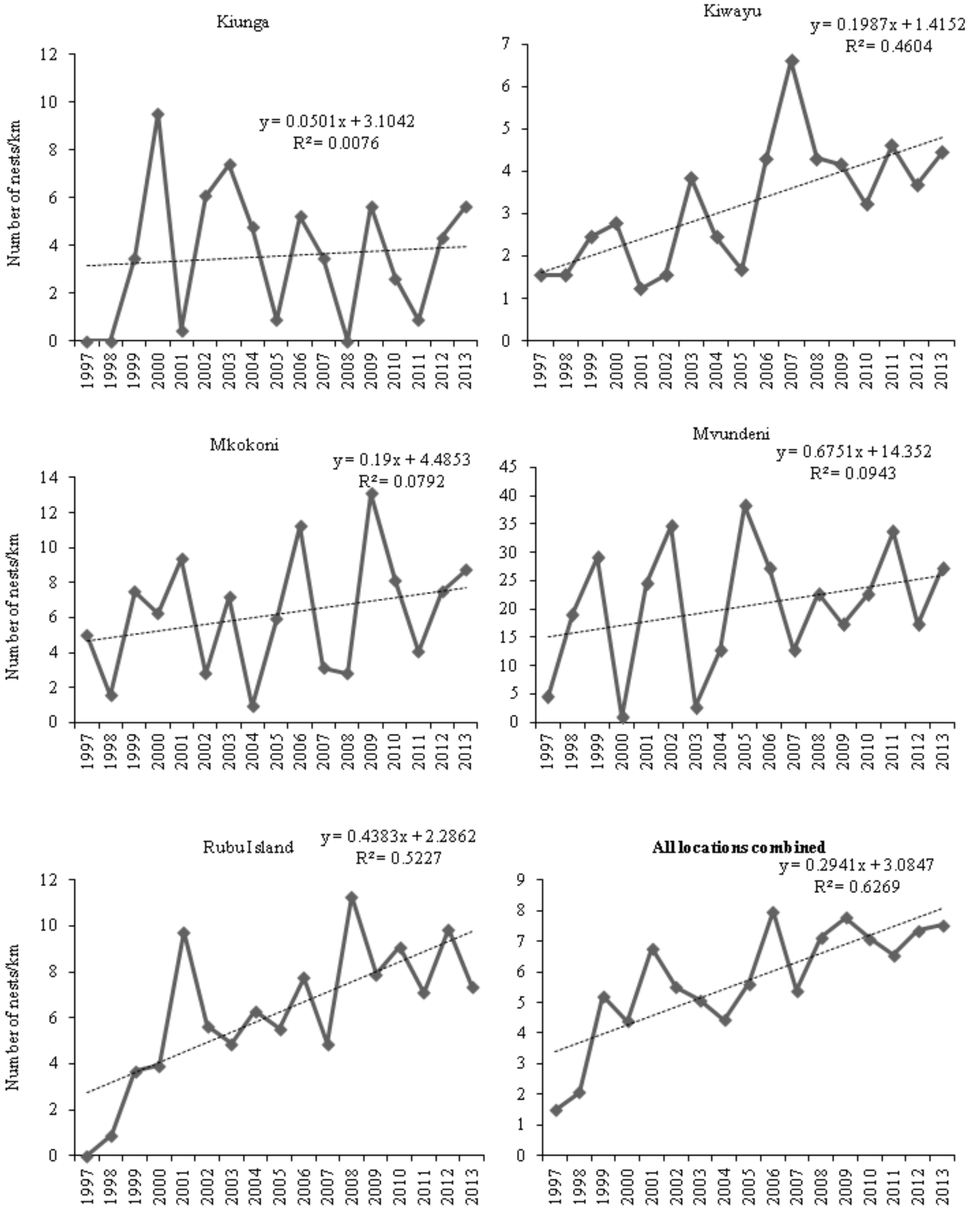

**Figure 2.** Spatial and temporal trends in sea turtle nest density in Lamu seascape, Kenya during the study period.

the day. Details recorded for turtle strandings were: species and sex, cause of mortality (by observing the injury category or possible viral infection), and size determination by measuring the curved carapace length (CCL, cm) using a flexible tape measure.

## Data analyses

Sea turtle nesting data collected over 6,205 days between 1997 and 2013 were analyzed in the five locations with a total beach length of 20.7 km for spatial and temporal trends in nest protection (nest density per km) and predation levels (%). Predation levels were assessed for seasonal patterns between months, location, and between *in situ* and translocated nests. Predation level was calculated as a percentage of the number of nests predated out of the total number of nests recorded. Data on sea turtle strandings for a total of 188 days between 2001 and 2014 over a total distance of 20.7 km were also analyzed for spatial and temporal trends in the rate of sea turtle strandings (number per km), and by identified causes of strandings. The parametric 1-way ANOVA was used to test for significant differences in nest densities among locations and the Tukey HSD test was used for post-hoc pair wise comparison analysis. Spatial differences in predation levels were tested by the non-parametric Kruskal-Wallis test. STATISTICA version 7.0 was used for all statistical analyses.

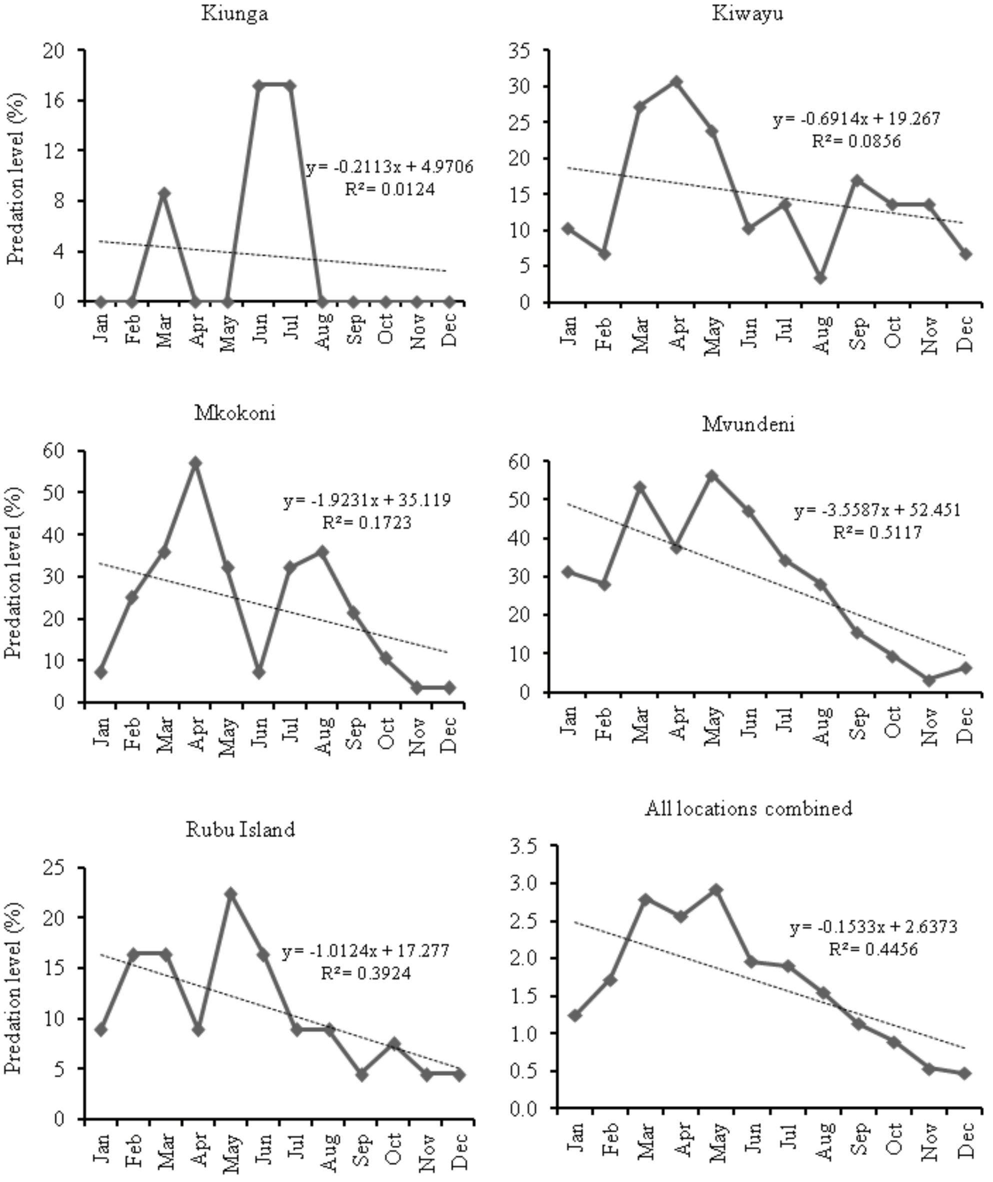

**Figure 3.** Trends in monthly predation levels (%) of sea turtle nests by location over the monitoring period in Lamu Seascape, Kenya.

# Results

## Spatial and temporal trends in sea turtle nesting

A total of 2021 sea turtle nests were recorded in 6,205 days between 1997 and 2013. In general, an increasing trend in annual sea turtle nest density was observed (Fig. 2; $R^2$ = 0.627). However, spatial differences in increasing trends were observed among the different locations, where higher trends were observed for Rubu Island ($R^2$ = 0.523) and Kiwayu ($R^2$ = 0.460). Overall, the annual mean number of translocated nests was significantly higher (76 ± 8 nests) than *in situ* nests (42 ± 5 nests) (1-way ANOVA: df = 1; f = 12.459; p = 0.001). The overall monthly mean number (± SE) of sea turtle nests was 168 ± 31. Higher numbers were recorded for translocated nests (108 ± 22) and much lower for *in situ* nests (60 ± 9). Higher numbers of sea turtle nests were observed between April and July, and lower numbers were observed between August and March.

Spatially, the mean (± SE) nest density over the study period was highest for Mvundeni (20 ± 3 nests/km) followed by Mkokoni and Rubu Island with 6 ± 1 nests/km. Kiunga and Kiwayu recorded the lowest nest densities of 4 ± 1 and 3 ± 1 nests/km respectively. There was a highly significant spatial difference in nest density among locations (1-Way ANOVA: df = 4; f = 15.614, p = 0.001). Post-hoc pair wise comparison confirmed that Rubu Island significantly differed from the rest of the locations (Tukey HSD: $p < 0.05$).

## Spatial and temporal trends in predation of sea turtle nests

From a total of 2,012 nests recorded between 1997 and 2013, 16.5% (n = 331) were predated. Decreasing trends in predation levels were observed in all locations and this was more pronounced in Mvundeni and Rubu Island (Fig. 3). Higher predation levels were observed mostly within the first six months of the year especially during the warmer months of January, February, March coinciding with the NEM season, and to some extent April and May at the beginning of the SEM season. Spatially, the mean monthly predation level was highest for Mvundeni followed by Mkokoni. The locations of Kiwayu, Rubu Island and Kiunga followed in that order (Fig. 4). Results of the Kruskal-Wallis test however, indicated no significant difference in predation levels among these locations (p = 0.085).

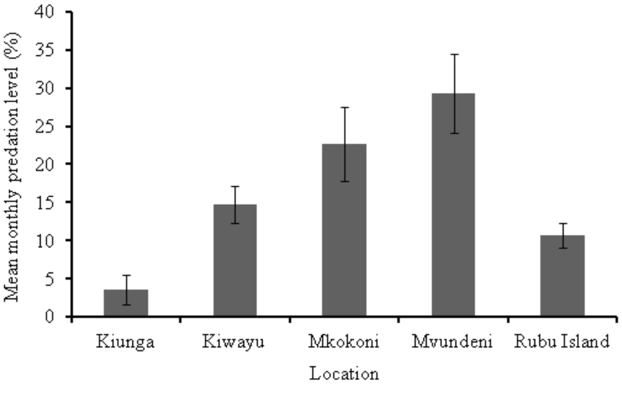

**Figure 4.** Mean (±SE) monthly predation levels of sea turtle nests by location over the monitoring period in Lamu seascape, Kenya.

## Spatial and temporal trends in sea turtle strandings

In general, a slight decreasing trend in shore-based monitoring effort for sea turtle strandings was apparent at all locations with higher effort between 2002 and 2005, and a peak in 2013 (Fig. 5). Shore-based monitoring for strandings occurred over a total of 188 days between 2001 and 2014, and a total of 227 sea turtle strandings were recorded. The sampling effort was an average of 14.5 ± 4 days annually with a general decreasing trend over time (Fig. 5). Sampling effort peaked between 2001 and 2005 with a drop between 2006 and 2011, another peak in 2013, and a drop again in 2014. The rate of sea turtle strandings ranged between 0.3 and 1.4 strandings/km at an annual average of 0.8 ± 0.1 strandings/km. There was an observed decreasing trend in sea turtle strandings with peaks in 2003, 2005 and 2013 (Fig. 6, all locations combined). On the other hand, each location was sampled at an average of 37.6 ± 10 days per year. Sampling by location was highest for Mkokoni (total of 67 days) followed by Kiwayu and Rubu Island with a total of 51 and 37 days respectively. Sampling was lowest for Kiunga (24 total days) and Mvundeni (9 total days). The rate of sea turtle strandings was highest for Mkokoni (24 strandings/km) followed by Kiunga (16 strandings/km). On the other hand Kiwayu, Mvundeni and Rubu Island recorded the lowest rates at 9, 8 and 6 strandings/km respectively.

The causes of sea turtle strandings differed by location (Fig. 7). The highest number of sea turtle strandings was attributed to fishery interactions (n = 121) in all the locations monitored, followed by unknown causes (n = 46), shark attacks (n = 30) and the viral disease fibropapillomatosis (n = 26). Hyena attacks and poaching incidents were reported at Mkokoni only, with 3 and 1 incidences respectively. Higher numbers of sea turtle strandings were observed in the months of January, February and March during the dry NEM season attributed mostly to fishing interaction causes (Fig. 8). Higher numbers of sea turtle strandings were also recorded between July and September. Lower numbers of strandings were recorded between October and December and the lowest in May and June, during the wet SEM season.

The curved carapace length (CCL), of stranded green turtles ranged between 10 and 130 cm CCL at an average size (± SE) of 68.9 ± 1.9 cm (n = 180; Fig. 9). The majority of these stranded turtles (94 %) measured between 30 and 110 cm CCL at an average size of 69.3 ± 1.8 cm CCL (n = 169). The fewest strandings were recorded for both the smallest and largest individuals of <30 cm at an average size of 23.9 ± 2.3 cm CCL (n = 6), and of >110 cm at an average size of 118.8 ± 3.8 cm CCL (n = 4) respectively. Sizes of stranded hawksbill turtles ranged between 20 – 80 cm at an average of 50.9 ± 2.1 cm CCL (n = 40) and the majority (87.5%) of these ranged between 30 – 70 cm at an average size of 50.6 ± 1.8 cm CCL (n = 35). Sizes of the stranded loggerhead turtles measured between 80 – 90 cm, at an average of 84.5 ± 0.5 cm CCL (n = 2), and the sizes of stranded olive ridley turtles ranged from 20 – 90 cm at an average of 51.4 ± 7.7 cm CCL (n = 5).

## Discussion

The long-term conservation of sea turtles in Kenya is highly dependent on protection of nesting sites, and continuous creation of awareness of sea turtle conservation among local communities (Okemwa *et al.*,

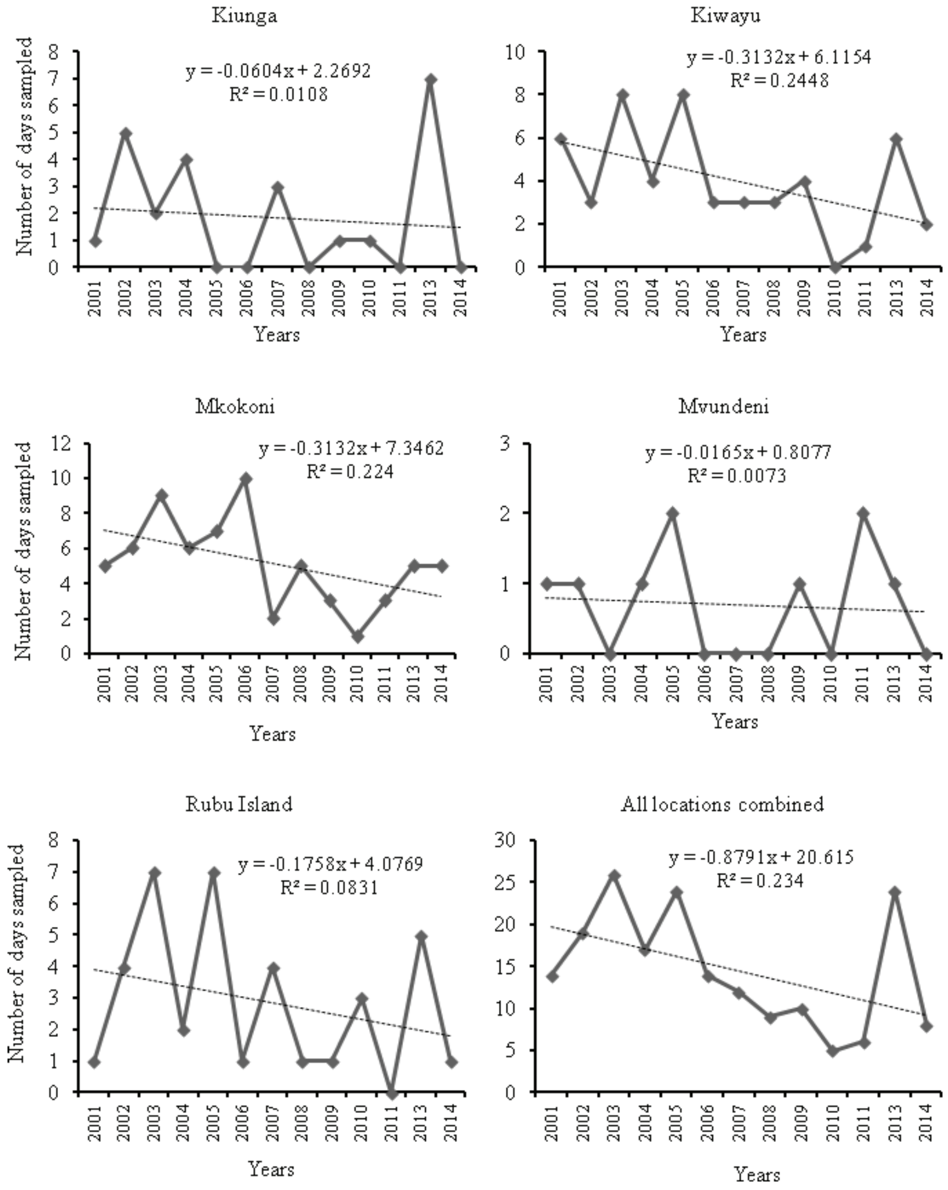

**Figure 5.** Spatial and temporal trends in sea turtle monitoring effort in Lamu seascape, Kenya during the study period.

2004). Fisheries related measures to protect sea turtle bycatch have also been tried especially in the bottom trawl shrimp fishery in the Malindi-Ungwana Bay area using Turtle Excluder Devices (Fennessy *et al.*, 2008). Perhaps as a result of these initiatives, results of this study indicate an increasing trend in sea turtle nest densities over the study period in the Lamu seascape, notwithstanding the spatial differences observed. These spatial differences in nest densities might be attributed to a number of factors including accessibility of the monitoring locations by the monitoring team, beach nesting preference by sea turtles (Domingo *et al.*, 2006), as well as differences in the intensity of human impact such as poaching for sea turtle eggs.

This increased trend in sea turtle nesting, as well as a slight decreasing trend in nest predation can be attributed to the increased sea turtle conservation efforts in the area. Lower nest predation levels were observed during the rainy southeast monsoon (SEM) season when nesting activity peaked, while higher nest predation levels coincided with the dry northeast monsoon (NEM) season. This seasonal difference could be attributed to the different weather conditions experienced, where during the dry NEM season risk exposure of turtle nests to predators could be higher than during the rainy SEM season. Turtle track marks are clearer and more exposed during the sunny NEM season and therefore, predators such as hyenas and porcupines can easily identify and locate these nests.

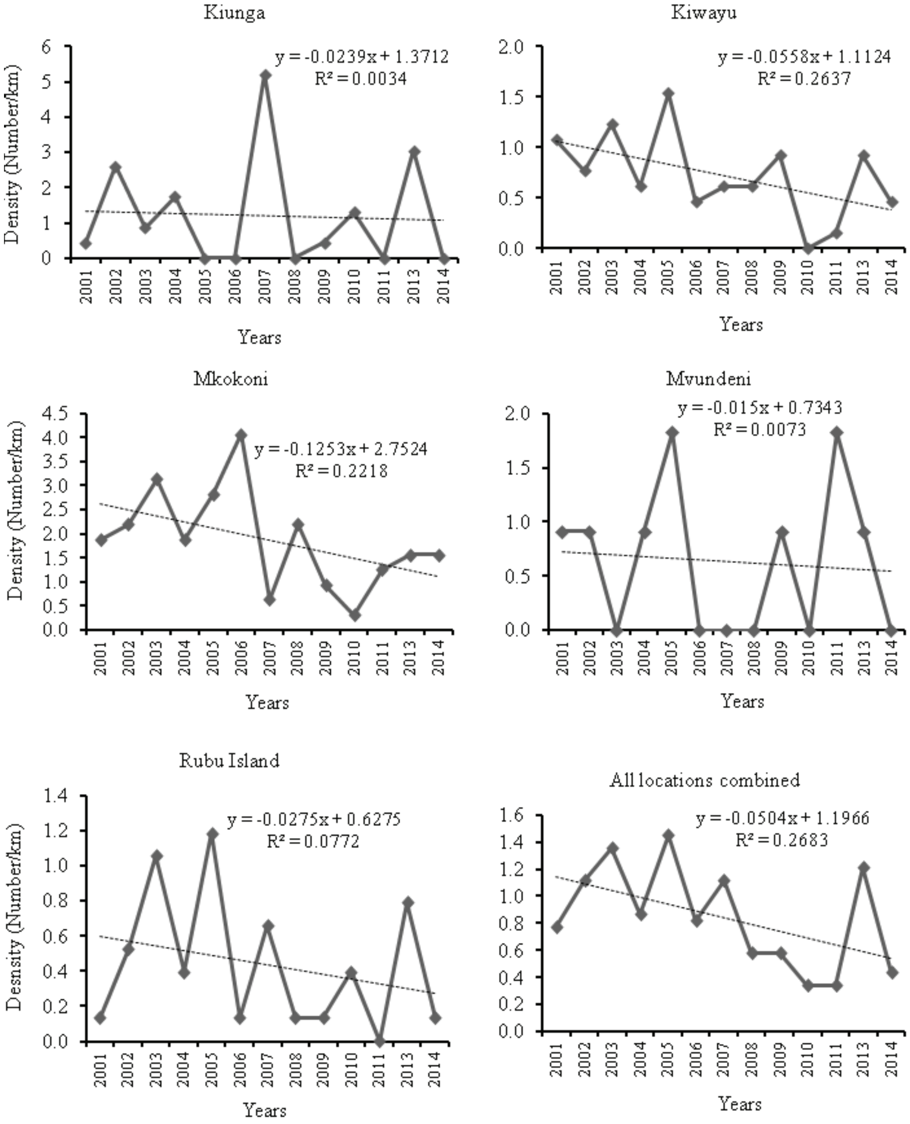

**Figure 5.** Spatial and temporal trends in sea turtle monitoring effort in Lamu seascape, Kenya during the study period.

Spatially, higher levels of nest predation levels were observed in Mvundeni and Mkokoni locations attributed mostly to the higher presence of wild animals especially hyenas and porcupines that were reported.

A slight decreasing trend in monitoring effort for sea turtle strandings was apparenrt for all the locations in the study area. This also coincided with a decreasing trend in the density of sea turtle strandings. This decreasing trend in stranding density despite reduced monitoring effort could be as a result of increased awareness of sea turtle conservation by the communities, especially the fishermen, whose activities contributed to the majorly of sea turtle strandings in the area. More pronounced stranding density was observed in two peaks of the year; between January and March (part of the NEM season), as well as between July and September; part of the SEM season. This is attributed mostly to increased fishing activity at offshore fishing grounds during the NEM season, as well as increased fishing effort in the sheltered inshore fishing grounds during the SEM season.

The highest number of sea turtle strandings, especially in Mkokoni and Kiwayu, were linked to interactions with fishing activities. Cases of sea turtles missing some of their flippers or their head were documented, similar to what has been found in other areas. This can be attributed to mutilation by fishermen while removing entangled sea turtles from gillnets (Domingo *et al.*,

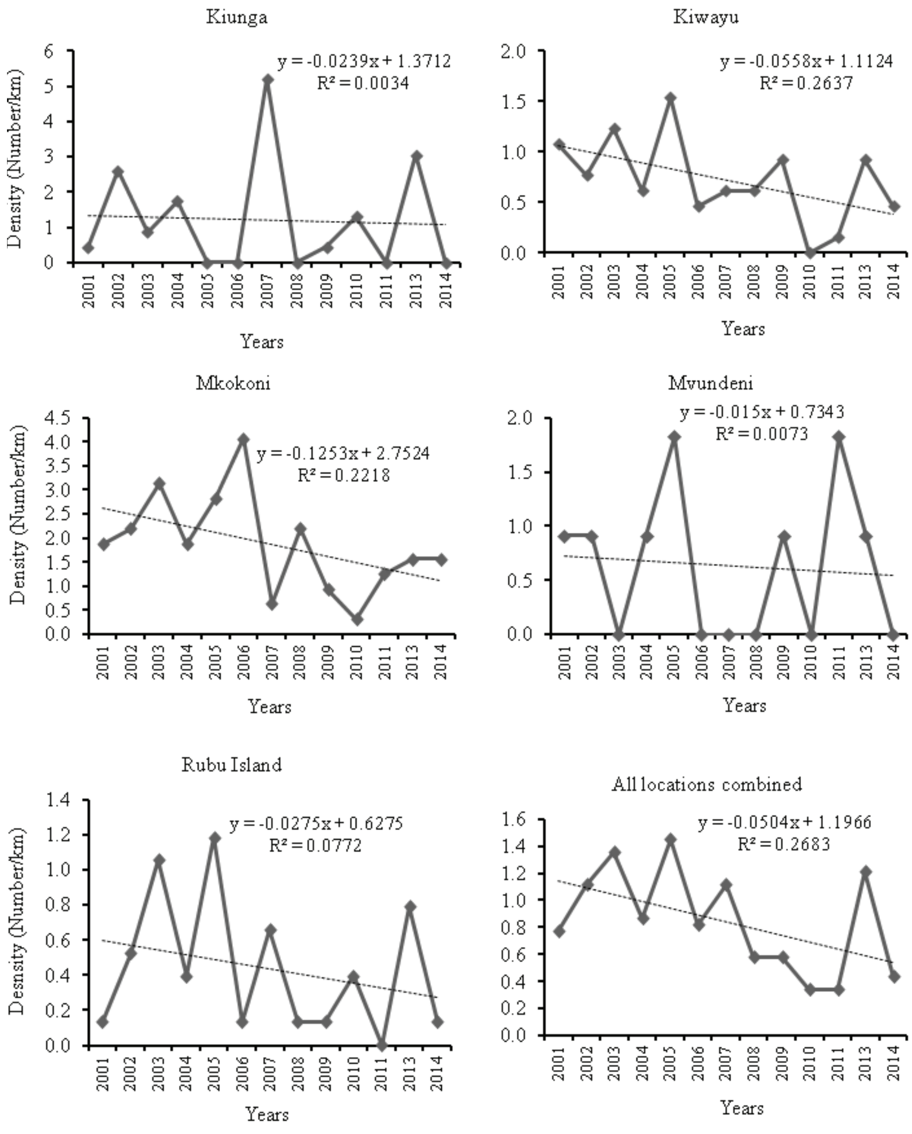

**Figure 6.** Spatial and temporal trends in the rate of sea turtle strandings in Lamu seascape, Kenya, during the study period.

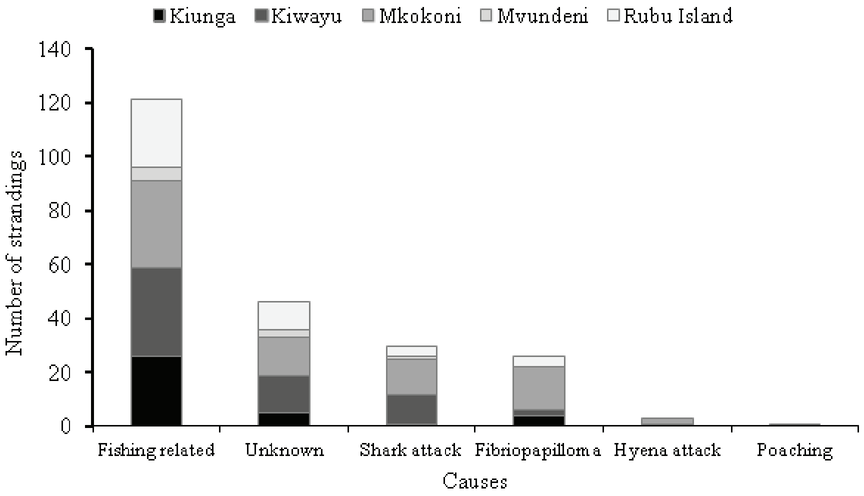

**Figure 7.** Sea turtle strandings by causes and locations in the Lamu seascape, Kenya during the study period.

2006), or decay. The viral fibropapillomatosis tumors and shark attacks were also common causes of sea turtle strandings or death in this present study. Sea turtles infected with fibropapillomatosis tumors are more likely to be weak and emaciated, and are more vulnerable to entanglement (Witherington *et al.*, 2006). The increasing prevalence of fibropapillomatosis infection in green turtle populations of the Western Indian Ocean (WIO) is a concern. In Madagascar it has been observed that only immature green turtles of between 40 and 80 cm CCL were affected by this desease, with prevalence in individuals between 50 and 59 cm (Leroux *et al.*, 2010). Similarly in Florida, tumors have been documented to be rare in the smallest and largest juveniles, indicating that the disease is acquired by juveniles after recruiting to coastal waters, with older juveniles either dying or recovering from the disease (Witherington *et al.*, 2006). There are indications that environmental factors are associated with the prevalence of the disease; however, more research is needed to determine these factors with certainty (Hamann *et al.*, 2010).

In this study, sea turtle strandings due to fishing related causes (incidental fisheries capture) seem to show a decreasing trend from the month of August onwards to the month of December, even though there is generally higher turtle strandings during this part of the year. Fishing related stranding cases appear to slightly increase from the month of January onwards to March, even with a generally lower

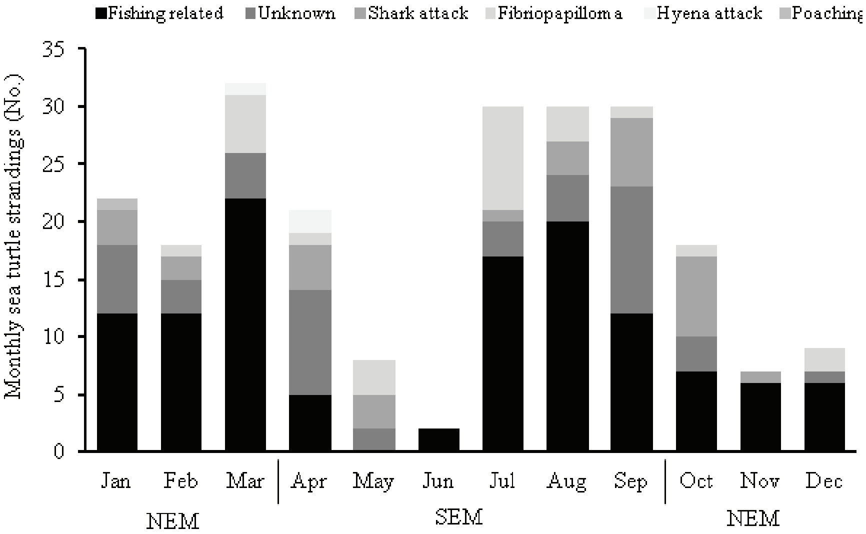

**Figure 8.** Monthly and seasonal distribution of sea turtle strandings by causes in Lamu seascape, Kenya during the study period.

number of strandings in this period. The months of April, May and June show the lowest fishing related sea turtle stranding level coinciding partly with the SEM season when fishing activity is lowest. In other areas of the Kenya coast, sea turtle strandings due to incidental fisheries capture has been reported to be generally similar to the pattern observed in the Lamu seascape. In the Watamu area, for example, during the second half of the year from June onwards, sea turtle strandings from gillnets contribute 80% (Zanre, 2005). This author also noted that the amount of sea turtle bycatch does not always correspond to the good fishing NEM season when fishing effort is highest, suggesting that there may be behavioral changes amongst local sea turtle populations at certain times of the year that affect their bycatch rates.

Findings of this study have shown that seasonality in fishing activity plays a key role in contributing to the seasonal patterns in sea turtle strandings. In the artisanal fishery along the Kenyan coast, fishing effort begins to increase in late September as the winds and sea start to calm with the onset of the NEM season. This enables fishing boats to venture beyond the fringing reef. By late October through until the end of March, fishing effort is at its highest. In the Lamu seascape, turtle strandings from fishing related causes is observed to be highest in the month of March (NEM season) followed by August and July (SEM season). Results of marine fisheries frame surveys conducted between 2004 and 2014 indicate relatively higher numbers of large fishing boats (*mashua* and *hori*) in Lamu as compared to other parts of the coast (Government of Kenya, 2014). These fishing boats are associated with large fishing nets (beach seines, gill nets and monofilament nets), and use long lines. Currently, the number of gill nets in Lamu stands at 1,138 with the most common mesh size being 6 inches. Also there are a total of 2,165 long line hooks, and 746 monofilament nets (Government of Kenya, 2014). The area has the highest concentration of beach seines, especially in the Amu and Faza fishing grounds. The fishing effort in Lamu, therefore, can be described as being relatively high. This ultimately contributes to the higher fishing related stranding of sea turtles within the Lamu seascape.

The highest number of sea turtle strandings was observed for green turtles followed by hawksbills. The lowest number of strandings occurred for olive ridley and the loggerhead turtle. The highest number of green turtle strandings coincided with the highest level of nesting in the area. Overall, most of the sea turtles that were stranded measured more than 40 cm CCL. In comparison, smaller green turtle individuals ranging

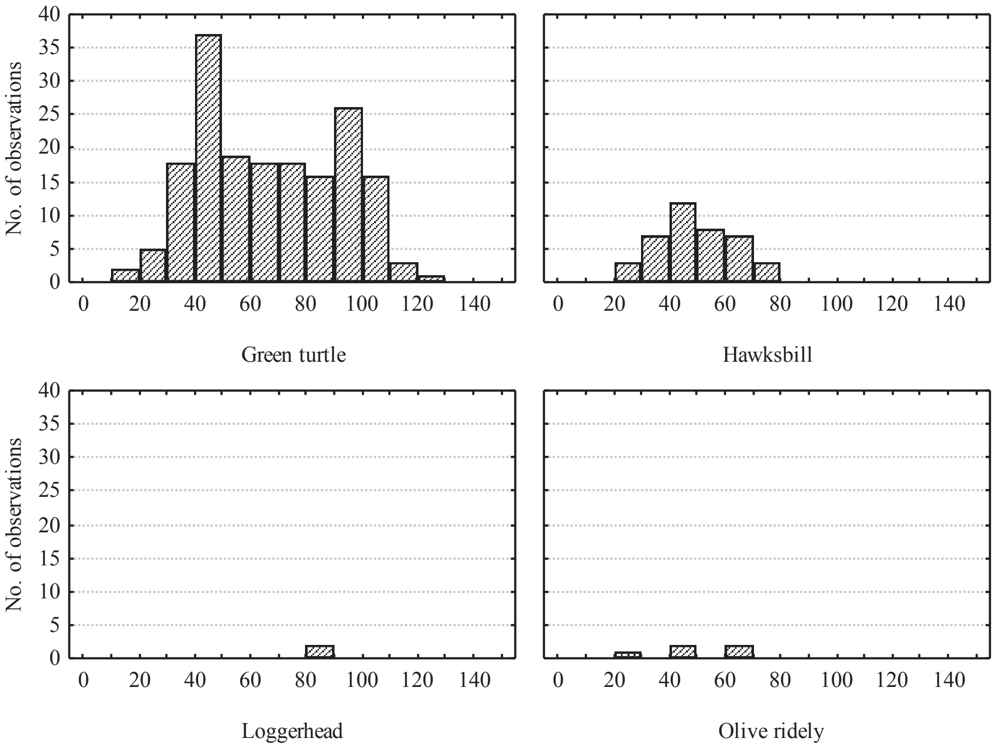

**Figure 9.** Curved carapace length (CCL) distribution of sea turtle strandings (sexes combined) by species in Lamu seascape, Kenya during the study period.

from 4.5 – 111.5 cm CCL (mean of 45.7 cm), and hawksbills ranging from 3.9 – 85.4 cm CCL (mean of 36.1 cm) were recorded in Watamu (Zanre, 2005), situated further south of the Lamu seascape. In Brazil, female green turtles have been documented to range between 101 and 143 cm CCL with a mean CCL of 116.8 cm (Moreira *et al*., 1995).

In conclusion, the success of sea turtle conservation efforts in the Lamu seascape, Kenya is clearly demonstrated by increased nesting density over time, as well as the reduced trends in sea turtle nest predation, and strandings. This is attributed to increased awareness among communities about sea turtle conservation. This study has confirmed that fishery related interaction is the major cause of turtle stranding in the area. We therefore recommend that in addition to shore-based monitoring of sea turtle nesting, predation, and strandings, there is need to enhance offshore monitoring to better quantify the interactions between fishers and sea turtles so as to better understand the in-water impacts and status of sea turtle populations in the Lamu seascape.

## Acknowledgements

We would like to extend our utmost gratitude to WWF Netherlands, WWF US and the Keane Family Foundation Trust for funding sea turtle conservation and data collection activities in the Lamu seascape. We would also like to thank WWF UK and the people postcode lottery (PPL) for supporting the analysis and conversion of this raw data into a publication. We also recognize the pivotal role of the local community in Lamu for their collaborative spirit and goodwill. They are the true custodians of sea turtles and indeed the champions of sea turtle conservation not only in Lamu but also the entire Kenya. Finally, we appreciate the partnership of the government agencies namely: Kenya Wildlife Service (KWS), State Department of Fisheries, Lamu County Government, and the Kenya Marine and Fisheries Research Institute (KMFRI).

## References

Antworth R, Pike D, Stiner JC (2006) Nesting ecology, status and conservation of sea turtles on an uninhabited beach in Florida. Biological Conservation 130: 10-15

Beggs JA, Horrocks JA, Krueger BH (2007). Increase in hawksbill sea turtle *Eretmochelys imbricate* nesting in Barbados, West Indies. Endangered Species Research Vol. 3: 159-168

Benny PN (2002) Variability of Western Indian Ocean currents. Western Indian Ocean Journal of Marine Science 1(1): 81-90

Bjorndal KA (1997) Foraging ecology and nutrition of sea turtles. In: Lutz PL, Musick JA (eds) The biology of sea turtles. CRC Press, Boca Raton, Florida, pp 199-232

Bourjea J, Nel R, Jiddawi NS, Koonjul MS, Bianchi G (2008) Sea turtle bycatch in the West Indian Ocean: Review, recommendations and research priorities. Western Indian Ocean Journal of Marine Science 7: 137-150

Church J, Palin O (2003) The sea turtle conservation initiative in the Kiunga Marine National Reserve, Lamu, Kenya from February 1997 to June 2003. Report for WWF East African Regional Programme Office, pp 107

Domingo A, Bugoni L, Prosdocimi L, Miller P, Laporta M, Monteiro DS, Estrades A, Albareda D (2006) The impact generated by fisheries on sea turtles in Southwestern Atlantic. WWF Programa Marino Para Latinoamerica y el Caribe, San Jose, Costas Rica, pp 70

FAO (2004) Technical consultation on sea turtles conservation and fisheries, Bangkok, Thailand, 29 November–2 December 2004. Sea turtle conservation concerns and fisheries management challenges and options. Food and Agriculture Organization of the United Nations, Rome, pp 329-370

Frazier JG (1982) Status of sea turtles in the Central Western Indian Ocean. In: Bjorndal K (ed.) Biology and conservation of sea turtles, Smithsonian Institute Press, Washington D.C. (reprinted 1995), pp 385-389

Fennessy, S.T., Vincent, X., Budeba, Y., Mueni, E., Gove, D.Z. (2008). An update on initiatives to reduce prawn trawl by-catch in the Western Indian Ocean. Western Indian Ocean Journal of Marine Science 7(2): 217-222

Garcia A, Ceballos G, Adayaa R (2003) Intensive beach management as an improved sea turtle conservation strategy in Mexico, Biological Conservation 111: 253-261

Gert JT (1989) A numerical study of the seasonal variability of the Somali current. PhD Thesis; Department of Geophysical Fluid Dynamics. The Florida State University, pp 1-141

Government of Kenya (2014) Marine waters fisheries frame survey 2014 report. Ministry of Agriculture, Livestock and Fisheries. State Department of Fisheries, Nairobi, 88 pp

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

Hamann M, Godfrey MH, Seminoff JA, Arthur K, Barata PCR, Bjorndal KA, Bolten AB (2010) Global research priorities for sea turtles: informing management and conservation in the 21st Century, Endangered Species Research 11: 245-269

Hilton-Taylor C (Compiler) (2000) 2000 IUCN Red List of threatened species. IUCN, Gland, Switzerland and Cambridge, UK, pp xviii + 61

Hirth HF (1997) Symptoms of the biological data on the green turtle *Chelonia mydas* (Linnaeus 1758). United States Fish and Wildlife Service Biological Report 97(1) pp 120.

IUCN (2004) 2004 IUCN Red List of threatened species. http://www.redlist.org. Accessed 20th July 2015

Jensen MP, Bell I, Limpus CJ, Hamann M, Ambar S, Whap T, David C, Fitzsimmons NN (2016) Spatial and temporal genetic variation among size classes of green turtles (*Chelonia mydas*) provides information on oceanic dispersal and population dynamics, Marine Ecology Progress Series 543: 241-256

Kairo JG, Kivyatu B, Koedam N (2002) Application of remote sensing and GIS in the management of mangrove forests within and adjacent to Kiunga marine protected area, Lamu, Kenya. Environment, Development and Sustainability 4: 153-166

Leroux G, Rakotonirina B, Ciccione S, Hawawini S, Campillo A (2010). First report of *Chelonia mydas* affected by cutaneous fibropapillomatis on the West coast of Madagascar. Indian Ocean Turtle Newsletter 11: 13-17

Lohmann KJ, Lohmann CMF, Brothers JR, Putman NF (2013) Natal homing and imprinting in sea turtles. In The Biology of Sea Turtles Vol. 3, Wyneken J, Lohmann KJ, Musick JA eds. (CRC Press), pp 59-77

McClanahan TR (1988) Seasonality in east Africa's coastal waters. Marine Ecology Progress Series 44(2): 191-199

McClanahan TR, Kaunda-Arara B (1996) Fishery recovery in a coral reef marine park and its effect on the adjacent fishery. Conservation Biology 10(4): 1187-1199

McLellan E, Arps E, Donelly M, Leslie A (2012) WWF Global Marine Turtle Strategy 2.0 2012 - 2020. 52 pp

Moreira L, Baptistotte C, Scalfon J, Thome JC, de Almeida APLS (1995) Occurrence of *Chelonia mydas* on the Island of Trinidade, Brazil. Marine Turtle Newsletter 70: 1-2

Obura D, Chuang YY, Olendo M, Amiyo N, Church J, Chen CA (2007) Relict *Siderastrea savignyana* (Scleractinia: Siderastreidae) in the Kiunga Marine National Reserve, Kenya. Zoological Studies Taipei 46(4): p 427

Okemwa GM, Nzuki S, Mueni EM (2004) The status and conservation of sea turtles in Kenya. In Godley BS, Broderick AC (eds.) Marine turtle newsletter No. 105: 1-6

Rees AF, Al-Kiyumi A, Broderick AC, Parathanasopoulou N, Godley BJ (2012)Conservation related insights into the behavior of the olive ridley sea turtle *Lepidochelys olivacea* nesting in Oman, Marine Ecology Progress Series 450: 195-205

Schott F (2001) The monsoon circulation of the Indian ocean. Progress in Oceanography, 51(1): 1-123

Spencer T, Laughton AS, Flemming NC (2005) Variability, interaction and change in the atmosphere ocean ecology system of the western Indian ocean. Philosophical Transactions of the Royal Society, 363(1826): 3-13

Wamukoya, GM, Kaloki, FP, Mbendo, JR (1997) Sea Turtle Recovery Action Plan for Kenya (STRAP). KESKOM Technical Report Series. 69 pp

Witherington B, Bresette, M, Herren, R (2006) *Chelonia mydas* – Green Turtle. In: Biology and Conservation of Florida Turtles – Peter A. Meylan, Ed. Chelonian Research Monographs 3: 90-104

WWF Lamu (2012) Sea turtle conservation practice – a field guide for community based conservation groups, Kiunga, Kenya

Zanre R (2005) Report on Watamu Turtle Watch's sea turtle bycatch release programme, Watamu, Kenya, April 1998 – May 2004. 95 pp

**WIO Journal of Marine Science** 15 (1) **2016** 15-29

# The decline in phytoplankton biomass and prawn catches in the Rufiji-Mafia Channel, Tanzania

Masumbuko Semba[1,2*], Ismael Kimirei[3], Margareth Kyewalyanga[4], Nyamisi Peter[5],
Luc Brendonck[1], Ben Somers[1]

[1] Laboratory of Aquatic Ecology,
Evolution and Conservation,
KU Leuven,
Charles Deberiotstraat 32
3000 Leuven, Belgium

[2] Nelson Mandela African
Institution of Science and
Technology, P.O. Box 447,
Arusha, Tanzania

[3] Tanzania Fisheries Research
Institute (TAFIRI), P.O. Box 90,
Kigoma, Tanzania

[4] Institute of Marine Sciences,
P. O. Box 668,
Zanzibar, Tanzania

[5] University of Dodoma,
P.O. Box, 339,
Dodoma, Tanzania

* Corresponding author:
lugosemba@gmail.com

## Abstract

The world's oceans have seen significant declines in phytoplankton-the primary food source in the marine environment. This decline in primary producers is likely to impact the food chain and functions of most coastal and marine ecosystems. Despite being one of the most productive marine fishing grounds in the Western Indian Ocean (WIO) region, the information about phytoplankton biomass in the Rufiji-Mafia Channel is poor. This study aimed to narrow this information gap by assessing phytoplankton biomass in the Channel and its association with the decline of the prawn fishery. We combined in-situ measurement and ocean colour satellite data to determine and assess trends in phytoplankton biomass and sea surface temperature between 2002 and 2014. These trends were related to a declining prawn fishery in the Channel. While phytoplankton displayed a significant declining trend during the southwest monsoon, sea surface temperature showed an insignificant increasing trend. Phytoplankton declined at the rate of 1.2 percent per year (*tau* = 1.2, z = 3.52, $p$ = 0.004) between 2002 and 2014. This declining trend in Chl-a matches well with the decreasing trend in the prawn fishery (*tau* = 0.57, z = 3.39, $p$ = 0.0006) and the insignificant increasing trend in sea surface temperature (*tau* = 0.02, z = 0.43, $p$ = 0.66). This study provides quantitative evidence of trends in chlorophyll and SST and the link with trends in the prawn fishery, which increases our understanding of the changes in marine primary productivity in the coastal waters of Tanzania.

**Keywords:** phytoplankton, Chl-a, sea surface temperature, Rufiji-Mafia Channel, Rufiji River, satellite data, prawn fishery, Tanzania

## Introduction

Phytoplankton are mostly single celled aquatic microalgae that use Chlorophyll-*a* (Chl-a) to carry out photosynthesis (Kyewalyanga, 2005; Kyewalyanga, 2015). Phytoplankton contain Chl-a, a green and photosynthetic pigment that absorbs photons from solar radiation and converts it into energy (Kevin *et al*., 2015; Roy, 2009), which stored as food. Phytoplankton are at the base of the food chain, composed of primary producers (Klemas, 2013). They not only form the diet of typical herbivorous zooplankton, but are also food sources of other invertebrates, fishes and large mammals, including whales (Roy, 2009). Generating roughly half the planetary primary production, marine phytoplankton affect the abundance and diversity of marine organisms, drive marine ecosystem functioning, and set the upper limits to fishery yields (Allan *et al*., 2014; Anilkumar *et al*., 2014; Baliarsingh *et al*., 2013; Bouman *et al*., 2006). Phytoplankton strongly influence climate processes and bio-geochemical cycles, particularly the carbon cycle (IPCC, 2014). The ocean absorbs about 25 percent of global carbon dioxide, which is the main source of global warming (Allan *et al.*, 2014).

Phytoplankton account for about half of global, and nearly all of marine primary productivity (Barlow *et al.*, 2011; Lamont *et al.*, 2014); consequently, any drop in phytoplankton biomass would almost certainly have severe ecological consequences (Rykaczewski and Dunne, 2011). Recently, Boyce *et al.* (2010) reported an alarming, century-long decline in marine phytoplankton biomass of 1% per year at a global scale. A similar trend has been observed in the northern hemisphere, where phytoplankton have decreased by 1% per year between 1998 and 2012 (Kevin *et al.*, 2015). This decreasing trend of phytoplankton biomass suggests major changes in ecosystem processes and biogeochemical cycling, with significant implications for ecological functioning of coastal and marine ecosystems (Bouman *et al.*, 2006; Boyce *et al.*, 2010; Jutla *et al.*, 2011; Marinov *et al.*, 2006), including fisheries.

While phytoplankton are invisible to the naked human eye (Kumar and Perumal, 2012), they can be detected from space by ocean color remote sensing – a technique used to gather information on Chl-a concentration without being in contact with the surface of the ocean (Grémillet *et al.*, 2008; Kachelriess *et al.*, 2014; Kratzer *et al.*, 2014; Picart *et al.*, 2014; Raitsos *et al.*, 2013; Rykaczewski and Dunne, 2011; Sherman *et al.*, 2011). Recent advances in observational satellite technology, free-floating drifters and other devices, have made large-scale monitoring of the oceans possible (Blondeau-Patissier *et al.*, 2014; Chawira *et al.*, 2013; Grémillet *et al.*, 2008; Kachelriess *et al.*, 2014; Vanhellemont and Ruddick, 2015). With the aid of remote sensing technology it is possible, for example, to determine with high accuracy the abundance of phytoplankton in surface waters using the color reflected by the Chl-a pigment (Grémillet *et al.*, 2008; Sherman *et al.*, 2011). The presence of Chl-a in surface water has been widely used as an indicator of primary production and ecological functioning of freshwater and marine ecosystems (Boyce *et al.*, 2010).

Marine phytoplankton have recently been observed, using satellite remote sensing, to vary on a global scale. Several studies have shown an alarming productivity decrease in the Indian and Pacific Oceans (Wernand *et al.*, 2013). Other studies have shown increasing trends associated with large inter-annual and decadal-scale variability (Boyce *et al.*, 2010; Rykaczewski and Dunne, 2011; Thangaradjou *et al.*, 2014; Wernand *et al.*, 2013). Although satellite ocean color data have been available since the early 1980s, empirical estimates of long-term trends in phytoplankton abundance in the Rufiji-Mafia Channel remain limited. Assessing long-term changes in phytoplankton and the ecosystem condition in the Channel is of increasing importance because of possible links to declining marine fishery resources (Jiddawi and Ohman, 2002; Slater *et al.*, 2014).

The Rufiji-Mafia Channel is one of the most important prawn fishing grounds in Tanzania. It contributes about half of the total annual prawn production (Masalu, 2003). Nutrient-rich waters and sediments flowing into the Channel from the Rufiji River contribute to its high primary production. It is the only fishing ground in the coastal waters of Tanzania where industrial and artisanal prawn fisheries are conducted (MLFD, 2012). The prawn fishery was amongst the major commercial fishing activities in Tanzania, but since 2000 this fishery has shown evidence of serious unsustainable exploitation levels. Increased fishing effort, exploitation above the maximum sustainable yield, and destruction of habitats were cited as causes for the decreasing catch rate. However, although fishing effort was reduced significantly, the yield continued to decline (MLFD, 2012). This suggested that the stocks had not only dwindled, but had shrunk, and the fishery was temporary closed in 2008 for two years to allow recovery. A prawn stock assessment survey conducted in 2011 found no sign of recovery. This finding led the government, through the Fisheries Division, to declare full closure of the prawn fishery in 2012 (MLFD, 2012).

This study, therefore, aimed at assessing the trend in phytoplankton production and changes in sea surface temperature (SST) in the Rufiji-Mafia Channel, and to relate these to the observed fluctuations in the prawn fishery in the Channel. We combined in-situ measurements and long-term time series data of moderate resolution ocean colour satellite images (Rousseaux and Gregg, 2015) in order to assess the trends in Chl-a concentration as a proxy for primary production.

## Methods

### Study area

The Rufiji–Mafia Channel is located between latitudes 06°50'S and 08°40'S and longitudes 39°20'E and 39°40'E (Fig. 1). The area includes the Rufiji Delta and the Mafia Channel within the bounds described above. The Channel is approximately 21 km wide at its narrowest (between the mainland and Bwejuu Island)

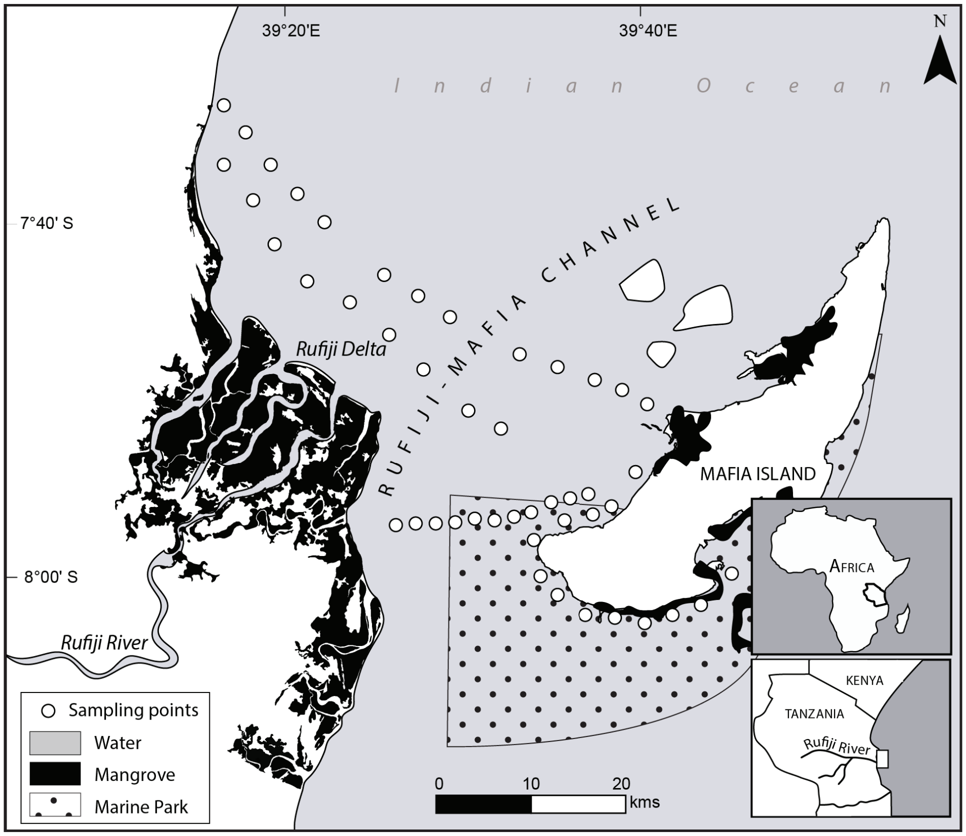

**Figure 1.** Map showing the location of the Rufiji-Mafia Channel, with in-situ sampling stations. The inset maps indicate the study area in Tanzania and its position in Africa.

and 70 km at its widest (just south of the mouth of the Rufiji River estuary). Much of the Channel is shallow. At the point where the Rufiji River flows into the Channel, the average depth is 6m. On average, the depth of the Channel is 22m and about 61% of the Channel area is less than 20m deep (Semba, unpublished data). Because the Channel is adjacent to a large estuary, it contains zones of fresh water, salt water and brackish water, with the freshwater zone in the vicinity of the mouth of the Rufiji River. Salinity varies from 0.5 to 10 ppt at the mouth of the Rufiji River to 18.7 to 36 ppt in the Channel.

The climate of the Channel is influenced by the seasonal reversal of monsoon winds. There are mainly two monsoon seasons, the northeast monsoon ("*Kaskazi*"), which prevails from November to March and is characterized by a mean surface temperatures of 30°C, and weaker winds and calm sea conditions. The other season is the southeast monsoon ("*Kusi*"), which runs from April to September and is marked by a mean surface temperature of 23°C, stronger winds and rough sea conditions. The area receives an annual average rainfall of 1800 mm, which is divided into two seasons - "long-" and "short" rains occurring mainly between March and May and from November to early December respectively. The Channel is strongly influenced by the Rufiji River which, apart from discharging a large quantity of fresh water (900 $m^3/s$), transports sediments and nutrients (Garpe and Öhman, 2003). The strongest outflows are in the northern Channels, with more saline conditions to the south. The Rufiji River flows into the Indian Ocean and influences the coastal environment within the Channel through the creation of productive brackish water in the estuary, maintenance of deltas, tidal flats and shorelines, and nourishment of mangroves and seagrass beds.

Known for both its beauty and bounty, the Rufiji-Mafia Channel forms one of the finest complexes of estuaries, mangroves, coral reefs and marine Channel ecosystem (Masalu, 2003). Mangroves and seagrass beds filter freshwater discharges from the Rufiji River that are rich in nutrients (Kimirei *et al.*, 2016) while the detritus from mangroves provide food for many commercially important species, mostly demersal fish and benthic invertebrates, thereby supporting a wide variety of sea life (Igulu *et al.*, 2014). The Channel is an extremely high primary and secondary productivity area and supports a great abundance and diversity of fish, birds, invertebrates and macro-fauna (Gaspare and Bryceson, 2013). The Channel was previously known for prawn production, which contributed about half of the total annual prawn production in Tanzania (Sobo and Mahongo, 2007)

## Data Collection, Processing and Analysis

### *In-situ measurements and Prawn data*

Biological, physical and chemical variables in the Rufiji-Mafia Channel were recorded in July 2013. July was chosen for sampling because it fell within the southeast monsoon season which has high primary productivity. A total of 48 stations in three transects were chosen for sampling (Fig. 1). The sampling stations were at an interval of 3 kilometers apart. The longitude and latitude coordinates of each sampling station were recorded using the Essential GPS App version 3.1 installed in a Samsung Galaxy Smartphone which was running on a Gingerbread Android Operating system, version 2.3.

Water samples for Chl-a analysis were collected and filtered through 0.45µm pore size membrane filters. Five litres (5L) of water were filtered per sample. Filters were then folded in aluminum foil, stored frozen in Ziploc bags and transported to Unguja Island for laboratory analysis at the Institute of Marine Sciences. Chl-a was extracted by adding 10ml of 90% (v/v) acetone to vials containing the filter papers. These tubes were then covered with aluminum foil and refrigerated for 24 hours. After that, the test tubes were centrifuged for 10 minutes at a speed of 3000 revolution per minute (rpm), and then stored in cuvettes. A fluorometer was used to determine the fluorescence value of Chl-a in the cuvettes. The fluorometer reading before addition of acid in the sample was recorded, to obtain corrected Chl-a, after which 2 drops of 10% hydrochloric acid was added to the cuvettes, and a new fluorometer reading recorded. The concentration of Chl-a in the sample was then calculated according to Lorenzen (1966). Ammonia was analyzed according to standard procedures and methods detailed in APHA (1998). The clarity (transparency) of water was measured at the sampling sites using a 20 cm black and white Secchi disc. The prawn catch data used in this study were obtained from the Tanzania Fisheries Research Institute (TAFIRI) in Dar es Salaam. The archive contains raw catch data for the commercial prawn fishery for three fishing zones - Bagamoyo, the Rufiji-Mafia Channel, and Kilwa. Since the Rufiji-Mafia Channel is the largest prawn fishing zone; and that no commercial prawn catch data are available in the Channel before 1991, we used all available data for the period 1991 - 2006. The monthly catch data during the prawn fishing season for each year was computed to obtain an annual mean average.

### *Satellite Data*

The strong thermal gradients and primary production associated with the monsoon seasons in the WIO make it particularly amenable to monitoring via satellite remote sensing observations, such as those derived from radiometry and microwave. Sea surface temperate (SST) and Chl-a (Chl-a) data from Moderate Resolution Imaging Spectroradiometer (MODIS) were used to assess trends in warming and primary productivity in the Rufiji-Mafia Channel. MODIS was launched by the National Aeronautics and Space Administration (NASA) in 2002 on board the Aqua satellite platform to study global dynamics including the oceans (David, 2002). MODIS captures data in 36 spectral bands ranging in wavelength from 0.4 um to 14.4 um and at varying spatial resolutions. The MODIS instrument images the entire Earth every 1 to 2 days. Level 3 standard mapped gridded MODIS SST and Chl-a data were obtained from the (SeaWIFS data center that archives and distributes satellite data (http://modis.gsfc.nasa.gov). The monthly gridded data with horizontal resolution of 4 kilometer at the Equator were downloaded in Hierarchical Data Format (HDF). For the purpose of this study only SST and Chl-a gridded MODIS data for Tanzanian coastal waters, where the Rufiji-Mafia Channel is found, were considered, for the period 2000-2014.

### *Data Processing*

Because of the inability of some GIS software to directly read the general purpose Hierarchical Data Format (HDF), the downloaded data were first processed to tab-delimited text data format and remapped using HDFView software that is freely available at the National Center for Supercomputing Applications website (http://hdf.ncsa.uiuc.edu//index.html). The raw data were then converted to spectral reflectance, which is used as a proxy for Chl-a concentration. The conversion process explained above was carried out using the metadata information (spatial resolution; number of rows and columns; no data value; southwest point for longitude and latitude) embedded in the MODIS data.

The physical, chemical, and biological variables, and position information (latitude and longitude) at each sampling station were collected. The satellite chlorophyll concentration at each sampling station was calculated from successive positions for the individual station. Prior to overlay of the gridded Chl-a satellite data on the sampling stations shapefile, the two datasets were transformed and projected to the same geographical coordinate system. The longitude and latitude of each sampling station were first converted into the GIS environment and presented as a point shapefile. The two datasets (gridded satellite of Chl-a and point shapefile) were the transformed into the World Geodetic System of 1984 (GCS WGS 84) and projected to the Universal Transverse Mercator (UTM). To obtain the satellite derived Chl-a value at the sampling locations, a point shapefile of the sampling stations was overlaid on gridded satellite data. Chl-a values from satellite data at each sampled locations were then extracted using the 'extract tool' of ArcGIS's Spatial Analyst Extension Version 10.2 (www.esri.com).

### *Depth classes and distance of sampling station from the coastline*

The water depth at every sampling station in the Channel was recorded using an echo sounder. The recorded depths were then grouped into depth classes which were used to create an ordinal variable of four depth classes; that is 0 – 9.9, 10 - 19.9, 20 - 29.9, and deeper than 30 meters. The relative distances of all in-situ sampling stations from the coastline in the Rufiji-Mafia Channel were computed using a linear referencing method in ArcGIS 10.2 (www.esri.com). The method has an advantage of storing nearest distances of each station using a relative position. The coastline of Channel was used as reference points. Three steps were involved to determine the distances of the sampling stations from the coastline. First, a vector shapefile representing the coastline of the Rufiji-Mafia Channel and its geographical positions was created by tracing the high resolution imagery acquired in 2012. The images were obtained from the National Bureau of Statistics of Tanzania (www.nbs.go.tz). Second, a coastline shapefile was converted to route, which stores both geographical locations and distance from a specified reference location. The distances of each surveyed station from the coastline were exported into a tabular form in ArcGIS. The linear distances of each sampling station to the relative position on the coastline were then estimated using linear referencing tools in ArcGIS. The calculated distances were ordered into classes at intervals of 5 kilometers to obtain three distance classes in kilometers (below 5, 5.1 – 10; above 10).

### *Statistical Analysis and Trend Estimations*

The Chl-a data from both in-situ and satellite measurements, and sea surface temperature (SST) data from satellite data, were checked for errors and cleaned before they were analyzed. Any inaccurate in-situ measurements or those that were mismatched with satellite observations were removed from the analysis. A non-parametric Spearman rank correlation was used to estimate the strength of the association (correlation coefficient) between in-situ and satellite Chl-a data. A Spearman rank correlation was also used to assess the association between the above parameters and catch rate over time. The annual satellite-derived sea surface temperature and Chl-a data did not conform to the assumptions of normal distribution and homoscedasticity (Steven, 2013), and therefore a non-parametric Mann-Kendall trend analysis test was used to assess the trends in Chl-a, sea surface temperature, and the prawn fishery. The Mann-Kendall test was used because it can detect trends even in noisy observations; and has the ability to detect both intra (seasonal) and inter-annual trends in data described with non-normality and heteroscedasticity.

The WIO region has two contrasting seasons that obscure linear trends over longer-time scales. To assess the trends therefore, the monsoon seasons were treated and analyzed separately. First, the satellite derived SST and Chl-a data were broken down into the southeast (June to September) and northeast (November to April) monsoon seasons. Then, the Mann-Kendall test was used to assess the direction of the trends (decreasing or increasing) at a 95% confidence level (Steven, 2013). The inter-annual mean differences in Chl-a, and SST were analyzed with a non-parametric Kruskal-Wallis test - a nonparametric equivalent of the One-Way ANOVA, because the data were non-normal. The difference in mean Chl-a concentration among depth and distance groups was tested using a Tukey HSD test. Statistical analyses were performed in R (version 3.1.2), python (version 2.7), and Matlab (version 8.5). Some of the statistical packages used include EnvStats in R environment; Numpy, scipy and pandas python packages; and the Statistics and Machine Learning toolbox in MATLAB.

## Results

### Influence of depth and distance on in-situ measured chemical and physical variables

The results of the in-situ measurements for the different parameters and depth levels are presented in Table 1. Most of the sampling stations (75%) were located within shallow waters (i.e. less than 10 meters

**Table 1.** Descriptive statistics showing the mean ±SD of Chl-a, dissolved oxygen, temperature, ammonia, and water transparency at different depths in the coastal water column of the Rufiji-Mafia Channel for July 2013. Different superscript letters indicate significant differences.

| Depth (m) | N | Chl-a (mg/L) | DO (mg/L) | Temperature (°C) | Ammonia (µg/L) | Transparency (m) |
|---|---|---|---|---|---|---|
| 0 – 10 | 6 | 0.28±0.22$^{a}$ | 6.00±0.76 | 29.34±0.77 | 0.77±0.41 | 2.48±2.26 |
| 10 – 20 | 36 | 0.10±0.01$^{b}$ | 6.71±0.52 | 28.65±0.51 | 1.14±0.58 | 10.38±0.75 |
| 20 – 30 | 4 | 0.26±0.27$^{ab}$ | 6.30±0.43 | 29.03±1.19 | 1.48±0.17 | 12.33±4.93 |
| > 30 | 2 | 0.15±0.03$^{ab}$ | 7.07±0.01 | 26.83±0.14 | 0.77±0.07 | 19.45±1.34 |

**Table 2.** Descriptive statistics showing mean ±SD of Chl-a, dissolved oxygen, water temperature, ammonia and water transparency at different distances from the coastline in the Rufiji-Mafia Channel for July 2013. Different superscript letters indicate significant differences.

| Distance (km) | Count (N) | Chl (mg/l) | DO (mg/l) | SST (°C) | Ammonia (µg/L) | Transparency (m) |
|---|---|---|---|---|---|---|
| Below 5 | 5 | 0.65±0.24$^{a}$ | 5.68±0.11 | 30.02±0.18 | 0.54±0.04 | 0.43±0.76 |
| 5.1-10 | 9 | 0.37±0.20$^{b}$ | 6.05±0.18 | 29.59±0.75 | 0.55±0.28 | 3.05±3.12 |
| Above 10 | 10 | 0.18±0.12$^{b}$ | 6.47±0.40 | 28.73±0.61 | 1.12±0.51 | 6.46±9.66 |

deep). While water transparency increased with depth in the Channel, Chl-a, dissolved oxygen, temperature and ammonia did not follow any visible trend (Table 1). Chl-a concentration (mean ± SD) varied from 0.28 ±0.22 mg/L in the shallow coastal waters (≤10 m) to 0.10 ±0.01 mg/L in water depths between 10.01 to 20.0 meters. There were significant differences in Chl-a concentrations between depth groups ($X^2_{(3,43)} = 14.68$, $p = 0.002$). However, the differences were only found between the shallower (≤ 10m) and the 10-19.9m depth groups (Tukey HSD test, $p < 0.001$). Dissolved oxygen ranged from 6.00 ±0.76 in shallow waters to 7.07 ±0.01 in water with depths ≥30 meters. While the shallow coastal waters had the highest surface temperature of 29.34 ± 0.77°C, stations in waters with depths above 30 meters had the lowest mean temperature of 26.83 ± 0.14°C. In contrast to temperature, high concentrations of ammonia were found in waters with depth ranging between 20 and 30 meters, and stations in shallow waters of less than 10 meters deep had the lowest concentrations (Table 1).

Table 2 shows mean (±SD) data of Chl-a concentration, dissolved oxygen, water temperature, ammonia, and water clarity at different distances from the coastline. Dissolved oxygen (DO), transparency and ammonia increased with distance from the coastline, while temperature and Chl-a decreased with distance from the coastline. The concentration of ammonia varied between 0.54 µg/L within 5 km from the coastline and 1.12 µg/L for coastal water at distance above 10 km from the coastline. The clarity of the water ranged from 43 cm in water within 5km from the shore to about 6.46 meters for water more than 10 km from the coastline, indicating that water close to shore is turbid, and gradually clears further from the shore. Contrary to DO, ammonia and transparency, sea surface temperature and Chl-a showed high values in waters close to the coastline that decreased with increasing distance from the coastline (Table 2). Chl-a concentrations were significantly different among distance groups ($X^2_{(22)} = 10.97$, $p = 0.004$) where coastal waters located within 5 km from the coastline had significantly higher Chl-a concentration than those above 10km (Tukey HSD test, $p = 0.0035$).

## In-situ and satellite derived Chl-a distribution

Chl-a concentration in the Rufiji-Mafia Channel was found to vary non-linearly and significantly with depth ($R^2 = 0.74$, $p < 0.014$; Fig. 2a) and distance from the Rufiji Delta ($R^2 = 0.42$, $p < 0.05$; Fig. 2b). Higher Chl-a values (>0.5mg/L) were found within the top 5 m (Fig. 2a) and within 8km from the coastline (Fig. 2b). Satellite data also indicated that nearshore waters had higher Chl-a concentrations than those further from the coastline (Fig. 3). The areas around the Rufiji Delta (western side of the Channel) had higher Chl-a values than around Mafia Island (eastern side) where pockets of high Chl-a were observed (Fig. 3). Although the in-situ Chl-a values were about

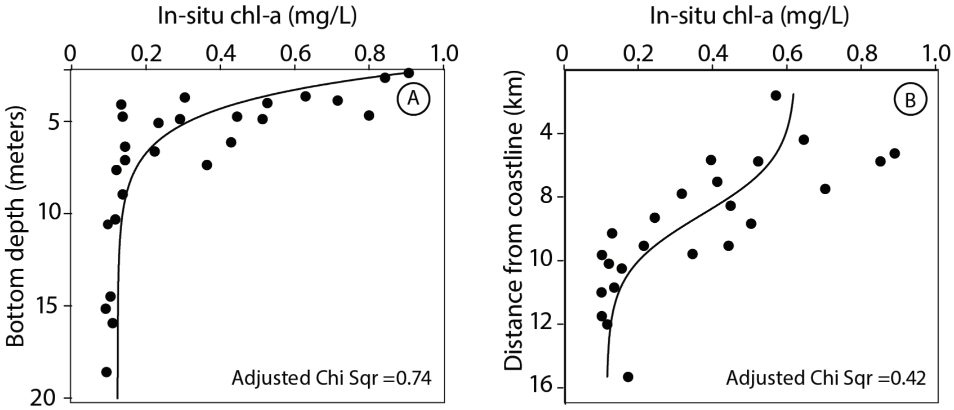

**Figure 2.** Non-linear plots of in-situ Chl-a data measured in the Rufiji-Mafia Channel plotted as a function of (a) depth and (b) distance from the coastline of the Rufiji River.

9 fold lower than those derived from the satellite data (Table 3), there is reasonably good agreement in large scale patterns of Chl-a concentration of the two datasets. There was a significant correlation between the in-situ and satellite Chl-a concentrations ($R^2 = 0.81$, $p < 0.05$; Fig. 4). The Spearman rank correlation model therefore explained about 81% of the differences in chlorophyll values, which indicates that the in-situ and satellite chlorophyll concentrations were remarkably similar.

## Trends in Chl-a, SST and prawn catches in the Rufiji-Mafia Channel

The concentration of chlorophyll from the MODIS satellite data indicated negative trends over time in the Rufiji-Mafia Channel (Table 4, Fig. 5). This decline in Chl-a was observed both in monthly and inter-annual values. The Mann-Kendall test shows a significant annual decreasing trend of Chl-a concentration ($z = 3.52$, $p < 0.05$) and an insignificant decreasing trend at a seasonal scale ($z < 1.98$, $p = 0.30$). Chl-a

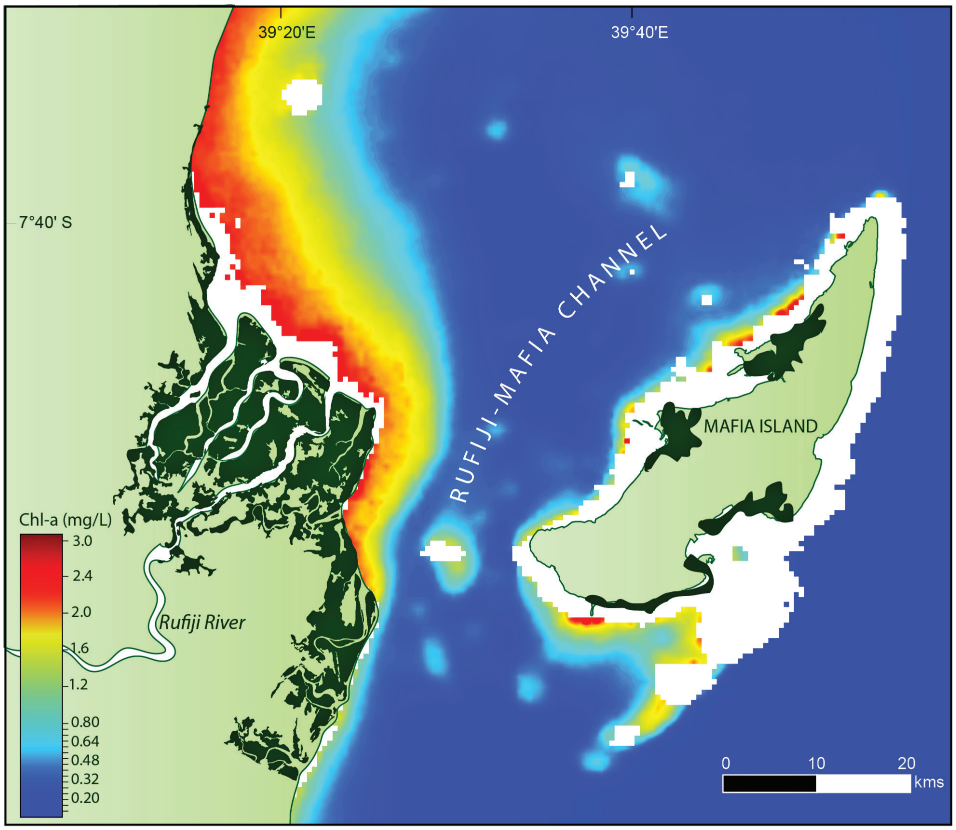

Figure 3. The spatial distribution of satellite derived mean concentration of Chl-a in the Rufiji-Mafia Channel.

**Table 3.** Summary statistics of minimum, maximum, mean and standard deviation (SD) of in-situ and satellite Chl-a concentration for July 2013.

| | | **Chl-a concentrations (mg/L)** | | |
|---|---|---|---|---|
| **Source** | **n** | **Minimum** | **Maximum** | **Mean ±SD** |
| In-situ | 38 | 0.09 | 0.91 | 0.27 ±0.23 |
| Satellite | 38 | 0.37 | 4.34 | 2.40±1.27 |

concentration showed an annual decreasing rate of 12% from a peak value (0.88mg/l) in 2003 to 0.62 mg/l in 2014 (Fig. 5). On the contrary, SST shows increasing seasonal and annual trends although the trends are insignificant ($z \geq 0.13$, $p \geq 0.43$; Table 4).

The Chl-a concentration across the Channel exhibited both annual and seasonal variability between 2002 and 2014 (Fig. 5). The annual concentration of Chl-a fell from an average of 0.75 mg/l in 2002 to the average of 0.60 mg/l in 2014. The strongest decline in Chl-a concentration occurred between 2003 and 2006. During the same period the concentration of Chl-a also slowed down in the Southeast and Northeast monsoon seasons (Fig. 5a). Both seasons experienced the same pattern of decline between 2002 and 2012. The decline in Chl-a during the southeast season is particularly important as this is the season of high primary production. In 2013, the mean Chl-a concentration increased from 0.61 mg/l to 0.71 mg/l and then fell to 0.65 mg/l in 2014 (Fig. 5a). But the decline of Chl-a concentration during the Northeast monsoon was gradual and reached the lowest average of 0.48 mg/l in 2014. The Hovmoller plot of Chl-a concentration from MODIS satellite is shown in Fig. 5b and represents the period from January 2002 to December 2014. In general, the pattern displayed in the Hovmoller plot suggests the presence high Chl-a concentration during the southeast monsoon season (April and August; Fig. 5b). In contrast, the northeast monsoon season shows the propagation of low Chl-a concentration. A closer look suggests that the onset of the high productivity season in the Channel was shifting during the study period.

Sea surface temperatures (SST) were slightly higher during the northeast monsoon season (Fig. 6a) compared to the southeast monsoon season (Fig. 6b). The northeast monsoon exhibited a decreasing trend in SST between 2002 and 2008, which was followed by a rapid increase in 2009/2010, and then a decrease gradually from 2011 to 2014. In contrast, the southeast monsoon season experienced a gradual increase in SST from 2002 to 2010, then a decrease between 2011 and 2013, followed by a slight increase in 2014 (Fig. 6b). The strength and position of the cold and warm months from 2002 to 2014 are shown in Fig. 7c. The inter-annual variability in temperature during the study period was insignificant, but SST in cold water months (June-September) were getting warmer over time (Figure 6c). This is consistent with increasing trend in SST during the southeast monsoon season (Fig. 6b).

Similar to Chl-a concentration, the prawn catch rates in the Rufiji-Mafia Channel showed an annual decreasing trend. The catch rates of the prawn fishery showed a monotonic decreasing trend, where catch rates declined from a peak (62 kg/hour) in 1991 to below 23kg/hour in 2006 (Fig. 7). The catches declined by more than 50% during the study period (Mann-Kendall test, *tau* = -57, $p < 0.05$), suggesting a significant decreasing trend in the annual prawn catch rates. Applying a non-parametric Spearman linear fit to the annual prawn catch rates over the study period yields a strong negative association (Fig. 7), suggesting a significant catch decline of about 81% since 1991 (rho = 0.81, $p < 0.001$). This indicates that the oceanographic processes driving the Chl-a trends may also be affecting prawn production.

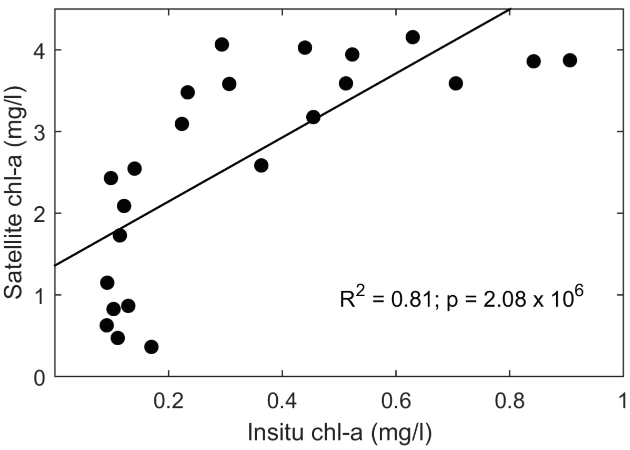

Figure 4. The association between in-situ and satellite Chl-a concentration in the Rufiji-Mafia Channel during the southeast monsoon season. The association used satellite Chl-a acquired on July, 2013, a time during which in-situ measurements were conducted.

**Table 4.** Mann-Kendall (*tau*) test results showing monthly and annual trends in Chl-a concentration and sea surface temperatures in the Rufiji-Mafia Channel.

| | | **Monthly Trend** | | | **Annual Trend** | | |
|---|---|---|---|---|---|---|---|
| **Variable** | **n** | ***tau*** | ***Z*** | ***p*** | ***tau*** | ***Z*** | ***p*** |
| SST | 156 | 0.09 | 0.13 | 0.5 | 0.02 | 0.43 | 0.66 |
| Chl-a | 156 | -0.27 | 3.84e-6 | 0.302 | -1.19 | -3.52 | <0.05 |

Z= Mann-Kendall Trend Statistic

## Discussion

In this study we assessed, for the first time, spatial and temporal patterns in phytoplankton biomass (measured as Chl-a concentration) in relation to selected environmental variables and distance from the shoreline in the Rufiji-Mafia Channel in Tanzania. We also attempted to find seasonal and annual trends in primary production and sea surface temperature in the Channel in order to unveil the underlying processes causing the dwindling prawn harvests in the Channel. By combining ocean colour satellite data with in-situ measured Chl-a concentration, we showed a trend of decreasing phytoplankton biomass. Both the northeast and the southeast monsoon seasons showed a decreasing trend in Chl-a concentration. However, it is the southeast monsoon season, which is the high productive season, that showed a significant decline in phytoplankton biomass. The phytoplankton biomass in the Rufiji-Mafia Channel has declined at a rate of 12% between 2002 and 2014. This declining trend is in agreement with recent findings on the large-scale declines in phytoplankton biomass in the WIO region (Kyewalyanga, 2015; Roxy *et al.*, 2016), the Indo-Pacific region (Mélin, 2016; Wernand *et al.*, 2013), and the Northern hemisphere ( Boyce *et al.*, 2010; Boyce *et al.*, 2012; Boyce *et al.*, 2014), but it is noted that Rykaczewski and Dunne (2011) and Wernand *et al.* (2013) have different views on declining chlorophyll in the Northern hemisphere. Moreover, a recent study led by NASA found that the population of phytoplankton

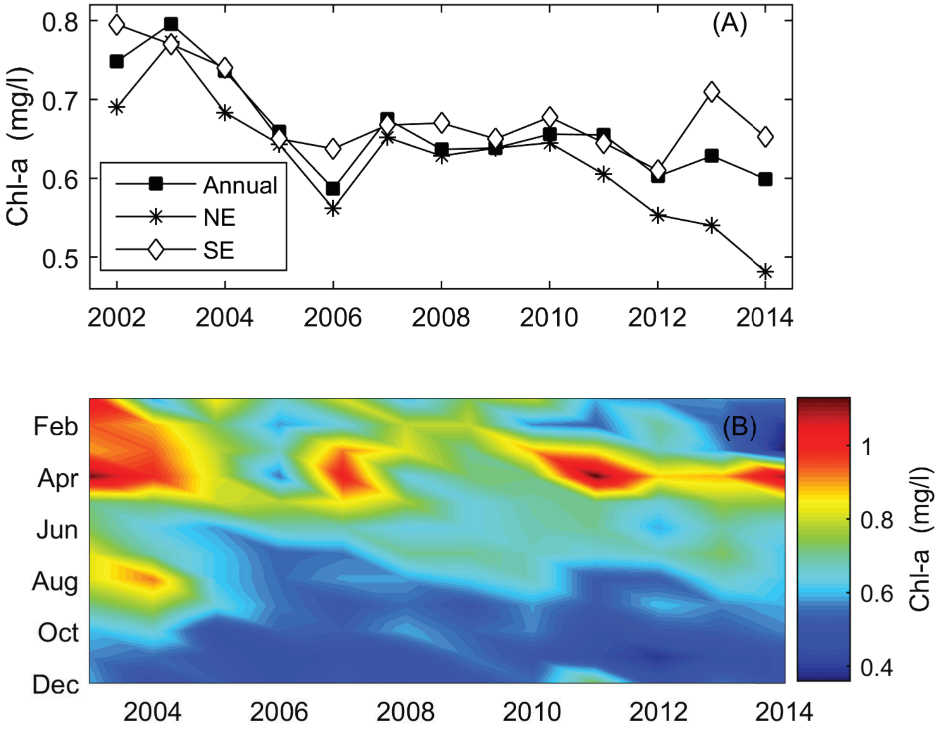

**Figure 5.** Evolution in satellite derived Chl-a concentrations between 2002 and 2014 for the Rufiji-Mafia Channel derived from MODIS Aqua satellite showing (A) annual variability, inter-annual trend during the Northeast monsoon season (October – April), inter-annual trend in the Southeast monsoon season (May – September) and (B) Hovmoller diagramme, which represents inter-annual and monthly change in Chl-a concentration.

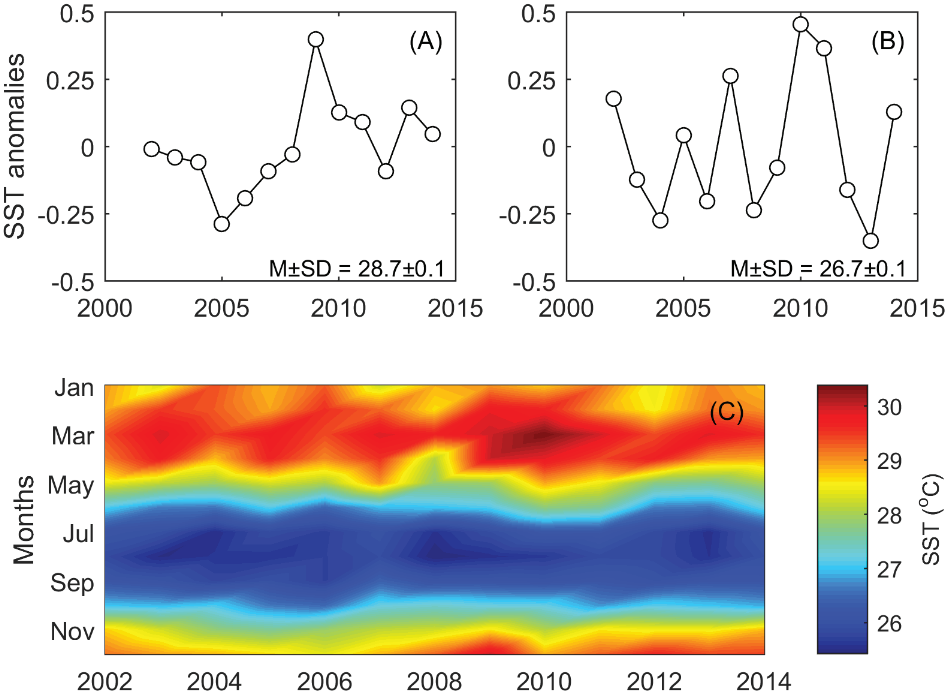

**Figure 6.** Climatological sea surface temperature (SST) between 2002 and 2014 derived from MODIS Aqua satellite showing (A) inter-annual SST anomaly during the northeast monsoon season (October–April), (B) inter-annual anomaly in southwest monsoon season (May – September) and (C) Hovmoller diagramme combining inter-annual and monthly sea surface temperature in the Rufiji-Mafia Channel.

have decreased in recent years (Kevin *et al.*, 2015), further supporting our findings. The decline in chlorophyll is not a worldwide phenomenon however, since some oceans have registered increasing trends (e.g. Atlantic, Mediterranean and the China Sea; Wernand *et al.*, 2013).

Phytoplankton production is influenced by several factors among which nutrient availablity, circulation, irradiance, water column stability and temperature are key (Barlow *et al.*, 2007). The Rufiji-Mafia Channel receives about 35,000 mm$^3$/yr and about 17 million tons/yr of water and sediment respectively, from the Rufiji River (Temple *et al.*, 1972; UNEP and WIOMSA, 2009). With agricultural intensification, which uses large quantities of chemical fertilizers, the Rufiji River is influencing the nutrients balance of the Channel. The nutrients that enter the ocean are often trapped in the nearshore zones, thereby enhancing productivity of the mangroves and the nearshore waters (Francis, 1992). Nonetheless, our data indicate that relatively higher ammonia concentrations were present in deep offshore waters as compared to inshore areas. This can be explained by higher nutrient turnover and uptake by phytoplankton, or remineralization, in inshore waters than is the case for offshore waters which are more likely to be stratified and less mixed. The present study found that nearshore areas and shallow waters had relatively higher Chl-a concentrations than distant and relatively deep offshore waters, which are less influenced by the discharge of nutrients-rich water from the Rufiji River.

While the nutrient input favours phytoplankton growth, the declining phytoplankton biomass does not agree follow this logic. Therefore, a different driver of phytoplankton production must be playing an accessory role to cause the observed decline. Local climate can induce variations around these long-term trends, and coastal processes such as land runoff from the Rufiji River may modify Chl-a trends in nearshore waters of the Channel. Multiple lines of evidence suggest that the linear drop in phytoplankton biomass during the study period is generally related to climatic and oceanographic variability, particularly to increasing SST over the past century.

This study also reports an increasing annual trend in SST data within the study area. The annual mean SST has increased from 27.17 °C in 2002 to 28.66 °C in 2014, indicating a 1.49 °C increase in temperature for that period. The cause-and-effect of high temperatures in oceans may not be simple or straight forward. However, high temperatures can affect the physiological function and behavior of phytoplankton. High irradiance for example can cause photo-inhibition where phytoplankton primary production is affected, resulting is low Chl-a concentrations (Kyewalyanga, 2015; Roxy *et al.*, 2016).

Phytoplankton have evolved taxon-specific pigments that can readily change in different light environment (Barlow *et al.*, 2007). For example, phytoplankton have photoprotective carotenoids that are prominent in surface, high temperature, and low-chlorophyll waters (Barlow *et al.*, 2007; Vidussi *et al.*, 2001). Also, high temperatures can increase water column stability, thereby locking nutrient supply and regeneration into the photic zone where primary production takes place. The negative effects of SST on the Chl-a trend is particularly pronounced in tropical and subtropical oceans, where increasing stratification of the water column limits nutrient supply into the productive layer (Barlow *et al.*, 2007). Phytoplankton production is the base of all marine biological resources and an important source of energy and carbon flows in oceans (Hu *et al.*, 2014). However, with the current projections of climate change (IPCC 2014) and the trend in global warming (IPCC 2014), much more reduction in phytoplankton production can be expected (Roxy *et al.*, 2016), which will have unprecedented consequences on the productivity of the world's major ecosystems and fisheries.

Tanzania's prawn fishery industry was the most important of the marine fisheries in terms of income and export value (de la Torre-Castro *et al.*, 2014; Jiddawi and Ohman, 2002). It also provided employment and income to fishers and business people, therefore making an important contribution to the gross domestic product (de la Torre-Castro *et al.*, 2014; Eriksson *et al.*, 2015; Frocklin *et al.*, 2013). The Rufiji-Mafia Channel was a rich prawn fishing ground which used to contribute over 80% of the prawn catches in Tanzania (Erftemeijer and Hamerlynck, 2005; Jiddawi and Ohman, 2002). High catches were primarily a result of high primary productivity in the Channel that receives terrestial nutrients inputs from the Rufiji River (Jury *et al.*, 2010). Mangroves and nearshore shallow habitats are known to be important nursery grounds for fish and prawns (Kimirei *et al.*, 2011; Kimirei *et al.*, 2016). The decrease of phytoplankton productivity in these habitats would indeed have great consequence on both recruitment and reproduction of prawn populations. In 2008, the Tanzania Fisheries Research Institute reported a serious decline in prawn stocks and by-catches (MLFD, 2012). The decline in catches of prawn was linked to high levels of resource exploitation, leading to the closure of the prawn fishery for two years, to allow for the overexploited stocks to recover (MLFD, 2012).

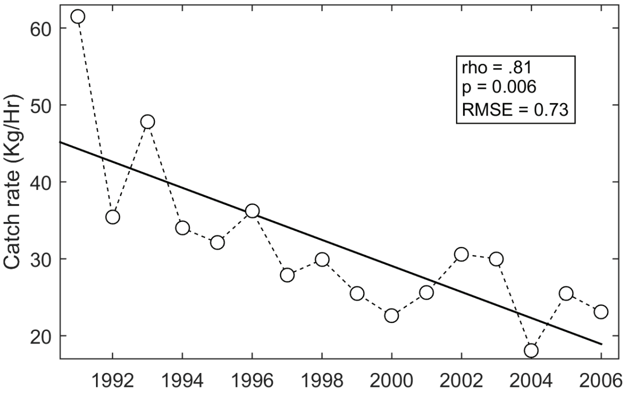

**Figure 7.** Annual mean catch rates of the prawn fishery in coastal waters of Tanzania between 1991 and 2006 showing a decreasing trend in catches and a negative relationship of catches over time.

Despite two years of closing the commercial prawn fishery from 2008 onwards, a stock assessment carried out in 2011 found no signs of recovery; to the contrary the situation has even worsened. Hence the then Ministry of Livestock and Fisheries Development decided on a total closure of all trawl fisheries in 2012. As reduction of the fishing pressure during two years of the closure did not yield the expected results, therefore other factors may be contributing to the reduced catch rates of prawns in the Channel. The decline in phytoplankton biomass, the food base for marine ecosystem, is probably another factor among many that could explain failure in prawn stock recovery. This illustrates that, although the importance of reducing fishing pressure is surely an important measure, it is also important to understand all potential causative factors, among which a decline in Chl-a (a proxy of primary productivity) could be important.

Although our study focused mainly on primary production, there are other factors such as fishing effort, especially by artisanal fishers who fish in non-trawlable areas close to shore, river runoff and discharges, changes in surface water circulation, and larval and post larval recruitment that play important roles in affecting prawn abundance. We acknowledge that these factors were not considered in this study, which would have painted a much clearer picture of the situation. Nonetheless, the results of this study clearly show that the decline in phytoplankton biomass and prawn catches are directly related. We are confident that the results can inform policy for the management of the prawn fishery in Tanzania.

Ocean colour remote sensing has been shown to be an important tool for monitoring and managing coastal and marine resource at reasonable spatial and temporal scales, particularly in data poor coastal areas like the Rufiji-Mafia Channel. This is because satellites have the ability to observe large areas at relatively short time intervals which makes it easy to analyze the spatial patterns and relations, rather than using localized in-situ measurement alone. This allows better and meaningful understanding of phytoplankton dynamics rather than relying on the conventional techniques alone. Unfortunately, the chlorophyll concentration discerned by satellites is only a gross indicator of a multitude of phytoplankton species which have a fairly diverse response to the environment (Roxy *et al*., 2016). Because the Rufiji River discharges nutrient-rich water into the Channel, there is a need to calibrate satellite observations with in-situ measurement because satellites tend to overestimate chlorophyll biomass, especially in coastal waters (Reinart *et al*., 2011).

The same tendency was also observed in our in-situ and satellite derived Chl-a concentration. When compared, the mean concentration of Chl-a derived from satellite was significantly higher than in-situ measurements. However, it is important to note that the discrepancy in the in-situ Chl-a readings and satellite estimates could be due to unavoidable errors caused by suspended solids (mainly sediments) and regional climatological bias (Mélin, 2016). Nevertheless, satellite data and in-situ observation used in this study provide for the first time evidence of a potential link between the declining trends in primary production in the Rufiji-Mafia Channel and the dwindling commercial prawn fishery catches.

The advances in ocean colour sensor technology and derived data in recent years, especially for coastal remote sensing has helped to understand the functioning of coastal ecosystems. The MODIS sensors provide valuable spatial and temporal information about the Rufiji-Mafia Channel, which is not easily recorded with the field observations. Throughout the Channel, MODIS satellite data showed that the mean chlorophyll concentration is generally high in the delta and near the shore. These data allow for the exploration of coastal and marine areas to identify particular environmental problems in ways that are not possible by means of in-situ measurement. Overall, a comparison of in-situ and satellite observations of Chl-a suggests that MODIS data is able to simulate the spatial and seasonal dynamics of primary productivity of the Rufiji-Mafia Channel with satisfactory accuracy, although some discrepancies were identified. Therefore, by combining satellite data and in-situ measurements in models, we can further improve our understanding of the Rufiji-Mafia Channel in a holistic manner, which can be used for spatial planning and devising best management options for coastal ecosystems within and even outside the Channel.

## Acknowledgements

This study was funded by a grant from the Interfaculty Council for Development Cooperation (IRO) of the KU Leuven. The authors also wish to thank WIO-RISE for financial support for the in-situ data collection and laboratory analysis. Specifically we thank the Institute of Marine Sciences (IMS), Zanzibar for the technical assistance and research equipment; the Mafia Island Marine Park Administration for permission to use their research boat and collect data inside the Marine Park. We are also grateful to Mr. Mwadini of IMS for laboratory analysis of water samples.

## References

Allan RP, Liu C, Loeb NG, Palmer MD, Roberts M, Smith D, Vidale PL (2014) Changes in global net radiative imbalance 1985-2012. Geophysical Research Letters 41: 5588-5597

Anilkumar N, Chacko R, Sabu P, Pillai HU, George JV, Achuthankutty CT (2014) Biological response to physical processes in the Indian Ocean sector of the Southern Ocean: a case study in the coastal and oceanic waters. Environmental Monitoring and Assessment 186: 8109-8124

APHA (1998) Standard Methods for the Examination of water and wastewater., in: Clceceri LS, Greenberg AE, Eaton AD (eds.), Advances in Algal Biology. American Public Health Association, Washington D.C.

Baliarsingh SK, Srichandan S, Naik S, Sahu KC, Lotliker AA, Kumar TS (2013) Distribution of hydro-biological parameters in coastal waters off Rushikulya Estuary, East Coast of India: a premonsoon case study. Pakistan Journal of Biological Sciences 16: 779-787

Barlow R, Stuart V, Lutz V, Sessions H, Sathyendranath S, Platt T, Kyewalyanga M, Clementson L, Fukasawa M, Watanabe S, Devred E (2007) Seasonal pigment patterns of surface phytoplankton in the subtropical southern hemisphere. Deep-Sea Research I 54: 1687-1703

Barlow R, Lamont T, Kyewalyanga M, Sessions H, van den Berg M, Duncan F (2011) Phytoplankton production and adaptation in the vicinity of Pemba and Zanzibar islands, Tanzania. African Journal of Marine Science 33: 283-295

Blondeau-Patissier D, Gower JFR, Dekker AG, Phinn SR, Brando VE (2014) A review of ocean color remote sensing methods and statistical techniques for the detection, mapping and analysis of phytoplankton blooms in coastal and open oceans. Progress in Oceanography 123: 123-144

Bouman HA, Ulloa O, Scanlan DJ, Zwirglmaier K, Li WK, Platt T, Stuart V, Barlow R, Leth O, Clementson L, Lutz V, Fukasawa M, Watanabe S, Sathyendranath S (2006) Oceanographic basis of the global surface distribution of Prochlorococcus ecotypes. Science 312: 918-921

Boyce DG, Lewis MR, Worm B (2010) Global phytoplankton decline over the past century. Nature 466: 591-596

Boyce DG, Lewis M, Worm B (2012) Integrating global chlorophyll data from 1890 to 2010. Limnology and Oceanography: Methods 10: 840-852

Boyce DG, Dowd M, Lewis MR, Worm B (2014) Estimating global chlorophyll changes over the past century. Progress in Oceanography 122: 163-173

Chawira M, Dube T, Gumindoga W (2013) Remote sensing based water quality monitoring in Chivero and Manyame lakes of Zimbabwe. Physics and Chemistry of the Earth 66: 38-44

David E, Steitz (2002) AQUA. National Aeronautics and Space Administration Washington, p 29

de la Torre-Castro M, Di Carlo G, Jiddawi NS (2014) Seagrass importance for a small-scale fishery in the tropics: the need for seascape management. Marine Pollution Bulletin 83: 398-407

Erftemeijer PLA, Hamerlynck O (2005) Die-Back of the Mangrove Heritiera littoralis Dryand, in the Rufiji Delta (Tanzania) Following El Nino Floods. Journal of Coastal Research 42: 228-235

Eriksson H, de la Torre-Castro M, Purcell SW, Olsson P (2015) Lessons for resource conservation from two contrasting small-scale fisheries. Ambio 44: 204-213

Francis J (1992). Physical processes in the Rufiji delta and their possible implications on the mangrove ecosystem. Hydrobiologia 247: 173-179

Frocklin S, de la Torre-Castro M, Lindstrom L, Jiddawi NS (2013) Fish traders as key actors in fisheries: gender and adaptive management. Ambio 42: 951-962

Garpe K, Öhman M (2003) Coral and fish distribution patterns in Mafia Island Marine Park, Tanzania: fish–habitat interactions. Hydrobiologia 498: 191-211

Gaspare L, Bryceson I (2013) Reproductive Biology and Fishery-Related Characteristics of the Malabar Grouper (*Epinephelus malabaricus*) Caught in the Coastal Waters of Mafia Island, Tanzania. Journal of Marine Biology 2013: 11

Grémillet D, Lewis S, Drapeau L, van Der Lingen CD, Huggett JA, Coetzee JC, Verheye HM, Daunt F, Wanless S, Ryan PG (2008) Spatial match-mismatch in the Benguela upwelling zone: should we expect chlorophyll and sea-surface temperature to predict marine predator distributions? Journal of Applied Ecology 45: 610-621

Hu Z, Tan Y, Song X, Zhou L, Lian X, Huang L, He Y (2014) Influence of mesoscale eddies on primary production in the South China Sea during spring inter-monsoon period. Acta Oceanologica Sinica 33: 118-128

Igulu MM, Nagelkerken I, Dorenbosch M, Grol MG, Harborne AR, Kimirei IA, Mumby PJ, Olds AD, Mgaya YD (2014) Mangrove habitat use by juvenile reef fish: meta-analysis reveals that tidal regime matters more than biogeographic region. PLoS One 9, e114715

IPCC (2014) Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, in: Pachauri, R.K., Meyer, L.A. (Eds.). IPCC, Geneva, Switzerland, p 151

Jiddawi NS, Ohman MC (2002) Marine fisheries in Tanzania. Ambio 31: 518-527

Jury M, McClanahan T, Maina J (2010) West Indian Ocean variability and East African fish catch. Marine Environmental Research 70: 162-170

Jutla AS, Akanda AS, Griffiths JK, Colwell R, Islam S. (2011) Warming oceans, phytoplankton, and river discharge: implications for cholera outbreaks. American Journal of Tropical Hygiene 85: 303-308

Kachelriess D, Wegmann M, Gollock M, Pettorelli N (2014) The application of remote sensing for marine protected area management. Ecological Indicators 36: 169-177

Kevin A, Victoria H, Simon B, Mitchell BG, Toru H, Marce lB (2015) Estimates of Net Primary Production from Space-based Measurements. Ocean Colour Remote Sensing in Polar Seas. Babin, M., Arrigo, K., Bélanger, S. and Forget, M-H. (eds.), IOCCG Report Series, No. 16, International Ocean Colour Coordinating Group, Dartmouth, Canada. pp 95-111

Kimirei IA, Igul, MM, Semba M, Lugendo BR (2016) Small Estuarine and Non-Estuarine Mangrove Ecosystems of Tanzania: Overlooked Coastal Habitats?, in: Diop, S., Scheren, P., Ferdinand Machiwa, J. (eds.), Estuaries: A Lifeline of Ecosystem Services in the Western Indian Ocean. Springer International Publishing, Cham, pp 209-226

Kimirei IA, Nagelkerken I, Griffioen B, Wagner C, Mgaya YD (2011) Ontogenetic habitat use by mangrove/seagrass-associated coral reef fishes shows flexibility in time and space. Estuarine, Coastal and Shelf Science 92: 47-58

Klemas V (2013) Fisheries applications of remote sensing: An overview. Fisheries Research 148: 124-136

Kratzer S, Therese Harvey E, Philipson P (2014) The use of ocean color remote sensing in integrated coastal zone management–A case study from Himmerfjärden, Sweden. Marine Policy 43: 29-39

Kumar CS, Perumal P (2012) Studies on phytoplankton characteristics in Ayyampattinam coast, India. Journal of Environmental Biology 33: 585-589

Kyewalyanga M (2005) Impact of mangrove deforestation on nutrients, phytoplankton community structure and biomass : MARG-1 final report submitted to: the Western Indian Ocean Marine Science Association (WIOMSA). WIOMSA, Zanzibar

Kyewalyanga M (2015) Phytoplankton primary production (Part IV, Chapter 16, 213-231). In: UNEP-Nairobi Convention and WIOMSA. The Regional State of the Coast Report: Western Indian Ocean. UNEP and WIOMSA, Nairobi, Kenya, 546 pp

Lamont T, Barlow RG, Kyewalyanga MS (2014) Physical drivers of phytoplankton production in the southern Benguela upwelling system. Deep Sea Research Part I: Oceanographic Research Papers 90: 1-16

Lorenzen, CJ (1966). A method for the continuous measurement of in vivo chlorophyll concentration. Deep-Sea Research 13: 223-227

Marinov I, Gnanadesikan A, Toggweiler JR, Sarmiento JL (2006) The Southern Ocean biogeochemical divide. Nature 441: 964-967

Masalu DCP (2003) Challenges of coastal area management in coastal developing countries—lessons from the proposed Rufiji delta prawn farming project, Tanzania. Ocean and Coastal Management 46: 175-188

Mélin F (2016) Impact of inter-mission differences and drifts on Chl-a trend estimates. International Journal of Remote Sensing 37: 2233-2251

MLFD (2012) Prawn Fishery Management Plan. Ministry of Livestock Development and Fisheries, Dar es Salaam, p 28

Picart SS, Sathyendranath S, Dowell M, Moore T, Platt T (2014) Remote sensing of assimilation number for marine phytoplankton. Remote Sensing of Environment 146: 87-96

Raitsos DE, Pradhan Y, Brewin RJ, Stenchikov G, Hoteit I (2013) Remote sensing the phytoplankton seasonal succession of the Red Sea. PLoS One 8, e64909

Reinart A, Toming K, Metsamaa L, Arst H, Paavel B (2011) Optical investigations of CDOM-rich coastal waters in Pärnu Bay. Estonian Journal of Earth Sciences 60: 102

Rousseaux CS, Gregg WW (2015) Recent decadal trends in global phytoplankton composition. Global Biogeochemical Cycles 29, 2015GB005139

Roxy MK, Modi A, Murtugudde R, Valsala V, Panickal S, Prasanna Kumar S, Ravichandran M, Vichi M, Lévy M (2016) A reduction in marine primary productivity driven by rapid warming over the tropical Indian Ocean. Geophysical Research Letters 43: 826-833

Roy S (2009) Do phytoplankton communities evolve through a self-regulatory abundance-diversity relationship? Biosystems 95: 160-165

Rykaczewski RR, Dunne JP (2011) A measured look at ocean chlorophyll trends. Nature: 472, E5-E6

Sherman K, O'Reilly J, Belkin IM, Melrose C, Friedland KD (2011) The application of satellite remote sensing for assessing productivity in relation to fisheries yields of the world's large marine ecosystems. ICES Journal of Marine Science 68: 667-676

Slater MJ, Mgaya YD, Stead SM (2014) Perceptions of rule-breaking related to marine ecosystem health. PLoS One 9, e89156

Sobo FS, Mahongo SB, (2007) Tanzania National Report on Fisheries Data Management, FAO Fisheries Report. South West Indian Ocean Fisheries Commission, Mombasa

Steven PM (2013) EnvStats: An R Package for Environmental Statistics. Springer

Temple PH, Sundborg XC (1972) The Rufiji River, Tanzania Hydrology and Sediment Transport. Geografiska Annaler. Series A, Physical Geography 54: 345-368

Thangaradjou T, Sarangi RK, Shanthi R, Poornima D, Raja K, Saravanakumar A, Balasubramanian ST (2014) Changes in nutrients ratio along the central Bay of Bengal coast and its influence on chlorophyll distribution. Journal of Environmental Biology 35: 467-477

UNEP/WIOMSA (2009) An assessment of hydrological and land use characteristics affecting river-coast interactions in the Western Indian Ocean region, UNEP, Nairobi Kenya, 109pp

Vanhellemont Q, Ruddick K (2015) Advantages of high quality SWIR bands for ocean colour processing: Examples from Landsat-8. Remote Sensing of Environment 161: 89-106

Vidussi F, Claustre H, Manca BB, Luchetta A, Marty J-C. (2001) Phytoplankton pigment distribution in relation to upper thermocline circulation in the easternMediterranean Sea during winter. Journal of Geophysical Research 106: 19939-19956

Wernand MR, van der Woerd HJ, Gieskes WW (2013) Trends in ocean colour and chlorophyll concentration from 1889 to 2000, worldwide. PLoS One 8, e63766.

# First records of sponge-associated Actinomycetes from two coastal sponges from Mauritius

Sandeep S. Beepat[1,*], Chandani Appadoo[2], Daniel E. P. Marie[3], Shamimtaz B. Sadally[4], José Paula[5], Kannan Sivakumar[6], Rashmi R. Rao[7], Maryam Salah[8]

[1,4] Department of Biosciences,
Faculty of Science,
University of Mauritius,
Reduit, 80837, Mauritius

[2] Department of Marine and
Ocean Science, Fisheries and
Mariculture, Faculty of Ocean
Studies, University of Mauritius,
Reduit, 80837, Mauritius

[3] Mauritius Oceanography
Institute, Avenue des Anchois,
Morcellement de Chazal,
Albion, Mauritius

[5] MARE, Faculdade de Ciências,
Universidade de Lisboa,
Campo Grande, 1749-016
Lisboa, Portugal

[6,7,8] Centre of Advanced Study
in Marine Biology,
Annamalai University,
Parangipettai, 608 502,
Tamil Nadu, India

* Corresponding author:
sann_1205@hotmail.com

## Abstract

Actinobacteria, commonly known as actinomycetes, are often constituents of sponge-associated bacterial communities and are well known producers of bioactive compounds. In the present study, 7 actinomycete species representing 3 genera were successfully isolated from the sponge *Spheciospongia vagabunda* (Ridley, 1884) and *Neopetrosia exigua* (Kirkpatrick, 1900) from Mauritius. *Neopetrosia exigua* hosted a higher actinomycete diversity resulting in 71% of the total number of actinomycete strains recorded. *Streptomyces* sp. and *Micrococcus* sp. were the most common actinomycete genera, both representing 43% of the total actinomycetes isolated from both host sponges. Actinomycete Isolation Agar was the most effective medium for the selection of actinobacteria, yielding in 57% of the total actinobacterial strains isolated. This study is the first to report on sponge-associated actinomycete communities from Mauritius and paves the way for future sponge-associated actinobacterial research in the Mascarene region.

**Keywords:** *Neopetrosia exigua*, *Spheciospongia vagabunda,* sponge, Actinobacteria, Mauritius

## Introduction

The symbiotic relationship between sponges and bacteria is one of the most ancient symbioses known between microbes and metazoan (Wilkinson, 1984). According to Wilkinson (1978), sponge-associated bacteria in certain sponge species can constitute up to 60% of the sponge biomass. Furthermore, some sponge species are also known to feed unselectively on particles up to 50 µm in size which is about the maximum size that their respective pores allow and therefore they feed on a wide array of microorganisms including several bacterial communities (Ribes *et al*., 1999).

Actinomycetes are non-motile slow growing gram positive bacteria which are phenotypically diverse, omnipresent in most natural environments (Goodfellow and Williams, 1983). Mangrove swamps (Sivakumar *et al*., 2005), deep sea (Weyland, 1984), ocean mud (Jie He *et al.,* 2011), hydrothermal vents (Teske *et al.,* 2002) as well as marine invertebrates (Montalvo *et al.,* 2005; Abdelmohsen *et al*., 2010) are all known to harbour significant diversity of actinomycetes. However, according to Kathiresan *et al*. (2008) and Peraud (2006), the distribution and abundance of actinomycetes in the marine environment have not been extensively investigated. Likewise, actinomycetes are also often the constituents of the sponge-associated bacterial communities (Abdelmohsen *et al.,* 2010; Sun *et al.,* 2015). However, the roles of actinomycetes in marine sponges are still relatively unclear. Peraud (2006) suggested that these microorganisms may be involved in the processing of metabolic wastes, or could also potentially protect the host sponge against predators, diseases and fouling.

Actinomycetes are known for their ability to produce antibiotics (Kathiresan, 2008). It has been reported that 70% of naturally occurring antibiotics are derived from actinomycetes (Pimentel-Elardo *et al.*, 2010). Antibiotics such as melanins originate from marine actinomycetes (Zenova, 1965). Other products are enzymes such as protease (Dixit and Pant, 2000), cellulase (Techapun *et al.*, 2003) and chitinase (Robbins *et al.*, 1988). In the Western Indian Ocean (WIO), sponge-bacteria derived compounds such as pyrroloiminoquinones, and tsitsikammamine A and B have been successfully isolated by Walmsley *et al.,* (2012). This is further supported by other studies where sponge-derived bioactive compounds have been reported (Davies-Coleman, 2010; Beedessee *et al.,* 2012; Tangman *et al.,* 2015).

To date, multiple reports of sponge-associated actinomycetes have come to light (Montalvo *et al.,* 2005; Abdelmohsen *et al.,* 2014). *Gordonia terrae, Gordinia polyisoprenivorans, Micrococcus luteus* and *Branchybacterium conglomeratum* were all isolated from *Xestospongia* sponge species from USA and Indonesia (Montalvo *et al.*, 2005). Moreover, 90 actinomycetes including 14 potentially new strains were isolated from 11 sponge species including *S. vagabunda* from Egypt and Croatia (Abdelmohsen *et al.,* 2010). However, given the huge number of marine sponge species [over 15,000 according to Hooper (2000)] represented in our oceans, current investigations on sponge-associated actinomycetes is still considered limited (Yang, 2013).

Actinomycetes from the WIO region have been previously reported from South Africa (Walmsley *et al.,* 2012), Reunion Islands (Gonzalez *et al.,* 2005), Tanzania (Sosovele *et al.,* 2012) and Mozambique (Canedo *et al.,* 2000). However, sponge-associated actinomycetes have only been reported from South Africa (Walmsley *et al.,* 2012) and Mozambique (Canedo *et al.,* 2000) respectively. No such studies have been reported from the Mascarene Islands. Likewise, sponge-associated actinomycetes have never been reported from Mauritius. The present study therefore aimed at describing for the first time the actinobacterial community associated with two coastal sponge species, namely *Spheciospongia vagabunda* (Ridley, 1984) and *Neopetrosia exigua* (Kirkpatric,1900), from Mauritius.

## Materials and methods

### Sampling

Sponge samples were collected along the west coast of Mauritius by snorkeling and free diving at depths of 1–3 m. *S. vagabunda* samples were collected at a depth of 1 m from the Albion lagoon (20°'12'29.11"S; 57°'24'32.47"E) whereas *N. exigua* samples were collected at depth of 3 m from the lagoon of Trou aux Biches (20°'14'30.77"S; 57°'47'03.54"E).

### Isolation of Actinobacteria

Three isolation media, namely Kuster's Agar, Yeast extract-malt extract Agar, and Actinomycete Isolation Agar, were used for the isolation of sponge-associated actinobacteria (Table 1). All media were supplemented with nalidixic acid (25µg/ml), cyclohexamide (100µg/ml), and nystatin (25µg/ml) to facilitate the isolation of slow-growing bacteria (Abdelmohsen *et al.*, 2010; Montalvo *et al.*, 2005). Sponge samples were rinsed several times in sterile seawater to remove any transient and loosely attached organisms. One section of the samples was then cut into pieces of approximately 1 $cm^3$ by using a sterile scalpel and then thoroughly homogenized in a sterile mortar with 10 volumes of sterile seawater. The mixture was filtered and the supernatant was diluted in ten-fold series ($10^{-1}$, $10^{-2}$ and $10^{-3}$). Aliquots (100 µl) from the fold series were subsequently plated out on triplicate agar plates (Abdelmohsen *et al.*, 2010; Montalvo *et al.*, 2005). Plates were incubated at 30°C for 6-9 weeks.

### Genomic extraction and Identification

Each distinct potential actinomycete colony morphotype observed on the isolation plates was picked and re-streaked until pure cultures were obtained. Isolates were then grown in their respective liquid culture for genomic extraction and identification. Isolates grown in liquid cultures were cryopreserved in medium supplemented with 30% glycerol at -80°C. Genomic DNA from each culture was extracted from its respective broth via a DNA Isolation Kit (UltraClean Microbial, Mo Bio Laboratories, Inc.) following manufacturer's instructions (Abdelmohsen *et al.*, 2010; Montalvo *et al.*, 2005).

16S rRNA genes (approximately 1500 bp) were amplified by polymerase chain reaction (PCR) using the universal primers 27F (GAGTTTGATCCTGGCTCAG) and 1492R (GGTTACCTTGTTACGACTT) in a Thermocycler (Applied Biosystems). Primers were selected according to the studies of Montalvo *et al.* (2005) and Abdelmohsen *et al.* (2010).

**Table 1.** Media composition for the isolation of actinomycetes from *Neopetrosia exigua* and *Spheciospongia vagabunda*.

| Medium | Composition | References |
|---|---|---|
| Kuster's Agar (KA) | Glycerol 10 g, Casein 0.3 g, Potassium Nitrate 2 g, Sodium Chloride 2 g, Magnesium Sulphate 0.05 g, Calcium Carbonate 0.02 g, Ferrous Sulphate 0.01 g, Agar 15 g; 1 L sterile seawater | Sivakumar, 2001 |
| Yeast extract-malt extract Agar (ISP2) | Dextrose 4 g, Yeast extract 4 g, Malt extract 10 g, Agar 15 g; 1 L sterile seawater | Abdelmohsen *et al.*, 2010; Montalvo *et al.*, 2005 |
| Actinomycete Isolation Agar (AIA) | Sodium Caseinate 2 g, Asparagine 0.1 g, Sodium Propionate 4 g, Dipotassium Sulphate 0.5 g, Magnesium Sulfate 0.1 g, Ferrous Sulphate 1 mg, Agar 15 g; 1 L sterile seawater | Montalvo *et al.*, 2005 |

Cycling conditions were as follows: initial denaturation at 95°C for 2 min, followed by 30 cycles of 95°C for 1 min, annealing at 55°C for 1 min and extension at 72°C for 1.5 min. A final extension of 10 min at 72°C was performed. The PCR mixture was composed of 5 µl of 10X DreamTaq Green buffer, 5 µl of dNTP mix, 5 µl of each universal primer, 5 µl of DNA template, 0.5 µl of DreamTaq Green DNA polymerase (including 20 mM $MgCl_2$) and 24.5 µl of MilliQ water in a final volume of 50 µl. PCR products were purified using a QIAquick PCR Purification Kit (Qiagen, Germany) by following the manufacturer's instructions.

### Phylogenetic analysis

Sequences were analyzed through the software FinchTV (Geospiza Inc.) and similarity searches were performed for 16S rRNA sequences of the actinomycete strains by applying their sequences to BLAST search of the NCBI (National Centre for Biotechnological Information, USA). Phylogenetic analysis was performed using the software package MEGA (Molecular Evolutionary Genetics Analysis) Version 6 after multiple alignments of data by ClustalW. A phylogenetic tree was reconstructed by using the neighbour-joining algorithm (bootstrap analyses based on 1000 replicates) following the method of Saitou and Nei (1987).

## Results

19 potential actinomycete samples were successfully amplified through polymerase chain reaction. BLAST analysis resulted in 7 colonies from the phylum *Actinobacteria* representing 3 genera namely, *Streptomyces* sp., *Micrococcus* sp., and *Brevibacterium* sp., respectively. Other bacterial strains isolated included 7 *Pseudomonas* sp., 3 *Bacillus* sp., 1 *Oceanobacillus* sp. and 1 *Staphylococcus* sp. respectively.

The number of actinomycetes isolated was different among the two host species. The sponge *N. exigua* hosted the highest actinomycete diversity (71% of the total number of isolates). On the other hand, only 2 actinomycete strains were isolated from the sponge *S. vagabunda*. The most common genera were *Streptomyces* sp. and *Micrococcus* sp. respectively.

Actinomycete Isolation Agar was the highest yielding media for the cultivation of actinomycetes resulting in 51% of the total number of actinobacteria isolated, followed by Kuster's Agar resulting in two strains (29% of total number of isolates), and Yeast-Extract Malt-Extract Agar resulting in a single actinomycete strain. Actinomycete Isolation Agar and Kuster's agar proved to be the more reliable media resulting in diversified actinomycete colonies (2 genera each) as compared to Yeast-Extract Malt-Extract agar (1 genus).

Similarities using BLAST search ranged from 69% - 99% as described in Table 2. The maximum similarity (99%) was noted between strain AG, isolated from *N. exigua* and *Micrococcus* sp. (KM886166.1). A 98% similarity was recorded between the cultured strain AL and *Brevibacterium* sp. (KJ534269.1). On the other hand, the minimum BLAST similarity was observed between strain Y (collected from *N. exigua*) and *Streptomyces fradiae* (EF017718.1) isolated from China.

**Table 2.** Actinomycetes isolated from *S. vagabunda* and *N. exigua* from Mauritius.

| Isolate | Closest Species | GenBank No. | Source Sponge | Isolation Medium | Nearest identified relative (BLAST entry) | Similarity to BLAST entry |
|---|---|---|---|---|---|---|
| **W** | *Streptomyces* sp. | KU981106 | *N. exigua* | AIA | *Streptomyces mutabilis* (EU570424.1) | 98% |
| **X** | *Streptomyces* sp. | KU981107 | *S. vagabunda* | ISP2 | *Streptomyces diastaticus* (KF447948.1) | 97% |
| **Y** | *Streptomyces* sp. | KU981108 | *N. exigua* | KA | *Streptomyces fradiae* (EF017718.1) | 69% |
| **AG** | *Micrococcus luteus* | KU981102 | *N. exigua* | AIA | *Micrococcus* sp. (KM886166.1) | 99% |
| **AI** | *Micrococcus luteus* | KU981103 | *S. vagabunda* | AIA | *Micrococcus yunnanensis* (JN999896.1) | 96% |
| **AJ** | *Micrococcus* sp. | KU981104 | *N. exigua* | AIA | *Micrococcus luteus* (FJ380993.1) | 97% |
| **AL** | *Brevibacterium* sp. | KU981105 | *N. exigua* | KA | *Brevibacteirum* sp. (KJ534269.1) | 98% |

Phylogenetic analysis (Fig.1) demonstrated three groups of actinomycetes. The first group consisted of *Streptomyces* sp. and included the strain X (isolated from *S. vagabunda*), strain W and strain Y (both isolated from *N. exigua*). Isolate X incorporated the Streptomyces clade, whereas isolates W and Y formed separated clades within the group. Likewise, in the *Micrococcus* sp. clade, isolate AI was closely related to the other three *Micrococcus* sp. sequences, whereas isolates AJ and AG formed separate clades. In the third group composed of *Brevibacterium* sp. Isolate, AL (isolated from *N. exigua*) was closely associated with *Brevibacterium oceani* (NR042458.1) and *Brevibacterium iodinum* (KF444388.1).

## Discussion

The 7 isolates in the present study originated from the order *Actinomycetales. Streptomyces* and *Micrococcus* were the most common genera, and related isolates were mostly associated with the sponge *N. exigua*. Both genera are well known to be prominent in the marine environment and have been reported in Sivakumar *et al.* 2005. *Streptomyces* and *Micrococcus* are also both known symbionts of marine sponges according to Lijun *et al.* (2012). Both genera have previously been isolated from other petrosid sponge species such as *Petrosia* sp. (Khan *et al.*, 2012) and *Petrosia ficiformis* (Chelossi *et al.*, 2004). Moreover, both genera were also reported from the sponge *S. vagabunda* as described by Abdelmohsen *et al.* (2010).

Initially described from terrestrial environments (Tuleva *et al.*, 2009), the genus *Micrococcus* has previously been isolated from the sponge *Xestospongia* sp. (Montalvo *et al.*, 2005) and *Halichondria panicea* (Schneemann *et al.*, 2010). *Micrococcus* sp. associated with the sponge *S. vagabunda* have also been reported from Egypt (Abdelmohsen *et al.*, 2010; Abdelmohsen *et al.*, 2014) suggesting that some selected *Micrococcus* sp. are possibly common bacterial associates of this sponge species.

Likewise, the representation of *Streptomyces* in the present study is also corroborated in other studies. Actinomycetes from this genus have been previously

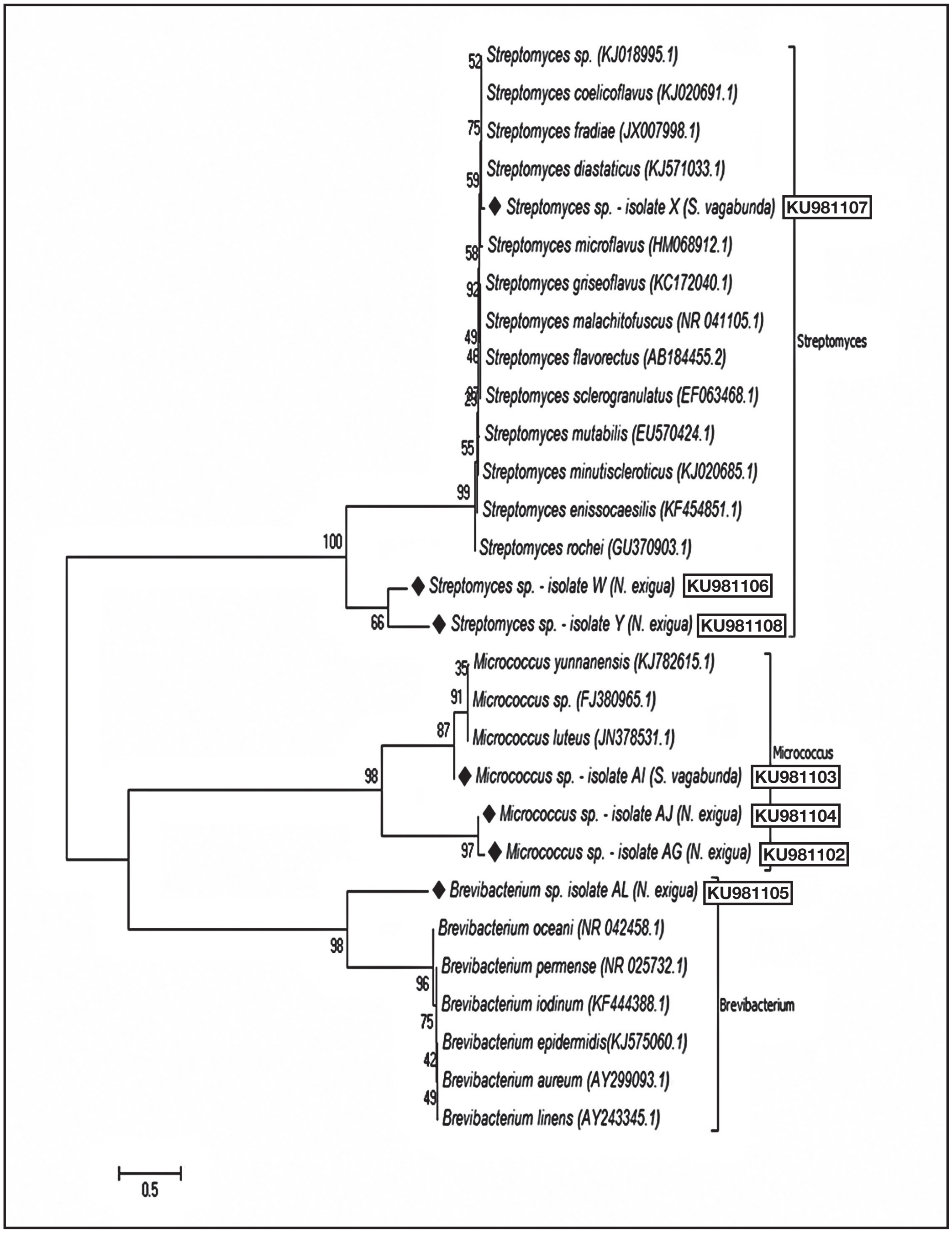

Figure 1. Neighbour-Joining tree of actinomycete strains and their representative species. (♦) denotes the 7 actinobacterial strains identified and their representative species. Scale bar indicates 0.5 substitutions per nucleotide position.

isolated from the sponge *Aplysilla rosea* (Mehbub and Amin, 2012), *Halichondria panicea* (Schneemann *et al.,* 2010) and *Dendrilla nigra* (Selvin *et al.,* 2004). According to Karuppiah (2011) and Abdelmohsen *et al.* (2014), *Streptomyces* are one of the most common genera represented in the marine environment, including sponges (Zhang *et al.,* 2008).

*S. vagabunda* samples collected from Mauritius resulted in two actinobacterial species, while eleven actinomycetes were previously isolated from *S. vagabunda* in Egypt (Abdelmohsen *et al*., 2010). However, the contrast in the number of isolates could be attributed to the diversity of cultivation media used in the two studies. In the present study, only three cultivation media were used for isolation of actinomycetes, while Abdelmohsen *et al.* (2010) opted for eight different cultivation media. Furthermore, the disparate habitat (or substrate type) of the sponge, and climatic conditions may also significantly influence the diversity and abundance of actinomycetes, as reported by Ghorbani-Nasrabadi *et al.* (2013). The recent study of Abdelmohsen *et al.*

(2014) clearly supports this disparity. While, *Xestospongia testudinaria* collected from Florida (USA) yielded a total of 209 actinomycete strains (Monltalvo *et al.,* 2005), no single strain was found on the same sponge species collected from the Red Sea, Saudi Arabia (Abdelmohsen *et al.,* 2014) confirming that geographical locations might have a major influence on sponge-associated actinomycete diversity.

Actinomycete Isolation Agar was the most prolific cultivation media throughout this study yielding up to four potentially different strains, followed by Kuster's Agar yielding up to two actinobacterial strains of disparate species, while Yeast-Extract Malt-Extract agar (ISP 2) resulted into a single actinomycete (*Streptomyces* sp.) strain. The use of selective media for the isolation of actinomycetes is critical since according to Webster *et al.* (2001), less than 1% of sponge-associated bacteria can potentially be cultivated. Amino acids and protein based media (such as AIA and KA respectively) resulted in a higher number of actinomycetes. In contrast, the lack of additional nutrients in the composition of ISP 2 medium resulted in the isolation of only a single actinomycete strain. The present observation is corroborated by several other studies such as Zhang *et al.* (2008), Selvin *et al.* (2004), Yang (2013) and Oner *et al.* (2014) which highlights the importance of salt, amino acid and protein in actinomycete cultivation media.

The isolation of actinomycetes using AIA and ISP2 is common (Montalvo *et al.,* 2005). In contrast, the successful isolation of actinomycete strains with Kuster's Agar (KA) indicates that glycerol associated with casein as a source of nitrogen enabled the development of actinobacterial micelles and also reduced other bacterial growth (Montalvo *et al.,* 2005). The present results also show some similarities with the studies of Sivakumar (2001) and Sahu *et al.* (2005) where both studies successfully isolated a greater number of actinomycetes using Kuster's Agar.

A relatively low similarity was observed between most of the actinomycete strains isolated in the present study when compared to other sponge-associated actinomycetes on Genbank. Most strains (with the exception of samples AG and AI) correlated with terrestrial actinobacterial strains. This specific observation has previously been reported by Abdelmohsen *et al.* (2010) and Hentschel *et al.* (2002), suggesting that actinomycete communities may not always be sponge-specific as reported. However, pairwise comparison of *S. vagabunda* associated *Micrococcus* sp. (GU318359) from the study of Abdelmohsen *et al.* (2010) and isolate AI from *S. vagabunda* in the present study showed consequential similarities (96%) with only ten nucleotides gaps. Moreover, a 99% BLAST similarity was observed between isolate AG and *Micrococcus* sp. (KM886166.1) from a non-specified marine sponge in the South China Sea, suggesting that some selected actinomycete species might be sponge-specific. However, additional in-depth research would be necessary to confirm actinomycete species specificity among sponge species.

The low sequence similarities of isolates Y (69%) and AI (96%) suggest that these two strains might belong to novel species. This was graphically supported by the phylogenetic analysis indicating separate clades from these respective genera. However, according to Saitou and Nei (1987), a novel species can only be proposed if a sequence similarity of less than 97% and gaps of less than 2 bp are apparent. With a reported gap of more than 2 bp observed for both isolates, strain Y (81 gaps) and AI (8 gaps) cannot be considered novel species even though the first criteria (< 97% sequence similarity) of Saitou and Nei (1987) was respected.

The present study is a pioneer assessment of sponge-associated actinomycetes in Mauritius. Considering that 70-100% of marine sponges of Mauritius are from off-reef habitats, the discovery of new sponge-associated actinomycete species could potentially play and important role in the development of useful natural products.

## Acknowledgements

This work was supported in part by the Western Indian Ocean Marine Science Association (WIOMSA), under Grant No. 8/2014. The views expressed herein are those of the author(s) and do not necessarily reflect the views of WIOMSA and Sida. WIOMSA and Sida are authorized to produce and distribute reprints for educational purposes notwithstanding any copyright notation that may appear hereon. The authors also wish to thank Dr. Nawsheen Taleb-Hossenkhan of the Faculty of Science, University of Mauritius for her assistance and guidance in the molecular aspects of this work.

## References

Abdelmohsen US, Pimentel-Elardo SM, Hanora A, Radwan M, Abou-El-Ela SH, Ahmed S, Hentschel U (2010) Isolation, Phylogenetic analysis and Anti-infective Activity screening of Marine sponge-associated Actinomycetes. Marine Drugs 8: 399-412

Abdelmohsen UR, Cheng C, Viegelmann C, Zhang T, Grkovic T, Ahmed S, Quinn RJ, Hentschel U, Edrada-Ebel R (2014) Depreplication strategies for targeted isolation of new antitrypanosomal actinosporins A and B from a marine sponge associates –Actinokineospora sp. EG49. Marine Drugs 12: 1220-1244

Beedessee G, Ramanjooloo A, Aubert G, Eloy L, Surnam-Boodhun R, Van Soest RW, Cresteil T, Marie DEP (2012) Cytotoxic activities of hexane, ethyl acetate and butanol extracts of marine sponges from Mauritian waters on human cancer cell lines. Environmental Toxicology and Pharmacology 34: 397-408

Canedo LM, Fernandez-Puentes JL, Baz JP (2000) IB-96212, a novel cytotoxic macrolide produced by a marine Micromonospora. II. Physico-chemical properties and structure determination. Journal of Antibiotics 53: 479-483

Chelossi E, Melanese M, Milano A, Pronzato R, Ricadi G (2004) Characterisation and antimicrobial activity and epibiotic bacteria from *Petrosia ficiformis* (Porifera: Demospongiae). Journal of Experimental Marine Biology and Ecology 309: 21-33

Davies-Coleman MT (2010) Natural Products Research in South Africa: End of an Era on Land or Beginning of an Endless Opportunity in the Sea? South African Journal of Chemistry 105: 105-113

Dixit V, Pant A (2000) Comparative characterization of two serine endopeptidases from *Nocardiopsis* sp. NCIM 5124, Biochimica et Biophysica Acta 1523: 261-268

Ghorbani-Nasbadi R, Greiner R, Alikhani HA, Hamedi J, Yakhchali B (2013) Distribution of Actinomycetes in different soil ecosystems and effect of media composition on extracellular phosphatase activity. Journal of Soil Science and Plant Nutrition 13: 223-236

Gonzalez I, Ayuso-Sacido A, Anderson A, Genilloud O (2005) Actinomycetes isolated from lichens: evaluation of their diversity and detection of biosynthetic gene sequences. FEMS Microbiology Ecology 53: 401-415

Goodfellow M, Williams ST (1983) Ecology of Actinomycetes. Annual Review of Microbiology 37: 189-216

Hentschel U, Hopke J, Horn M, Friedrich AB, Wagner M, Hacker J, Moore BS (2002) Molecular evidence for a uniform microbial community in sponges from different oceans. Applied Environmental Microbiology 68: 4431-4440

Hooper JNA (2000) Sponguide: Guide to sponge Collection and Identification, Queensland Museum, South Brisbane, Australia, 138 pp

Jie HE, Ying XU, Sahu MK, Xin-Peng T, Li J, Nie G, Si zhang, Sivakumar K, Li WJ (2012) *Actinomadura sediminis* sp. nov., a novel marine actinomycete isolated from mangrove sediment in Little Andaman, India. International Journal of Systematic and Evolutionary Microbiology 62: 1110-1116

Karuppiah V (2011) Ecology, diversity and bioactivity of marine actinobacteria of the Gulf of Mannar Biosphere Reserve, India. PhD Thesis, Annamalai University, 10 pp

Kathiresan K, Manivannan S, Sivakumar K (2008) Marine Actinobacteria: An overview. In: Training workshop on isolation and identification of marine actinobacteria, 3 pp

Khan ST, Takagi M, Shin-Ya K (2012) Actinobacteria associated with the marine sponges *Cinachyra* sp., *Petrosia* sp. and *Ulosa* sp. and their culturability. Microbes and Environments 27: 99-104

Lijun X, Jisheng R, Ying H (2012) Diversity and biosynthetic potential of culturable actinomycetes associated with marine sponges in the China Seas. International Journal of Molecular Sciences 16: 5917-5932

Mehbub MF, Amin AKMR (2012) Isolation and identification of actinobacteria from two south Australian marine sponges *Aplysilla rosea* and *Aplysina* sp. Bangladesh Research Publications Journal 7: 345-354

Montalvo NF, Mohamed NM, Enticknap JJ, Hill RT (2005) Novel Actinobacteria from marine sponges. Antonie Van Leeuwenhoek 87: 29-36

Oner O, Ekiz G, Hmes EE, Demir V, Gube O, Can-Ozgaya F, Yokes MB, Uzel A, Bedir E (2014) Cultivable sponge-associated actinobacteria from coastal area of eastern Mediterranean Sea. Advances in Microbiology 4: 306-316

Peraud O (2006) Isolation and Characterization of a sponge-associated actinomycete that produces Manzamines. PhD Thesis, Institute of Marine and Environmental Technology, 34 pp

Pimentel-Elardo SM, Kozytska S, Bugni TS, Ireland CM, Moll H, Hentschel U (2010) Anti-parasitic compound from *Streptomyces sp*. Strains Isolated form Mediterranean Sponges. Marine Drugs 8: 373-380

Robbins PW, Albright C, Benfield B (1988) Cloning and expression of a *Streptomyces plicatus* chitinase (chitinase-63) in *Escherichia coli*. The Journal of Biological Chemistry 263: 443-447

Ribes M, Coma R, Gili JM (1999) Heterogeneous feeding in benthic suspension feeders: the natural diet and grazing rate of the temperature gorgonians *Paramuricea clavata* (Cnidaria: Octocorallia) over a year cycle. Marine Ecology Progress Series 183: 125-137

Sahu MK, Sivakumar K, Kanan L (2005) Isolation of actinomycetes form various samples of Velar estuary, southeast coast of India. Environmental Science and Pollution Research 24: 45-48

Saitou N, Nei M (1987) The neighbour–joining method: a new method for reconstructing phylogenetic trees. Molecular Biology and Evolution 4: 406-425

Schneemann FK, Nagal I, Kajahn A, Labes J, Wiese J, Imhoft JF (2010) Comprehensive investigation of marine actinobacteria associated with the sponge *Halliondria panacea.* Applied Environmental Microbiology 76: 3702-3714

Sivakumar K (2001) Actinomycetes from an Indian mangrove (Pichavaram) environment: An inventory. PhD Thesis, Annamalai University, 91 pp

Sivakumar K, Sahu MK, Kathiresan K (2005) Isolation of actinomycetes from the mangrove environment of the South East coast of India. Ecology, Environment and Conservation 11: 355-357

Selvin J, Sonia J, Asha KRT, Majusha WA, Sangeeta VS, Jayasima DN, Antony MC, Vinitha DAJ (2004) Antibacterial potential of antagonistic Streptomyces sp. isolated from the marine sponge Dendrilla nigra. FEMS Microbiology Ecology 50: 117-122

Sosovele ME, Hosea KM, Lyimo TJ (2012) In vitro antimicrobial activity of crude extracts from marine *Streptomyces* isolated from mangrove sediments of Tanzania. Journal of Biochemical Technology 3: 431-435

Sun W, Zhang F, He L, Karthik L, Zhiyoung L (2015) Actinomycetes from South China Sea sponges: isolation, diversity, and potential for aromatic polyketides discovery. Frontiers in Microbiology 6: 1048

Tangman S, Govinden-Soulange J, Marie D (2015) Bioactive profile of *Plakortis nigra,* a sea sponge from Mauritius islands. Journal of Coastal Life Medicine 3: 44-51

Techapun C, Poosaran N, Wantabe M, Sazaki K (2003) Thermostable and alkaline-tolerant microbial cellulose-free xylanases produced from agricultural waste and the properties required for use in pulp bleaching bioprocess: A review. Process Biochemistry 38: 1327-134

Teske A, Hanrichs KU, Edgcomb V, Gomez AD, Kysena D, Sylva SP, Sogin ML, Jannasch HW (2002) Microbial diversity of hydrothermal sediments in the Guaymas Basin: Evidence for anaerobic methanotrophic communities. Applied Environmental Microbiology 68: 1994-2007

Tuleva B, Cristova N, Cohen R, Antonova D, Todorov T, Stoineva I (2009) Isolation and characterization of trehalose tetraester biosufactants from a soil strain *Micrococcus luteus BN56.* Process Biochemistry 44: 135-141

Walmsley TA, Matcher GF, Zhang F, Hill RT, Davies-Coleman MT, Dorrington RA (2012) Diversity of bacterial communities associated with the Indian Ocean sponge *Tsitsikamma favus* that contains the bioactive pyrroloiminoquinones, tsitsikammamin A and B. Marine Biotechnology 14: 681-691

Webster NS, Hill RT (2001) The culturable microbial community of the great barrier reef sponge *Rhopaloeides odorabil.* Applied Environmental Microbiology 138: 843-851

Weyland H (1984) Distribution of Actinomycetes on the seafloor. Zentralbl Bakteriol Naturwiss 11: 185-193

Wilkinson CR (1978) Microbial associations in sponges. II. Numerical analysis of sponge and water bacterial population. Marine Biology 49: 169-176

Wilkinson CR (1984) Immunological evidence for the precambarian origin of bacterial symbioses in marine sponges. Proceedings of the Royal Society of London 1221: 509-517

Yang C (2013) Isolation, Phylogentic analysis and antibiotic activity screening of Red Sea sponge-associated Actinobacteria. MSc Thesis. King Abduallah University of Science and Technology, 21 pp

Zenova GM (1965) Melanoid pigments of Actinomycetes. Mikrobiologiya 34: 278-283

Zhang H, Zhang W, Jin Y, Jin XY (2008) A comparative study on the phylogenetic diversity of culturable actinobacteria isolated from five marine sponge species. Antonie van Leeuwenhoek 93: 241-248

# Effect of feeding frequency and feeding rate on growth performance of juvenile silver pompano, *Trachinotus blochii*

Salum S. Hamed[1,2,*], Narriman S. Jiddawi[1], Philip O.J. Bwathondi[3], Aviti J. Mmochi[1]

[1] University of Dar es Salaam,
Institute of Marine Sciences,
P.O. Box 668, Zanzibar,
Tanzania

[2] University of Dodoma,
College of Natural and
Mathematical Sciences,
Department of Biotechnology
and Bioinformatics,
P.O.Box 259, Dodoma, Tanzania

[3] University of Dar es Salaam,
College of Agricultural
Sciences and Fisheries
Technology (CoAF),
Dep. of Aquatic Sciences and
Fisheries, P.O. Box 35064
Dar es Salaam, Tanzania

*Corresponding author:
salumhus@gmail.com

## Abstract

The silver pompano *Trachinotus blochii* is ideal species for aquaculture and its success depends on the identification of proper feeding regimens. The objective of this work was to evaluate the ideal feeding rate and frequency for juvenile silver pompano. The experiments were carried out concurrently in a randomized design. A total of 180 fish (7.6 ±0.5g and 10.52±0.01 cm) were stocked in 18 tanks (1000 L) for 8 weeks and fed at 3%, 5%, 10% body weight (BW) per day either in single, or 3x and 6x equal feedings. Weight gain and the specific growth rate increased significantly with feeding rate. The apparent feed conversion ratio showed a significant difference, with the lowest value observed for fish fed 10% (BW/day) in a single feeding. Fish fed at higher feeding rates accumulated significantly more lipid within the body and had associated decreases in moisture, protein, and ash content, but carcass composition was unaffected by feeding frequency. Juvenile pompano show better growth performance when fed 10% BW/day 3 and 6 times a day. It is suggested that the growth of juvenile pompano can be optimized when they are fed at 10% BW/day in three daily feedings.

**Keywords:** *Trachinotus blochii*, feed management, marine fish culture.

## Introduction

Global aquaculture is growing steadily and is feeding an almost equal the number of people as capture fisheries globally with total production reaching an amount of 66.6 million tons in 2012 (FAO, 2014). However, huge continental disparities exist in terms of production, where Asia leads and Africa remains behind despite high demand for food security, producing a mere 1.3 million tons in 2010 (FAO 2012). The demand for fish protein is expected to increase in with the world population growth (FAO, 2009). Good nutrition in animal production systems is essential result in an economically viable healthy product. Nutrition in fish farming is critical because feed presents 40-60% of the production cost (Craig, 2002). Fish nutrition has advanced dramatically in recent years with the development of new, balanced commercial diets that promote optimal fish growth and health. The development of the new species-specific diet formulations support the aquaculture industry as it expands to satisfy increasing demand for affordable, safe and high quality fish and sea food products (Ndome *et al*., 2011).

Development of sustainable aquaculture production depends on various factors such as suitable feeds, culture technology and farming species (FAO, 2014). Despite the technologies available, selection of new fish species with good potential for aquaculture is crucial for the sustainable development of this growing industry (Tutman *et al.,* 2004). The potential species must possess a diverse array of traits to ensure that it is economically viable to farm, including environmental capability and ecological acceptance (Tutman *et al.,* 2004). Silver pompano (*T. blochii*) has already been considered a suitable candidate for mariculture due to its easy adaptation to culture systems, acceptance of formulated feeds, and fast growth rates (Chavez *et al.,* 2011). The silver pompano is a pelagic and active species that is easy to domesticate and culture in tropical and subtropical marine waters. The pompano species tolerate a wide range of salinities (McMaster *et al.,* 2004), are resistant to low dissolved oxygen and handling stress, readily consume pelleted rations, successfully breed in captivity (Weirich, 2006), and are excellent candidates for aquaculture in a variety of systems (McMaster *et al.,* 2004). However, the specific nutritional requirements of pompano are little known and the available diets mainly consist of fishmeal which accounts for up to 70% of the variable cost (Heilman and Spieler, 1999; Webster *et al.,* 1999).

Several studies have been conducted to assess the culture of this species (Gopakumar *et al*., 2011; 2012; Nazar *et al*., 2012; Kalidas *et al*., 2012). Like other marine species, successful culture of pompano requires high dietary crude protein (CP), with a diet containing 45% CP being the minimum requirement for growth of juvenile pompano (Lazo *et al.,* 1998). Pompano fed with a practical diet with 40% CP resulted in high growth and survival rate, buth poor feed efficiency due to high metabolic rate and poor digestibility (Watanabe, 1995; Lazo *et al.,* 1998). The feed efficiency of juvenile pompano improves when fed with practical diets consisting of 53% CP and 13% crude lipids (CL) at various feeding frequencies (Weirich *et al.,* 2006). Pompano are highly active marine species and it has been suggested that the appropriate diet for successful growth of juvenile pompano requires a high level of digestible energy (DE) to support metabolic and growth demands (Weirich *et al.,* 2006).

Different studies indicate that feeding management practices affect growth and feed conversion ratio of the cultured species (Wang *et al.,* 1998; Cho *et al.,* 2007), and reduce size class variation (Jobling, 1994). Moreover, feeding regimes optimizing feeding frequency and feeding rate may minimize feed wastage and lead to an improvement in environmental safety, greater size-class homogeneity and economic return (Dwyer *et al.,* 2002; Tucker *et al.,* 2006; Cho *at al.,* 2007; Kim *et al.,* 2007; Booth *et al.,* 2008). Insufficient feeding frequency leads to poor growth and high mortality, especially in intensive systems (Carneiro and Mikos, 2005). For example, sporadic feeding and low feeding rates may contribute to reduced growth as well as increased hunger, intraspecific aggression, and increased rate of cannibalism (Folkvord and Ottera, 1993). However, increasing frequency requires more labor and increases production costs (Carneiro and Mikos, 2005). Moreover, fish require food to supply the energy they need for movement and all other functions, and as the "building blocks for growth." The gross energy (or gross calorific value) of food (GE), is the total energy contained in the food and is essential for proper body function. Unfortunately, the maximum growth and the lowest feed conversion ratios do not coincide at the same feeding rate. The lowest feed conversion occurs at feeding rates below those at which maximum growth occurs (De Silva and Anderson, 1995; Goddard, 1996). Thus it is evident that there is a range of possible feeding rates, which depend on whether maximum growth, optimal food conversion, or a balance between the two is sought. Fish carcass composition is a good indicator of physiological condition but it is relatively time consuming to routinely measure (Ali *et al.,* 2006). Feeds and feeding are among the major factors influencing carcass composition and fish quality. Sensory evaluation of fish is an important index in its overall assessment, and determination of the quality of fish. Eating quality therefore is an important determinant of the overall impression of a food (Ochang *et al.,* 2007). Overall, proper feeding frequency and feeding rates vary with fish size, rearing system, temperature and feed quality (Ruohonen *et al*., 1998; Lovell, 2002). The objective of this work was to evaluate the ideal feeding rate and frequency for juvenile silver pompano.

## Methods

### Sampling methods

Juvenile silver pompano with an average weight of 7.6g were obtained from Nungwi Beach, which is located at the northern tip of Unguja Island, Zanzibar, and collected using beach seine nets of 2.5 cm mesh size prior to being loaded into 100 L tanks equipped with a supplemental oxygen supply system. Fingerlings were transported early in the morning with the tank tops covered with plastic material to avoid exposure to direct sun light. The tanks were filled with water to 50% of their volume and water exchange was carried out every 30 minutes while fingerlings were transported by boat to the Institute of Marine Sciences Mariculture Center (IMS-MC) at Pangani, Tanga.

Fish were acclimated to the facilities for two weeks and fed with a commercial fish meal diet (crude protein = 50% minimum, crude fat = 11% minimum, crude fiber = 3% maximum, crude ash = 6% maximum; average pellet size = 1mm), to apparent satiation. Subsequently ten fingerlings were stocked randomly into 1m$^3$ concrete tanks directly connected to a flow through seawater system, and supplemental aeration provided by a regenerative air blower and air diffusers. Fish were cultured under conditions presumed optimal for silver pompano growth (see water quality information below) and fed available artificial feed at 3, 5 and 10% of body weight BW/ day, either in a single feeding (1×) or divided equally among three and six feedings. The feeding frequencies were selected based on about 1% BW per feeding to achieve optimum growth at 1, 3 and 6 feedings per day. While fish are normally fed twice a day, these intervals were changed to elucidate the effect of feeding frequencies on growth rate. Each feeding rate, feeding frequency treatment combination was randomly assigned to three replicate tanks ($n$ = 3). Feeding rates were adjusted to account for growth every 10 days after group- weighing the fish by tank. Fish in the 1× treatments were fed at 13:00, whereas fish in the 3× treatments were fed at 08:00, 13:00 and 18:00, and those in the 6× treatments were fed between 08h00 and 18h00 at 2-hour intervals.

### Measurement of environmental parameters

Water quality parameters such as dissolved oxygen (DO), salinity, temperature and pH were measured twice a day for the whole period of the experiment at 09:00 and 16:00 with a WTW multi-parameter probe. Water samples for analysis of ammonium ions were collected twice a week in 250 ml plastic bottles and stored frozen at -20 °C at IMS-MC for the whole experimental period. The samples were then transported in an ice box to the IMS in Zanzibar for analysis. The concentration of ammonia in the water samples was determined as in the UNESCO (1993) protocol. Throughout the experiment, photoperiod was maintained at a 12 h light: 12 h dark cycle, tank inflow rates were maintained at 0.5 L/min, and water quality conditions were maintained as follows (mean ± SD): temperature = 29.6 ± 0.9°C, salinity = 31.1 ± 0.2 g/L, DO = 6.5 ± 0.6 mg/L, total ammonia nitrogen = 0.34 ± 0.08 mg/L, nitrite-nitrogen = 0.35 ± 0.13 mg/L, and pH = 7.61 ± 0.02.

### Growth and feed utilization

The total weight gain (TWG), relative growth rate (RGR (%)), specific growth rate (SGR (%/day)), total feed intake (TFI), feed conversion ratio (FCR), protein intake (PI), protein efficiency ratio (PER) and survival (%) were determined according to the methods of De Silva and Anderson (1995). The percentage survival rates were examined based on Jobling (1996).

### Proximate analysis

A total of 9 fish per treatment were collected at the end of the experiment, sun dried and frozen at -20$^0$C in preparation for the proximate analysis. The proximate composition of feed ingredients was analyzed at the Department of Animal Science and Production of Sokoine University of Agriculture (SUA) in Morogoro, Tanzania. Crude protein, crude fiber, crude lipid, moisture and ash content were analyzed. Analyses were performed according to standard methods (AOAC, 1995). Moisture content was determined by drying samples in an oven at 105°C to constant weight. Crude lipid was determined using a Soxhlet extractor with petroleum ether (40-60°C boiling range). Crude protein was determined by the Kjeldahl method using digestion block and steam distillation, and ash was determined by incineration of the feed sample in a muffle furnace at 550°C to constant weight.

### Statistical analysis

One-way analysis of variance and Duncan's new multiple range tests using the SPSS Statistical Package (SPSS, 21) were carried out to determine if significant differences existed among the means of the above parameters.

## Results

The overall mean water quality parameters were typical for these systems. The values of all water quality parameters were consistent and within acceptable ranges for pompano production (Watanabe, 1995). Weight gain, specific growth rate, feed conversion ratio and feed intake increased significantly with feeding rate and feeding frequency. The apparent feed conversion ratio showed significant difference, with the lowest value observed for fish fed 10% BW/day in a single feeding (Table 1).

Growth performance of pompano fingerlings with different feed regimens is presented in Fig. 1. Initially *T. blochii* fingerlings had similar weights and exhibited no significant difference among the treatments ($p < 0.05$). After the 8 week feeding trial, final fish weight and growth generally showed a linear increase with increasing feeding rate (Fig. 1). The highest growth (38.23±0.27) was observed in fish fed six times per

**Table 1.** Effect of feeding level and feeding rate on growth performance of *T.blochii* during the 8 weeks feeding trial. Results of the One-Way ANOVA test.

| Parameters | Feeding level | Feeding frequency | Interaction |
|---|---|---|---|
| **Weight gain (g)** | $P = 0.013$ | $P = 0.04$ | $P = 0.003$ |
| **Specific growth rate** | $P < = 0.004$ | $P < = 0.001$ | $P = 0.052$ |
| **Feed Conversion Ratio** | $P = 0.002$ | $P = 0.03$ | $P = 0.07$ |
| **Feed intake** | $P = 0.002$ | $P = 0.028$ | $P = 0.045$ |

day with 10% BW, followed by (30.337±0.9) in fish fed three times per day at 10% BW, with the lowest value (9.03±0.41) found in fish fed once a day with 3% BW. Fish weight increased significantly over the course of the 50-day experiment, with treatment groups becoming significantly distinct from one another by day 20 (Fig. 1). Weight gain and SGR increased significantly with feeding rate (Fig. 2). Regardless of feeding rate, growth was generally greater and more efficient in the 6× groups than in the 1× groups. The growth-enhancing effect of greater feeding frequency was particularly evident within the 10% BW treatment. Feed intake varied expectedly with feeding rate (Fig. 2). Although feeding rates were constant within individual rate treatments, feed intake expressed as a percentage of body weight was elevated among fish in the 6× group fed at 10% BW relative to the 1× group. Carcass proximate composition was affected by feeding rate, but not by feeding frequency (Table 2). Pompano fed at higher feeding rates accumulated significantly more lipid within the body and had an associated decrease in moisture, protein, and ash content. Significantly highest survival was recorded in fish fed six times a day at 5% BW and those fed a 10% BW/d. There was no significant difference in survival rate among the fish fed at different feed application rates ($P<0.05$).

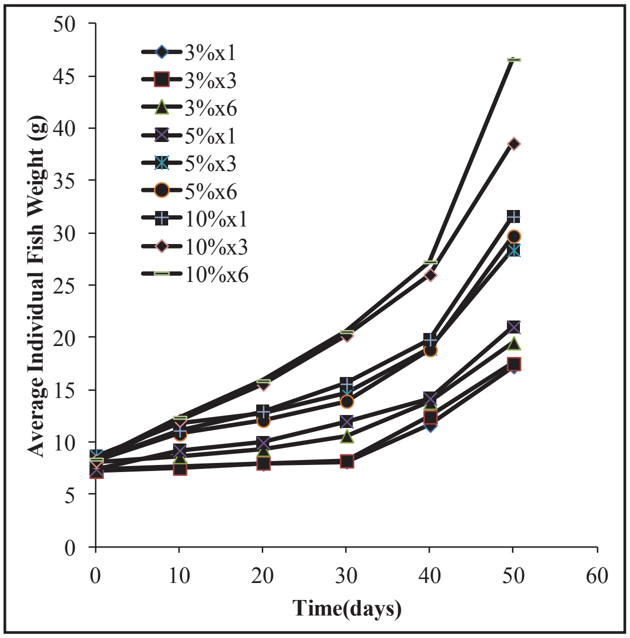

**Figure 1.** Growth performance and feed utilization of fish feed for different feeding levels and frequency in *T. blochii*.

## Discussion

The results from this study indicate that *T. blochii*, fed at the higher rate of 10% a day gain more weight than those fed at a lower rate of 3% a day. Similar observations were reported by Wang *et al.,* (2007) whereby *Nibea miichthioides* fed 1–6% BW/d grew more at the highest feeding rates with less nitrogen retention efficiency, and higher carcass lipid level accumulation. Moreover, related results were observed for cobia (*Rachycentron canadum*) juvenile, which presented a greater SGR when fed with 7% BW/d, rather than with 3% BW/d (Sun *et al.,* 2006). Other comparable findings have been reported for other fish species such as rainbow trout *Oncorhynchus mykiss*, white sturgeon *Acipenser transmontanus*, gilthead seabream *Sparus aurata*, grass carp *Ctenopharyngodon idella*, olive flounder *Paralichthys olivaceus* and Chinese sucker *Myxocyprinus asiaticus* (Storebakken *et al.*, 1991; Hung *et al.*, 1993; Mihelakakis *et al.*, 2002; Du *et al.*, 2006; Kim *et al.,* 2007; Yuan *et al.,* 2010). In the present study, the optimum feeding rate for juvenile silver pompano was 10% BW/d, since growth was lower in fish fed with 3% BW/d, comparable to results reported for *T. marginatus* (Cunha *et al.*, 2013) and other tropical fish species including *Clarias gariepinus* (8% BW/d; Marimuthu *et al.,* 2011) and *Colossoma macropomum* (10% BW/d: Silva *et al.,* 2007). These values are higher that subtropical fishes where optimum feeding rates are reported to vary between 2% and 3% BW/d for species such as *Sparus aurata*, *Paralichthys olivaceus* and *Limanda ferruginea* (Mihelakakis *et al.,* 2002; Puvanendran *et al.,* 2003; Kim *et al.,* 2007). The highest values of feeding rate observed in tropical fishes has been suggested to be due to high body metabolic rate (Cunha *et al.,* 2013).

However, while feeding rate has a strong influence on fish growth performance, feeding frequency can

**Table 2.** Carcass proximate composition of *T.blochii* in the 8-week feeding trial (N=6).

| Ingredients % | 3 | 5 | 10 | P value |
|---|---|---|---|---|
| **Moisture** | $69.3 \pm 0.115^{a}$ | $66.6 \pm 0.208^{ab}$ | $63.5 \pm 0.057^{b}$ | 0.0257 |
| **Crude Protein** | $17.3 \pm 0.251^{a}$ | $16.6 \pm 0.251^{a}$ | $16.2 \pm 0.503^{a}$ | 0.0507 |
| **Crude Lipid** | $9.5 \pm 0.152^{a}$ | $10.6 \pm 0.10^{ab}$ | $12.3 \pm 0.10^{b}$ | 0.0273 |
| **Ash** | $3.7 \pm 0.404^{a}$ | $3.0 \pm 0.152^{ab}$ | $2.6 \pm 0.152^{b}$ | 0.0273 |

$^{a,\,b}$ Treatment means within the same row with different superscript letters are significantly different ($P < 0.05$)

independently or interactively affect the growth and growth efficiency. The optimum feeding frequency varies from one species to another, and the development of the optimum feeding frequency for specific species depends on several aspects, including culture system, water quality, feed quality and fish development phase (Zuanon *et al.,* 2004). The feeding frequency is higher with no significant reduction of growth rates in fish that are fed at levels below satiation (Ribeiro *et al.,* 2012). It is well known that increasing the feeding frequency tends to increase total feed intake up to a threshold, when fish are fed to apparent satiation (Jobling, 1994). Feeding rate is effectively increased and growth is enhanced with increased feeding frequency, as observed in various species including the Korean rockfish *Sebastes schlegeli*, yellowtail flounder *Limanda ferruginea,* black sea trout *Salmo trutta labrax* and pikeperch *Sander lucioperca* (Lee *et al.,* 2000; Dwyer *et al.,* 2002; Wang *et al.,* 2009). An increase in feeding frequency tends to improve fish growth performance when fish are fed at a fixed rate (Trushenski *et al.,* 2012), and the effect has been found to be diminished to a certain level due to gastrointestinal adaptation in conversion efficiency (Peterson and Small, 2006). The present study has demonstrated that juvenile silver pompano grow better when fed six times a day compared to one or three times. Similar observations were reported by Cunha *et al*. (2013), where the juvenile pompano *T. marginatus* expressed maximum growth when fed eight times daily at a

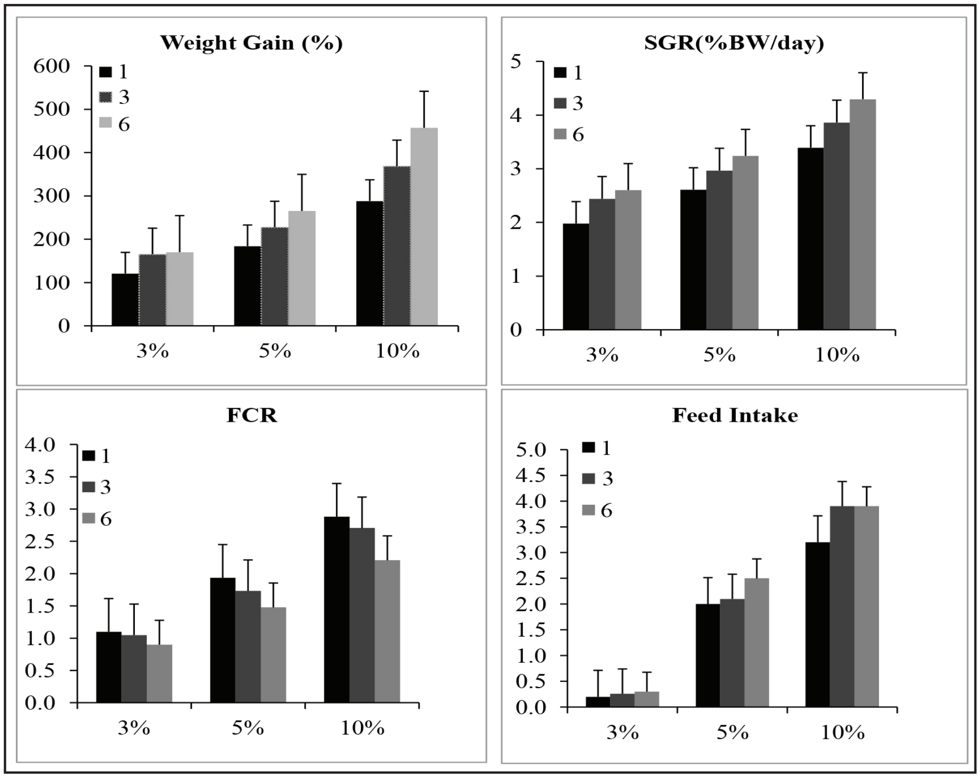

**Figure 2.** Effect of feeding rate and frequency on weight gain, feed intake, feed conversion ratio and specific growth rate in *T. blochii.*

fixed ratio compared to one or two feedings. Moreover, it has been found that an increase in feeding frequency to ten times daily does not affect growth, but rather increases the value of FCR. Largely consistent results were also reported for red-spotted grouper *Epinephelus akaara* (Kayano *et al.,* 1992), *Plecoglossus altivelis* (Cho *et al.,* 2003), Australian snapper *Pagrus auratus* (Tucker *et al.,* 2006), Asian seabass *Lates calcarifer* (Salama, 2008; Biswas *et al.,* 2010), and Atlantic spadefish *Chaetodipterus faber* (Trushenski *et al.,* 2012). The FCR was highest in the fish fed once daily (1.1, 1.9 and 2.9 respectively for feeding levels of 3%, 5%, and 10% daily).

The result of whole body composition analysis of silver pompano indicates that fish fed at higher feeding rates accumulated significantly more lipid within the body and had associated decreases in moisture, protein, and ash content, but carcass composition was unaffected by feeding frequency. Similar results were reported by Ayo-Olalusi and Ugwumbwa (2009) where *Clarias gariepinus* carcass and muscle components were not affected by feeding frequency. Also Bureau *et al.* (2006) report that fish fed at low feeding levels showed positive protein deposition but negative lipid deposition, suggesting that fish fed at low levels mobilize body lipid reserves to support protein deposition (Table 2).

The growth rate of silver pompano is higher when compared to many other farmed fish. The average total grow-out time from post-hatchery fry to 0.5 kg market-ready fish is about 8 months (Chavez *et al.,* 2011). Feeding frequency has a strong influence on fish growth performance and survival rates (Lee *et al.,* 2000; Wang *et al.,* 1998). However, the effect of feeding frequency on survival appears to be species-specific. In the present study, the survival rate was not affected by feeding frequency, similar to what was observed for *Sebastes schlegeli* (Lee *et al.,* 2000) and *T. marginatus* (Cunha *et al.,* 2013). For juvenile *Pagellus erythrinus* survival decreases when feeding frequency is decreased from 4 to 1 times a day (Mihelakakis *et al.,* 2002). Also high survival rates for *T. blochii* grown in cages were reported by Chavez *et al.,* (2011), and lower survival rates were reported by Cremer and Jian (1999) for *T. ovatus* in cages (72%) and by Mc Master *et al.* (2006) in ponds (42%). The high survival rate in the present experiment can be attributed to feeding rate and the species' ability to adapt to manufactured feeds.

## Conclusion

Juvenile silver pompano show better growth performance when fed at a feeding rate of 10% BW at a frequency of six times with equal quantities of feed per day. Despite this, the general feeding frequency in commercial production facilities is 2- 3 times per day, probably due to the high of time and labour costs associated with more frequent feeding which will increase production cost.

## Acknowledgements

We would like to express our sincere gratitude to the staff of the Institute of Marine Sciences of the University of Dar es salaam, the Zanzibar Ministry of Fisheries and Livestock, and WIOMSA for their support during data collection and laboratory analysis. We also would like thank Sida who financed this study through the Institute of Marine Sciences.

## References

Ali MZ, Hossain MA, Mazid MA (2006) Effect of mixed feeding schedules with varying dietary protein levels on the growth of sutchi catfish, *Pangasius hypophthalnus* (Sauvage) with silver carp, *Hypophthalmichthys molitrix* (Valenciennes) in ponds. Aquaculture Research 36: 627-634

AOAC (1995) Official Methods of Analysis. Association of Official Analytical Chemists, Arlington, USA. 684 pp

Ayo-Olalusi, Ugwumbwa AA (2009) Influence of Feeding Frequency on Feed Intake and Nutrient Utilization of Juvenile *Clarias gariepinus*. Journal of Aquaculture Feed Science and Nutrition 1: 39-43

Biswas GA, Thirunavukkarasu R, Sundaray JK, Kailasam M (2010) Optimization of feeding frequency of Asian seabass (*Lates calcarifer*) fry reared in net cages under brackishwater environment. Aquaculture 305: 26-31

Booth MA, Tucker BJ, Allan GL, Fielder DS (2008) Effect of feeding regime and fish size on weight gain, feed intake and gastric evacuation in juvenile Australia snapper *Pagrus auratus*. Aquaculture 282: 104-110

Bureau DP, Hua K, Cho CY (2006) Effect of feeding level on growth and nutrient deposition in rainbow trout (*Oncorhynchus mykiss* Walbaum) growing from 150 to 600g. Aquaculture Research 37: 1090-1098

Carneiro PCF, Mikos JD (2005) Feeding frequency and growth of silver catfish, *Rhamdia quelen*, fingerlings. Ciência Rural 35: 187-191

Chavez HM, Fang AL, Carandang AA (2011) Effect of stocking density on growth performance, survival and production of silver pompano, *Trachinotus* *blochii*, (Lacepede, 1801) in marine floating cages. Asian Fisheries Sciences 24: 321-330

Cho S H, Lim YS, Lee JH, Lee JK, Park S, Lee SM (2003) Effect of feeding rate and feeding frequency on survival, growth, and body composition of ayu post-larvae *Plecoglossus altivelis*. Journal of the World Aquaculture Society 34: 85-91

Cho S H, Lim YS, Lee JH, Lee JK, Park S, Lee SM (2007) Effect of feeding rate and feeding frequency on survival, growth, and body composition of ayu post-larvae *Plecoglossus altivelis*. Journal of the World Aquaculture Society 34: 85-91

Cremer MC, Jian Z (1999) Pompano (*Trachinotus ovatus*) growth performance in 1.5 m3 cages with soybean meal and fish meal based feed rations. American Soybean Association. http://www.aces.edu/dept/fisheries/ aquaculture/pdf/documents / 99 PompanolVHDtrShenzh

Craig S, Helfrich LA (2002) Understanding Fish Nutrition, Feeds and Feeding. Cooperative Extension Service, Virginia State University, USA, Publication. 420-256

Cunha VL, Marcelo RP, Marcelo HO, Ricardo VR, Luís André S (2013) Feeding rate and frequency on juvenile pompano growth. Pesq. agropec. bras., Brasília 48: 950-954

De Silva SS, Anderson TA (1995) Fish Nutrition in Aquaculture. Chapman and Hall Aquaculture Series, London. 319 pp

Du ZY, Liu YJ, Tian LX, He JG, Cao JM, Liang GY (2006) The influence of feeding rate on growth, feed efficiency and body composition of juvenile grass carp (*Ctenopharyngodon idella*). Aquaculture International 14: 247-257

Dwyer KS, Brown JY, Parrish C, Lall SP (2002) Feeding frequency affects food consumption, feeding pattern and growth of juvenile yellowtail flounder (*Limanda ferruginea*). Aquaculture 213: 279-292

FAO (2009) World Agriculture: towards 2030-2050 an FAO Perspective, Rome, Italy

FAO (2012) Food and Agriculture Organization of the United Nations. The State of World Fisheries and Aquaculture. Rome, Italy. 230 pp

FAO (2014) Food and Agriculture Organization of the United Nations. The State of World Fisheries and Aquaculture Opportunities and challenges. Rome, Italy. 243 pp

Folkvord A, Ottera H (1993) Effects of initial size distribution, day length, ° and feeding frequency on growth, survival, and cannibalism in juvenile Atlantic cod (*Gadus morhua L.*). Aquaculture 114: 243-260

Goddard S (1996) Feed Management in Intensive Aquaculture. Chapman and Hall, New York. 194 pp

Gopakumar G, Syda Rao G, Abdul Nazar AK, Jayakumar R, Tamilmani G, Kalidas C, Sakthivel M, Rameshkumar P, Hanumantha R, Murugan A, Premjothi R, Balamurugan V, Ramkumar B, Jayasingh M (2011) Silver pompano: A potential species for mariculture in India – breeding and seed production of silver pompano (*Trachinotus blochii*). Fishing Chimes 31: 58-60

Gopakumar G, Abdul Nazar AK, Jayakumar R, Tamilmani G, Kalidas C, Sakthivel M, Rameshkumar P, Hanumantarao G, Premjothi R, Balamurugan V, Ramkumar B, Jayasingh M, Syda RG (2012) Broodstock development through regulation of photoperiod and controlled breeding of silver pompano, *Trachinotus blochii* (Lacepede, 1801) in India. Indian Journal of Fisheries 59: 53-57

Heilman MJ, Spieler RE (1999) The daily feeding rhythm to demand feeders and the effects of timed meal-feeding on the growth of juvenile Florida pompano, *(Trachinotus carolinus*). Aquaculture 180: 53-64

Hung SS, Conte FS, Hallen EF (1993) Effects of feeding rates on growth, body composition and nutrient metabolism in striped bass (*Morone saxatilis*) fingerlings. Aquaculture 112: 349-361

Jobling M (1994) Fish bioenergetics. Chapman and Hall, London. 309 pp

Jobling M (1996) Environmental biology of fishes. Chapman and Hall, London. 455 pp

Kayano Y, Yao S, Yamamoto S, Nakagawa H (1992) Effects of feeding frequency on the growth and body constituents of young red-spotted grouper, *Epinephelus akaara*. Aquaculture 110: 271-278

Kalidas M, Sakthivel C, Tamilmani G, Ramesh Kumar P, Abdul Nazar AK, Jayakumar R, Balamurugan, Ramkumar, Prem J, Gopakumar G (2012) Survival and growth of juvenile silver pompano *Trachinotus blochii* (Lacepède, 1801) at different salinities in tropical conditions Indian Journal Fisheries 59: 95-98

Kim KD, Kang YJ, Kim KW (2007) Effects of feeding rate on growth and body composition of juvenile flounder, *Paralichthys olivaceus*. Journal of the World Aquaculture Society 38: 169-173

Lazo JP, Davis DA, Arnold CR (1998) The effects of dietary protein level on growth, feed efficiency and survival of juvenile Florida pompano *Trachinotus carolinus*. Aquaculture, 169: 225-232

Lee SM, Cho SH, Kim DJ (2000) Effects of feeding frequency and dietary energy level on growth and body composition of juvenile flounder, *Paralichthys olivaceus* (Temminck and Schlegel). Aquaculture Research 31: 917-921

Lovell RT (2002) Diet and fish husbandry. In: Halver JD, Hardy RW (Eds.) Fish nutrition. 3rd ed. San Diego: Academic Press. 704-755 pp

Marimuthu K, Umah R, Muralikrishnan S, Xavier R, Kathiresan S (2011) Effect of different feed application rate on growth, survival and cannibalism of African catfish, *Clarias gariepinus* fingerlings. Emirates Journal of Food and Agriculture 23: 330-337

McMaster MF, Kloth TC, Coburn JF (2004) Prospects for commercial pompano mariculture. Aquaculture America. 15 pp

Mihelakakis A, Tsolkas C, Yoshimatsu T (2002) Optimization of feeding rate for hatchery-produced juvenile gilthead sea bream *Sparus aurata*. Journal of the World Aquaculture Society 33: 169-175

Nazar Ak, Jayakumar R, Tamilmani G, Sakthivel M, Kalidas C, Ramesh Kumar P, Anbarasu M, Sirajudeen S, Balamurugan V, Jayasingh M, Gopakumar G (2012) Larviculture and seed production of the silver pompano, *Trachinotus blochii* (Lacepede, 1801) for the first time in India. Indian Jornal of Fisheries 59: 83-87

Ndome CB, Ekwu AO, Alfred AA (2011) Effect of Feeding Frequency on Feed Consumption, Growth and Feed Conversion of *Clarias gariepinus* X *Heterobranchus longifilis* Hybrids. American-Eurasian Journal of Scientific Research 6: 06-12

Ochang SN, Fagbenro OA, Adebayo OT (2007) Influence of dietary palm oil on growth response, carcass composition, haematology and organoleptic properties of juvenile Nile tilapia, *Oreochromis niloticus*. Pakistan Journal of Nutrition 6: 424-429

Peterson BC, Small BC (2006) Effect of feeding frequency on feed consumption, growth, and feed efficiency in aquarium-reared Norris and NWAC103 channel catfish (*Ictalurus punctatus*). Journal of the World Aquaculture Society 37: 490-495

Puvanendran V, Boyce DL, Brown JA (2003) Food ration requirements of yellowtail flounder *Limanda ferruginea* (Storer) juveniles. Aquaculture 220: 459-475

Ribeiro FS, Leonardo AV, João Batista KF, Nilva KS (2012) Feeding level and frequency for freshwater angelfish. Research Brazil Zootechnology 41: 1550-1554

Ruohonen K, Vielma J, Grove DJ (1998) Effects of feeding frequency on growth and food utilization of rainbow trout (*Oncorhynchus mykiss*) fed low-fat herring or dry pellets. Aquaculture 165: 111-121

Salama AJ (2008) Effect of different feeding frequency on the growth, survival and feed conversion ratio of the Asian sea bass *Lates calcarifer* juveniles reared under hypersaline seawater of the Red Sea. Aquaculture Research 39: 561-567

Silva CR, Gomes LC, Brandão FR (2007) Effect of feeding rate and frequency on tambaqui (*Colossoma macropomum*) growth, production and feeding costs during the first growth phase in cages. Aquaculture 264: 135-139

Sun L, Chen H, Huang L, Wang Z, (2006) Growth, faecal production, nitrogenous excretion and energy budget of juvenile cobia (*Rachycentron canadum*) relative to feed type and ration level. Aquaculture 259: 211-221

Storebakken T, Hung SS, Calvert CC, Plisetskaya EM (1991) Nutrient partitioning in rainbow trout at different feeding rates. Aquaculture 96: 191-203

Trushenski J, Artur R, Michael HS, John B, Brian G, Brendan D, Luis AS (2012) Feeding Rate and Frequency Affect Growth of Juvenile Atlantic Spadefish. North American Journal of Aquaculture 74: 107-112

Tucker BJ, Booth MA, Allan GL, Booth D, Fielder DS (2006). Effects of photoperiod and feeding frequency on performance of newly weaned Australian snapper *Pagrus auratus*. Aquaculture 258: 514-520

Tutman P, Glavic N, Kozul V, Skaramuca B, Glamuzina B (2004) Preliminary information on feeding and growth of pompano, *Trachinotus ovatus* (Linnaeus 1758) (Pisces; Carangidae) in captivity. Aquaculture International 12: 387-393

UNESCO (1993) Manuals and Guides: Nutrient analysis in tropical marine waters. Practical guidance and safety notes for the performance of dissolved micronutrient analysis in sea water with particular reference to tropical waters, 24 pp

Wang N, Hayward RS, Noltie DB (1998) Effect of feeding frequency on food consumption, growth, size variation, and feeding pattern of age of hybrid sunfish. Aquaculture 165: 261-267

Wang Y, Kong LJ, Li K, Bureau DB (2007). Effect of feeding frequency and ration level on growth, feed utilization and nitrogen waste output of cuneate drum (*Nibea miichthiodes*) reared in net pens. Aquaculture 271: 350-356

Wang N, Xu X, Kestemont P (2009) Effect of temperature and feeding frequency on growth performances, feed efficiency and body composition of pikeperch juveniles (*Sander lucioperca*). Aquaculture 289: 70-73

Watanabe WO (1995) Aquaculture of the Florida pompano and other jacks (Family Carangidae) in the Western Atlantic, Gulf of Mexico, and Caribbean basin: status and potential. In: K. L. Main and C. Rosenfeld (eds.). Culture of high-value marine fishes. Oceanic Institute, Honolulu, HI. 185-205 pp

Webster CD, Tiu LG, Morgan AM, Gannam A (1999) Effect of partial and total replacement of fish meal on growth and body composition of sunshine bass *Morone chrysops, M. saxatilis* fed practical diets. Journal of World Aquaculture Society 30: 443-453

Weirich CR, Groat DR, Reigh RC, Chesney EJ, Malone RF (2006) Effect of feeding strategies on production characteristics and body composition of florida pompano reared in marine recirculating systems. North American Journal of Aquaculture 68: 330-338

Yuan YC, Yang HJ, Gong SY, Luo Z, Yuan HW, Chen XK (2010) Effects of feeding levels on growth performance, feed utilization, body composition, and apparent digestibility coefficient of nutrients for juvenile Chinese sucker, *Myxocyprinus asiaticus*. Aquaculture Research 41: 1030-1042

Zuanon JA, Asano M, Fernandes JB (2004) Performance of Tricogaster (*Trichogaster trichopterus*) submitted to different feeding levels and stocking densities. Revista Brasileira de Zootecnia 33: 1639-1645

# Microalgal distribution, diversity and photo-physiological performance across five tropical ecosystems around Mauritius Island

Shamimtaz B. Sadally[1], Nawsheen Taleb-Hossenkhan[1], Ranjeet Bhagooli[1,2,*]

[1] Department of Biosciences,
Faculty of Science,
University of Mauritius,
Réduit 80837, Republic of
Mauritius

[2] Department of Marine and Ocean
Science, Fisheries and Mariculture,
Faculty of Ocean Studies,
University of Mauritius,
Réduit 80837, Republic of Mauritius

* Corresponding author:
r.bhagooli@uom.ac.mu

## Abstract

Microalgal density, diversity, photo-physiology and estimated productivity along with physico-chemical conditions across five tropical ecosystems, both at the water column and sediment levels, were assessed around Mauritius Island. The ecosystems studied were the coral reefs of Blue Bay (CRBB), the seagrass bed of Mahebourg (SEBM), the mangrove ecosystem at Pointe D'Esny (MAPD), the sandy beach of Blue Bay (SBBB) and the estuarine area of Le Goulet (ESTLG). Physico-chemical (nutrients, temperature, salinity and pH) and biological (chlorophyll *a* and microalgal density, diversity and distribution) parameters were measured and analysed. Photo-physiological status, (relative electron transport rate (*rETR*) and non-photochemical quenching (NPQ)), of microalgal cells was also determined and primary productivity was estimated using chlorophyll *a* and $rETR_{max}$ data. Microalgal density in the water column (micro-phytoplankton) was highest in the MAPD (2.55±0.22 x $10^6$ cellsL$^{-1}$) and the CRBB areas (2.20±0.13 x $10^6$ cellsL$^{-1}$), while for the sediment (micro-phytobenthos) the SBBB samples had the highest density (2.43±0.14 x $10^5$ cellsL$^{-1}$). Diatoms were the most abundant microalgal group, followed by dinoflagellates and cyanobacteria. A total of 41 micro-phytoplankton genera and 33 micro-phytobenthos genera were recorded. Higher diversity of micro-phytoplankton and micro-phytobenthos occurred at SBBB. Although *Navicula* spp. was consistently present in high abundance in all the studied ecosystems, other species such as *Cylindrotheca*, *Stauroneis*, *Oscillatoria* and *Alexandrium* species occurred in high percentages in the water column at CRBB, SBBB and ESTLG areas. Chlorophyll *a* concentration was higher in the water column of the MAPD (1.49 ± 0.08 mgm$^{-3}$), and sediment of the CRBB (31.68 ± 6.59 mgm$^{-2}$) and the SBBB (28.10 ± 5.28 mgm$^{-2}$) areas. The relative electron transport rate ($rETR_{max}$) of micro-phytoplankton/micro-phytobenthos in the water column and sediment of CRBB, SBBB and MAPD area were similar while the $rETR_{max}$ value in the sediments was higher than that of the water column for the ESTLG. Micro-phytoplankon of MAPD, SEBM and ESTLG had higher non-photochemical quenching (NPQ) values compared to those found in sediment. Estimated productivity was about 10-40 fold higher in the micro-phytobenthos of the sediment compared to the micro-phytoplankton of the water column, though the latter had a higher diversity of microalgae.

**Keywords:** chlorophyll *a*, D-PAM, estimated productivity, microalgae, micro-phytoplankton, micro-phytobenthos, photo-physiology, tropical ecosystems.

## Introduction

Microalgae are found both in the water column (micro-phytoplankton) and in sediment (micro-phytobenthos) and inhabit aquatic (including marine) ecosystems. Micro-phytoplankton are photosynthesising microorganisms that live in the euphotic zone of the ocean (Dongyan, 2008) and have limited locomotion ability. They are the primary producers of the sea and play an important role in biogeochemical cycles (Khenari *et al.*, 2010). Micro-phytobenthos communities, apart from being primary producers (Cahoon and Safi, 2002), are important in terms of coastal ecology and they play an important role in the production and cycling of organic matter, as well as in the stabilisation of sediments (Suthers and Rissik, 2009). Microalgae are present in different habitats with a wide range of temperature and salinity regimes, such as creeks, rivers, lakes, estuaries and seas. Moreover, different microalgae have also been found to adapt to various substrates, such as aquatic plants, rocks, sand grains and unconsolidated sediments (Dongyan, 2008).

In shallow coastal ecosystems, the combined effect of mixing and inputs of nutrients as a result of wind, tides, discharges and benthic fluxes, have been found to affect microalgal community structure and primary production (Claquin *et al.*, 2010). Several factors have been found to affect microalgal distribution and abundance, including temperature, pH (Brock, 1973; Goldman and Shapiro, 1973; Hinga, 1992; Goldman *et al.*, 1982), dissolved oxygen, turbulence, nutrients (Sadally *et al.*, 2014a; b), competition, grazing, allelopathic interactions, and light. However, these factors showed significant temporal variation extending from short-term events to seasons (Pannard *et al.*, 2008; Sadally *et al.*, 2014b). Micro-tides on coral reefs have also been reported to affect microalgal diversity and distribution (Sadally *et al.*, 2016).

Light, together with the abundance and photosynthetic competence of microalgae, are determinant factors conditioning primary production of ecosystems (MacIntyre and Cullen, 1996). Light is an important factor that has a direct impact on microalgal photo-physiology which depends on light availability to manufacture food. However, high light intensities may hinder the proper functioning and may even cause permanent damage of photosystems, termed 'photoinhibition', possibly leading to the death of microalgae. This may in turn disturb the functioning of the ecosystem and threaten marine life (MacIntyre and Cullen, 1996).

The coastal areas of Mauritius comprise several ecosystems, which harbour a wide range of microalgal species. During recent years, the coastal areas have faced an increased level of threats due to the coastal activities and development linked to the expanding tourism industry (Ramessur, 2013; Turner *et al.*, 2000). These have impacted coastal ecosystems in various ways. Studies on pelagic micro-phytoplankton and micro-phytobenthos are very limited around Mauritius, probably because of the difficulties encountered in extracting, enumerating and identifying them. Photo-physiological investigations on marine microalgae are also almost non-existent. This study therefore aimed at investigating the photo-physiological performance of microalgae (both micro-phytoplankton and micro-phytobenthos) across five tropical ecosystems: an estuarine, coral reef, sandy beach, seagrass, and mangrove area around an oceanic island.

The study aimed at testing whether microalgal density, distribution, diversity, and photophysiology varied across the different tropical ecosystems at both the water column (micro-phytoplankton) and sediment (micro-phytobenthos) levels. The objectives of the study were: to measure physico-chemical parameters at all sampling sites; to collect and analyse water column and sediment samples for chlorophyll *a* and microalgal density, distribution and diversity; to assess the photo-physiological performance of microalgal cells in both the water column and sediments, in terms of relative electron transport rate and non-photochemical quenching across the studied ecosystems; and to determine the estimated productivity of microalgae in each studied ecosystem.

## Sampling and methods

### Study sites

Five sampling sites (Fig. 1) were selected to represent the five ecosystems (coral reefs, seagrass bed, mangroves, sandy beaches and estuaries). The sampling sites were Blue Bay sandy beach area (site 1: S 20° 26.512', E 57° 42.994'), Blue Bay coral reef area (site 2: S 20° 26.610', E 57° 42.708'), Mahebourg seagrass bed area (site 3: S 20° 24.335', E 57° 42.596'), Pointe D'Esny mangrove area ( site 4: S 20° 25.506', E 57° 48.392') and Le Goulet estuarine area ( site 5: S 20° 06.407' / E 57° 31.031').

The sandy beach and the coral reef patch are situated in Blue Bay lagoon (Fig. 1), which is found on the South East Coast, and has been proclaimed a Marine Park by the Government since 1997. The sandy beach area is a public beach and has undergone much development due to the expanding tourism industry. The beach has not been affected by erosion and it does not harbour rich biodiversity. Fragments of dead corals are often found in this area as opposed to the reef area which contains rich biodiversity comprising of about 50 coral species and more than 50 fish species belonging to 25 families.

The seagrass bed is found at Mahebourg (Fig. 1-C) and the substrate consists of soft sediment. Seagrass occurs in the intertidal zone in shallow waters. This ecosystem serves as a nursery site for many species of fish and invertebrates.

The mangrove ecosystem is located at Pointe D'Esny. The site is a marine wetland consisting of pond-like depressions which are usually interconnected at low tide and submerged at high tide, and are dominated by the mangrove *Rhizophora mucronata*. During recent years, the coastal village of Pointe D'Esny has experienced much development due to the expanding tourism industry (Fig. 1D).

The estuarine area of Le Goulet (Fig. 1) is found around the mouth of the river Citron and extends into the river. The water is brackish and the bottom consists of soft sediments. This region has also undergone much development because of the tourism industry.

### Seawater sampling

For characterization of both pelagic and benthic components of micro-phytoplankton, 10 L of seawater was filtered through a 5 µm plankton net and the residue inside the net was collected in an opaque 250 ml plastic bottle. Samples were collected between 6 and 8 am between high and low tides during the month of February 2012. Fifteen samples (five for each analysis) were collected at each site and these were brought to the laboratory for later analyses. For nutrient analysis, 500 ml clean and labelled plastic bottles were used to collect water at each sampling sites. Five water samples were collected at each site and all samples were kept in the dark and at low temperature in isotherm boxes. In the laboratory, samples for chlorophyll a analysis and micro-phytoplankton samples for density and diversity determination were processed, while seawater samples for nutrient analyses were kept at -20°C for later processing.

### Sediment sampling

Sediment sampling was carried out according to Montoya *et al.* (2006). Five samples for chlorophyll *a*, micro-phytobenthos and photo-physiological analysis were collected using a petri-dish (5 cm diameter and 1.3 cm height) at a depth not exceeding 1 m. This included inserting the petri-dish into the substrate and placing a spatula under the petri dish to trap the contents during the retrieval process. All samples were kept at low temperature in the dark prior to analyses in the laboratory. In the laboratory, the sediment samples were washed with 2 L filtered seawater and filtered twice, first with a coarse filter of mesh size of 600 µm, and then with the 5 µm plankton net. The residue was then collected in a 250 ml opaque plastic bottle.

### Measurement of physico-chemical parameters

Temperature (Comark 314), salinity (Erma) and pH (Hanna H1 9024C) were measured *in situ*. Water

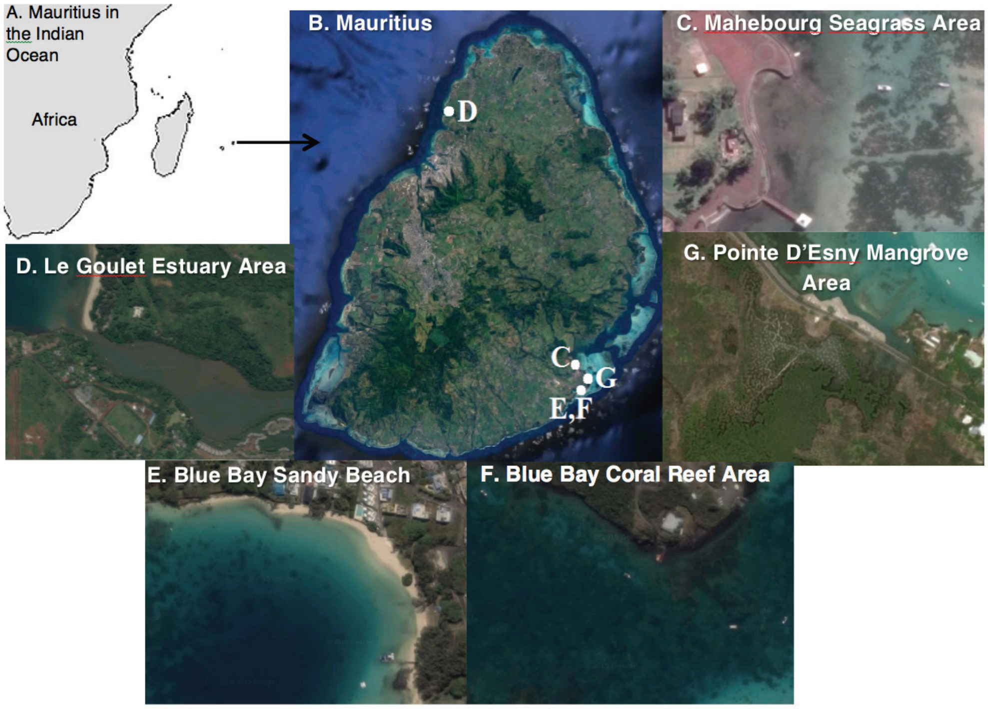

**Figure 1.** A. Location Mauritius in the Indian Ocean (Source: http://www.washburn.edu/cas/history/stucker/IndianOceanMap.html); B. Location of the sampling sites in Mauritius Island; C. Mahebourg Seagrass area; D. Le Goulet Estuary Area; E. Blue Bay Sandy Beach Area; and F. Blue Bay Coral Reef Area (Source: Google Earth)

samples collected for nutrient (nitrate, phosphate and silicate) analysis were tested according to Greenberg *et al.* (1992).

### Chlorophyll *a*, micro-phytoplankton count and identification

Water samples collected from the water column and sediments for micro-phytoplankton/ micro-phytobenthos analysis were centrifuged (Häder, 1995) on the same day at a speed of 3000 rpm for 5 minutes (Khenari *et al.*, 2010). The supernatant was discarded and the pellet was dissolved in 6 ml filtered seawater for measurement of chlorophyll *a* fluorescence using a Diving-PAM (Underwater Fluorometer, HeinzWatz GmbH, 1998) and chlorophyll *a* analysis using the spectrometric method. One ml of sample was preserved in Lugol's iodine for later enumeration and identification.

For determination of chlorophyll *a* concentration, 90% acetone was used for extraction of chlorophyll *a* pigment at 4°C for 24hrs (Jeffrey and Humphrey, 1975). Concentration of chlorophyll *a* was determined by spectrophotometry (Spectronic® Genesys™ 8 spectrophotometer). Micro-phytoplankton/ micro-phytobenthos was identified according to Tomas (1997), Smith and Johnson (1996), and Verlencar and Desai (2004) and quantification was done using a Sedgewick Rafter Counting Chamber (Devassy and Goes, 1991) under a light microscope.

### Fluorometric determination of photo-physiology and non-photochemical quenching of micro-phytoplankton

Light that stimulates photosynthesis is known as photosynthetically active radiation (PAR) and $F_V/F_M$ is the maximum quantum yield (calculated as $(F_M'–F_0)/F_M'$), which determines the amount of solar energy that can be converted to fixed carbon.

PAM fluorometry was used to assess the photo-physiology of microalgal cells by measuring the fluorescence of chlorophyll *a*, thus determining the relative electron transport rate (*rETR*) and non-photochemical quenching (NPQ) when exposed to a series of rapidly (10s) changing light climates (RLC) (McMinn *et al.* 2012). Following the RLCs' recordings, samples were dark-adapted for 30 mins prior to $F_v/F_m$ measurements. The *rETR* and NPQ were estimated, at each irradiance, using the RLC and the values were plotted as in Louis *et al.* (2016) and Bhagooli *et al.* (2008).

At each irradiance the respective relative electron transport rate (*rETR*) was calculated by the formula below (Underwood *et al.*, 2005):

$$rETR = 0.5 \text{ x } \phi_{PSII} \text{ x PAR}$$

where:

PAR is the photosynthetically active radiance;

$\phi_{PSII}$ is the effective quantum yield and is calculated as: $(F_M' — F)/F_M'$, where $F_M'$ and $F$ is the maximum and minimum fluorescence yield, respectively.

The 0.5 terms in the equation account for 50% of absorbed photons used by PSII.

Non-photochemical quenching (NPQ) is the process by which oxygenic photoautotrophs harmlessly dissipate excess light absorbed as heat and fluorescence (Roth, 2014; Szabò *et al.*, 2005). When light energy absorption exceeds the capacity for utilization, there is a need to dissipate the energy to protect the light harvesting structures from photo-oxidative damage. NPQ is derived from the formula:

$$NPQ = (F_m - F_m')/F_m'$$

where:

$F_m$ the maximal fluorescence of a dark-'adapted' sample and $F_m'$ is the maximal fluorescence of a light-exposed alga under a given irradiance.

The double exponential decay function of Platt *et al.* (1980) was employed to fit curves to the RLCs and $rETR_{max}$, $\alpha$ (initial slope before the onset of saturation), $I_k$ (minimum saturating irradiance) were determined (Louis *et al.*, 2016). Estimation of productivity for both water column and sediment samples from the five ecosystems was calculated using the following formula (McMinn *et al.*, 2005):

Estimated productivity = $rETR_{max}$ x [Chlorophyll *a*]

### Statistical analyses

Computing and statistical analyses were used Statistica 10.0 software. One-Way analysis of variance (ANOVA) followed by the Posthoc Tukey Honest Significance Difference (HSD) analysis for comparison of means were carried out to test for differences in parameters at the five ecosystems, namely, coral reef patch, sandy beach, mangrove, seagrass and estuary. Microalgae density data was $\log_{10}$ transformed while temperature, salinity, pH, chlorophyll *a*, nitrate, phosphate and silicate data were arcsin (square root) transformed prior to ANOVA analyses. Shannon's Diversity (H) and Similarity Index (SI) were also calculated for micro-phytoplankton in the water column and the micro-phytobenthos in the sediment at the five ecosystems sampled.

## Results

### Micro-phytoplankton distribution and biomass across the five ecosystems

One-Way ANOVA analyses revealed that all tested parameters, including total micro-phytoplankton/micro-phytobenthos, diatom, dinoflagellate, cyanobacteria density, chlorophyll *a* concentration and nutrient concentrations (nitrate, phosphate and silicate) were significantly different ($P < 0.001$) among the different sampling sites; that is, among the different ecosystems in both water column and sediment (Table 1).

### Total micro-phytoplankton/micro-phytobenthos density and chlorophyll *a* concentration

Micro-phytoplankton density in the water column (Fig. 2A) was significantly higher in the mangrove area and the coral reef area compared to the other ecosystems. These were followed by the sandy beach, seagrass and estuary areas, respectively. In the sediment (Fig. 2B), highest density of micro-phytoplankton was recorded in the coral reef and the sandy beach area, while lowest density was recorded in the seagrass bed area (Table 2).

Chlorophyll *a* concentration in the water column was highest and lowest in the mangrove and estuary area, respectively (Fig. 2C). Moreover, there was no significant difference in chlorophyll *a* concentration between coral reef and estuarine area samples. In the sediment samples, significantly higher chlorophyll *a* concentration was recorded in the coral reef and the sandy beach area compared to the other ecosystems, while the estuary area had the lowest chlorophyll *a* concentration (Fig. 2D). No significant difference was observed in chlorophyll *a* concentration in the sediment of the mangrove and seagrass area.

Diatoms dominated the micro-phytoplankton population in both the water column and sediment samples collected at the different ecosystems (Fig. 2E; F). Higher density was recorded in the water column in the mangrove area, followed by the coral reef, sandy beach, seagrass, and estuary area (Fig. 2E). In the sediment, significantly higher density of diatoms was recorded for the sandy beach and the coral reef while estuarine and seagrass bed sediment had lower density (Fig. 2F). No significant difference was observed between coral reef and mangrove area sediment samples.

Higher densities of dinoflagellates were recorded in the water column of the coral reef, sandy beach and estuary area (Table 2). The water column in the mangrove and the seagrass bed area had a significantly lower density of dinoflagellates compared to the other ecosystems (Fig. 2E). Dinoflagellates were more abundant in the sediment of the estuarine area compared to the other ecosystems (Fig. 2F; Table 2).

Cyanobacteria were the least abundant micro-phytoplankton. Significantly higher density was obtained in the water column of the seagrass and estuary area compared to the other ecosystems (Fig. 2E; Table 2).

**Table 1.** One-Way ANOVA comparing different parameters at the five ecosystems (coral reef, sandy beach, mangrove, seagrass and estuary). Asterisks indicate significant differences at 5% level. (* = $P< 0.05$; ** = $P< 0.01$; *** = $P< 0.001$).

| | | Water column | | | | Sediment | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Parameters** | **DF** | **SS** | **MS** | **F** | ***P*-Value** | **SS** | **MS** | **F** | ***P*-Value** |
| **TPD** | 4 | 2.607 | 0.652 | 511.5 | *** | 0.859 | 0.215 | 21.49 | *** |
| **Diatom density** | 4 | 4.181 | 1.045 | 952.4 | *** | 1.334 | 0.334 | 27.14 | *** |
| **Dinoflagellate density** | 4 | 4.685 | 1.171 | 26.45 | *** | 1.052 | 0.263 | 9.03 | *** |
| **Cyanobacteria density** | 4 | 3.876 | 0.970 | 49.21 | *** | 1.265 | 0.316 | 14.11 | *** |
| **Chlorophyll *a*** | 4 | 0.150 | 0.038 | 477.2 | *** | 0.353 | 0.088 | 27.30 | *** |
| **Nitrate** | 4 | 0.993 | 0.248 | 45.503 | *** | - | - | - | - |
| **Phosphate** | 4 | 0.461 | 0.115 | 18.57 | *** | - | - | - | - |
| **Silicate** | 4 | 0.042 | 0.010 | 50.24 | *** | - | - | - | - |

**Table 2.** Tukey HSD Posthoc Tests for comparing means of studied parameters at the five ecosystems. Asterisks indicate significant differences at 5% level. (* = *P*< 0.05; ** = *P*< 0.01; *** = *P*< 0.001; NS = not significant). CRBB: coral reef area; SBBB: sandy beach area; MAPD: mangrove area; SEBM: seagrass bed area; ESTLG: Estuary area

| | | | Water column | | | | | Sediment | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Parameters** | | **CRBB** | **SBBB** | **MAPD** | **SEBM** | **ESTLG** | **CRBB** | **SBBB** | **MAPD** | **SEBM** | **ESLG** |
| Biological parameters | **Total micro-phytoplankton/ micro-phytobenthos Density** | CRA | - | ** | NS | *** | *** | - | NS | NS | *** | *** |
| | | SBA | ** | - | *** | *** | *** | NS | - | * | *** | *** |
| | | MA | NS | *** | - | *** | *** | NS | * | - | ** | ** |
| | | SA | *** | *** | *** | - | *** | *** | *** | ** | - | NS |
| | | EA | *** | *** | *** | *** | - | *** | *** | ** | NS | - |
| | **Diatom Density** | CRA | - | * | *** | *** | *** | - | NS | NS | *** | *** |
| | | SBA | * | - | *** | *** | *** | NS | - | * | *** | *** |
| | | MA | *** | *** | - | *** | *** | NS | * | - | *** | *** |
| | | SA | *** | *** | *** | - | *** | *** | *** | *** | - | NS |
| | | EA | *** | *** | *** | *** | - | *** | *** | *** | NS | - |
| | **Dinoflagellate Density** | CRA | - | NS | *** | *** | NS | - | NS | NS | NS | *** |
| | | SBA | NS | - | * | *** | NS | NS | - | NS | NS | ** |
| | | MA | *** | * | - | * | * | NS | NS | - | NS | ** |
| | | SA | *** | *** | * | - | *** | NS | NS | NS | - | * |
| | | EA | NS | NS | * | *** | - | *** | ** | ** | * | - |
| | **Cyanobacteria Density** | CRA | - | NS | NS | *** | *** | - | NS | NS | NS | ** |
| | | SBA | NS | - | NS | *** | *** | NS | - | * | *** | *** |
| | | MA | NS | NS | - | *** | *** | NS | * | - | NS | * |
| | | SA | *** | *** | *** | - | NS | NS | *** | NS | - | NS |
| | | EA | *** | *** | *** | NS | - | ** | *** | * | NS | - |
| | **Chlorophyll *a*** | CRA | - | ** | *** | *** | NS | - | NS | ** | *** | *** |
| | | SBA | ** | - | *** | *** | *** | NS | - | *** | *** | *** |
| | | MA | *** | *** | - | *** | *** | ** | *** | - | NS | * |
| | | SA | *** | *** | *** | - | *** | *** | *** | NS | - | NS |
| | | EA | NS | *** | *** | *** | - | *** | *** | * | NS | - |
| Physico-chemical parameters | **Nitrate** | CRA | - | ** | *** | *** | NS | - | - | - | - | - |
| | | SBA | ** | - | NS | *** | *** | - | - | - | - | - |
| | | MA | *** | NS | - | ** | *** | - | - | - | - | - |
| | | SA | *** | *** | ** | - | *** | - | - | - | - | - |
| | | EA | NS | *** | *** | *** | - | - | - | - | - | - |
| | **Phosphate** | CRA | - | *** | NS | NS | NS | - | - | - | - | - |
| | | SBA | *** | - | *** | *** | *** | - | - | - | - | - |
| | | MA | NS | *** | - | NS | NS | - | - | - | - | - |
| | | SA | NS | *** | NS | - | NS | - | - | - | - | - |
| | | EA | NS | *** | NS | NS | - | - | - | - | - | - |
| | **Silicate** | CRA | - | *** | NS | *** | NS | - | - | - | - | - |
| | | SBA | *** | - | *** | * | *** | - | - | - | - | - |
| | | MA | NS | *** | - | *** | NS | - | - | - | - | - |
| | | SA | *** | * | *** | - | *** | - | - | - | - | - |
| | | EA | NS | *** | NS | *** | - | - | - | - | - | - |

Likewise, density of cyanobacteria was higher in the sediment from the seagrass and estuary area. However, no significant difference was obtained when comparing seagrass data to samples from the coral reef and mangrove area (Fig. 2F; Table 2).

### Diversity of micro-phytoplankton/ micro-phytobenthos in the different ecosystems

A total of 42 genera were sampled during this study at the five ecosystems (Table 3). Higher Shannon's Diversity Index (H) was recorded in the water column of the seagrass bed area (H= 2.848), followed by the coral reef (H= 2.815), sandy beach (H= 2.703), mangrove (H= 2.547) and estuary area (2.540). In the sediment samples, the sandy beach area had the highest H value (H= 2.588), followed by the mangrove area (H= 2.44), the coral reef area (H= 2.389), the seagrass bed area (H= 2.214) and the estuary area (H=2.010).

The water column samples comprised a total of 41 micro-phytoplankton genera, while 33 genera of micro-phytobenthos were recorded in the sediment. All the 33 genera recorded in the sediment were also present in the water column, except the genera *Gomphonema*. The genera *Leptocylindricus*, *Synedra*, *Meuniera*, *Thalassiothrix*, *Stauroneis*, *Chaetoceros*, *Rhizosolenia*, *Diatoma* and *Phormidium* were only recorded in the water column samples. *Navicula* spp. was consistently present in high abundance in all the different ecosystems but a higher percentage of *Cylindrotheca*, *Stauroneis*, *Oscillatoria* and *Alexandrium* were recorded in the water column of the coral reef, sandy beach and estuarine area, respectively (Table 3). *Cocconeis* was also found to be dominant in the sediment of the estuarine area.

The Similarity Index (SI) for the water column samples from the sandy beach, mangrove, coral reef and

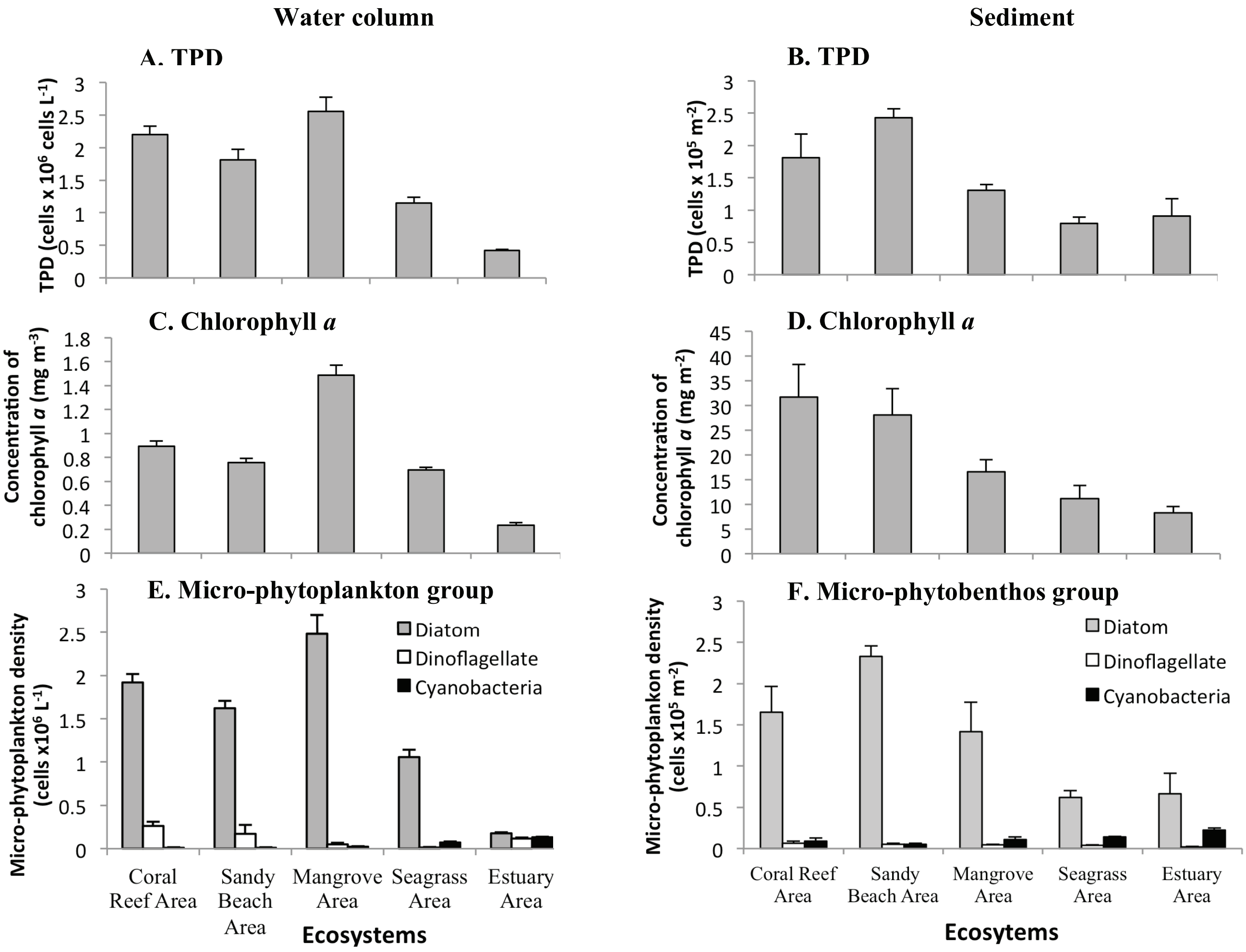

**Figure 2.** Total micro-phytoplankton/micro-phytobenthos density (TPD) in the water column (A) and sediment (B), chlorophyll *a* concentration in water column(C) and sediment (D) in the different ecosystems and micro-phytoplankton group (diatom, dinoflagellate and cyanobacteria) density in the water column (E) and sediment (F) in the five ecosystems studied. Data represent mean ± sd (n = 5).

**Table 3.** Percentage and Shannon's Diversity Index (DI) of micro-phytoplankton/micro-phytobenthos genera recorded in the water column and sediment of the five ecosystems (coral reef, sandy beach, mangrove, estuary and seagrass bed ecosystems).

| **Ecosystems** | **Coral reef** | | **Sandy beach** | | **Mangrove** | | **Estuary** | | **Seagrass bed** | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Micro-phytoplankton// micro-phytobenthos genera** | **Water column** | **Sediment** | **Water column** | **Sediment** | **Water column** | **Sediment** | **Water column** | **Sediment** | **Water column** | **Sediment** |
| *Cylindrotheca* sp. | 24.2 | 1.3 | 3.1 | 1.9 | 0.5 | 2.1 | 3.1 | 0.0 | 1.5 | 3.6 |
| *Navicula* sp. | 11.9 | 19.5 | 11.6 | 30.8 | 15.3 | 31.9 | 7.6 | 15.4 | 18.8 | 25.0 |
| *Pseudonitzschia* sp. | 3.6 | 1.3 | 2.3 | 0.0 | 0.5 | 3.2 | 0.8 | 2.6 | 1.5 | 0.0 |
| *Thalassiosira* sp. | 0.5 | 0.0 | 1.6 | 0.0 | 1.0 | 1.1 | 0.8 | 1.3 | 0.8 | 0.0 |
| Pleurosigma | 1.5 | 0.0 | 0.0 | 0.0 | 6.6 | 8.5 | 0.8 | 0.0 | 9.8 | 3.6 |
| *Cymatopleura* sp. | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.1 | 0.0 | 0.0 | 0.8 | 0.0 |
| *Melosira* sp. | 1.5 | 0.0 | 0.8 | 1.9 | 3.6 | 3.2 | 0.8 | 2.6 | 1.5 | 0.0 |
| *Cocconeis* sp. | 5.2 | 19.5 | 0.8 | 7.7 | 0.5 | 13.8 | 11.5 | 44.9 | 9.0 | 0.0 |
| *Mastogloia* sp. | 0.0 | 0.0 | 0.8 | 0.0 | 0.5 | 5.3 | 0.0 | 0.0 | 1.5 | 0.0 |
| *Fragilaria* sp. | 4.1 | 16.9 | 1.6 | 11.5 | 5.1 | 8.5 | 0.0 | 0.0 | 3.0 | 10.7 |
| *Achnanthes* sp. | 1.5 | 3.9 | 2.3 | 3.8 | 1.5 | 3.2 | 0.0 | 1.3 | 1.5 | 3.6 |
| *Gomphosphaeria* sp. | 0.5 | 0.0 | 2.3 | 1.9 | 14.3 | 4.3 | 3.8 | 2.6 | 0.0 | 14.3 |
| *Lyngbya* sp. | 0.5 | 1.3 | 0.0 | 1.9 | 0.5 | 2.1 | 12.2 | 5.1 | 3.8 | 10.7 |
| *Coscinodiscus* sp. | 1.5 | 0.0 | 1.6 | 1.9 | 1.5 | 1.1 | 0.0 | 0.0 | 11.3 | 3.6 |
| *Asterionellopsis* sp. | 3.1 | 5.2 | 0.8 | 0.0 | 1.0 | 1.1 | 0.8 | 0.0 | 2.3 | 0.0 |
| *Lioloma* sp. | 1.5 | 1.3 | 1.6 | 5.8 | 2.0 | 1.1 | 0.0 | 0.0 | 0.8 | 3.6 |
| *Manguinea* sp. | 1.0 | 0.0 | 0.8 | 1.9 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Diploneis* sp. | 3.6 | 7.8 | 0.8 | 3.8 | 4.1 | 0.0 | 1.5 | 2.6 | 2.3 | 0.0 |
| *Nitzschia* sp. | 8.8 | 0.0 | 10.1 | 1.9 | 0.5 | 0.0 | 0.0 | 0.0 | 1.5 | 3.6 |
| *Cavinula* sp. | 0.5 | 5.2 | 2.3 | 3.8 | 1.0 | 1.1 | 0.8 | 2.6 | 11.3 | 14.3 |
| *Leptocylindricus* sp. | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 0.0 | 0.8 | 0.0 | 0.8 | 0.0 |
| *Biddulphia* sp. | 2.1 | 0.0 | 0.0 | 0.0 | 3.6 | 0.0 | 0.0 | 1.3 | 0.8 | 0.0 |

| **Ecosystems** | **Coral reef** | | **Sandy beach** | | **Mangrove** | | **Estuary** | | **Seagrass bed** | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Micro-phytoplankton// micro-phytobenthos genera** | **Water column** | **Sediment** | **Water column** | **Sediment** | **Water column** | **Sediment** | **Water column** | **Sediment** | **Water column** | **Sediment** |
| *Prorocentrum* sp. | 2.6 | 2.6 | 3.9 | 1.9 | 0.5 | 1.1 | 3.1 | 1.3 | 0.0 | 0.0 |
| *Protoperidinium* sp. | 4.6 | 1.3 | 6.2 | 1.9 | 0.5 | 1.1 | 11.5 | 1.3 | 1.5 | 3.6 |
| *Licmophora* sp. | 4.1 | 0.0 | 0.8 | 3.8 | 0.0 | 0.0 | 0.0 | 0.0 | 2.3 | 0.0 |
| *Striatella* sp. | 0.0 | 0.0 | 0.0 | 3.8 | 0.0 | 0.0 | 0.0 | 0.0 | 2.3 | 0.0 |
| *Thalassionema* sp. | 0.5 | 0.0 | 0.8 | 1.9 | 0.0 | 0.0 | 0.8 | 1.3 | 1.5 | 0.0 |
| *Synedra* sp. | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.8 | 0.0 |
| *Meuniera* sp. | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.3 | 0.0 |
| *Thalassiothrix* sp. | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Lyrella* sp. | 1.5 | 1.3 | 0.8 | 1.9 | 0.0 | 2.1 | 0.0 | 1.3 | 0.8 | 0.0 |
| *Oscillatoria* sp. | 0.0 | 1.3 | 0.8 | 0.0 | 1.0 | 2.1 | 15.3 | 5.1 | 3.0 | 0.0 |
| *Climacosphenia* sp. | 0.0 | 2.6 | 0.0 | 1.9 | 0.0 | 0.0 | 3.8 | 7.7 | 0.0 | 0.0 |
| *Gomphonema* sp. | 0.0 | 0.0 | 0.0 | 1.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Pinnularia* sp. | 1.0 | 6.5 | 14.7 | 0.0 | 15.3 | 0.0 | 3.1 | 0.0 | 0.0 | 0.0 |
| *Stauroneis* sp. | 1.0 | 0.0 | 18.6 | 0.0 | 17.3 | 0.0 | 0.0 | 0.0 | 0.8 | 0.0 |
| *Chaetoceros* sp. | 0.0 | 0.0 | 0.8 | 0.0 | 0.0 | 0.0 | 2.3 | 0.0 | 0.0 | 0.0 |
| *Alexandrium* sp. | 5.2 | 0.0 | 7.8 | 0.0 | 0.5 | 1.1 | 15.3 | 0.0 | 0.8 | 0.0 |
| *Craticula* sp. | 0.5 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Rhizosolenia* sp. | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Diatoma* sp. | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Phormidium* sp. | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| No. of genera | 31 | 18 | 27 | 22 | 27 | 22 | 22 | 17 | 30 | 12 |
| Shannon DI | 2.815 | 2.389 | 2.703 | 2.588 | 2.547 | 2.440 | 2.540 | 2.010 | 2.848 | 2.214 |

**Table 4.** Similarity index (SI) for every combination in both the water column and sediment of the five ecosystems sampled for micro-phytoplankton/micro-phytobenthos genera. WC: water column; SED: sediment.

| | | Coral Reef | | Sandy Beach | | Mangrove | | Estuary | | Seagrass | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | WC | SED | WC | SED | WC | SED | WC | SED | WC | SED |
| **Coral Reef** | WC | - | | | | | | | | | |
| | SED | 0.653 | - | | | | | | | | |
| **Sandy Beach** | WC | 0.828 | 0.667 | - | | | | | | | |
| | SED | 0.717 | 0.650 | 0.735 | - | | | | | | |
| **Mangrove** | WC | 0.793 | 0.667 | 0.852 | 0.653 | - | | | | | |
| | SED | 0.679 | 0.700 | 0.776 | 0.636 | 0.816 | - | | | | |
| **Estuary** | WC | 0.642 | 0.600 | 0.694 | 0.545 | 0.735 | 0.682 | - | | | |
| | SED | 0.625 | 0.629 | 0.636 | 0.667 | 0.636 | 0.667 | 0.718 | - | | |
| **Seagrass** | WC | 0.754 | 0.583 | 0.772 | 0.615 | 0.807 | 0.769 | 0.615 | 0.596 | - | |
| | SED | 0.558 | 0.533 | 0.462 | 0.647 | 0.615 | 0.647 | 0.412 | 0.414 | 0.524 | - |

estuary areas did not show great variation, except for the estuary area, which had lower similarity values compared to the other ecosystems (Table 4). In the sediment samples, seagrass and estuary areas were dissimilar compared to the other ecosystems (SI = 0.414). Comparison between the water column and sediment samples showed that the mangrove sediment and water column were more similar (SI = 0.816), while the water column and sediment at the seagrass area was more dissimilar (SI = 0.524).

### Photo-physiological status of micro-phytoplankton/ micro-phytobenthos

The physiological status ($rETR_{max}$, $NPQ_{max}$ and estimated relative productivity) of micro-phytoplankton/ micro-benthos were significantly different in both the water column and the sediment at the five different ecosystems, with the exception of the effective quantum yield ($\phi_{PSII}$) (Table 5).

### Photochemical efficiency

The mean photochemical efficiency of $\phi_{PSII,}$ of micro-phytoplankton/micro-phytobenthos sampled in the water column and sediments measured from Diving PAM was computed for each site (Fig. 3). The photo-physiology of micro-phytoplankton from the water column and sediments were relatively similar for the different ecosystems.

### Relative electron transport rate (rETR) and non-photochemical quenching

The $rETR_{max}$ values for the water column and sediments at the coral reef, sandy beach, and mangrove area were found to be comparatively the same, indicating little variation in photo-physiology (Fig. 4A-C). However, at the seagrass bed area (Fig. 4D), the $rETR_{max}$ values for the water column was found to be much higher compared to that of sediments, while the contrary was observed for the estuarine area (Fig. 4E). Thus microalgae in the water column had a much higher photosynthetic activity than those present in the sediments.

The $NPQ_{max}$ values for the water columns and sediments at the coral reef and sandy beach area were found to be relatively the same, indicating equal capacity for the dissipation of excess light energy (Fig. 4F; G). However, at the mangrove (Fig. 4H), seagrass bed (Fig. 4I), and the estuarine area (Fig. 4J), the $NPQ_{max}$ value for the water column was found to be moderately higher compared to that of sediments at the mangrove area. Thus, the micro-phytoplankton in the water column had a higher capacity for energy dissipation as compared to those from the sediments.

### Mean $rETR_{max}$ values, and $I_k$ for each ecosystem

The mean $rETR_{max}$ value was highest in estuarine sediment followed by sandy beach, with the lowest value was obtained in the seagrass bed and mangrove area, based on samples from the water column (Fig. 5). Moreover, the mean $rETR_{max}$ was lower in the sediment of the seagrass bed ecosystem compared to the water column in that ecosystem.

The $I_k$ values for the water column for the coral reef, sandy beach, mangrove, seagrass bed, and estuarine

**Table 5.** One-way ANOVA to test the photo-physiological status ($\phi_{PSII}$, $rETR_{max}$, $NPQ_{max}$ and estimated relative productivity) of micro-phytoplankton at the five ecosystems (coral reef, sandy beach, mangrove, seagrass and estuary). Asterisks indicate significant differences at 5% level. (* = P< 0.05; ** = P< 0.01; *** = P< 0.001).

| | Dependent variables | Source of variation | df | MS | F | P-value |
|---|---|---|---|---|---|---|
| **Water column** | $\phi_{PSII}$ | 0.004 | 4 | 0.001 | 0.577 | NS |
| | $rETR_{max}$ | 3712 | 4 | 928.1 | 4.807 | ** |
| | $NPQ_{max}$ | 0.020 | 4 | 0.005 | 3.791 | * |
| | Estimated Productivity | 4812 | 4 | 1203 | 39.82 | *** |
| **Sediment** | $\phi_{PSII}$ | 0.005 | 4 | 0.001 | 0.707 | NS |
| | $rETR_{max}$ | 11067 | 4 | 2767 | 22.69 | *** |
| | $NPQ_{max}$ | 0.2481 | 4 | 0.062 | 61.12 | *** |
| | Estimated Productivity | 1265 | 4 | 316.3 | 17.54 | *** |

areas were 212.39±58.18, 159.66±43.02, 94.75±7.90, 163.45±41.07, 167.44±35.56, respectively. While for the sediment samples, the $I_k$ values were 157.21±42.53, 272.16±74.41, 232.99±87.86, 39.15±9.91, 343.29±100.59 in these ecosystems, respectively.

### Estimated Productivity

The water column of the sandy beach and the coral reef area had the highest estimated productivity while the seagrass bed area had the lowest (Fig. 6A). Productivity estimates were highest in the sediment of the coral reef and sandy beach area, and lowest in the estuarine area (Fig. 6B).

### Physical parameters

The tidal pool of the mangrove swamp at Pointe D'Esny had the highest temperature (33±0.41°C), whereas temperature was lowest in the coral reef area of Blue Bay (27.7±0.24°C). Highest salinity was obtained in the mangrove area (40.7±0.47 ppt), with the lowest value recorded in the estuarine area (28.7±0.47 ppt) (Fig. 7A). The pH was highest in the estuarine area of Le Goulet (pH = 8.5±0.30), and lowest in the mangrove area (pH = 7.4±0.14) (Fig. 7B).

Nutrient concentrations differed among the different ecosystems (Table 1). Significantly higher nitrate

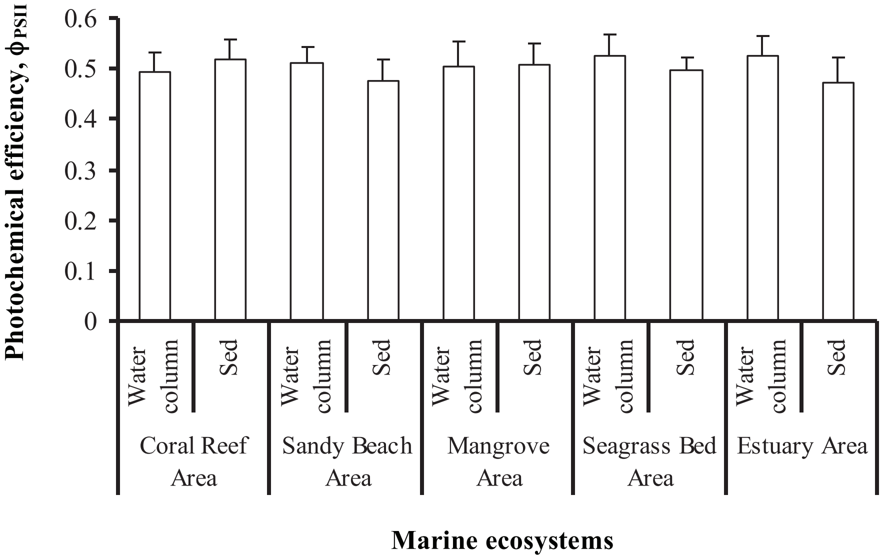

**Figure 3.** Photochemical efficiency, $\phi_{PSII}$, of micro-phytoplankton/micro-phytobenthos sampled from the water column and sediment (Sed) in different marine ecosystems. Data represent mean ± sd (n=5).

(0.86±0.06 mg $L^{-1}$) and silicate (1.46±0.05 mg $L^{-1}$) concentrations were obtained in water samples collected in the estuary area (Fig. 7C). Although there was no significant difference in nitrate concentration between the seagrass and mangrove area, and between the coral reef and sandy beach area, nitrate was higher in the coral reef area (0.44±0.08 mg $L^{-1}$) than in the seagrass bed area (0.35±0.03 mg $L^{-1}$). However, phosphate concentration was significantly lower in the sandy beach area (0.13±0.06 µg $L^{-1}$), while no significant difference was obtained for the other ecosystems. Silicate concentration was higher in the estuarine (1.46±0.05 mg $L^{-1}$) and the sandy beach area (1.25±0.06 mg $L^{-1}$) (Table 2) while no significance difference was obtained between the coral reef (0.85±0.07 mg $L^{-1}$), mangrove (0.83±0.09 mg $L^{-1}$), and seagrass area (0.88±0.10 mg $L^{-1}$).

## Discussion

### Micro-phytoplankton in the water column

The higher total micro-phytoplankton density (TPD) and chlorophyll *a* concentration in the mangrove ecosystem indicates that this ecosystem is highly

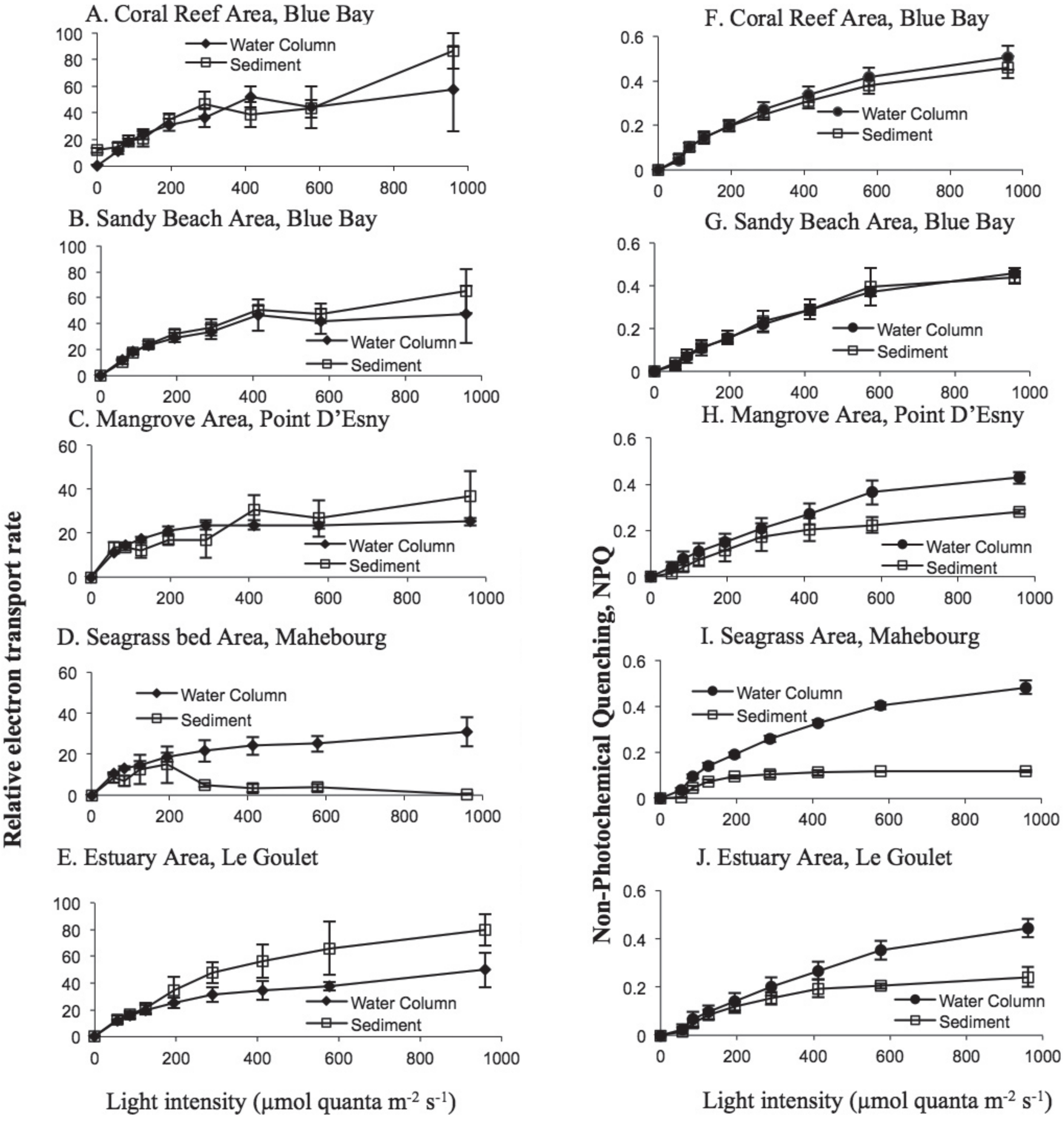

**Figure 4.** Relative electron transport rates (A-E) and non-photochemical quenching (F-J) of micro-phytoplankton/micro-phytobenthos collected from the water column (•) and sediment (□) from five near shore marine ecosystems (coral reef, sandy beach, mangrove, seagrass bed, and estuary).

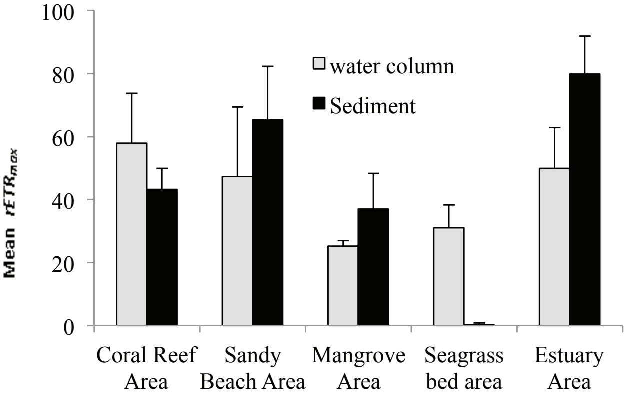

**Figure 5.** *rETR*$_{max}$ for each marine ecosystem. Data represent mean ± sd (n = 5).

productive compared to the other studied ecosystems. Indeed, the nutrient enrichment in the mangroves ecosystem is due to the presence of highly efficient nutrient retention mechanisms, characteristics of mangrove swamps (Alongi, 2002). Availability of nutrients in these ecosystems appeared to be a determinant of micro-phytoplankton (Teissier *et al.*, 2011) with higher TPD recorded at higher nutrient concentration, except in the coral reef and estuarine area. In the coral reef area, nutrients seemed to be a limiting factor, and their lower concentration may be attributed to their uptake by micro-phytoplankton.

However, the contrary was observed in the estuarine area where low density of TPD was recorded despite the high level of nutrients prevailing there. Although estuaries have high productivity, this does not necessarily extend to the water column, and phytoplankton production may be lower compared to other marine environments (Cloern, 1987). Considering the high level of nutrients recorded in the estuarine area at Le Goulet, micro-phytoplankton density and estimated productivity were expected to be higher, but the contrary was observed. This might be attributed to high level of turbidity observed at the time of sampling, which may have been due to river inputs, suspended particulate matter and/or suspension of bottom sediments (Cloern, 1987). Light availability greatly affects primary production (Diehl *et al.*, 2002), and the high turbidity limits light penetration, which in turn reduces algal production. This explains the low density of micro-phytoplankton and low productivity estimates at the estuarine area.

The degree of turbulence at the different ecosystems may contribute to the difference in micro-phytoplankton densities observed during the study, since primary production has often been correlated to turbulence and mixing (Jouenne *et al.*, 2007). Higher turbulence at the coral reef and sandy beach area may contribute to the higher TPD prevailing there compared to the seagrass bed, estuarine and mangrove ecosystems. In conditions of high turbulence, phytoplankton displacement is higher compared to their maximum sinking rate (Cullen and MacIntyre, 1998). The interaction between turbulence, coupled with solar radiation and depth regulation behavior,

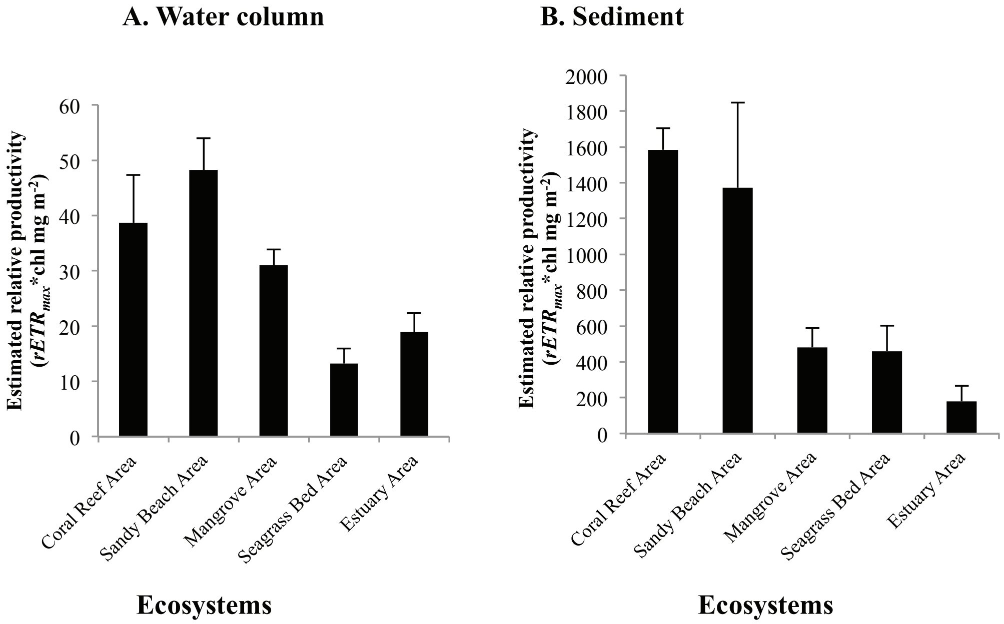

**Figure 6.** Variation in estimated relative productivity (expressed as the product of *rETR*$_{max}$ and chl mg m$^{-2}$) in the water column (A) and sediment (B) in different ecosystems. Data represent mean ± sd (n=5).

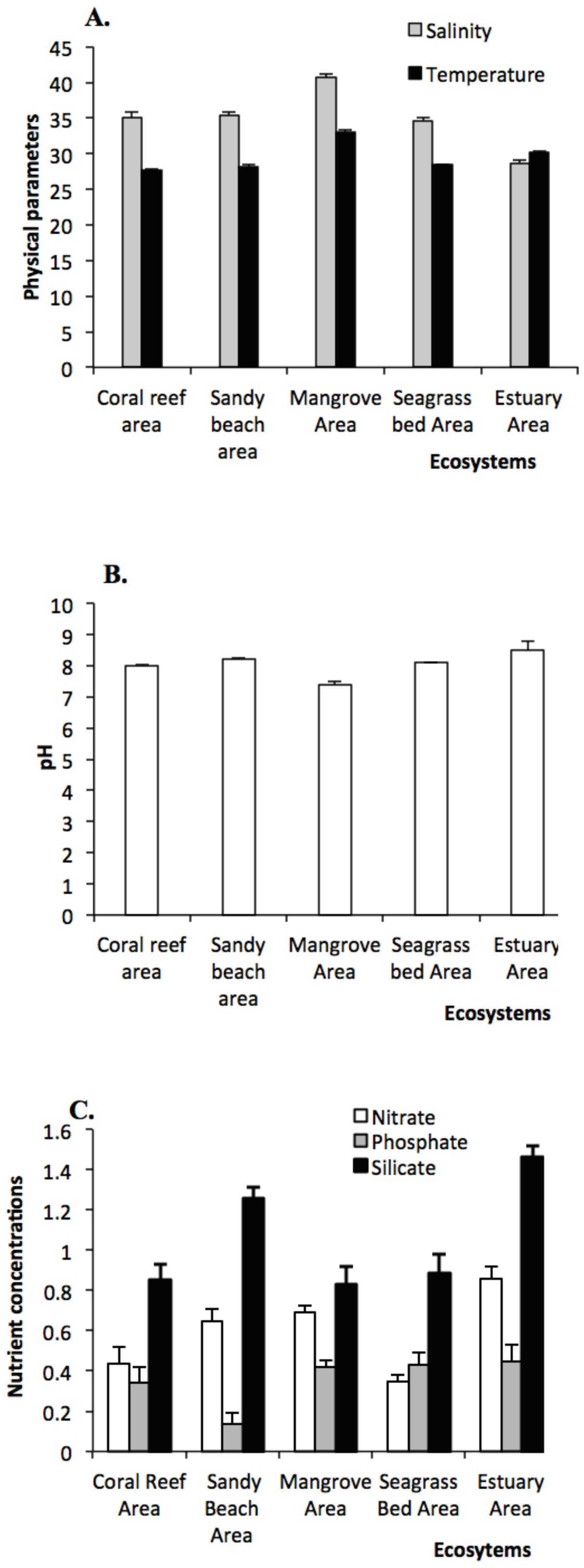

**Figure 7.** Physical parameters (pH, salinity (ppt) and temperature ($^{o}$C)) measured in the water column and/or sediments in the five ecosystems (a); pH (b); Nitrate, phosphate and silicate concentrations, measured as mg $L^{-1}$ (for nitrate and silicate) and µg $L^{-1}$ (for phosphate) (c), in the water column from five near shore ecosystems. Data represent mean ± sd (n=5).

plays an important role in determining the irradiance experienced by phytoplankton. These phytoplankton, in turn, respond to variations in irradiance through a series of adjustments known as photoacclimation (Cullen and MacIntyre,1998). The turbulent environment may favour large species which may have higher resistance to physical disturbance, but it also contributes to the resuspension of small benthic species (Jouenne *et al.*, 2007).

Other factors, including wind, waves and tidal currents, also contribute to the deep mixing of the water column, transporting phytoplankton cells to the bottom. However, this deposition in shallow waters is counteracted by the effect of the velocity and turbulence of bottom currents, which may exceed the settling velocity of organic material (Huettel and Rusch, 2000). The low wave characteristics of the mangrove area, together with high nutrient concentrations, may have accounted for the high density of micro-phytoplankton found here. Micro-phytoplankton respond quickly to increasing nutrient by increasing their growth rate and standing crop (Alongi, 2002).

## Micro-phytobenthos in the sediment

Substrate type is usually one of the main factors governing phytoplankton assemblages (Potapova and Charles, 2005) and is considered as an important variable influencing the biomass and composition of benthic microalgae (Cahoon and Safi, 2002). For example, Cahoon *et al.* (1999) reported higher phytoplankton biomass in sandier substrates while others contradict this finding and reported higher phytoplankton biomass associated with finer sediments (Underwood and Kromkamp, 1999). This study is in accordance with the study of Cahoon *et al.* (1999), where higher TPD and chlorophyll *a* was recorded in the sandy sediment in the coral reef and sandy beach ecosystems while lowest density was recorded in the estuarine and seagrass bed area. The lower density in the seagrass ecosystem is because the sediment is coarse and loose, and micro-phytobenthos in the sediment are easily exported from the sediment to the water column.

The transportation of phytoplankton into and within the sediment is limited to the open pore size of the substrate, as well as the phytoplankton cell characteristics. The depth at which these phytoplankton penetrate the sediment is determined by the size, shape, density, surface characteristics of the algae, and the movement of living cells (Huettel and Rusch, 2000). Permeable shelf sands have been proposed to efficiently filter particulate organic matters, at the same time acting as a catalyst, increasing the rate of mineralization of organic carbon and nutrient recycling. This explains the higher micro-phytobenthos density in the sandy sediments of the sandy beach and coral reef area. However, sediment sizes at the different ecosystems were not investigated during this study.

Benthic phytoplankton plays an important role in nutrient uptake from pore water, as well as in the water column (Brito *et al.*, 2009). Nutrient enrichment in the mangrove ecosystem might have contributed to increased benthic macro-invertebrate density, which may directly feed on phytoplankton (Blumenshine *et al.,* 1997), reducing their density. Moreover, the fact that mangroves serve as a nursery ground for a wide range of aquatic organisms that feed directly or indirectly on phytoplankton, coupled with filter feeders, could account for the lower TPD in the mangrove sediment. Although micro-phytoplankton density in the water column of the mangrove area was comparatively high, their lower densities in the sediment compared to the other ecosystem might also be due to reduced light penetration which would limit the growth of autotrophic microalgae attached to the micro-phytoplankton (Blumenshine *et al.*, 1997).

Well-illuminated shallow bottoms and moderate to high nutrient loadings in estuarine ecosystems offer an optimum environment for the growth of benthic microalgae, contributing to total primary production in these ecosystem (Cahoon and Safi, 2002). However, this was not the case for the estuarine area at Le Goulet where lower TPD and diversity were recorded. Land disturbing activities (construction of hotels in this case) are known to contribute to increased sediment loading, especially fine-grained materials, to receiving waters, leading to the accumulation of fine sediments in estuaries (Wanielista and Yousef, 1993). This anthropogenic sedimentation may thus lower the total biomass of micro-phytoplankton, and may also alter the composition of phytoplankton communities in estuarine ecosystem (Cahoon and Safi, 2002). According to these authors, this might be attributed to several factors such as reduced interstitial space volumes, level of nutrients, and light penetration in the muddy sediments, all contributing to lower biomass of micro-phytoplankton. Another explanation might be that muddy substrates harbour a taxonomically different assemblage of benthic microalgae as compared to sandier substrates, and these differ in their growth rates, standing crop, or differences in their dislodgment or grazing susceptibilities (Cahoon and Safi, 2002). However, this study showed that micro-phytoplankton assemblages in the sediment did not differ from those in the water column with the 33 genera recorded in the sediment also present in water column, with the exception of the genera *Gomphonema.* Therefore, micro-phytobenthos differences in the sediments at the different ecosystems in this case might be attributed to light regime, biovolume and nutrient fluxes.

### Micro-phytoplankton/micro-phytobenthos diversity

Different micro-phytoplankton taxa may exhibit vertically heterogeneous distributions. Usually these are due to the ability of species to regulate their position in the water column by actively swimming (flagellates) or by controlling their buoyancy (cyanobacteria) (Klausmeier and Lichman, 2001). Moreover, under optimum resource conditions such as high irradiance and nutrient concentrations, diatoms have a greater growth rate compared to flagellates of the same size (Cermeno *et al.*, 2005), accounting for their dominance in both the water column and sediment samples in the 5 studied ecosystems. Cyanobacteria density was higher compared to dinoflagellates in the sediment samples in the different ecosystems, probably because these are benthic organisms.

Although diversity indices showed no great variation in micro-phytoplankton in the water column among the different ecosystems, the species composition was different. This difference in species composition appears to be dependent on the resources available that might favour the growth of particular species. In highly productive ecosystems, large-size phytoplankton form the bulk of phytoplankton biomass, while smaller ones are dominant in unproductive regions (Cermeno *et al.*, 2005). Similar observations were made in the present study where the dominance of the larger-sized *Staureneis* sp. in the sandy beach and mangrove area, and *Cylindrotheca* sp. in the coral reef area, was recorded. Dominance of smaller micro-phytoplankton such as *Oscillatoria* sp, *Cocconeis* sp. and *Navicula* sp. were recorded in the estuarine and seagrass bed ecosystems.

A total of 33 micro-phytobenthos genera were recorded in the sediment in the different ecosystems studies. Diatoms were the most dominant micro-phytobenthos group, compared to dinoflagellates and cyanobacteria, and this corroborates with previous studies

(Vant and Budd, 1993; Vant and Safi, 1996). Micro-phytobenthos diversity was slightly higher in the sandy beach area (H = 2.588), followed by the mangrove (H = 2.44), coral reef (H = 2.389), seagrass bed (H = 2.214), and the estuary area (H = 2.010). Microscopic analysis of sediment samples from the different ecosystems showed the dominance of the pennate diatom, *Navicula* spp. in the sediment of the sandy beach, coral reef, mangrove, and seagrass bed areas, and *Cocconeis* in the estuarine area. Similar results were also obtained from studies carried out in other estuaries, where pennate diatoms were dominant, along with centric diatoms (Cahoon and Safi, 2002). Vant and Budd (1993) also reported diatom genera, which were large centric or pennate forms. This is because these species can easily be suspended by the effect of tides and waves, compared to more firmly attached benthic phytoplankton. This may explain the dominance of *Navicula* spp. in both the water column and sediment in almost all the studied ecosystems.

Although micro-phytoplankton from the water column were more diverse with a total of 41 genera compared to the 33 genera from the sediment samples, they did not show great variation in terms of taxonomic composition as 32 genera from the sediment samples were also present in the water column. The genus *Gomphonema* was only present in the sediment while the genera *Leptocylindricus*, *Synedra*, *Meuneira*, *Thalassiothrix*, *Stauroneis*, *Chaetoceros*, *Rhizosolenia*, *Diatoma* and *Phormidium* were only recorded in the water column samples. This similarity could be due to mixing of micro-phytoplankton through sinking, or from the re-suspension of those in the benthos.

## Photo-physiology of micro-phytoplankton/micro-phytobenthos

The growth of phytoplankton is limited by light (De Swart *et al.*, 2009) and its availability greatly affects primary production and may influence the positioning and density of the phytoplankton layer (Klausmeier and Lichman, 2001). However, it has been shown that high light intensity may result in photoinhibition and the relative strength of the process is dependent on the exposure time at high irradiance. Prior to photoinhibition, phytoplankton maintain high photosynthesis during the first few minutes following exposure to saturating or inhibiting light (Macedo and Duarte, 2006). To adapt and respond to light regimes in their environment, phytoplankton have developed a series of mechanisms known as photoacclimation (Cullen and MacIntyre, 1998).

The $rETR_{max}$ of micro-phytoplankton/micro-phytobenthos in the water column and sediments for the coral reef, sandy beach, and mangrove area were similar, while the $rETR_{max}$ value in the water column was higher than that of sediments for the seagrass bed area. However, micro-phytobenthos in the sediment of the estuarine area had a higher electron transport rate compared to those in the water column. This implies that the micro-phytoplankton/micro-phytobenthos in the water column and sediment of the coral reef, sandy beach and mangrove area are ecophysiologically close and they are acclimated to similar environmental factors, including light regime. The higher $rETR_{max}$ recorded for micro-phytobenthos species living in the sediment of the estuarine area might be due to the vertical migration of micro-phytoplankton to escape high light intensities during the day. Similar observations were also made by Perkins *et al.* (2002), where it was noted that high light levels may drive the downward movement of microalgal cells, probably as a mechanism to prevent excessive exposure to disturbances, including predation or physical disturbances (Saburova and Polikarpov, 2003). Similarly, epipelic diatoms have been found to migrate downward in the sediment when exposed to high irradiance to avoid photoinhibition and increase photosynthetic performance (Cartaxana *et al.*, 2016). For the species in the seagrass bed sediments, they were probably more protected from light by the seagrasses and sediments, as they only reached their $rETR_{max}$ at a light intensity of 200 µmol quanta $m^{-2}s^{-1}$.

Micro-phytoplankton in the water column and sediment of the different studied ecosystems are exposed to distinct light regimes towards which they have developed adaptations enabling them to thrive in such conditions. Therefore, their response varies according to their level of tolerance to high light intensity. When exposed to increasing light intensities, there was no difference in $rETR_{max}$ and NPQ in micro-phytoplankton/micro-phytobenthos samples from both the sediment and water column in the coral reef and sandy beach area, probably because these are exposed to similar light regimes given that the coastal water in both these areas is clear.

The difference in $rETR_{max}$ of micro-phyoplankton/micro-phytobenthos between the water column and sediment of the seagrass and estuarine area, and NPQ between the water column and sediment of the mangrove, seagrass and estuarine area indicates the differential physiological state and responses of these organisms. This implies that at higher light intensity, $rETR_{max}$ and NPQ of micro-phytobenthos in sediment are greatly reduced which could be attributed to photoinhibition and damage to photosystem II (PSII). This could be due to their photosynthetic acclimation characteristics in response to their natural environment, and the characteristics of the ecosystem may help to explain the observed results. The shading effect provided by seagrass blades in the seagrass bed area and the mangrove roots in the mangrove area might result in the micro-phytoplankton/micro-phytobenthos being exposed to low light intensity in their natural habitat. This may have a strong effect in reducing the exposure time of phytoplankton cells to inhibiting light intensity and may explain the decrease in $rETR_{max}$ and $NPQ_{max}$ when exposed to high light intensities. Therefore, these organisms appear to have developed adaptations which may result from interaction of structural, behavioural, physiological and biochemical factors, which enable them to survive and grow in conditions of low light intensity (Richardson *et al.*, 1983).

According to Barlow *et al.* (2010), phytoplankton readily adapt to variations in light intensity and quality and they have developed specific sets of pigments enabling them to respond to fluctuating light regimes in different ecosystems. At low irradiance, photosynthesis is limited by the rate at which light harvesting complexes absorbed protons (Cermenõ *et al.*, 2005). In this study, it appears that micro-phytoplanktkon/micro-phytobenthos in the water column and sediment at the different ecosystems had different adaptation strategies which could be due to their photoacclimation and photoadaptation to the irradiance regime at these ecosystems.

The different responses of micro-phytoplankton/micro-phytobenthos in the water column and sediment of the seagrass bed, mangrove and estuarine area is not only dependent on the ecosystem characteristics (Macedo and Duarte, 2006) but on the species composition as well (Jouenne *et al.*, 2007). Different phytoplankton taxa have varying ability to adapt (Cullen and MacIntyre, 1998) with some species being able to exert some control over their light environment by regulating their position in the water column (Richardson *et al.,* 1983). For example, diatoms (e.g. *Thalassiosira pseudonana*) that are adapted to low light intensity have been shown to strongly inhibit short-term photosynthesis, adapt and survive when exposed to high light intensity, while the cyanobacteria *Oscillatoria agardhii*, showed inhibition of photosynthesis and could not survive when exposed to short-term exposure to much higher than saturating irradiance (Cullen and MacIntyre, 1998). According to Cermeno *et al.* (2005), there has been previous evidence of taxon-related differences in $F_v/F_m$. This probably explains the lower $F_v/F_m$ of micro-phytoplankton samples in the estuarine area, where the dominance of the cyanobacteria *Oscillatoria* spp. was recorded.

The presence of a higher percentage of the cyanobacteria *Gomphosphaeria* sp., coupled with the dominance of benthic microalgae, including *Pinnularia* sp., *Stauroneis* sp., *Navicula* sp., and *Cocconeis* sp., in the water and sediment samples of the mangrove area might have contributed to the lower $rETR_{max}$ at this sampling site, since cyanobacteria have very low $F_v/F_m$ (Koblizek *et al.*, 2001), and benthic microalgae have a low ability to adapt to increasing light intensity. This could explain the lower estimated productivity (which is the product of $rETR_{max}$ and chlorophyll *a* concentration), although higher microalgal densities and chlorophyll *a* concentration was recorded in the mangrove area.

There are several new ways of measuring primary productivity, including Fast Repetition Rate fluorometry (FRRf), as described by Oxborough *et al.* (2012), that enable the direct calculation of the absorption cross section of PSII photochemistry, but this study focused mainly on relative values, for example through the use of chlorophyll data. It is suggested that future studies should focus on the use of different techniques in measuring photophysiology of micro-phytoplankon/micro-phytobenthos. It is imperative to better understand the photo-physiological responses of micro-phytoplankton/micro-phytobenthos to varying environmental conditions, especially because climate change-driven disturbances are increasingly exerting pressures on coastal ecosystems. Future attention is also needed to better understand the functioning of these different ecosystems to contribute to the improved management of coastal areas.

## Conclusion

This study has shown that although the different ecosystems varied in terms of total micro-phytoplankton/micro-phytobenthos density, they had almost similar micro-phytoplankton composition, with diatoms being the dominant group, followed by dinoflagellates and cyanobacteria. This might due to the fact that diatoms have a high growth rate. The lower density of dinoflagellates is possibly because they can actively swim and regulate their position in the water column avoiding collection, while cyanobacteria were least sampled because these are benthic. This study also showed that even if estuarine areas are known to be highly productive, anthropogenic sedimentation may alter their functioning and productivity. The ecosystems' characteristics and physico-chemical parameters influenced density patterns, and higher densities were recorded in nutrient-rich waters. Light is the factor that has been found to greatly influence the density of micro-phytobenthos. Lower densities were recorded in turbid water or in waters with higher micro-phytoplankton densities, which limit light penetration to bottom micro-phytobenthos. A total of 41 micro-phytoplankton genera were recorded in the water column at the different ecosystems, while a total of 33 genera were obtained in the sediment samples. However, with the exception of *Gomphonema*, all micro-phytobenthos genera present in the sediment samples were also recorded in the water column. Both the water column and sediment samples had very similar micro-phytoplankton/micro-phytobenthos assemblages, which can either result from mixing from micro-phytoplankton sinking, or re-suspension of benthic micro-phytoplankton. The same photo-physiological responses towards increasing light intensities were observed for micro-phytoplankton/micro-phytobenthos from both the water column and sediment in the sandy beach and coral reef ecosystems. In the other ecosystems, a decrease in $rETR_{max}$ and $NPQ_{max}$ with increasing light intensities in sediment samples was observed. This implies that these organisms are adapted to live in conditions of low light intensity and they are susceptible to increasing light intensities, exposure to which can result in death, hindering the proper functioning of these ecosystems. The need to study the photo-physiological status of micro-phytoplankon/micro-phytobenthos in different ecosystems is crucial if we are to better manage coastal ecosystems, which are under increasing threat from climate change.

## Acknowledgements

The authors are thankful to the Department of Biosciences, Faculty of Science, University of Mauritius for logistics and technical support. SBS would like to acknowledge the Mauritius Research Council for a Postgraduate Award. The authors are grateful to the two anonymous reviewers for their insightful comments.

## References

Alongi DM (2002) Present state and future of the world's mangrove forests. Environmental Conservation 29(3): 331-349

Barlow R, Lamont T, Kyewalyanga M, Sessions H, Morris T (2010) Phytoplankton production and physiological adaptation on the southeastern shelf of the Agulhas ecosystem. Continental Shelf Research 30: 1472-1486

Bhagooli R, Baird AH, Ralph P (2008) Coral host protects its photosynthetic symbionts from thermal and light stresses. Proceedings of the 11th International Coral Reef Symposium 2008, Fort Lauderdale, Florida, USA. pp. 113-118

Blumenshine SC, Vadeboncoeur Y, Lodge DM, Cottingham KL, Knight SE (1997) Benthic-pelagic links: Responses of benthos to water-column nutrient enrichment. Journal of the North American Benthological Society 16(3): 466-479

Brito A, Newton A, Tett P, Fernandes T (2009) Understanding the importance of sediments to water quality in coastal shallow lagoons. Journal of Coastal Research SI56: 381-384

Brock TD (1973) Lower pH limit for the existence of blue-green algae: evolutionary and ecological implications. Science 179: 480-483

Cahoon LB, Nearhoof JE, Tilton CL (1999) Sediment grain size effect on benthic microalgal biomass in shallow aquatic ecosystems. Estuaries 22: 735-741

Cahoon LB, Safi KA (2002) Distribution and biomass of benthic microalgae in Manukau Harbour, New Zealand. New Zealand Journal of Marine and Freshwater Research 36: 257-266

Cartaxana P, Cruz S, Gameiro C, Kühl M (2016) Regulation of Intertidal Microphytobenthos Photosynthesis Over a Diel Emersion Period Is Strongly Affected by Diatom Migration Patterns. Frontiers in Microbiology 7: 872 doi: 10.3389/fmicb.2016.00872

Cermeño P, Estévez-Blanco P, Marañón E, Fernández E (2005) Maximun photosynthetic efficiency of size-fractionated phytoplankton assessed by $^{14}C$ uptake and fast repetition rate fluorometry. Limnology Oceanography 50(5): 1438-1446

Claquin P, Longphuirt SN, Fouillaron P, Huonnic P, Ragueneau O, Klein C, Leynaert A (2010) Effects of simulated benthic fluxes on phytoplankton dynamic and photosynthetic parameters in a mesocosm experiment (Bay of Brest, France). Estuarine, Coastal and Shelf Science 86: 93-101

Cloern JE (1987) Turbidity as a control on phytoplankton biomass and productivity in estuaries. Continental Shelf Research 7: 1367-1381

Cullen JJ, MacIntyre JG (1998) Behaviour, physiology and the niche of depth-regulating phytoplankton. Physiological Ecology of Harmful Algal Blooms G41: 1-21

De Swart HE, Schuttelaars, HM, Talke SA (2009) Initial growth of phytoplankton in turbid estuaries: A simple model. Continental Shelf Research 29: 136-147

Devassy VP, Goes JI (1991) Phytoplankton assemblages and pigments in the exclusive economic zone of Mauritius (Indian Ocean). Indian Journal of Marine Sciences 20: 163-168

Diehl S, Berger S, Ptacnik R, Wild A (2002) Phytoplankton, light, and nutrients in a gradient of mixing depths: field experiments. Ecology 83(2): 399-411

Dongyan L (2008) Phytoplankton diversity and ecology in estuaries of southeastern NSW, Australia. Thesis (PhD), University of Wollongong

Goldman JC, Shapiro MR (1973) Carbon dioxide and pH: effect on species succession of algae. Limnology and Oceanography 182: 306-307

Goldman JC, Riley CB, Dennett MR (1982) The effect of pH in intensive microalgal cultures. 11. Species competition. Journal of Experimental Marine Biology and Ecology 57: 15-24

Greenberg EA, Clesceri LS, Eaton AD (1992) Standard methods for the examination of water and wastewater, eighteenth ed. American Public Health Association, Washington

Häder DP (1995) Novel method to determine vertical distributions of phytoplankton in marine water columns. Environmental and Experimental Botany 35: 547-555

Hinga KR (1992) Co-occurrence of dinoflagellate blooms and high pH in marine enclosures. Marine Ecology Progress Series 86: 181-187

Huettel M, Rusch A (2000) Transport and degradation of phytoplankton in permeable sediment. Limnology and Oceanography 45(3): 534-549

Jeffrey SW, Humphrey GF (1975) New spectrophotometric equation for determining chlorophyll *a*, *b*, $c_1$ and $c_2$. Biochemie und Physiologie der Pflanzen 167: 194-204

Jouenne F, Lefebvre S, Véron B, Lagadeuc Y (2007) Phytoplankton community structure and primary production in small intertidal estuarine-bay ecosystem (eastern English Channel, France). Marine Biology 151: 805-825

Khenari AG, Maznah WOW, Yahya K, Najafpour S, Najafpour GD, Vahedi M, Roohi A, Fazli H (2010) Seasonal succession of phytoplankton community structure in the Southern Part of Caspian Sea. American-Eurasian Journal of Agricultural and Environmental Sciences 8(2): 146-155

Klausmeier CA, Litchman E (2001) Algal game: The vertical distribution of phytoplankton in poorly mixed water columns. Limnology and Oceanography 46(8): 1998-2007

Koblizek M, Kaftan D, Nedbal L (2001) On the relationship between the non-photochemical quenching of the chlorophyll fluorescence and the Photosystem II light harvesting efficiency. A repetitive flash fluorescence induction study. Photosynthesis Research 68: 141-152

Louis YD, Kaullysing D, Gopeechund A, Mattan-Moorgawa S, Bahorun T, Dyall SD, Bhagooli R (2016) In hospite *Symbiodinium* photophysiology and antioxidant responses in *Acropora muricata* on a coast-reef scale: implications for variable bleaching patterns. Symbiosis 68: 61-72

Macedo MF, Duarte P (2006) Phytoplankton production modeling in three ecosystems- static versus dynamic approach. Ecological Modelling 190: 299-316

MacIntyre H, Cullen JJ (1996) Primary production by suspended and benthic microalgae in a turbid estuary: time-scales of variability in San Antonio Bay, Texas. Marine Ecology Progress Series 145: 245-268

McMinn A, Hirawake T, Hamaoka T, Hattori H, Fukuchi M (2005) Contribution of benthic microalgae to ice covered coastal ecosystems in northern Hokkaido, Japan. Journal of the Marine Biological Association of the United Kingdom 85: 283-289

McMinn A, Ashworth C, Bhagooli R, Martin A, Salleh S, Ralph P, Ryan K (2012) Antartic coastal microalgal primary production and photosynthesis. Marine Biology DOI 10.1007/s00227-012-2044-0

Montoya JV, Roelke DL, Winemiller KO, Cotner JB, Snider JA (2006) Hydrological seasonality and benthic algal biomass in a Neotropical floodplain river. Journal of the North American Benthological Society 25(1): 157-170

Oxborough K, Moore CM, Suggett DJ, Lawson T, Chan HG, Geider RC (2012) Direct estimation of functional PSII reaction center concentration and PSII electron flux on a volume basis: a new approach to the analysis of Fast Repetition Rate fluorometry (FRRf) data. Limnology and Oceanography: Methods 10: 142-154

Pannard A, Claquin P, Klein C, Le Roy B, Véron B (2008) Short term variability of the phytoplankton community in coastal ecosystem in response to physical and chemical conditions' changes. Estuarine Coastal and Shelf Science 80: 212-224

Perkins RG, Oxborough K, Hanlon ARM, Underwood GJC, Baker NR (2002) Can chlorophyll fluorescence be used to estimate the rate of photosynthetic electron transport within microphytobenthic biofilms? Marine Ecology Progress Series 228: 47-56

Platt T, Gallegos CL, Harrison WG (1980) Photoinibition of photosynthesis in natural assemblages of marine phytoplankton. Journal of Marine Research 38: 687-701

Potapova M, Charles DF (2005) Choice of substrate in algae-based water-quality assessment. Journal of the North American Benthological Society 24(2): 415-427

Ramessur RT (2013) A review of coastal zone management facing climate change and natural disasters in Mauritius. Geography and Natural Disasters, S1: 003 doi: 10.4172/2167-0587.S1-003

Richardson K, Beardall J, Raven JA (1983) Adaptation of unicellular algae to irradiance: An analysis of strategies. New Phytologist 93: 157-191

Roth MS (2014) The engine of the reef: photobiology of the coral–algal symbiosis. Frontiers in Microbiology 5: 422 doi:10.3389/fmicb.2014.00422

Saburova MA, Polikarpov IG (2003). Diatom activity within soft sediments: behavioural and physiological processes. Marine Ecology Progress Series 251: 115-126

Sadally SB, Taleb-Hossenkhan N, Bhagooli R (2014a) Spatio-temporal patterns of density of dominant micro-phytoplankton genera in two tropical coral reefs of Mauritius. African Journal of Marine Science 36(4): 423-438

Sadally SB, Nazurally N, Taleb-Hossenkhan N, Bhagooli R (2014b) Micro-phytoplankton distribution and biomass in and around a channel-based fish farm: implications for sustainable aquaculture. Acta Oceanologica Sinica 33(12): 180-191

Sadally SB, Taleb-Hossenkhan N, Casareto BE, Suzuki Y, Bhagooli R (2016) Micro-tidal dependent micro-phytoplankton C-biomass dynamics of two shallow tropical coral reefs. Western Indian Ocean Journal of Marine Science. 14(1/2): 53-72

Smith DL, Johnson KB (1996) A guide to marine coastal plankton and marine invertebrate larvae. 2nd Ed. Iowa: Kendall/Hunt Publishing Company

Suthers IM, Rissik D (2009) Plankton- A guide to their ecology and monitoring for water quality. Australia: CSIRO Publishing

Szabò I, Bergantino E, Giacometti GM (2005) Light and oxygenic photosynthesis: energy dissipation as a protection mechanism against photo-oxidation. EMBO Reports 6(7): 629–63 doi: 10.1038/sj.embor.7400460

Teissier S, Peretyatko A, De Backer S, Triest L (2011) Strength of phytoplankton-nutrient relationship: evidence from 13 biomanipulated ponds. Hydrobiologia 689(1): 1-13

Tomas CR (1997) Identifying Marine Phytoplankton. San Diego: Academic Press

Turner JR, Klaus R, Hardman E, Fagoonee I, Daby D, Bhagooli R, Persand S (2000) The reefs of Mauritius. In: Souter D, Obura D, Linden O eds. Coral Reef Degradation in the Indian Ocean: Status Report 2000. Stockholm, 94-107

Underwood GJC, Kromkamp J (1999) Primary production by phytoplankton and microphytobenthos in estuaries. Advances in Ecological Research 29: 93-153

Underwood GJC, Perkins RG, Consalvey MC, Hanlon ARM, Oxborough K, Baker NR, Paterson DM (2005) Patterns in microphytobenthic primary productivity: Species-specific variation in migratory rhythms and photosynthetic efficiency in mixed-species biofilms. Limnology and Oceanography 50(3): 755-767

Vant WN, Budd RG (1993) Phytoplankton photosynthesis and growth in contrasting regions of Manukau Harbour, New Zealand. New Zealand Journal of Marine and Freshwater Research 27: 295-307

Vant WN, Safi KA (1996) Size fractionated phytoplankton biomass and photosynthesis in Manukau Harbour, New Zealand. New Zealand Journal of Marine and Freshwater Research 30: 115-125

Verlencar X, Desai S (2004) Phytoplankton identification manual. 1st Ed. Goa: National Institute of Oceanography

Wanielista MP, Yousef YA (1993) Stormwater management. New York: J. Wiley and Sons, 579pp.

# Temporal and Spatial variability in Reef fish Density and Biomass within the Dar es Salaam Marine Reserve System, Tanzania

Pagu Julius[1,2,*], Magnus Ngoile[1], Prosper Mfilinge[1]

[1] Department of Aquatic Sciences
and Fisheries, College of Natural
and Applied Sciences,
University of Dar es Salaam,
P.O. Box 35064, Dar es Salaam,
Tanzania

[2] Marine Parks and Reserves Unit
Tanzania; P. O. Box 7565,
Dar es Salaam, Tanzania

* Corresponding author:
juliuspagu@yahoo.com

## Abstract

This study was conducted within the Dar es Salaam Marine Reserve System with the aim of investigating temporal and spatial variations in reef fish biomass and density. Benthic cover which is a key factor for fish distribution was also estimated. Sampling was conducted from August 2014 to April 2015. Underwater Visual Census (UVC) techniques were used for the assessment of reef fish density and biomass, and line intercept transect (LIT) was used for the estimation of benthic cover. Results showed that there was a significant seasonal and temporal variation in fish density and biomass at both Mbundya and Bongoyo Islands. Benthic cover of live coral was significantly higher at Mbudya than at Bongoyo. It was concluded that Mbudya Island has less seasonal variation than Bongoyo due to the existence of a larger fraction of live coral cover. These results have implications for the management of marine reserves with regard to destructive fishing practices, a key factor impacting the stability and biomass of reef fish populations.

**Keywords:** Reef fish density, reef fish biomass, seasonal variation, Marine Reserves, Tanzania

## Introduction

Identifying the scales of spatial and temporal variation relevant to patterns of distribution and abundance of species is a first step in the process of understanding the forces that govern their community structure (Underwood *et al*., 2000). Size structure of fish populations are related to seascape structure, including water depth, suggesting that non-linear variations exist in secondary production, seasonal variation, and biomass turnover rates across spatial and temporal scales (Fowler, 1990; Malcolm *et al*., 2007). Ecological processes such as predation risk and foraging success/food availability are considered among the core factors underpinning fish population dynamics in putative nursery habitats (Kimirei, 2012). Coral reef fishes often exhibit a high degree of structure in their distribution and abundance, but the factors that influence their spatial and temporal arrangement are poorly understood (Lecchini *et al*., 2003; Malcolm *et al*., 2007; Tuya *et al*., 2011). Despite considerable research effort, particularly in recent decades, the processes that determine such characteristics are still contentious and a source of debate (Fowler, 1990; Akin, 2003; Borges *et al*., 2007). Patterns in reef fish abundance, diversity and assemblage structure remains largely unexplored; even less understood is the extent to which any spatial and temporal pattern remains consistent through time (Tuya *et al*., 2011; Huijbers, 2015). There have been no previous studies on temporal and spatial variability of reef fish density and biomass within the Dar es Salaam Marine Reserve system (DMRs) on which this study is focussed.

DMRs has two sections. The Northern Dar es Salaam Marine Reserve system (NDMRs) was gazetted in June 1975 due to the high biodiversity found there and its high aesthetic, recreational, and educational and research value, as stipulated under the Fisheries Act No. 6 of 1970 and in the General Management Plan (GMP). The Southern Dar es salaam Marine Reserves (SDMRs) was gazetted in 2007 and lacks a GMP. Earlier studies in the NDMRs indicated that some parts had significant live coral cover and were important tourist attractions, while some areas were already degraded as a result of dynamite fishing (Hamilton, 1975; Wagner, 2000; 2004). In general, the DMRs were characterized by unregulated fishing, including the widespread use of beach seines, spear fishing and dynamite, prior to the Marine Parks and Reserves Unit (MPRU) taking over their management and the introduction of a GMP in 2005. Benno (1992) also observed that the natural systems within the DMRs had been degraded due to the widespread use of dynamite and destructive fishing techniques prior to the MPRU taking control.

The NDMRs comprises a chain of small islets (Bongoyo, Mbudya and Pangavini) and the Fungu Yasini sand bank. The SDMRs comprise inner and outer Sinda and Makatube Islands, and Kendwa Island. Both areas are located close to Dar es Salaam City, being separated from the mainland by the main entrance of Dar es Salaam harbour. The islands are surrounded by diverse and unique habitats including coral reefs, seagrass beds, sandy beaches and rocky shores, and lie within waters of less than 20 m depth.

Various studies have been carried out in the DMRs. Hamilton (1975) described the coral fauna of the East African Coast, Kamukuru (1997) carried out an assessment of the biological status of the DMRs, and McClanahan *et al.* (1999) assessed the effect of Marine Parks and fishing on coral reefs. Most studies in the DMRs have investigated the status of coral reefs (Kamukuru, 1997;

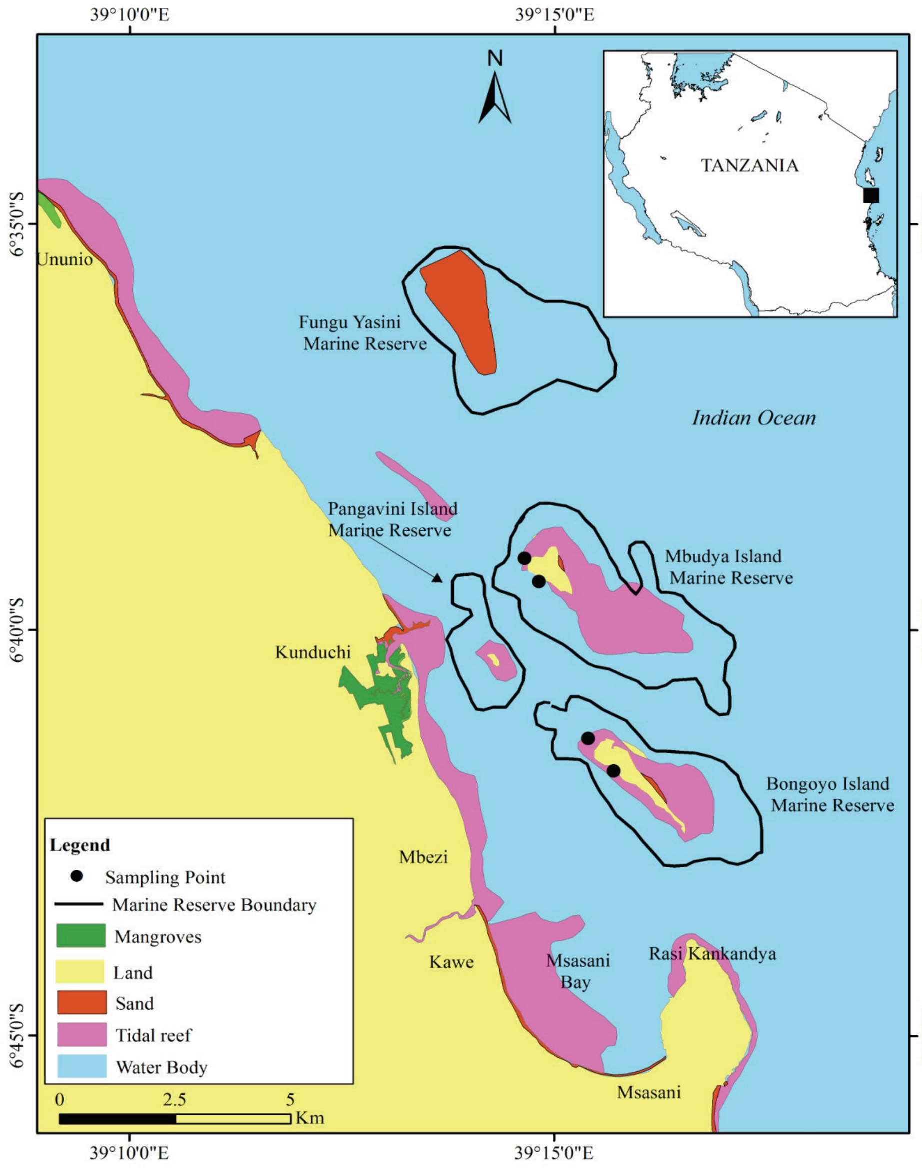

**Figure 1.** Map of Dar es Salaam Marine reserve showing study sites

Muhando and Francis, 2000; Mohammed *et al.*, 2000; Wagner, 2004; McClanahan *et al.,* 2009). However, information on fish biomass and density within the DMRs is not exhaustive. Kamukuru, (2009) studied the trap fishery and reproductive biology of the white spotted rabbit fish *Siganus sutor* (Siganidae) within NDMRs.

Tuya *et al.* (2011) reported that, at small spatial scales (>10 <100 km), the physical structure of the reef plays a key role in the organization of fish assemblages by providing protection from predators and accessibility to food. The relationship between reef habitat and fish population structure is becoming a major tool for the sustainable management of fisheries and marine park planning (Anderson and Millar, 2004; García-Charton *et al.*, 2004). This study aimed to investigate temporal and spatial variation in coral reef fish biomass and density within the DMRs, and was replicated in the dry season (August and September, 2014), intermediate rainy season (January and February, 2015) and wet season (April, 2015) in order to capture seasonal variations.

## Methodology

This study was conducted within the DMRs located 26 km from Dar es Salaam City centre (Fig. 1). Sampling sites details are shown in Table 1. Rapid assessment using the manta tow technique was conducted in the shallow waters around Mbudya and Bongoyo Islands for the general description of sampling sites. At each Island two sites were established based on coral health status. Eight belt transects (50m x 10m) with three swim tracks were conducted for observation of fish biomass and density for each sampling season. The Underwater Visual Census (UVC) technique (English *et al.,* 1994) was adopted to assess reef fish density, biomass and diversity. A 50m fibreglass tape was laid on the reef flat where reef fish were assessed within a distance of 5m on either side of tape. Three swimming tracks were conducted along each belt transect, with a 20 minute interval between them to allow fish to return to the area. A total of 8 belt transects were conducted at each site per sampling season.

Fish observed along each swimming transect were identified with the aid of laminated colour photographs of reef fish. Fish were counted and the size category estimated and recorded on a plastic slate. The size categories used were named as Juvenile (0-10 cm), Recruit (11-20 cm), and Adult (21cm-above). Fish counts were undertaken by swimming at a slow and constant speed along the transect line while recording fish by size category and species. A 10m transect was laid on the reef to assess the benthic cover based on the Line-Intercept Transect (LIT) technique of English *et al.* (1994). Benthic cover was recorded as live hard coral, rubble, sea grass, sand, rock, and algae.

In addition, a GPS was used for marking the study sites, an underwater camera was used for taking photographs of reef fish for later identification, and a portable multiprobe Horiba instrument was used for measuring temperature, oxygen, turbidity, conductivity, salinity and pH.

## Data analysis

Fish density (counts) was computed as individuals/ha. Fish biomass in kg/ha was estimated from published length-weight relationships (See www.fishbase.org) using conversion equations (W = a * Lb) where a and b are constants for each fish. Statistical analysis was carried out using Graph Pad Instant Statistical software,

**Table 1.** Location of sampling sites.

| Site | Sampling Location | | Coordinates |
|---|---|---|---|
| **mbudya** | West | Latitude | 06°39′07″ S |
| | | Longitude | 39°14′39″E |
| | South | Latitude | 06°39′24″ S |
| | | Longitude | 39°14′49″E |
| **Bongoyo** | West | Latitude | 06°41′20″ S |
| | | Longitude | 39°15′24″E |
| | South | Latitude | 06°41′44″ S |
| | | Longitude | 39°15′42″E |

Version 3.06. Both number of individuals and biomass was tested for normality before data analysis, with the software providing the best option for analysis thereafter. The Kruskal-Wallis test was used to compare data between sampling dates, and the nonparametric Spearman correlation coefficient for relation between fish density and coral cover.

## Results

Most of the water quality parameters measured were significantly different along the seasons, except for Dissolved Oxygen and Turbidity (see Figs. 2 and 3). Benthic categories and their cover at Mbudya and Bongoyo are described in Fig. 4 and Table 2. Mbudya displayed the highest percentage of live coral cover (87.3 ± 1.22%) while Bongoyo had the highest percentage of coral rubble (33.03 ± 2.02%). Both types of cover differed significantly ($P < 0.0001$) between the study sites.

Reef fish size structure revealed a prevalence of individuals of <10cm in both study sites, signifying a dominance of small-bodied fishes, mainly of the family Pomacentridae (Fig. 5). Very few individuals of >20cm were observed in the study areas; possibly an impact of overfishing.

The mean number of reef fish counted in Bongoyo for each sampling phase was 2419 (August/September, 2014), 3485 (January/February, 2015), and 3607 (April, 2015) ind/ha respectively (Fig. 6). Fish density varied significantly between sampling phases (Kruskal-Wallis Test (Hc) = 23.429, $P < 0.0001$). The mean reef fish biomass at Bongoyo for each sampling season was 65, 170 and 221 kg/ha during phase one (August and September, 2014), phase two (January and February, 2014) and phase three (April, 2015) respectively (Fig. 7). There was a significant difference in fish biomass between the three sampling phases (Kruskal-Wallis Test (Hc) = 27.631, $P < 0.0001$).

The mean number of reef fish counted in Mbudya for each season was 12413, 13988, and 10517 individuals/ha during phase one (August and September, 2014), phase two (January and February, 2014) and phase

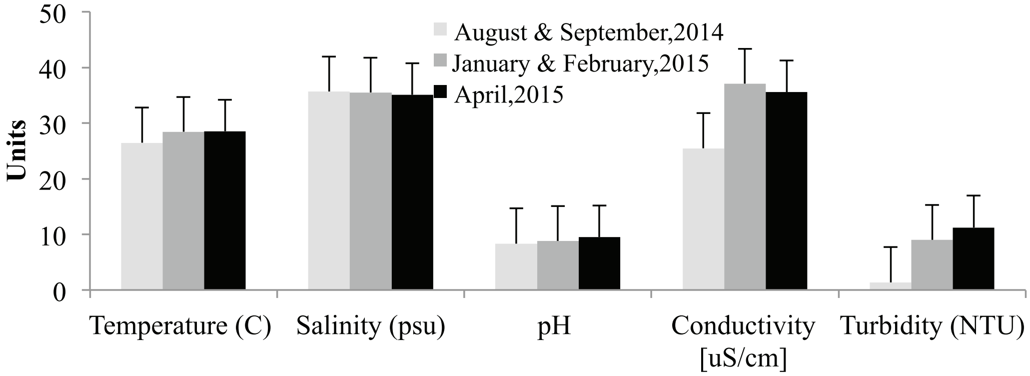

**Figure 2.** Variation of selected water parameters at the study sites in Mbudya and Bongoyo islands.

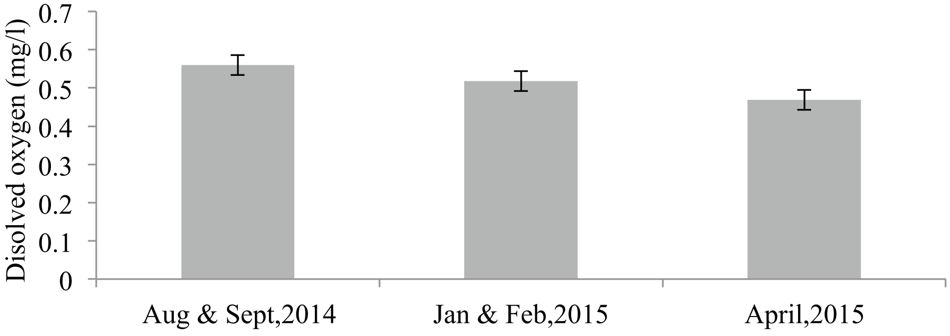

**Figure 3.** Dissolved oxygen variation at the study sites in Mbudya and Bongoyo islands.

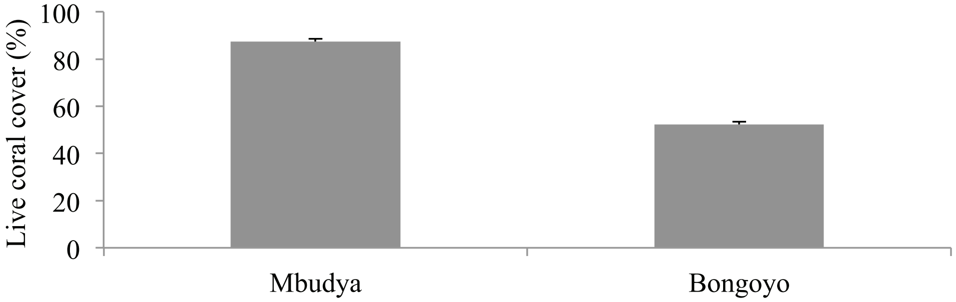

**Figure 4.** Benthic cover at Mbudya and Bongoyo Islands Marine Reserves.

three (April, 2015) respectively (See Fig. 8), and there was a significant difference in fish density between sampling phases (Kruskal-Wallis Test (Hc) = 42.352, P < 0.0001). The mean reef fish biomass at Mbudya for each sampling season was 697, 471 and 934 kg/ha during phase one (August and September, 2014), phase two (January and February, 2014) and phase three (April, 2015) respectively (see Fig. 9). There was a significant difference in fish biomass between sampling phases (Kruskal-Wallis Test (Hc) = 32.957, P < 0.0001).

It was found that an almost perfect positive correlation existed between fish density and live coral cover. Nonparametric Spearman Correlation Coefficient for Mbudya was (r) = 0.9971, n = 96, p< 0.0001 and at Bongoyo (r) = 0.9963, n = 96, p< 0.0001.

Overall, Mbudya displayed higher fish biomass than Bongoyo, mainly composed by members of the family Pomacentridae (27%), followed by Pomacanthidae (10%), and Scaridae (6%). The remaining biomass was made up of several other species. Reef fish of all sizes were observed at Mbudya, as compared to mainly juveniles observed at Bongoyo Island. At Bongoyo, reef fish density is directly correlated to fish biomass. Biomass was made up mainly of individuals of small size, mostly juveniles. This means that the fewer individuals present, the less the biomass, and vice versa, which was the case around Bongoyo Island. A few fish families made up the greatest contribution to biomass, namely the families Kyphosidae (19%), Chaetodontidae (11%) and Blenniidae (11%) (see also Julius, 2015).

## Discussion

Water parameters measured were within the required range for coral reef survival, and live coral cover at Mbudya and Bongoyo Islands was significantly different. Benthic cover has a direct link to biomass and density in that those areas with higher live coral cover have higher numbers of juveniles, recruits and adults. The positive correlation between fish density and live coral cover corroborates that coral cover is a key substratum for reef fish.

**Table 2.** Benthic cover at study sites (%).

| Benthic cover | Mbudya (Mean + SE) | Bongoyo (Mean + SE) | Islands' comparison |
|---|---|---|---|
| **Live coral cover** | 87.28+ 1.22 | 52.23 + 1.27 | Two sample t-test. P < 0.0001 |
| **Rubble** | 5.95 + 0.60 | 33.03 + 2.02 | Two sample t-test P < 0.0001 |
| **Seagrass** | 4.25 + 0.57 | 8.09 + 0.69 | Two sample t-test P = 0.0024 |
| **Sand** | 1.83 + 0.18 | 5.16 + 0.38 | Mann-Whitney Test. P < 0.0001 |
| **Rock (RCK)** | 0.39 + 0.16 | 0.75 + 0.17 | Mann-Whitney Test. P = 0.0480 |
| **Algae (soft & Turf)** | 0.28 + 0.11 | 0.76 + 0.14 | Mann-Whitney Test. P =0.0041 |

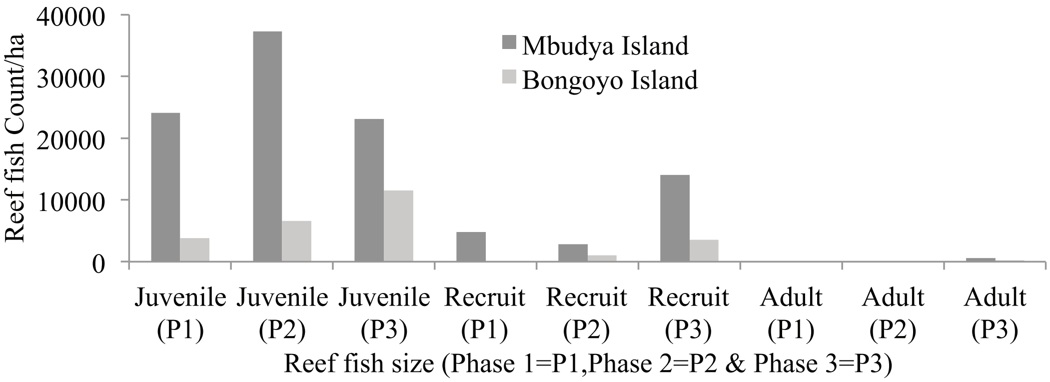

**Figure 5.** Reef fish population size structure in Mbudya and Bongoyo islands.

The dominant fish size class was juvenile reef fishes. The possible reason for this observation is displacement of juveniles by adults from the adjacent coral reef at Mbudya Island Marine Reserve, perhaps as a mechanism for juveniles to avoid predation. The density of reef fishes is often influenced by the availability of potential shelter sites (Steele, 1999). Juvenile, recruit and adult reef fish have specific habitat requirements that determine spatial size distribution. The separation of juveniles in nursery habitats from the adults on the coral reef implies migration from nursery habitats (such as seagrass beds and mangroves) to the coral reef. Further, these migrations may be related to diet shift with size (Cocheret de la Morinie`re *et al*., 2003).

Lugendo *et al*. (2005), Igulu *et al.* (2013), and Kimirei *et al.* (2013) all reported that the presence of seagrass is a potential component for juvenile settlement among reef fish, and Bongoyo Island has a large occurrence of seagrass cover. Various factors, including microhabitat and physical structures that may provide shelter from predators (such as corals, rocks and macroalgae) influence the spatial and temporal pattern of reef fish density (Jones, 1991; Hixon and Beets, 1993; Caley *et al*., 1996). In such habitats predation of juveniles may be reduced and migration to alternative habitats could be an important defence mechanism. This indicates strong linkages between adjacent habitats at a local spatial scale, and emphasizes the importance of the inclusion of a diversity of habitats in Marine Protected Areas (Beets *et al.,* 2003).

Reef fish density at Mbudya showed an increase from phase one to phase two, with a decline in phase three. This decline was possibly attributed to an increase in the abundance of adult fish observed during this last phase, which reduced the abundance of juveniles due to predation or migration to safer habitats. Biomass declined from phase one to phase two when mostly small individuals were present on the reef. However, in phase three, where adult fish were dominant, the decrease in density coincided with an increase in biomass.

Observations on the spawning seasons of East African reef fishes show that most species are characterised

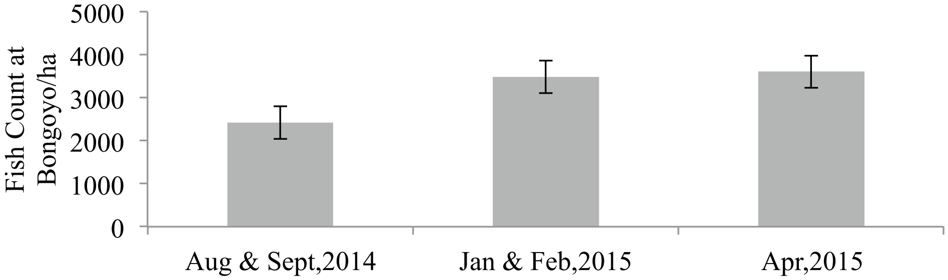

**Figure 6.** Reef fish density at Bongoyo Island.

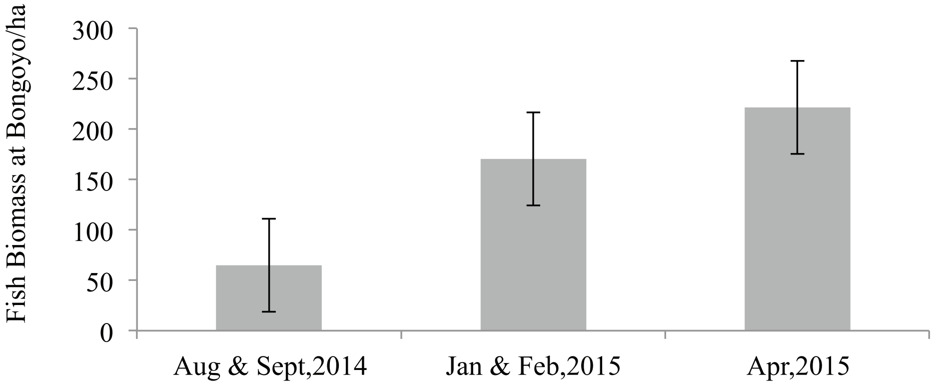

**Figure 7.** Reef fish biomass at Bongoyo Island Marine Reserve.

by protracted spawning periods during the northeast monsoon, with two peaks in January to March, and September to November (Nzioka, 1979). The increase in adult reef fish observed during phase three (April) in this study may reflect the aggregation of reef fish for spawning at that time. Kamukuru (2009) reported that *Siganus sutor* exhibits a protracted spawning season in the DMRs, extending from December to May, and peaking in March, which coincides with observations during phase three (April) in the present study. It was reported by Ntiba and Jaccarini (1990) that *S. sutor* in inshore Kenyan waters exhibits two sharply defined spawning seasons occurring in January/February and May/June. Further, it was reported by Bwathondi (1981) that Siganids breed throughout the year in Tanzanian coastal waters. The above information is somewhat contradictory and further investigation is needed to conclusively link spawning behaviour to the temporal and spatial variation of reef fish in the present study.

As in this study, it was found previously (1996/7; 2004/5) that Mbudya supports a higher reef fish biomass than Bongoyo (McClanahan *et al.,* 1999; McClanahan *et al.,* 2009). These earlier studies found that fish biomass increased at both Mbudya (214.kg/ha to 298.6kg/ha) and Bongoyo (129.1kg/ha to 159.1kg/ha) between the survey dates, probably linked to more effective management. These results reflect those found in other MPAs in the region which are effectively protected, such as Kisite Marine National Park in Kenya. In Kisite, biomass almost doubled after seven years of effective protection (McClanahan *et al.*, 2009). However, the above studies at Mbudya and Bongoyo did not account for possible seasonal variation, possibly resulting in an under estimate of biomass. Effective management began in the DMRs in 2002 and in 1978 at Kisite. The current study adds to the body of evidence that effective management has led to an increase in biomass over time in most MPAs of the Western Indian Ocean.

The current study has also shown that high live coral cover is directly linked to high fish biomass. With similar conditions and coral diversity, it is likely that fish biomass in the DMRs can increase further to the levels found in Kisite with effective management over time.

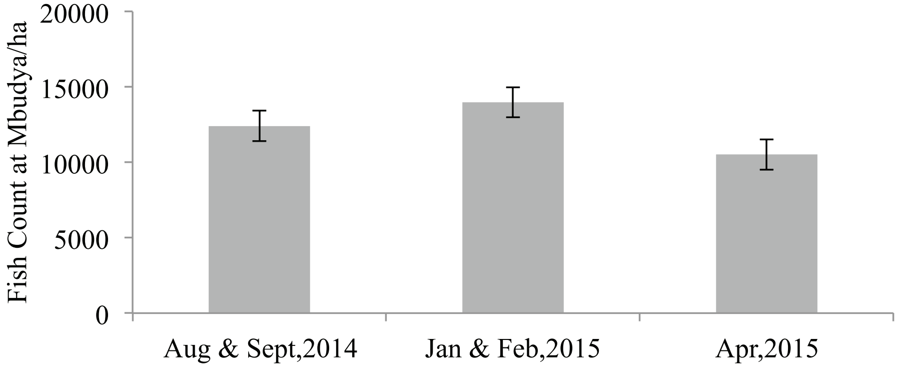

**Figure 8.** Reef fish density at Mbudya Island Marine Reserves.

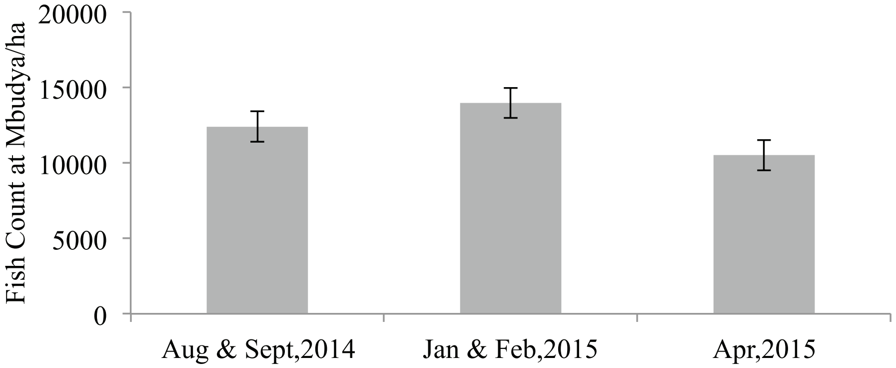

**Figure 9.** Reef fish biomass at Mbudya Island Marine Reserves.

Based on the information presented here on reef fish density and biomass at Mbudya and Bongoyo Islands within the DMRs, the following conclusions can be drawn:

1. Mbudya Island Marine Reserve has a higher reef fish biomass during all seasons attributable to fish populations comprising juveniles, recruits and adults, while Bongoyo Island has lower biomass comprising mostly juveniles and recruits.
2. Reef fish size structure and biomass was significantly different between seasons at both Islands.
3. Live coral cover is higher at Mbudya as compared to Bongoyo.

This study recommends the following:

4. Efforts to ensure the effective management of the DMRs need to be continued, with the GMP as the primary guidance document, as per the existing Marine Park and Reserve Act, No 29 of 1994 directives.
5. Demarcation buoys need to be placed at least at the corner points and buffer zone of the Marine Reserves.
6. Review and strengthen the enforcement for the DMRs and ensure that surrounding communities are effectively involved.
7. Further investigation on spawning aggregations of highly-targeted fish species such as the Siganids and Serranids is needed to assist with management decisions aimed at protecting spawning aggregations.

## Acknowledgements

We acknowledge the Western Indian Ocean Marine Science Association (WIOMSA) for financial support of this research through a Marine Research Grant (MARG) Programme. We appreciate the support from the University of Dar es Salaam for providing SCUBA diving facilities and other equipment for our research. We further acknowledge the assistance from the Marine Park and Reserve Unit (MPRU) for support and permission to conduct this study in the Marine Reserves. We acknowledge the contribution for Dr AT Kamukuru for valuable input in preparation of this manuscript.

## References

Akin S, Winemiller KO, Gelwick FP (2003) Seasonal and spatial variations in fish and macrocrustacean assemblage structure in Mad Island Marsh estuary, Texas. Estuarine, Coastal and Shelf Science 57: 269-282

Anderson MJ, Millar RB (2004) Spatial variation and effects of habitat on temperate reef fish assemblages in northeastern New Zealand. Journal of Experimental Marine Biology and Ecology 305: 191-221

Beets J, Muehlstein L, Haught K, Schmitges H (2003) Habitat Connectivity In Coastal Environments: Patterns and Movements of Caribbean Coral Reef Fishes With Emphasis On Bluestriped Grunt, *Haemulon sciurus.* Gulf and Caribbean Research 14(2): 29-42

Benno BL (1992) Some features of beach seine fishery along the Dar es Salaam coast, Tanzania. MSc Thesis, University of Kuopio, Finland. 68 pp

Borges R, Ben-Hamadou R, Chícharo A, Re´ P, Emanuel J, Goncalves EM (2007) Horizontal spatial and temporal distribution patterns of near shore larval fish assemblages at a temperate rocky shore. Estuarine, Coastal and Shelf Science 71:412-428

Bwathondi POJ (1981) The culture of rabbitfish *Siganus* spp. in Tanzania. Stockholm, IFS. 35 pp.

Caley MJ, St John J (1996) Refuge availability structures assemblages of tropical reef fishes. Journal of Animal Ecology 65: 414-428

Cocheret de la Morinière E, Pollux BJA, Nagelkerken I, Van der Velde G (2003) Diet shifts of Caribbean grunts (Haemulidae) and snappers (Lutjanidae) and the relation with nursery-to-coral reef migrations. Estuarine, Coastal and Shelf Science 57: 1079-1089

English S, Wilkinson C. Baker, V. (eds.) (1994) Survey Manual for Tropical Marine Resources. Australian Institute of Marine Science, Townsville. 368 pp

FishBase. FishBase World Wide Web electronic publication. Accessed at http://www.fishbase.org/

Fowler A J (1990) Spatial and temporal patterns of distribution and abundance of chaetodontid fishes at One Tree Reef, southern GBR. Marine Ecology Progress Series 64: 39-53

García-Charton JA, Perez-Ruzafa A, Sánchez-Jerez P, Bayle-Sempere JT, Reñones O, Moreno D (2004) Multi-scale spatial heterogeneity, habitat structure, and the effect of marine reserves on western Mediterranean rocky reef fish assemblages. Marine Biology 144: 161-182

Hamilton HGH (1975) A description of the coral fauna of the East African Coast. MSc Thesis, University of Dar es Salaam. 264 pp.

Hixon MA, Beets JP (1993) Predation, prey refuges and the structure of coral-reef fish assemblages. Ecological Monographs 63: 77-101

Huijbers CM, Nagelkerken I, Layman CA (2015) Fish movement from nursery bays to coral reefs: a matter of size? Hydrobiologia 750: 89-101 [DOI 10.1007/s10750-014-2162-4]

Igulu M.M, Nagelkerken I, Van der Beek M, Schippers M, Van Eck R, Mgaya YD (2013) Orientation from open water to settlement habitats by coral reef fish: behavioural flexibility in the use of multiple reliable cues. Marine Ecology Progress Series 493: 243-257

Jones GP (1991) Post recruitment processes in the ecology of coral reef fish populations: a multifactorial perspective. In: Sale, P.F. (ed.) The Ecology of Fish on Coral Reefs. Academic Press, San Diego, CA, pp 294-330

Julius P (2015) Assessment of Reef Fish Biomass and Density in the Dar Es Salaam Marine Reserves, Tanzania". Final report, WIOMSA, MARG I. 22pp

Kamukuru AT (1997) Assessment of the biological status of the Dar es Salaam Marine Reserves System off the Kunduchi coast, Tanzania. Report to the Western Indian Ocean Marine Science Association (WIOMSA), Zanzibar and IOC/UNESCO Paris, France. 31 pp

Kamukuru AT (2009) Trap fishery and reproductive biology of the white spotted rabbitfish *Siganus sutor* (Siganidae), within the Dar es Salaam Marine Reserves, Tanzania. Western Indian Ocean Journal of Marine Science 8 (1): 75-86

Kimirei IA (2012) Importance of mangroves and seagrass beds as nurseries for coral reef fishes in Tanzania. PhD Thesis, Faculty of Science, Radboud University Nijmegen, The Netherlands. 204 pp.

Kimirei IA, Nagelkerken I, Trommelen M, Blankers P, Van Hoytema N, Hoeijmakers D, Huijbers CM. Mgaya YD, Rypel AL (2013) What Drives Ontogenetic Niche Shifts of Fishes in Coral Reef Ecosystems. Ecosystems. 16: 783-796

Lecchini D, Adjeroud M, Pratchett MS, Cadoret L, Galzin R (2003) Spatial structure of coral reef fish communities in the Ryukyu Islands, southern Japan. Oceanologica Acta 26: 537-547

Lugendo BR, Pronker A, Cornelissen I, Groene A, Nagelkerken I, Dorenbosch M, van der Velde G, Mgaya YD (2005) Habitat utilisation by juveniles of commercially important fish species in a marine embayment in Zanzibar, Tanzania. Aquatic and Living Resources 18: 149-158

Malcolm HA, Gladstone W, Lindfield S, Wraith J, Lynch TP (2007) Spatial and temporal variation in reef fish assemblages of marine parks in New South Wales, Australia - baited video observations. Marine Ecology Progress Series 350: 277-290

McClanahan TR, Muthiga NA, Kamukuru AT, Machano H, Kiambo RW (1999) The effects of marine parks and fishing on coral reefs of northern Tanzania. Biological Conservation 89: 161-182

McClanahan TR, Muthiga N, Maina J, Kamukuru AT, Yahya S (2009) Changes in northern Tanzania coral reefs during a period of increased fisheries management and climatic disturbance. Aquatic Conservation: Marine and Freshwater Ecosystems 19:10.1002/aqc.19 (7): 758-771

Mohammed MS, Muhando CA, Machano H (2000). Assessment of coral reef degradation in Tanzania: Results of coral monitoring 1999. In: Souter D, Obura D, Linden O (eds.). Coral Reef Degradation in the Indian Ocean: Status Report 2000, CORDIO. pp 35-4

Muhando CA, Francis J (2000) The status of coral reefs in the Dar-es-salaam marine reserves system and the state of reefs in other marine protected areas of Tanzania. IMS/UNEP/ICRAN Report. 32pp

Muhando CA, Mohammed SM (2002) Coral reef benthos and fisheries in Tanzania before and after the 1998 coral bleaching and mortality event. Western Indian Ocean Journal of Marine Science 1: 43-52

Ntiba MJ, Jaccarini V (1990) Gonad maturation and spawning times of *Siganus sutor* off the Kenya coast: evidence for definite spawning seasons in tropical fish. Journal of Fish Biology 37: 315-325

Nzioka RM (1979) Observations on the spawning seasons of East African reef fishes. Journal of Fish Biology 14: 239-342

Steele AM (1999) Effects of shelter and predators on reef fishes. Journal of Experimental Marine Biology and Ecology, 233: 65-79

Tuya F, Wernberg T, Thomsen MS (2011) The relative influence of local to regional drivers of variation in reef fishes. Journal of Fish Biology 79: 217-234 [doi:10.1111/j.1095 8649.2011.03015]

Underwood AJ, Chapman MG, Connell SD (2000). Observations in ecology: you can't make progress on processes without understanding the patterns. Journal of Experimental Marine Biology and Ecology 250: 97-115

Wagner GM (2000) Synthesis of literature on coral reefs in Tanzania. Prepared on Behalf of Science and Technical Working Group (STWG) of Tanzania Coastal Management Partnership (TCMP)

Wagner GM (2004) Coral Reefs and Their Management in Tanzania, Western Indian Ocean Journal of Marine Science 3 (2): 227-243

# Local knowledge of fishermen in weather prediction in Moa and Kwale coastal villages, Tanzania

Mwanahija S. Shalli

Institute of Marine Sciences,
University of Dar es Salaam
P.O.BOX 668, Zanzibar, Tanzania
**mshalli2012@yahoo.com**
**shalli@ims.udsm.ac.tz**

## Abstract

This study investigated local knowledge of fishermen in weather prediction in Moa and Kwale coastal villages, Tanzania. Focus group discussions, seasonal calendars, time line analysis, key informant interviews, questionnaire surveys and documentary reviews were used to gather data. The SPSS programme was used to analyze quantitative data while qualitative data was analyzed using content analysis. Fishermen were found to observe the behaviour of sea water, plants, fish species, sea worms, marine mammals, terrestrial animals, amphibians, human beings, birds, insects, sea rubbish, moon, clouds, rainbow, sun, sea sand, stars and sky, to predict weather change in their localities. Of the many weather parameters mentioned, wind and rainfall were regarded as the most important weather parameters to consider when planning for fishing expeditions. It was also noted that the majority of fishermen are aware of climate change through long term observation of local weather patterns in their localities. Fishermen were found to be able to predict typical weather conditions and productivity seasons throughout a year. However, despite the usefulness of local prediction, this important knowledge is challenged with a number of issues that threatens its existence. The study recommends various approaches to strengthen and sustain the effectiveness of local weather prediction.

**Keywords:** Fishermen; local knowledge; local indicators; weather prediction; weather parameters

## Introduction

Climate and weather issues have been of increasing interest and concern in many countries over recent years. The Inter-governmental Panel on Climate Change (IPCC) (2001) and the Assessment of Impact and Adaptation to Climate Change (AIACC) (2005) reported that climate change and variability will continue to adversely affect water resources, agriculture, forestry, fisheries, human settlements, ecological systems and human health in many parts of the world, including Tanzania.

In Tanzania, about 95% of the total marine catch is from artisanal marine fisheries using traditional vessels and gears. This fishery supports fishermen and large numbers of people processing and selling fish, as well as others who make and repair boats and gears (Jiddawi and Ohman, 2002). Climate change and adverse weather events are threatening this important coastal livelihood activity (Terada, 1968) to the extent that, if not well monitored, may undermine national efforts to attain the Millennium Development Goals (MDGs) and places poverty reduction efforts within fishing communities in jeopardy. Timmers (2012) reported that extreme weather events limit the number of days on which fishing is possible, which may adversely impact the livelihoods of coastal communities. Moreover, extreme weather events may cause accidents to traditional fishing vessels which threaten the lives of fishermen and their fishing equipment. Reliable climate information services and timely seasonal weather forecasts can offer great potential to inform fishing decision making in the face of increasing climate variability and help fishermen adapt to the changing climatic conditions. However, despite significant progress in the provision of scientific weather forecasts in East Africa, most of the seasonal forecasts are not specific to particular localities and are not reliable (Mahoo *et al*., 2015).

Historically, local communities have used traditional knowledge to understand and predict weather and climate patterns (Kadi *et al*., 2011) through observation and monitoring of environmental changes and behaviour of animals, birds, plants and insects and non–living things such as wind and clouds (EPMS, 2010). The recognition and application of this knowledge is not uniform across communities and differences are rooted on occupations, geographic locations, ethnic origin etc. (Spencer-Oatey, 2012). There is an increasing number of studies on local weather prediction in different parts of Tanzania. It is noted that many of these have been in terrestrial areas focusing on farmers' knowledge. For example, a study by Chang'a *et al*. (2010) revealed how farmers in the South-western Highlands of Tanzania predict rainfall using local environmental indicators and astronomical factors. Kijazi *et al*. (2013) reported on the role of famers' and pastoralists' indigenous knowledge in weather and climate predictions in Mahenge and Ismani wards in Morogoro and Iringa Regions, respectively. Few studies have focused on marine areas. However, Tobisson *et al*. (1998) carried out a study to try and understand how fishing communities in Zanzibar make optimal use of local knowledge of tides and monsoons in their fishing activities. Unfortunately, it was not explicitly reported in this study how fishermen's knowledge is used to predict different weather parameters.

The present study aimed to document fishermen's local knowledge related to weather prediction in some coastal communities of Mkinga District in Tanga Region, Tanzania, and recommend the best approaches to sustain the effectiveness of local forecasts. The study was considered important since local knowledge is under threat of disappearing due to many reasons including the lack of systematic documentation, and coordinated research to investigate its accuracy and reliability, and the death of old people who are the main custodians of the knowledge (Mahoo *et al*., 2015). In addition, the disappearance of some living indicators due to anthropogenic activities and the effects of climatic change, are also challenges to traditional weather forecasting (Risiro *et al*., 2012; Kijazi *et al*, 2013).

## Materials and methods

### Description of Study Sites

Mkinga District, which is found in Tanga Region, is the northernmost part of the coast of mainland Tanzania, and borders Kenya. The district has an area of 2,948 square kilometers and a total population of 118,065 (NBS, 2013). Historically, Tanga coastal communities were reported by Wells *et al*. (2007) to hold considerable local knowledge of natural resources and their environment. However, no detailed studies on fishermen's local knowledge in weather prediction has been conducted and documented. Two coastal villages; Moa and Kwale (Fig.1), were purposely selected for the study based on their proximity to the ocean, and because they are established villages that practice a diversity of traditional fishing methods.

In a recent village census (2014), Moa village had 1,512 inhabitants with 362 households. The main tribes are Segeju and Digo. Fishing, agriculture (cassava and rice), and small businesses such as kiosks mainly selling raw and cooked food, are the main livelihood activities in the village. The majority (about 90%) of fishermen practice hook and line fishing. Other fishing practices are net fishing (gill net), gleaning for invertebrates, and diving for octopus and lobsters. In 2014, Kwale village had 1,117 inhabitants with 236 households. The main tribes are Digo and people from Pemba Island. Livelihoods include fishing, farming (maize, cassava, and coconut), livestock keeping (cows, goats, sheep, chicken and donkeys) and some formal employment. The main fishing practices in the area are diving for octopus, basket trap fishing, net fishing and hook and line fishing.

### Data Collection and Analysis

Data collection started in November 2014 and ended in March, 2015. Both qualitative and quantitative social research methods were applied with the former approach being dominant. Qualitative data were obtained through Focus Group Discussions (FGDs), Seasonal Calendars, Time-line analysis, and Key Informant interviews. Quantitative data were obtained through questionnaire surveys using both closed and open-ended questions. In all research methods questions asked focused on local indicators and their interpretations by fishermen in weather prediction, fishermen's perceptions about the changing climate, challenges of depending on local weather prediction, and views on the potential of using local predictions. In addition, relevant published and unpublished documents from websites and government offices were reviewed and synthesized to complement and validate field data.

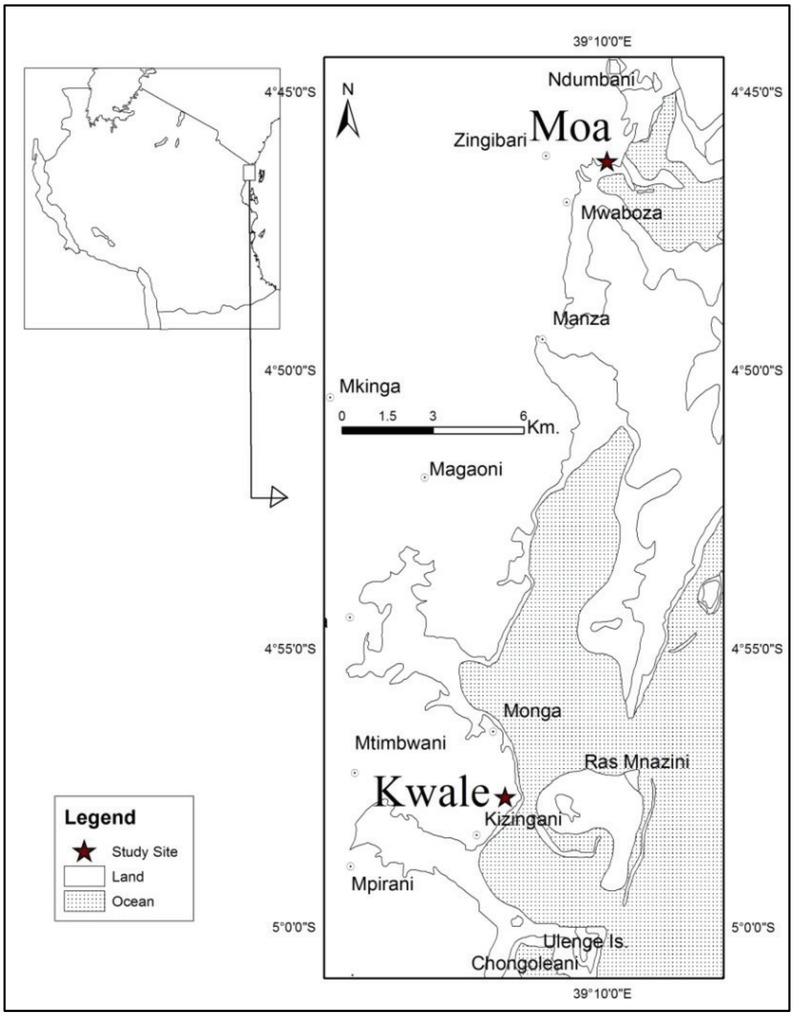

**Figure 1.** Map of Mkinga District showing the study sites (Source; Institute of Marine Sciences Database).

One FGD was carried out in each study village. The groups consisted of 5 and 4 fishermen of different ages and different gear types, for Moa and Kwale villages, respectively. The mix of participants of different categories was appropriate in order to capture all the necessary information needed for the study. Saunders *et al.* (2007) recommends that a typical FGD should involve 4 to 12 participants depending on interviewer skill and subject matter. During FGDs, seasonal calendars and time-line analysis were conducted to solicit further information on local weather patterns. In these participatory methods, participants were asked to determine weather patterns such as the months of rainfall and strong wind, and their implications. In addition, time line analysis was used to list all notable weather events and their associated dates of occurrence.

The questionnaire survey was administered to 30 fishermen in each study village. Respondents were chosen based on the requirement that they were practicing traditional fishers and had been involved in traditional fishing activities for at least 10 years. In rural coastal areas, traditional fishers who have been involved in fishing for a lengthy period are assumed to have more experience on local weather forecasting, and have observed many weather events. Three stage sampling was employed in the selection of respondents. In the first stage, fishermen who use traditional fishing methods were identified. In the second stage, traditional fishermen that have been involved in fishing for 10 years or more were identified. In the third stage, 30 traditional fishermen who have 10 years or more of fishing experience were randomly selected from each study village for the questionnaire survey. According to Bailey (1994), a sample of 30 respondents is sufficient for statistical analysis irrespective of the population size.

In-depth interviews were done with Key Informants (Village Leaders and Village Elders). In addition, the Tanga Meteorological Station Manager was interviewed to explore his views on modern weather prediction, to gauge his perception on the relevance of local weather prediction, and to obtain his recommendations for improved weather predictions at the local level.

Quantitative data collected from questionnaire surveys were analyzed using the Statistical Package for Social Sciences (SPSS) to generate descriptive statistics (percentages). Qualitative information from Focus Group Discussions (FGDs), Seasonal Calendars, Timeline analysis, and Key Informant interviews were analyzed using content analysis whereby the text was coded into manageable categories on a variety of levels - word, phrase, sentence, or theme; then inferences were made about the messages within the texts.

## Results and discussion

### Local Indicators Used by Fishermen in Weather Prediction

The study found that fishermen have their own knowledge to predict weather conditions. Table 1 summarizes the indicators used by fishermen to predict the weather. In both study villages it emerged that fishermen rely on physical observation and behavior of plants, marine and terrestrial animals, insects, birds, human beings, meteorological indicators (eg. clouds), astronomical objects (eg. stars and moon) and other non-living things such as sea rubbish, to predict upcoming weather. They observe a combination of these local indicators to inform fishing decisions especially on what, where, when and how to fish. Many of the listed indicators were used to predict rainfall and wind (strength and direction), which might occur within a short period of time, usually within the next few hours, to one week. Other indicators mentioned are used to predict wave heights, temperature and water current speed.

Fishers identified the behaviour of plants, such as the wilting of mangrove flowers (*Sonneratia alba*) and the drying-up of trees as indicators of change in wind direction associated with the southeast to northeast monsoon. Fishermen translated this period as conducive for fishing, especially for those using traditional fishing gears. Other studies in Tanzania and other parts of Africa also report that plant phenology is commonly used in predicting weather events. For example, a study by Chang'a *et al*. (2010) in the south-western highlands of Tanzania established that farmers use the phenology of trees such as *Erythrina abyssinica* and *Brachystegia speciformis* to predict rainfall. A study by Elia *et al*. (2014) also indicated that some farmers in Dodoma and Singida villages make use of plant phenology such as the sprouting of tree leaves, flowering, and plant growth to predict rainfall onset, and a good or bad crop year. In Bukina Faso, flowering of fruit trees and the occurrence of good fruit yields of trees such as mangos were mentioned as the indicator of abundant rainfall associated with good harvests (Roncoli *et al*., 2002).

Fishermen interpreted meteorological indicators such as the appearance of clouds as signs of particular weather conditions in the next few hours or days. For instance, the formation of clouds in the southeast; red clouds at sunset; clouds associated with strong winds and thunder from inland; formation of cloud cover throughout the sky; and the formation of dark clouds in just one area, were all reported to predict heavy rainfall accompanied by strong winds in the next few hours/days. When these conditions are observed, artisanal fishers postpone their fishing plans until further indicators are noticed. Apart from fishing communities, farming communities also use cloud appearance as an indicator of rainfall. A study by Okonya and Kroschel (2013) undertaken in selected villages in six regions of Uganda found that farmers predict the start of the rainy season by observing the appearance of clouds in the morning and evening.

Behaviour of some marine and terrestrial animals, and human beings, was also used to predict a change in weather parameters. During focus group discussions, fishermen explained that the abundance of mullet fish (*Mkizi*) is a sign that the northeast monsoon wind is about to start. The northeast season was said to be associated with calmness, short rains and fairly good catches. Fishermen also said that a lot of sea worms on the surface of the sea is an indication of high temperature in the next few days. Hot periods were related to unpredictable rains, winds and currents, but were associated with a fairly good catch. The presence of marine mammals, particularly dolphins, when jumping and splashing their tails in the water, is interpreted as a sign of calmness in the sea which is associated with increased temperature. Terrestrial animals also provided signs that indicated the upcoming weather. For example, cows running with their tails upward is an indication of rainfall in the next few days. Similarly, when people feel pains throughout their bodies or numbness in their limbs, this is an indication that there will be rainfall in the next few days.

**Table 1.** Local indicators/knowledge used in predicting weather changes in Moa and Kwale fishing villages.

| Indicator | Indicator Description | Weather parameter predicted |
|---|---|---|
| Sea water | Formation of sparks-like in sea water | Indication of rainfall associated with strong wind in the next few hours or days |
| | Presence of yellow or red seawater oily like | |
| | Movement of seawater to the northern side | |
| | Sudden change in water movement from normal to high speed | |
| | Mixing-up of water with soil in the sea | Indication of high water waves |
| | Spring tide periods (Moon days 14 – 15 and 29 – 30) | Prediction of high water current speed |
| | Calm spring tide | Indication of increased temperature |
| Plant Phenology | Shading of mangrove flowers (*Sonneratia alba*) | It is time to turn into northeast monsoon wind |
| | Standing of mangrove seeds (*Rhizophora mucronata*) in large number around the intertidal area | Indication of rainfall in the next few days |
| | Shading of flowers and leaves of a wild fig tree | |
| | Sprouting of tree leaves | Indication of the start of southeast monsoon wind |
| | Dry-up of trees. | Indication of the start of northeast monsoon wind |
| Fish species | Availability of many mullet fish (*Mkizi*) | It is time to turn into northeast monsoon season |
| Sea worms | Presence of sea worms on the surface of seawater | Indication of high temperature |
| Marine mammals | Jumping of dolphins while splashing their tails in the water | The sign of calmness in the sea which is associated with increased temperature |
| Terrestrial Animals | Cows running with their tails upward | Indication of rainfall in the next few days |
| Amphibians | Cheeping of frogs continuously | |
| Human beings | Feeling of pains throughout the body especially in stitched areas | Indication of rainfall in the next few hours or days |
| | Feeling of numbness | |
| Sea rubbish | Appearance of rubbish (reddish line) along intertidal water | |
| Moon | Red and round moon | |
| | Circular shade surrounding moon | |
| | Thin and bright moon | Indication of strong wind |

| **Indicator** | **Indicator Description** | **Weather parameter predicted** |
|---|---|---|
| Insects | Appearance of small black ants in large numbers | Indication of sunny days in the next few days |
| | Appearance of red headed ants and safari ants from the ground | Indication of rainfall in the next few days |
| | Appearance of red insects in the farms | |
| | Entering of safari and small black ants into houses | |
| | Flying of bees from south to north side | Indication of the start of northeast monsoon wind |
| | Flying of bees from north to south | Indication of the start of southeast monsoon wind |
| Clouds | Formation of cloud at the southeast side of the study villages | Indication of heavy rainfall associated with strong wind in the next few hours/days |
| | Dark cloud cover leaving only a small space uncovered by clouds | |
| | Red clouds formation during sun set | |
| | Cloud formation associated with thunder and strong wind from land side | |
| | Dark cloud formation in one area | |
| | Fast formation of clouds | Indication of rainstorms in the next few hours |
| | Appearance and fast movement of clouds by the sea side | Indication of high speed wind in the next few hours |
| | Formation of dark clouds throughout the sky | |
| | Formation of dark clouds by the sea side (at the lower level) | Indication of a storm in the next few hours |
| | Formation of clouds with the shape of an animal | |
| | Formation of light red clouds | |
| Rainbow | Appearance of a quarter rainbow (*Kisiki*) on the southern or western side which stays for less than an hour | Indication of heavy rainfall associated with strong wind and thunders in the next few hours or days |
| Sun | Presence of wide sun rays | Indication of rainfall in the next few hours or days |
| | Increased heat | |
| | Red sun during sunrise | Indication of high speed wind in the next few hours |
| Sea sand | Jumping of sea sand during rising of water waves | Indication of rainfall in the next few hours/days |

| Indicator | Indicator Description | Weather parameter predicted |
|---|---|---|
| Birds | Flying of bats from south to north | Indication of the start of northeast wind season |
| | Flying of bats from north to south | Indication of the start of southeast wind season |
| | Appearance of many hawks ‘*mwewe*’ | Sign of calmness to the sea ‘*umande*’ |
| | Appearance of small bats ‘*popo nundu*’ from upland to the sea side | |
| | Non-stop cheeping of a kingfisher, a bird locally known as ‘M*tilili*’ | Indication of rainfall in the next few hours/ days |
| | Flying of small groups of white birds flying and cheeping | |
| | Flying of many birds at high sky | |
| | Passing of a bird (*Mwalukombe*) around the trees (especially around mangrove trees) at a high height while cheeping | Indication of calm season associated with increased temperature |
| | Passing of a bird (*Mwalukombe*) around the trees (especially mangrove trees) at a lower height while cheeping | Indication of strong wind in the next few days |
| | Cheeping of birds ‘*kozi*’ around the trees | |
| Stars | Blinking of small stars | Indication of rainfall associated with strong wind in the next few hours/ days |
| | Assemblage of about ten stars in a group | |
| Sky | Clear sky | Indication of high temperature |

Insects and birds were also local indicators in weather prediction. The appearance of many small black ants indicates sunny days will follow, while the appearance of red headed ants and safari ants from the ground, and the entering of safari and small black ants in houses, indicates the onset of a period of rain. When bees and bats fly from south to north, this is an indication of the start of northeast monsoon winds, and when they fly from north to south this indicates the start of southeast monsoon winds. The appearance of many hawks and small bats over the sea and the flying of a bird known as ‘*mwalukombe*’ at the high altitudes signify the onset of calmness (‘*umande*’) in the sea. These signs indicate that artisanal fishermen should get prepared for a fishing expedition. However, when ‘*mwalukombe*’ flies at a lower altitude around the trees (especially mangrove forests), this signifies the start of strong wind in the next few hours or days. This is a sign of upcoming danger in the sea due to strong wind. Unique behaviour of astronomical objects such as the moon and stars was reported to indicate seasons in some cases. Fishermen elaborated that when the moon becomes red and round or when surrounded by a circular halo, or when it is thin and bright, and when small stars are blinking or assemble as a small group in one place, that this signifies that in few days there will be rainfall associated with strong wind. This is a very dangerous period for artisanal fishermen who use traditional fishing vessels and gears. They would then postpone fishing activities until the onset of a calm period.

## Fishermen’s Perceptions on Climate Change

Perception of fishermen on climate change over the past 10 years was assessed. As shown in Table 2, of the 60 respondents interviewed, the majority (98.3%) were aware of climate change in their localities. They relate climate change to long-term changes in weather patterns such as rainfall intensity, rainfall periods, monsoonal wind periods and wind speed, occurrence of storms, temperature, and changes in the water currents and waves.

Since local people detect climate change through observing local weather patterns (Howe *et al*., 2013), this study asked respondents about the long-term trend of different weather parameters in their area over the past 10 years (Fig. 2). In both study sites, the majority of respondents (96.7%) reported a decrease in rainfall intensity and 60% perceived a change of rainfall seasons. A nearly equal number of respondents observed both an increase and decrease of wind speed in the southeast and northeast monsoons, while the majority (56.7%) observed a slight change in wind direction. Wave height and current speed were perceived to have increased as observed by 46.7% and 53.3% of respondents in the two villages, respectively. The majority of respondents (80%) rarely observed storms in the study area. In addition, the majority of respondents (86.7%) indicated that temperature has been increasing over the past 10 years.

Since wind and rainfall were mentioned as the most important weather parameters to understand before deciding to embark on fishing expeditions, fishermen based their explanations on long term experience of these two parameters. Southeast monsoonal winds were reported to now last longer as compared to 10 years ago. One fisherman said "*Nowadays, you may find that it is supposed to be a calm wind period - a period of inter-monsoonal wind (changing winds from southeast to northeast winds) but strong southeast winds may still prevail*". These changes have implications to fishermen's lives and livelihoods. An extended period of strong wind poses risks to fishing activities, impairing livelihoods and the lives of people at sea.

On another note, fishermen described the long term observed changes in rainfall intensity and the major rainfall seasons (short rains - *Vuli* and long rains - *Masika*). During focus group discussions at both study sites, fishermen reported that the long rain season is now becoming shorter and the short rain season is becoming longer. Fishermen went so far as to report that nowadays, even a little rainfall may cause flooding. Fishermen linked rainfall with fish availability and farm crops. For instance, in the past, they reported that they caught large quantities of anchovy/sardines (*dagaa*) during the short rains period (October – December). This is no longer the case, with sardines nowadays mostly available during the long rains (March – May). Related to this, unpredictable rains means that decisions about when to farm are more difficult to make. These changes create confusion among fishermen, who are mostly also farmers, because of uncertainty about what and when to fish and/or farm.

As a result of their long-term experience of weather patterns, fishermen established that nowadays the climate has changed and is already impacting their fishing operations. With the prolonged southeast wind, coupled with other extreme parameters such as strong currents, high waves and heavy rainfall, the ocean becomes unsuitable for fishing, especially for those using traditional fishing gears and vessels. In these periods, many fishermen postpone fishing activities and this impacts their livelihoods. However, changes in some parameters may also be beneficial to fishers, especially to those using modern fishing equipment. For example, Bezerra *et al*. (2012) reported that the transport of water induced by strong wind performs an important role in the circulation of the ocean. This causes vertical water movements (upwelling) which bring nutrients to the surface that favor the development of phytoplankton which attracts fish shoals.

Furthermore, this study found that through repeated observation of weather events, fishermen are able to predict typical weather conditions and productivity seasons throughout the year, as indicated in Fig. 3. This includes, for example, months of weak and strong rainfall, strong wind and calm periods, periods of lower and higher fish catches, and good farming

**Table 2.** Awareness of respondents of climate change in the study area.

| Perception status | % Responses | | |
|---|---|---|---|
| | **Moa (n = 30)** | **Kwale (n = 30)** | **Total (n = 60)** |
| Yes | 100.0 | 96.7 | 98.3 |
| No | 0.0 | 3.3 | 1.7 |

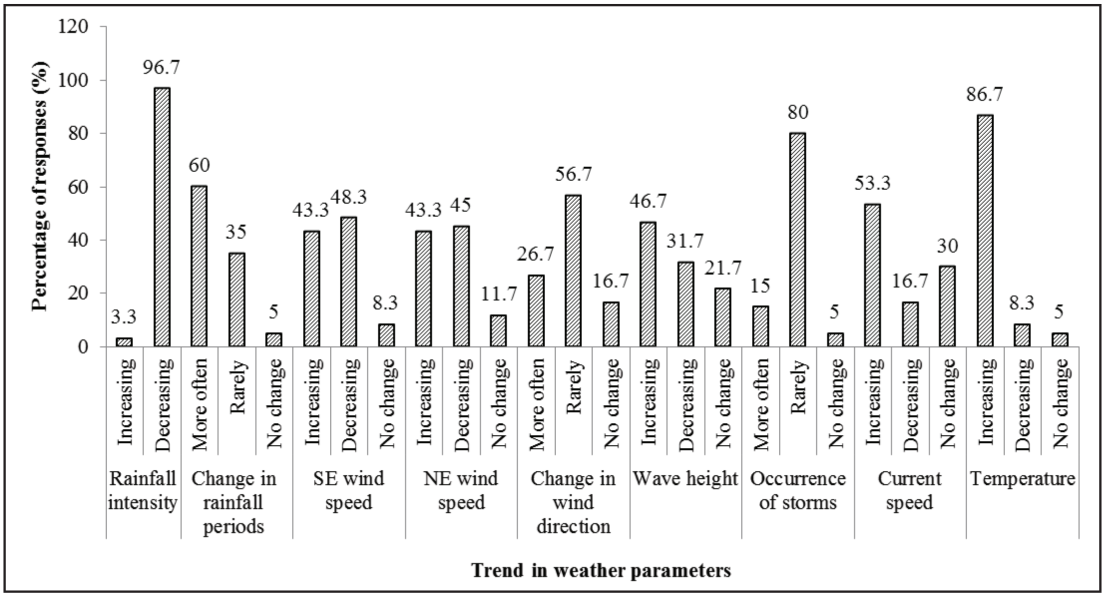

**Figure 2.** Fishermen's perceptions of trends in different weather parameters over the past 10 years.

seasons. This local knowledge of annual weather patterns helps them to decide when, how and where to fish, and to conduct other livelihood activities in an appropriate manner.

## Challenges facing Local Weather Prediction

Despite its usefulness, fishermen identified a number of issues which limits the wide usage, and threatens the existence of, local weather prediction. Table 3 summarizes the challenges associated with depending on local weather predictions, as identified by fishermen. Of the seven challenges mentioned, the existence of few people with the local knowledge to predict the weather (65.0%), uncertainty over the accuracy of local weather predictions (41.7%), and the lack of close monitoring of local indicators (38.3%), received the most responses. In both study areas, it was realized that many elders and fishermen who are experienced in local weather prediction have passed away without transmitting their knowledge to the younger generations. This is coupled with a decrease in the belief in local knowledge and its practices, especially by young people who perceive traditional knowledge as an obsolete belief system. Moreover, the current

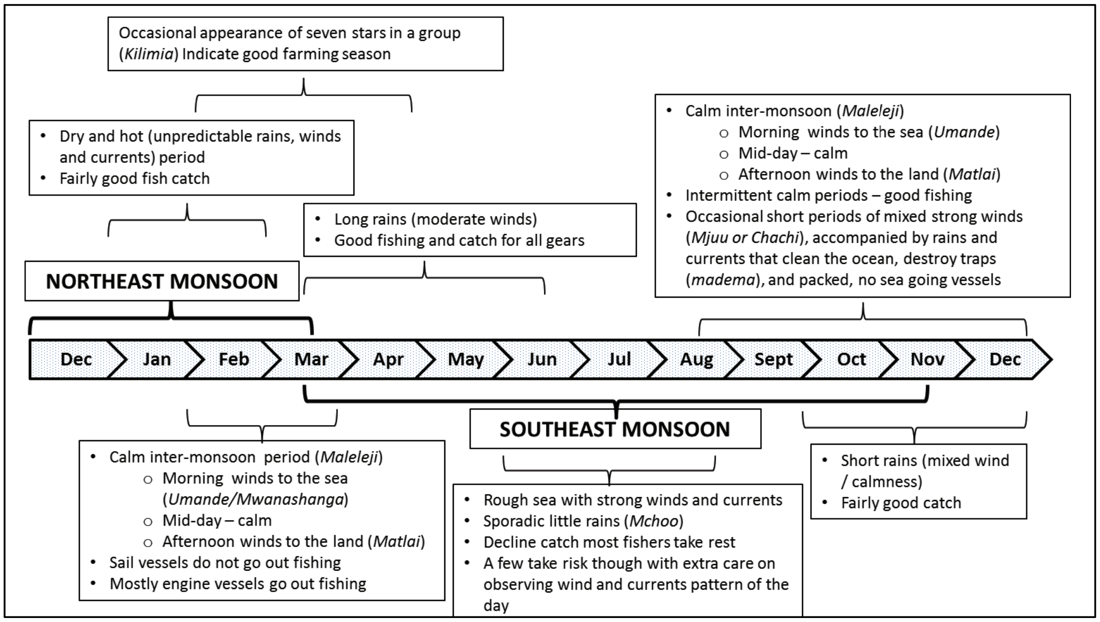

**Figure 3.** Seasonal calendar of weather parameters in the study villages, based on local knowledge.

Table 3. Multiple responses on the challenges of depending on local weather predictions.

| Challenges | % Responses (n = 60) |
|---|---|
| Few (elderly) people with local knowledge to predict weather | 65.0 |
| Close monitoring of local indicators | 38.3 |
| Uncertainty of local weather prediction | 41.7 |
| Not better than during the past | 8.3 |
| Absence of cooperation between local and scientific forecasters | 8.3 |
| Changes/disappearance of local indicators | 10.0 |
| Disrespect of local knowledge | 5.0 |

uncertainty about local predictions is attributed to the disappearance of some living indicators that were used in weather prediction. It was observed that some plant and animal species that were used to predict weather patterns are now endangered or extinct. For instance, dolphins which are used to predict calm condition in the sea, are now not often found in the area. Kijazi *et al*. (2013) reported similar findings in that one of the challenges facing local forecasting in Mahenge and Ismani wards is the disappearance of indicators such as some bird and fruit tree species.

## Concluding remarks and recommendations

This study provided an understanding of how fishermen in the Moa and Kwale communities make use of local knowledge to predict weather. This knowledge is very important to them in planning their fishing expeditions. Of the many weather parameters, wind and rainfall were regarded as the most important to consider when planning to go fishing. As a result, many local indicators identified were related to the prediction of wind and rainfall (intensity and periods). Fishermen rely on physical observation and behavior of the sea, plants, fish, sea worms, marine mammals, terrestrial animals, amphibians, human beings, birds, insects, sea rubbish, moon, clouds, rainbows, sun, sea sand, stars and sky, to predict weather conditions in the near future and to and decide on their actions.

Furthermore, the results show that many fishermen are aware of the changing climate through long term observation of local weather patterns. Also, through long-term observation, fishermen were able to predict typical weather conditions and productivity seasons throughout the year. This finding may have important implications to fishermen. Through long-term observations of weather patterns, fishermen develop adaptation measures to cope with the changing climate because they know when, how and where to fish, and conduct other livelihood activities such as farming.

Despite the usefulness of local weather and climate prediction, this important information is challenged by a number of issues that lessen its reliability and threaten its sustainability. To enhance and sustain its effectiveness there should be: (1) strong cooperation between local and scientific weather prediction experts; (2) increased awareness programmes on the application of local weather information in the planning of fishing activities; (3) recognition of local weather experts by the government; (4) further documentation of local weather information in other coastal areas; and (5) establishment of at least one meteorological station in each District to compare local and modern weather information at the local level. This study also recommends further investigation on how local and scientific weather experts can cooperate to provide reliable and acceptable weather information that is useful to local fishermen.

## Acknowledgements

I am grateful to the Western Indian Ocean Marine Science Association (WIOMSA), through its Marine Research Grant (MARG 1) programme, for funding this research. I extend my sincere gratitude to the Institute of Marine Sciences, University of Dar es Salaam, for providing working facilities during the entire period of this study.

## References

Assessment of Impact and Adaptation to Climate Change (2005) Sustainable livelihood approach for assessing community resilience to climate change: case studies from Sudan. AIACC Working Paper; no.17 [Online]. http://www.aiaccproject.org, retrieved on 09 December, 2016

Bailey KB (1994) Methods of Social Research. The Free Press, New York, 345 pp

Bezerra DMM, Nascimento DM, Ferreira EN, Rocha PD, Mourão JS (2012) Influence of Tides and Winds on Fishing Techniques and Strategies in the Mamanguape River Estuary, Paraíba State, NE Brazil. Anais da Academia Brasileira de Ciências 84(3): 775-78

Chang'a LB, Yanda PZ, Ngana J (2010) Indigenous knowledge in seasonal rainfall prediction in Tanzania: a case of the south-western highland of Tanzania. Journal of Geography and Regional Planning 3(4): 66-72

Elia EF, Mutula S, Stilwell C (2014) Indigenous Knowledge use in seasonal weather forecasting in Tanzania: the case of semi-arid central Tanzania. South African Journal of Libraries and Information Science 80(1): 18-27

Environmental Protection and Management Services (2010) Identification, Documentation and Dissemination of Indigenous Knowledge forecasting to adapt to climate change within selected communities in Tanzania: A guide for mainstreaming indigenous knowledge weather forecasting in planning processes. A Climate Change and Development - Adapting by Reducing Vulnerability (CC-DARE) Project, UNEP/UNDP, 9 pp

Inter-governmental Panel on Climate Change (2001) Climate Change 2001: Impacts, adaptation vulnerability's contribution of working group II to the third assessment report of the intergovernmental panel on climate change. Cambridge: Cambridge University Press.

Jiddawi NS, Öhman MC (2002) Marine fisheries in Tanzania. Ambio 31 (7-8): 518-527

Kadi M, Njau LN, Mwikya J, Kamga A (2011) The state of climate information services in East African countries. CCAFS Working Paper 5. Copenhagen. www.ccafs.cgiar.org viewed on 10 December, 2016

Kijazi AL, Chang'a LB, Liwenga ET, Kanemba A, Nindi SJ (2013) The use of indigenous knowledge in weather and climate prediction in Mahenge and Ismani wards, Tanzania. Journal of Geography and Regional Planning 6(7): 274-280

Mahoo H, Mbungu W, Yonah I, Recha J, Radeny M, Kimeli P, Kinyangi J (2015) Integrating Indigenous Knowledge with Scientific Seasonal Forecasts for Climate Risk Management in Lushoto District in Tanzania. CCAFS Working Paper no. 103. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). www.ccafs.cgiar.org, viewed on 10 December, 2016

NBS (2013) 2012 Population and Housing Census: Population Distribution by Administrative Areas, Tanzania, 264 pp

Okonya JS, Kroschel J (2013) Indigenous knowledge of seasonal weather forecasting: A case study in six regions of Uganda. Agricultural Sciences 4 (12): 641-648

Risiro J, Mashoko D, Tshuma DT, Rurinda E (2012) Weather Forecasting and Indigenous Knowledge Systems in Chimanimani District of Manicaland, Zimbabwe. Journal of Emerging Trends in Educational Research and Policy Studies 3(4): 561-566

Roncoli C, Ingram K, Kirshen P (2002) Reading the rains: local knowledge and rainfall forecasting in Burkina Faso. Society and Natural Resources: an international Journal 15(5): 409-427

Saunders M, Lewis P, Thornhill A (2007) Research Methods for Business Students, 4th Edition. FT Prentice Hall, Harlow-England, 624 pp

Spencer-Oatey H (2012) What is culture? A compilation of quotations. GlobalPAD Core Concepts. http://go.warwick.ac.uk/globalpadintercultural, viewed on May, 2016

Terada K (1968) Fishermen and the Weather. FAO Fisheries Technical Paper No. 71. Food and Agriculture Organization of the United Nations. Rome, Italy, 93 pp

Timmers B (2012) Impacts of climate change and variability on fish value chain in Uganda. Project Report 2012-18. WorldFish Center, Malaysia

Tobisson E, Andersson J, Ngazi Z, Rydberg L, Cederlöf U (1998) Tides, monsoons and seabed: Local knowledge and practice in Chwaka Bay, Zanzibar. Ambio 27 (8): 677-685

Wells S, Makoloweka S,Samoilys M (2007) Putting Adaptive Management into Practice:Collaborative Coastal Management in Tanga, Northern Tanzania, 107 pp

# The benthos and ichthyofauna of Baixo São João, Ponta do Ouro Partial Marine Reserve, southern Mozambique

Michael H. Schleyer[1], Marcos A.M. Pereira[2,*], Raquel S. Fernandes[2]

[1] Oceanographic Research Institute, PO Box 10712, Marine Parade, 4056 Durban, South Africa

[2] Centro Terra Viva – Estudos e Advocacia Ambiental, PO Box 2046, Maputo, Mozambique

* Corresponding author: marcospereira@gmx.net

## Abstract

A reef survey was conducted at Baixo São João, southern Mozambique, in July 2015. This involved point intercept analysis of photo-quadrat transects of the benthos recorded in the northern, central and southern parts of the reef, on the reef top and its inshore and offshore slopes. Visual techniques were used to describe the ichthyofauna. The coral community proved to be uniform within all reef zones and relatively rich compared to other southern Mozambican reefs, but with no unique or fragile species. Hard corals were predominant (mean cover = 32.3%), followed by soft corals (mean cover = 12.8%). Little coral damage was evident. A total of 97 species of reef fish, belonging to 30 families was recorded. Large specimens (>30 cm) were common, including species of commercial importance, as well as top predators. The reef merits protection in view of its good condition, remoteness and depth (>12 m), attributes that may endow it with a measure of resilience to bleaching associated with increased sea temperatures and make it useful as a reference site for baseline and comparative studies.

**Keywords:** hard coral; soft coral; reef fish; sanctuary; southern Mozambique

## Introduction

Coral reefs are declining globally and this is attributed to a variety of human-related disturbances (Wilkinson, 2008). Such reefs are rich in biodiversity making them a focal point for fishing, tourism and scuba diving. This renders them valuable as an economic resource to local communities and recreational stakeholders. This is very much the case in the Western Indian Ocean (WIO) region and Mozambique, where a large proportion of the population lives in the coastal zone and depends heavily on marine and coastal resources (Hicks, 2011).

Reefs in the Ponta do Ouro Partial Marine Reserve in southern Mozambique are a valuable asset: they play a pivotal role in the tourism industry in the area (Daly *et al.*, 2015), with social and economical benefits to the local communities (Come, 2014), and constitute a prominent and unique ecological feature, comprising some of the highest-latitude reefs in the world (Celliers and Schleyer, 2008).

Baixo São João lies in the northern section of the Ponta do Ouro Partial Marine Reserve, just south of Inhaca Island. It was surveyed when the development potential of the southern Mozambique coast was assessed in 1996, at which time the mean benthic cover was visually estimated to be 33% (Robertson *et al.*, 1996). More recent visits by scientists indicated that this has improved (Pereira *et al.*, 2015), resulting in this study.

## Methods

### Study Area

Baixo São João is a rocky massif lying approximately 4 km off the southern Mozambican coast between ~26.351°S - 26.363°S at ~32.974°E. It appears similar in structure to the reefs known as Baixo Danae north

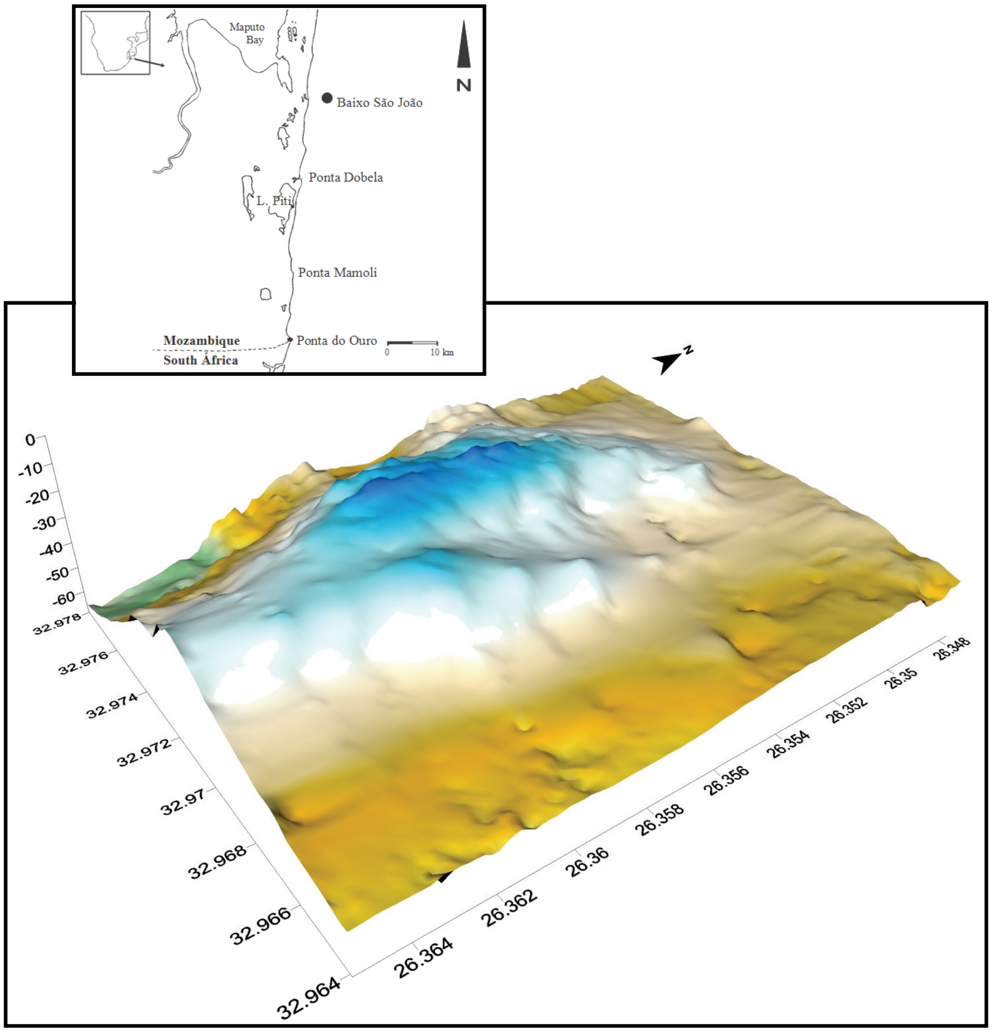

**Figure 1.** Location, bathymetry and coordinates for Baixo São João, Reserva Marinha Parcial da Ponta do Ouro.

of Inhaca Island, and Aliwal Shoal south of Durban in KwaZulu-Natal. These consist of dune rock known as aeolianite, derived from beach dunes that fossilised prior to the most recent rise in sea levels (Ramsay, 1996). Baixo São João runs parallel to the coast and is a large reef with a smaller side-branch bifurcating from its southern base (Figure 1). It is just over 1 km long, ~400 m wide at the widest point, and rises from a depth of ~30 m at its periphery to 12 m at its narrow crest.

## Data Collection

Data were collected between 22 and 25 July 2015. A preliminary bathymetry study was conducted using a combination GPS/fishfinder (Garmin GPSMap 441s) before the reef surveys. A pre-determined grid that was superimposed on existing nautical charts was used, and tracked depth data were collected in transects across the reef. These data were analysed using Surfer 12 software, according to the methodology described by Heyman *et al.* (2007). A representation of the three-dimensional

**Table 1.** Number of transects undertaken on Baixo São João and the number of photo-quadrats recorded in each. N, C and S denote the north, central and south regions; I, T, and O denote the inner slope, reef top and outer slope respectively.

| | Reef zone | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | NI | NT | NO | CT | CO | SI | ST | SO |
| **No.** | 53 | 150 | 80 | 54 | 90 | 88 | 184 | 22 |
| **Depth (m)** | 15-23 | 12-15 | 15-20 | 12-18 | 18-26 | 14-18 | 12-14 | 15-22 |

reef structure (Figure 1) was then used to determine the location of the benthic surveys.

Reef surveys were conducted using SCUBA and a digital camera in an underwater housing. Eight transects were recorded within bathymetric and physiognomic zones for laboratory analysis, these being in the northern, central and southern (N, C, S) parts of the reef on the reef top and its inshore and offshore slopes (T, I, O). The photographs were taken while swimming with the camera held at right angles to the reef face at a distance of 93 cm, the latter being regulated by a spacer bar attached to the camera housing. The area photographed in each camera frame was thus constant, being 0.32 m², and the distance between each photograph was 2-4 m, this being dictated by a pause in the camera

**Table 2.** List of living biota and non-living substrata recorded in photo-quadrats on Baixo São João with their percentage cover (±SD). Information in bold is referred to in the text.

| Categories | % Cover | Sd | Categories | % Cover | Sd |
|---|---|---|---|---|---|
| **Hard coral** | | | **Soft coral (cont.)** | | |
| *Acanthastrea* | 0.4 | 2.8 | *Lobophytum* | 1.1 | 6.9 |
| ***Acropora*** | **3.0** | 9.3 | *Rumphella* | <0.1 | 1.5 |
| *Alveopora* | 1.5 | 10.4 | *Sarcophyton* | 1.1 | 6.7 |
| ***Astreopora*** | **5.8** | **14.2** | ***Sinularia*** | **8.8** | **20.0** |
| *Coscinaraea* | <0.1 | 0.6 | *Stereonephthya* | <0.1 | 0.6 |
| *Cyphastrea* | <0.1 | 0.4 | *Tubipora* | <0.1 | 1.1 |
| *Echinopora* | 1.1 | 7.0 | **Other Cnidaria** | | |
| *Favia* | 0.4 | 2.3 | Corallomorpharia | <0.1 | 0.4 |
| *Favites* | 0.7 | 3.6 | **Bivalves** | | |
| *Fungia* | <0.1 | 0.4 | *Tridacna* | <0.1 | 0.8 |
| *Galaxea* | <0.1 | 0.8 | **Macroalgae** | | |
| *Goniastrea* | 0.2 | 1.9 | *Padina* | **<0.1** | **0.4** |
| *Goniopora* | <0.1 | 0.4 | Turf | **14.6** | **15.5** |
| *Gyrosmilia* | <0.1 | 0.8 | Other macroalgae | 0.1 | 1.1 |
| *Hydnophora* | <0.1 | 0.8 | **Other live** | | |
| *Leptoria* | <0.1 | 0.8 | *Diplosoma* | 0.2 | 2.2 |
| *Montastrea* | <0.1 | 0.4 | *Diadema* | 0.1 | 1.0 |
| ***Montipora*** | **13.5** | 19.2 | Other sea urchins | <0.1 | 0.8 |
| *Mycedium* | <0.1 | 0.4 | Sponges | 0.4 | 3.3 |
| Other poritids | <0.1 | 0.8 | **Dead coral (DC)** | | |
| *Oulophyllia* | 0.2 | 1.9 | DC + algae | **0.1** | **1.5** |
| *Platygyra* | 0.8 | 4.1 | Old DC | **0.8** | **3.0** |
| ***Pocillopora*** | **3.6** | 7.8 | Recent DC | **0.6** | **2.5** |
| *Porites* | 1.3 | 7.3 | **Coralline Algae** | | |
| *Psammocora* | <0.1 | 0.4 | Coralline algae | 2.7 | 0.8 |
| *Turbinaria* | <0.1 | 0.8 | **Bare reef, sand rubble** | | |
| Other faviids | 0.4 | 2.3 | Bare reef | **21.4** | **17.4** |
| **Soft coral** | | | Rubble | **6.9** | **12.3** |
| *Anthelia* | 0.8 | 3.4 | Sand | **5.3** | **10.1** |
| *Cladiella* | 0.9 | 5.0 | **Unknown** | | |
| *Dendronephthya* | <0.1 | 0.8 | Unknown | 1.0 | 2.7 |

recording system (Nikon Coolpix 4800). The path of the transects was tracked using a floating GPS (Garmin eTrex), their length being determined by the width of the zone in which they were recorded. Fish communities were visually assessed using a semi-quantitative method for species abundance in three categories (Samoilys and Carlos, 2000): present (<5 individuals per dive), common (6-10) and abundant (>10).

### Data Analysis

Data were extracted from the reef transects employing a point-intercept technique in which the photographic images, or photo-quadrats, were screened on a computer as JPEG images using Coral Point Count with Excel extensions (CPCe) software (http://www.nova.edu/ocean/cpce; Kohler and Gill, 2006). The biota or substrata underlying ten randomly-placed points were recorded to at least genus level, where possible. The number of intercepts in each category was considered to be directly proportional to the planar area covered by that category (Carleton and Done, 1995); percentage cover could therefore be calculated using the CPCe software. This yielded information on the community structure of the benthos at the sampling sites and the untransformed data were subsequently subjected to similarity analysis using Primer (http://www.primer-e.com).

## Results

### Coral Communities

A total number of 721 photographs were recorded within the eight transects (Table 1). More were planned but severely inclement weather prevented their execution. Low underwater visibility also made identification of the benthos beyond genus dubious in some cases and data were thus only extracted and analysed to the generic level.

In structure, the reef itself was not rugose and offered little topographic variation to the life it harboured and supported. Results of CPCe analysis of the photo-quadrats (Table 2) revealed that the mean (±SD) algal cover (17.5±16.5%), primarily in the form of algal turf and coralline encrustations, was high on the reef. Hard corals were predominant with a mean cover of 32.3±25.3%; the mean cover of soft corals was 12.8±21.9%. *Montipora* (13.5±19.2%), *Astreopora* (5.7±14.2%), *Pocillopora* (3.6±7.8%) and *Acropora* (3.0±9.3%) were the most abundant hard corals and *Sinularia* (8.8±20.0%) the most abundant soft coral. Substrata devoid of living material (e.g. bare reef, sand, old dead coral) comprised 34.3±21.1% of the reef surface. Indeed, much of the surface of the reef was lightly coated with sand. Little coral damage, disease or mortality was observed on the reef (pers. obs. and DC in Table 2).

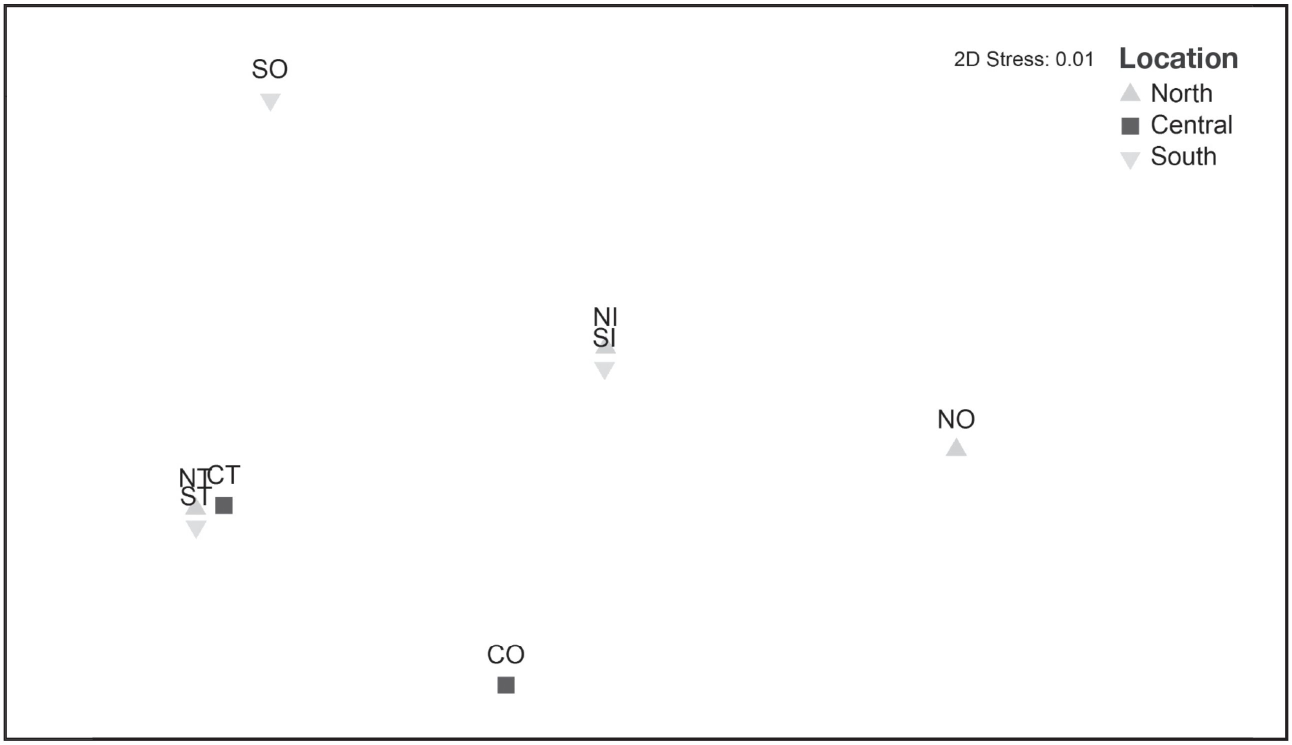

**Figure 2.** Multi-dimensional analysis of the CPCE results from transects in the different reef zones on Baixo São João. N, C and S denote the north, central and south regions.

**Table 3.** Results of CPCe analysis of data extracted from the photo-quadrats recorded on Baixo São João; only the highest 15 records are presented. N, C and S denote the north, central and south regions; I, T, and O denote the inner slope, reef top and outer slope respectively; numbers in parentheses after the transect codes are the number of genera recorded in the photo-quadrats.

| NO (18) | | NT (29) | | NI (23) | | CO (33) | | CT (24) | | SI (25) | | ST (28) | | SO (14) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Taxon** | **%** | **Taxon** | **%** | **Taxon** | **%** | **Taxon** | **%** | **Taxon** | **%** | **Taxon** | **%** | **Taxon** | **%** | **Taxon** | **%** |
| Algae | 36 | *Montipora* | 27 | Algae | 34 | Algae | 27 | Algae | 26 | Algae | 38 | *Sinularia* | 23 | *Montipora* | 36 |
| *Alveopora* | 23 | Algae | 21 | *Astreopora* | 20 | *Montipora* | 18 | *Montipora* | 24 | *Astreopora* | 19 | *Montipora* | 23 | Algae | 34 |
| *Astreopora* | 16 | *Sinularia* | 13 | *Montipora* | 17 | *Sinularia* | 13 | *Sinularia* | 13 | *Montipora* | 18 | Algae | 23 | Sponges | 7 |
| *Montipora* | 6 | *Acropora* | 9 | *Acropora* | 4 | *Astreopora* | 11 | *Pocillopora* | 7 | *Sinularia* | 6 | *Pocillopora* | 8 | *Acropora* | 7 |
| *Sinularia* | 6 | *Pocillopora* | 6 | *Echinopora* | 4 | *Porites* | 7 | *Acropora* | 6 | *Pocillopora* | 3 | *Acropora* | 6 | *Pocillopora* | 4 |
| *Pocillopora* | 4 | *Astreopora* | 4 | *Porites* | 4 | *Echinopora* | 6 | *Astreopora* | 4 | *Acropora* | 2 | *Astreopora* | 5 | *Astreopora* | 2 |
| *Porites* | 3 | *Sarcophyton* | 3 | *Sinularia* | 3 | *Sarcophyton* | 3 | *Cladiella* | 4 | *Anthelia* | 2 | *Lobophytum* | 2 | *Favia* | 2 |
| *Sarcophyton* | 2 | *Lobophytum* | 3 | *Pocillopora* | 3 | *Lobophytum* | 2 | *Favites* | 2 | *Favites* | 2 | *Anthelia* | 1 | *Goniastrea* | 2 |
| *Platygyra* | 1 | *Cladiella* | 3 | Other faviids | 2 | *Pocillopora* | 2 | *Platygyra* | 2 | *Sarcophyton* | 1 | *Acanthastrea* | 1 | *Porites* | 2 |
| *Favites* | 1 | *Platygyra* | 2 | *Favites* | 1 | *Cladiella* | 2 | *Porites* | 2 | *Platygyra* | 1 | *Cladiella* | 1 | *Sinularia* | 2 |
| *Echinopora* | <1 | *Porites* | 1 | Other | 1 | *Anthelia* | 1 | Other faviids | 2 | *Porites* | 1 | *Sarcophyton* | <1 | *Favites* | <1 |
| *Lobophytum* | <1 | *Anthelia* | 1 | *Platygyra* | 1 | *Favites* | 1 | *Lobophytum* | 2 | *Echinopora* | <1 | *Echinopora* | <1 | *Montastrea* | <1 |
| *Anthelia* | <1 | *Echinopora* | 1 | *Alveopora* | <1 | *Oulophyllia* | 1 | *Echinopora* | 1 | *Diplosoma* | <1 | *Platygyra* | <1 | *Platygyra* | <1 |
| *Acanthastrea* | <1 | *Favia* | 1 | *Goniastrea* | <1 | *Favia* | <1 | Other | <1 | Other faviids | <1 | Sponges | <1 | *Sarcophyton* | <1 |

The calculated means yielded high standard deviations; these were indicative of patchiness in the distribution of the benthos as well as relatively low sampling intensity imposed by the inclement weather and logistical constraints.

Further analysis of the CPCe data within the different reef zones revealed fine nuances in the differential abundance of the major biota (Table 3). Multiple dimensional analysis of these data showed that the reef top results were similar, as were those collected on the inner reef slopes; the results for the outer reef slopes were divergent (Figure 2). Differences in the abundance of biota that seemed responsible for this divergence were *Alveopora*, *Montipora*, *Sinularia* and the algae (Table 4). Nevertheless, the level of similarity between all the reef zones was high (Table 5).

Finally, apart from the biota listed in Table 3, a few other organisms were encountered amongst the benthos on Baixo São João. These were the sea cucumber *Holothuria nobilis*, the giant anemone *Heteractis magnifica* and the hard coral *Goniopora*. While sponges were grouped together in the analyses, *Theonella* was notably abundant and *Jaspis* and *Callyspongia* were also encountered.

### Fish Communities

A total of 97 reef fish species, belonging to 30 families, were observed on Baixo São João. The great majority (64.9% or 63 species) were present in low abundance (less than five individuals per dive), 14 species were common and 20 species abundant. The relatively low number of species observed reflects the poor sampling coverage which was dictated by the unfavourable weather and logistical constraints. The ichthyofauna of Baixo São João was primarily composed of Indo-Pacific species, where the most speciose families proved to be Labridae, Chaetodontidae and Acanthuridae with 15, 12 and 8 species respectively (Table 6). Large-sized specimens (>30 cm in length) were commonly observed, including species of commercial importance, as well as top predators such as the potato bass (*Epinephelus tukula*) and several species of rays and sharks; these provide a good indication of the health of the fish fauna on Baixo São João.

**Table 4.** Results of CPCe analysis of the Baixo São João data grouped according to their separation by MDS analysis; only the highest 15 records are presented. N, C and S denote the north, central and south regions. Information in bold is referred to in the text.

| Reef top | | Inner reef | | Outer reef | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | N | | C | | S | |
| **Taxon** | **%** | **Taxon** | **%** | **Taxon** | **%** | **Taxon** | **%** | **Taxon** | **%** |
| *Montipora* | 25 | Algae | 36 | **Algae** | **36** | **Algae** | **27** | ***Montipora*** | **36** |
| *Algae* | 23 | *Astreopora* | 19 | ***Alveopora*** | **23** | ***Montipora*** | **18** | **Algae** | **34** |
| *Sinularia* | 16 | *Montipora* | 17 | *Astreopora* | 16 | ***Sinularia*** | **13** | Sponges | 7 |
| *Pocillopora* | 7 | *Sinularia* | 5 | ***Montipora*** | **6** | *Astreopora* | 11 | *Acropora* | 6 |
| *Acropora* | 7 | *Acropora* | 3 | ***Sinularia*** | **5** | *Porites* | 7 | *Pocillopora* | 4 |
| *Astreopora* | 4 | *Pocillopora* | 3 | *Pocillopora* | 4 | *Echinopora* | 6 | *Astreopora* | 2 |
| *Cladiella* | 3 | *Echinopora* | 2 | *Porites* | 3 | *Sarcophyton* | 3 | *Favia* | 2 |
| *Lobophytum* | 2 | *Porites* | 2 | *Sarcophyton* | 2 | *Lobophytum* | 2 | *Goniastrea* | 2 |
| *Platygyra* | 2 | *Favites* | 2 | *Platygyra* | 1 | *Pocillopora* | 2 | *Porites* | 2 |
| *Sarcophyton* | 1 | *Anthelia* | 1 | *Favites* | 1 | *Cladiella* | 2 | ***Sinularia*** | **2** |
| *Favites* | 1 | Other faviids | 1 | *Echinopora* | <1 | *Anthelia* | 1 | *Favites* | <1 |
| *Porites* | 1 | *Platygyra* | 1 | *Lobophytum* | <1 | *Favites* | 1 | *Montastrea* | <1 |
| *Echinopora* | 1 | Other | <1 | *Anthelia* | <1 | *Oulophyllia* | 1 | *Platygyra* | <1 |
| *Anthelia* | 1 | *Sarcophyton* | <1 | *Acanthastrea* | <1 | *Favia* | <1 | *Sarcophyton* | <1 |

## Discussion

While Baixo São João is a massive underwater structure, the reef itself is fairly low in profile and offers relatively little topographical variation to the life it harbours and supports. Two quantitative assessments of the benthos have been undertaken: the present study and a visual survey by Robertson *et al*. (1996). It is apparent that the coral cover has changed between these surveys and is presently higher (45%) than it was in 1996 (33%). Furthermore, the most abundant hard coral genera on the reef (*Acropora*, *Astreopora*, *Montipora* and *Pocillopora*) are known for their rapid growth (e.g. Anderson *et al*., 2012). Thus, it is possible that the coral abundance on Baixo São João varies with fluctuations in the populations of these genera. Since the reef topography is low, such fluctuations may be caused by high turbulence, high turbidity and substantial sand movement. Evidence for this can be found in the strong currents that flow over the reef, the widespread distribution of sediment on its surface, and the absence of fragile coral genera. Examples of these amongst the hard corals would be *Blastomussa*, *Leptoseris*, *Seriatopora*, *Stylophora* and certain fungiids; and amongst the soft corals, *Heteroxenia* and *Xenia*. These are relatively common on more sheltered reefs in the region.

Reefs immediately to the south and closer inshore have higher coral cover and diversity. Cover ≥65% has been recorded at Techobanine (Pereira, 2003) and on South African reefs (Schleyer, 2000); on the latter, 55 genera were recorded compared to the 34 genera on Baixo São João. While a greater diversity of corals would undoubtedly be found on Baixo São João with more extensive study, it must be borne in mind that the variety of habitat on this reef is limited. Furthermore, environmental conditions on the reef would preclude its colonisation by the aforementioned fragile genera.

The fish population on Baixo São João, on the other hand, despite having relatively low diversity, manifested little evidence of fishing pressure and top predators were well represented. The low diversity of the fish community must be attributed at least partially to the lack of variety in the reef habitat, but further study would undoubtedly yield more species.

**Table 5.** Levels of similarity between the different reef zones on Baixo São João generated by Primer SIMPER analysis. N, C and S denote the north, central and south regions; I, T, and O denote the inner slope, reef top and outer slope respectively.

| | NO | NT | NI | CO | CT | SI | ST |
|---|---|---|---|---|---|---|---|
| **NT** | 48.14 | | | | | | |
| **NI** | 69.70 | 60.46 | | | | | |
| **CO** | 59.12 | 73.26 | 72.99 | | | | |
| **CT** | 51.98 | 86.43 | 68.71 | 74.09 | | | |
| **SI** | 72.18 | 64.25 | 84.57 | 73.35 | 67.95 | | |
| **ST** | 47.67 | 83.25 | 60.90 | 71.13 | 83.16 | 64.01 | |
| **SO** | 51.73 | 67.49 | 66.38 | 56.92 | 68.94 | 64.92 | 63.21 |

**Table 6.** Most speciose fish families at Baixo São João, Ponta do Ouro Partial Marine Reserve.

| Family | Species |
|---|---|
| Labridae | 15 |
| Chaetodontidae | 12 |
| Acanthuridae | 8 |
| Pomacentridae | 7 |
| Serranidae | 7 |
| Balistidae | 6 |
| Pomacanthidae | 5 |

Based on these facts, Baixo São João would seem to have little merit for protection within the Ponta do Ouro Partial Marine Reserve. However, other factors must be considered. Baixo Danae, some 50 km to the north, is similar in many respects to Baixo São João, but is more accessible and is heavily dived (unpublished data; pers. obs.) and fished (Pereira and van der Elst, 2014). Aliwal Shoal, in turn, lies 500 km further south and is thus below the latitudinal limits for extensive coral growth. It falls within a marine protected area but is heavily dived and was largely 'fished out' before it received protection (Olbers *et al.*, 2009). Baixo São João thus has unique attributes within the region. Its coral communities, although not as rich as those on some inshore reefs, are in good condition, as is its fish community. The reef is remote and showed little damage during the survey: it appears to be naturally protected from human disturbance. It is also located offshore in deeper water, which will protect it to some extent from the coastward drift of warmer water associated with climate change: this should give it a measure of protection from coral bleaching (Graham *et al.*, 2015). Corals on deeper reefs of this nature are also known to be more fecund (Holstein *et al.*, 2015) and Baixo São João may provide a coral breeding refuge for replenishment of more southern reefs. These attributes potentially make it a useful reference site for baseline and comparative studies. It is often difficult to establish whether changes in environments used by humans are attributable to anthropogenic disturbance or natural events; sites such as Baixo São João could provide decisive evidence in this regard.

## Acknowledgements

This study was funded by the Peace Parks Foundation. Field support was provided by Mark "Spiggles" Eardley and Filimone Javane. Logistical support was provided by the Ponta do Ouro Partial Marine Reserve and Anvil Bay Lodge at Chemucane. Oceana Diving kindly provided diving equipment for the expedition and Dr Sean Porter undertook the data analyses with Primer.

## References

Anderson K, Pratchett M, Baird A (2012) Summer growth rates of corals at Lord Howe Island, Australia. Proceedings of the 12th International Coral Reef Symposium, 9-13 July 2012, Cairns, Australia

Carleton JH, Done TJ (1995) Quantitative video sampling of coral reef benthos: large-scale application. Coral Reefs 14: 35-46

Celliers L, Schleyer MH (2008) Coral community structure and risk assessment of high-latitude reefs at Sodwana Bay, South Africa. Biodiversity and Conservation 17: 3097-3117

Come JA (2014) Contribution of tourism to coastal livelihoods in Ponta do Ouro, southern Mozambique. MSc thesis. Cape Town, University of Cape Town, 90 pp

Daly CAK, Fraser G, Snowball JD (2015) Willingness to pay for marine-based tourism in the Ponta do Ouro Partial Marine Reserve, Mozambique. African Journal of Marine Science 37: 33-40

Graham NAJ, Jennings S, MacNeil MA, Mouillot D, Wilson SK (2015) Predicting climate-driven regime shifts versus rebound potential in coral reefs. Nature 518: 94-97

Heyman WD, Ecochard JB, Biasi FB (2007) Low-cost bathymetric mapping tool for tropical marine conservation - A focus on reef fish spawning aggregation sites. Marine Geodesy 30: 37-50

Hicks CC (2011) How do we value our reefs? Risks and tradeoffs across scales in “biomass-based” economies. Coastal Management 39: 358-376

Holstein DM, Smith TB, Gyory J, Paris CB (2015) Fertile fathoms: deep reproductive refugia for threatened shallow corals. Scientific Reports 5: 12407 [doi: 10.1038/srep12407]

Kohler KE, Gill SM (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. Computers and Geosciences 32: 1259-1269

Olbers JM, Celliers L, Schleyer MH (2009) Zonation of benthic communities on the subtropical Aliwal shoal, Durban, Kwazulu-Natal, South Africa. African Zoology 44: 8-23

Pereira MAM (2003) Recreational scuba diving and reef conservation in southern Mozambique. MSc thesis. Durban, University of Natal, 109 pp

Pereira M, van der Elst R (2014) Recreational and sport fishing in Maputo Bay. In: Bandeira S, Paula J (eds) The Maputo Bay Ecosystem. WIOMSA, Zanzibar, 341-344 pp

Pereira MAM, Fernandes RS and Louro CMM (2015) Monitoring of reef communities at the Ponta do Ouro Partial Marine Reserve: Preliminary reef assessment at the northern section. Maputo, CTV, 6 pp

Ramsay PJ (1996) Quaternary marine geology of the Sodwana Bay continental shelf, northern Kwazulu-Natal. Bulletin of the Geological Survey of South Africa 117: 1-86

Robertson WD, Schleyer MH, Fielding PJ, Tomalin BJ, Beckley LE, Fennessy ST, van der Elst RP, Bandeira S, Macia A, Gove D (1996) Inshore marine resources and associated opportunities for development of the coast of southern Mozambique: Ponta do Ouro to Cabo de Santa Maria. Oceanographic Research Institute, Unpublished Report 130: 1-51

Samoilys MA, Carlos G (2000) Determining methods of underwater visual census for estimating the abundance of coral reef fishes. Environmental Biology of Fishes 57: 289-304

Schleyer MH (2000) South African coral communities. In: McClanahan TR, Sheppard C, Obura D (eds) Coral reefs of the Indian Ocean: their ecology and conservation. New York, Oxford University Press, 83-105 pp

Wilkinson C (ed) (2008) Status of coral reefs of the world: 2008. Townsville, Global Coral Reef Monitoring Network and Reef and Rainforest Research Centre, 298 pp

# Community-Based Milkfish Farming in Tanzania

Aviti J. Mmochi

Institute of Marine Sciences
University of Dar es Salaam
P.O Box 668,
Zanzibar, Tanzania
avitimmochi@gmail.com

## Abstract

In the 1990s the Institute of Marine Sciences (IMS) conducted an experiment on integrated earthen pond mariculture of finfish, shellfish and seaweeds in a flow through system. Among the finfish tested were milkfish (*Chanos chanos*). This species proved to have better growth, survival, tolerance to a wide range of environmental parameters, and resistance to diseases, compared to three other species tested, namely rabbit fish (*Siganus canaliculatus* and *S. sutor*), mullet (*Mugil cephalus*), and Zanzibar tilapia (*Oreochromis urolepis hornorum*). The project, supported mainly by the Western Indian Ocean Marine Science Association (WIOMSA), culminated in a stakeholders' workshop in 2004 translating the results of the experiment into community-based projects. Before this workshop there were three milkfish mariculture ponds in Tanzania, one of which was established by IMS. Following the workshop, pond milkfish mariculture took off in coastal Tanzania and by 2006 the first commercially operated farm at Bagamoyo produced 1 MT/ha/yr, earning the group 2000 USD. Ever since, finfish farming has spread to all coastal districts with the highest production of 7.5 MT/ha/yr realized at Ndumbwe, Mtwara in 2011. This paper documents the developments of community-based pond milkfish mariculture in Tanzania with a special emphasis of the effect brought about through support from the ReCoMaP Projects (2008 – 2011).

**Keywords:** Finfish farming, milkfish, community-based aquaculture.

## Introduction

Aquaculture is the farming of aquatic organisms including fish, molluscs, crustaceans and aquatic plants in brackish and seawater environments (FAO, 1990; El-Sayed, 2006). Aquaculture covers a wide range of species and farming methods. Worldwide aquaculture grew at 8.3% per year between 1970 and 2008 (FAO, 2011), the fastest-growing animal-food-producing sector over the past 50 years (Troell, 2009; FAO, 2012). Aquacultures contribution to world fish food consumption rose from 33.8% in 2000 to 45.6% in 2010 (FAO, 2011).

The Asia-Pacific region has continued to dominate the aquaculture sector, accounting for 89.1% of global production, with China alone contributing 61.5% (40,508,119 MT) in 2008 (Hall *et al.*, 2011). Aquaculture production from China, South and Southeast Asia is dominated by carp (FAO, 2007 Hall *et al.*, 2011), while production from the rest of East Asia consists of high-value marine fish. Aquaculture production in Central and Eastern Europe is dominated by carps while channel catfish production dominates in the United States of America, and Atlantic and Pacific salmon dominates in Canada (FAO, 2007).

African aquaculture production is dominated by finfish (99.3% by volume), with only small fractions from marine shrimps (0.5%) and marine molluscs (0.2%) (FAO, 2012). Despite the low contributions in global aquaculture production, Africa has continued to increase its overall production from 1.2 % to 2.2% in the past ten years (FAO, 2012). Production increased in volume by 56% and more than 100% in value between 2003 and 2007 due to the increase in global prices along with the emergence and spread of small and medium enterprises. Egypt has continued to dominate production in Africa producing 92% of the total aquaculture production in the region (FAO, 2011). In recent years Nigeria, Kenya, Zambia and Uganda have made rapid progress to become significant producers in the region (FAO, 2012). Uganda and Nigeria have increased production of catfish (*Clarias gariepinus*) replacing tilapia since 2004. Other countries which have shown aquaculture progress include Madagascar with production of black tiger shrimp (*Penaeus monodon*), Tanzania which produces red seaweed (*Eucheuma denticulatum*), and South Africa with production of niche species such as abalone (Mmochi, 2015; Troell *et al*., 2011).

The increasing scarcity of freshwater, especially in the arid regions, accompanied by the decline in capture fishery stocks, has increased pressure to develop aquaculture in brackish and seawater where there is less competition and seawater is abundant (Mmochi *et al*., 2002). The target is to diversify aquaculture practices either by introducing new candidate species or by adaptation of culture methods to suit existing species (Troell *et al*., 2011).

Systematic studies on finfish mariculture in Tanzania started in 2000 at the Integrated Mariculture Pond System (IMPS) at Makoba Bay, Zanzibar. Pond milkfish farming in coastal Tanzania started in 2004 following the training in Zanzibar, which was attended by Coastal District Fisheries Officers. During the Sustainable Coastal Communities and Ecosystems (SUCCESS) Project which was run from 2004 to 2009 by the Coastal Resources Centre (CRC), WIOMSA and IMS with funding from USAID, three demonstration farms were developed in Bagamoyo (1 ha) and Mkuranga (2 ha), and 3 training workshops were conducted for all the Coastal District Fisheries Officers (Requintina *et al*., 2008; Sullivan *et al*., 2010). The highest achievement was a harvest of 1 MT/ha/yr from the Regent Group Changwahela, Bagamoyo, in 2006 (Requinitina *et al*., 2008; Mmochi, 2010; Mmochi, 2011). From 2008 to 2010 the University of Dar es Salaam (UDSM) together with WIOMSA ran a project under the Regional Programme for the Sustainable Management of the Coastal Zones of the Indian Ocean Countries (ReCoMaP) funded by the European Union during which support to community-based milkfish farming was continued. The aim of this paper is to review the effect of ReCoMaP on milkfish farming from 2008 to 2011, and its effects on mariculture development in Tanzania as a whole.

## Materials and methods

During ReCoMaP 75 trainees representing farmer groups, fisheries officers, environment officers and land surveyors, from Pemba Island, Mtwara and Tanga Regions, were selected and trained in aquaculture in the areas of: 1) site selection, 2) earthen pond construction, 3) pond preparation and fingerling collection, 4) fish feed, feeding and pond management, and 5) harvesting and marketing. The five-week training programme was carried out over a two-year period. Within this period 1 Ha demonstration ponds (Fig. 1) were constructed in Mtwara, Pemba and Tanga, with each divided into six smaller ponds; the two central

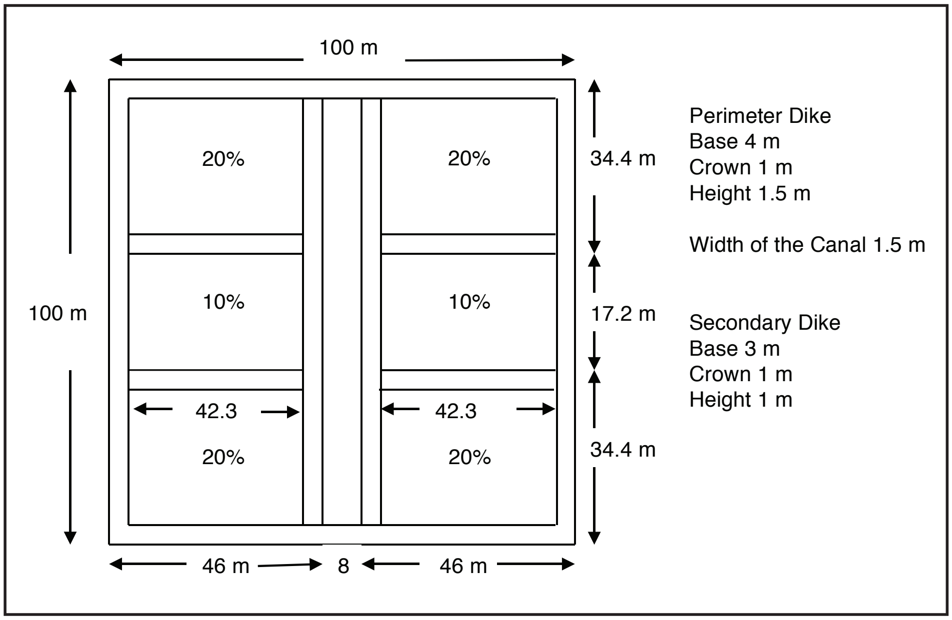

**Fig. 1.** Specification of the demonstration ponds constructed at Mtwara, Pemba and Tanga.

ponds (covering 20% of the pond area) being dedicated to rearing, while the remaining ponds (covering 80%) were dedicated to grow-out. A complete cycle of fish farming was then carried out during this period. Ponds were fertilized using animal manure while fingerlings were collected from the wild and stocked at 1-3 fingerlings/$m^2$ (Requintina *et al.,* 2008). The fish in the demonstration ponds were fed using a feed formulation of 28% protein (Mmochi, 2011). After 6-9 months the fish were harvested, weighed and sold in the respective villages. The trainees, some of whom were already working in fish farming, were encouraged to develop their own ponds to the demonstration pond specifications, and those who succeeded were rewarded by receiving assistance with the construction of the main and pond gates. The farmers were then left to continue the farming on their own. At the end of four years the farmers in Mtwara were visited, their records examined, and used as the basis for this review.

## Results and Discussion

By mid-2011, a total of 43 ha under aquaculture had been developed in Pemba Island, Tanga and Mtwara Regions. The annual production per ha changed from the maximum of 1 MT/ha/yr (Requintina *et al*., 2008) to 7.5 MT/ha/yr, equivalent to 10 000 USD/year, with an average of 1.5 MT/ha/yr as shown in table 1 (Mmochi *et al*., 2010), although the data varied widely between individual farms. Based on cost estimates for earthen pond construction in Tanzania, including construction, and one cycle of milkfish production at a level of 1 MT/ha/yr, and a five year cash flow cycle, the payback period will be between 18 months to 3 years, depending mostly on the initial (construction) cost (Requintina *et al*., 2008). There are therefore very clear indications that milkfish aquaculture is feasible. However, there were several shortcomings that would need to be addressed to ensure longer-term success. Most of the ponds that were made by the farmers during ReCoMaP were not excavated, but relied on dykes being built at ground level. Accordingly, a quarter to half of the ponds remained completely dry most of the time except during spring tides. In some years, especially when there was poor rainfall, serious shortages of fingerlings were reported, and most of the ponds were under-stocked during these times.

During ReCoMaP the number of farmers increased and the area covered by ponds grew from 4.5 ha in 2008 to 43 ha in 2010, with Mtwara district alone contributing 17.6 ha in 2009. Because of the positive trends observed, and following advice from ReCoMaP project personnel, two NGOs were formed (POSIMCO - Pemba Organisation for Sea Inhabitants and Mangrove Conservation; and UWASA – 'Umoja wa Wafugaji Samaki Mtwara' or Union of Mtwara Fishfarmers), in 2010 and 2011 respectively. UWASA subsequently obtained funding from SWISSAID (Government of Switzerland Aid) ranging from 70,000 to 150,000 USD/year for 5 years to consolidate finfish farming mainly through improving the farming systems and producing fingerlings. In 2014 the newly established union had 174 members, 64 of whom were women, from 19 fish farming groups, with a pond area of 17 ha producing and average of 0.7 MT/ha/yr and earning an average of USD 650/ha/year.

The first activity undertaken by UWASA was to deepen the ponds to ensure they could hold water to a depth of at least 0.5 m, and to reshape the ponds to ensure that they could be completely drained. This had several advantages such as to control temperature and salinity ranges in the water and to reduce the chances of predation due to depth. Furthermore, record keeping charts were developed and used by specially trained field officers who also supervised the farming.

**Table 1.** Statistics of finfish farming during the ReCoMaP project (Extracted from Mmochi 2011)

| | Number of Members | Number of Women | Cost of construction (USD) | Size of Pond (m2) | Stocking density (ind/m2) | Survival rate | Harvest (Kg) | Price/kg (USD) | Kg/ ha | Total income (USD) | Income/ ha (USD) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total | 233 | 107 | 19848 | 131357 | | | 14463 | | | 13728 | |
| Maximum | 14 | 10 | 5119 | 25375 | 3,67 | 1,00 | 3380,00 | 1,67 | 7500 | 2400 | 10000 |
| Mean | | | 1103 | 5711 | 1,50 | 0,44 | 657,41 | 1,26 | 1549 | 572 | 2073 |
| SD | 9 | 5 | 1215 | 5386 | 1,06 | 0,30 | 863,16 | 0,44 | 2363 | 682 | 4582 |
| Median | 18 | 11 | 867 | 3496 | 1,245 | 0,395 | 400 | 1,33 | 625 | 250 | 745 |

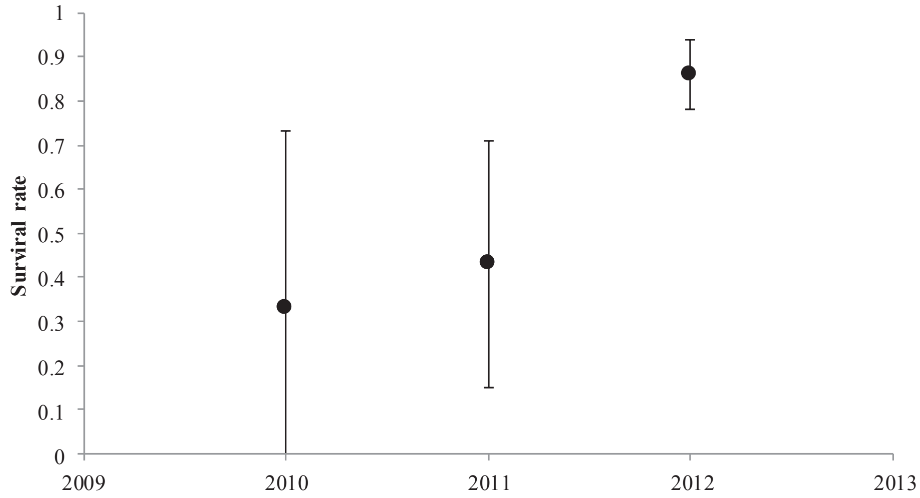

**Fig. 2.** Survival Rate of Milkfish in ReCoMaP and later UWASA ponds

The results of these improvements were a significant increase in survival rates (Fig. 2) and tonnage produced between 2010 and 2012.

Initially the farmers were selling their fish in bunches at the pond site within the villages; often by auction which is a typical method used in Tanzania for capture fisheries. During auctioning the weight of the fish is not considered, but analysis showed that the price realized during 2011 either through direct sale or auctioning was between 0.33 and 1.67 USD/kg with a mean of 1.26±0.44 USD/kg. In 2012 the farmers were trained in value chain analysis, packaging and marketing (Onyango, 2012), and UWASA organized a poster and radio advertising campaigns to alert the public when they would be harvesting and set a price of 3.8 USD/kg. Furthermore, UWASA purchased iceboxes to better preserve the fish. The marketing was successful and led to an improvement in the average income per farm (Fig. 3) and total income (Fig. 4). The large variation in earnings between farms in 2012 is an indicator of differences in the levels of adoption of the improved farming and marketing techniques.

With the production of around 0.7 MT/ha/yr in Mtwara, UWASA farms were producing what would be considered a 'good' harvest in Southeast Asia, where milkfish have been farmed for centuries. Production levels of 0.79MT/ha/yr in China (FAO, 2011), and 0.70 MT/ha/yr in India (Troell, 2009) are comparable to those found in Tanzania during the present study.

## Conclusions

There have been many attempts by local communities to undertake brackish and marine finfish farming in ponds constructed on the landward side of mangrove forests in Tanzania. Some have been more successful than others, but indications are that improved knowledge of value chains, new marketing strategies, and the use of iceboxes to avoid post-harvest losses, will contribute to growing success in Tanzania. Challenges such as ensuring a reliable source of fingerlings

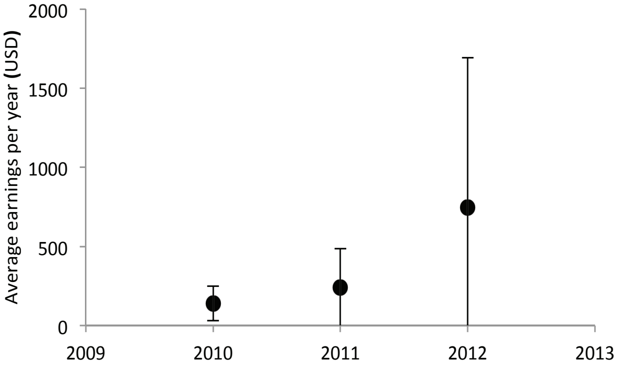

**Fig. 3. Average earning per year per farming group.**

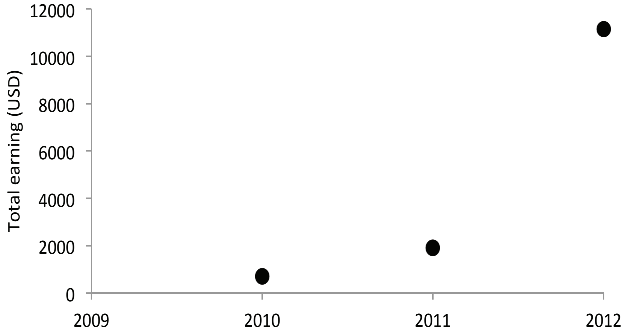

**Fig. 4. Total income from milkfish farming during ReCoMaP and thereafter (2010 -2012)**

remain, and the establishment of hatcheries for milkfish and other species that are low in the food chain such as mullet and tilapia, is considered as critical to support the development of the sector. In addition, further effort to consolidate farming and marketing techniques is needed.

## References

El–Sayed AM (2006) Tilapia culture in salt water: environmental requirements, nutritional implications and economic potentials. In Suarez LEC, Marie DR, Salazar MT, Lopez MGN, Villareal, C., Ortega, YAG (eds.) Avances en Nutricion Aquicola VIII. VIII Symposium Internacional de Nutricional Acuicola. 15-17 Noviembre. Universidad Autonoma de Nuevo Leon, Monterrey, Nuevo Leon, Mexico

FAO (2007) The state of world fisheries and aquaculture 2006. Fisheries and Aquaculture Department, Rome. 162 pp

FAO (1990) The definition of aquaculture and collection of statistics. FAO Aquaculture Minutes 7: 4 pp

FAO (2011) World Aquaculture 2010. Aquaculture Technical Paper 500/1, Rome. 105 pp

FAO (2012) The State of World Fisheries and Aquaculture 2012. FAO Fisheries and Aquaculture Department, Rome. 209 pp

Hall SJ, Delaporte A, Phillips MJ, Beveridge M, O'Keefe M, (2011) Blue frontiers: Managing the Environmental Costs of Aquaculture. The World Fish Center, Penang, Malaysia. 92 pp

Mmochi A (2015) Mariculture. In: UNEP-Nairobi Convention and WIOMSA (eds.) The Regional State of the Coast Report: Western Indian Ocean. UNEP and WIOMSA, Nairobi, Kenya. pp 289-303

Mmochi AJ (2011) Feasibility Study for Finfish Project in Mtwara District. Report submitted to SWISSAID in June/July, 2011. 25 pp

Mmochi AJ (2010) Sustainable Milkfish Farming: Cost-Effective Methods to Increase Food Supply, Incomes and Employment in Mtwara/Lindi, Tanga and Pemba Coastal Communities. Report Submitted to WIOMSA, ReCoMaP/07/01/408. 28 pp

Mmochi AJ, Mozes N, Powell H, Dubi AM, Gordin H, Jiddawi N, Kissil G, Msuya F, Mwangamilo J (2001) Design and preliminary results of an integrated mariculture pond system (IMPS) at Makoba, Zanzibar, Tanzania. In: Richmond MD, Francis J (eds.) Proceedings of the 20th Anniversary on Advances of Marine Sciences in Tanzania. WIOMSA Book Series No. 1. pp 431-450

Mmochi AJ, Dubi AM, Mamboya F, Mwandya A (2002) Water quality variations in Makoba integrated mariculture pond system. Western Indian Ocean Journal of Marine Science 1: 53-63

Onyango PO (2012) UWASA Value Chain Analysis Report. Training Report Submitted to UWASA, April, 2012, UWASA Repository. 12 pp

Requintina ED, Mmochi AJ, Msuya FE (2008) A Guide to Milkfish Farming in the Western Indian Ocean Region. Western Indian Ocean Marine Science Association, Institute of Marine Sciences and Coastal Resources Center of the University of Rhode Island. WIOMSA book series. 38 pp

Sullivan KA, Mmochi AJ, Crawford B (2010) Food security and poverty alleviation through milkfish farming: Is Tanzania ready? World Aquaculture 2010: 50-58

Troell M (2009) Integrated marine and brackish water aquaculture in tropical regions: research, implementation and prospects. In: Soto D (ed.) Integrated mariculture: a global review. FAO Fisheries and Aquaculture Technical Paper 529, Rome, FAO. pp 47-131

Troell M, Hetcht T, Beveridge M, Stead S, Bryceson I, Kautsky N, Ollevier F, Mmochi A (2011) Mariculture in the WIO Region "Challenges and Prospects". Proceedings from the Workshop on Mariculture, December 2009. WIOMSA Book Series 11: 72 pp

# Instructions for Authors

Thank you for choosing to submit your paper to the Western Indian Ocean Journal of Marine Science. These instructions ensure we have everything required so your paper can move through peer review, production, and publication smoothly.

## Editorial Policy

The Western Indian Ocean Journal of Marine Science (WIOJMS) is the research publication of the Western Indian Ocean Marine Science Association (WIOMSA). It publishes original research papers or other relevant information in all aspects of marine science and coastal management as original articles, review articles, and short communications (notes). While submissions on tropical and subtropical waters of the western Indian Ocean and the Red Sea will be given primary consideration, articles from other regions of direct interest to the western Indian Ocean will also be considered for publication.

All manuscripts submitted to the Western Indian Ocean Journal of Marine Science are accepted for consideration on the understanding that their content has not been published elsewhere and is not under consideration by any other journal. Manuscripts and all illustrations should be prepared according to the instructions provided below. Submissions will be subject to a pre-review by the Editor-in-Chief or a member of the Editorial Board and those that fall within the remit of the journal, make a substantial contribution to the field of research, and are in the correct style and format will be sent for review. Manuscripts that do not meet these criteria will be rejected. Every manuscript will be reviewed by at least two referees competent in the field of interest. The choice of reviewers is made by the Editor-in-Chief or the Editorial Board.

## Submission

Authors should submit an electronic version of the manuscript online by registering as an author on the AJOL. info WIOJMS website and following the submission prompts. This can be accessed directly or via the link provided at the journal's page on the WIOMSA website. Authors are asked to suggest the names of at least two referees with respective email contacts in the submission message to the editor.

## The Manuscript

**1.** The manuscript is your own original work, and does not duplicate any other previously published work, including your own previously published work.

**2.** The manuscript has been submitted only to the Western Indian Ocean Journal of Marine Science; it is not under consideration or peer review or accepted for publication or in press or published elsewhere.

**3.** By submitting your manuscript to the Western Indian Ocean Journal of Marine Science, you are agreeing to any necessary originality checks your manuscript may undergo during the peer-review and production process.

**4.** Contributions must be written in English. Any consistent spelling and publication styles may be used. Please use single quotation marks, except where 'a quote is "within" a quotation'. Long quotations of 40 words or more should be indented without quotation marks. If English is not your first language we suggest that an English-speaker edits the text, before submission.

**5.** All persons who have a reasonable claim to authorship must be named in the manuscript as co-authors; the corresponding author must be authorized by all co-authors to act as an agent on their behalf in all matters pertaining to publication of the manuscript, and the order of names should be agreed by all authors.

**6.** The manuscript must be typed in a normal type font (e.g. Times Roman, font size 12) and at least with 1.5 line spacing. The total number of pages should not exceed 20 manuscript pages (excluding figures and tables), both for Original Articles and Review Articles. Short Communications must not exceed 8 manuscript pages. A separate sheet should be used for each table and figure.

**7.** Species names must be in italics; the genus is written in full at the first mention in the Abstract, again in the main text and the figure and table legends, and abbreviated thereafter.

**8.** Illustrations (figures, tables) should be placed separately at the end of the manuscript. Originals of all figures should be in black and white (graphs) but colour is acknowledged for figures such as maps and diagrams, and complex graphs where black and white does not allow good separation of patterns; the lettering should be of a size readable after reduction for the final layout. Figure legends (captions) should be written on a separate page. Table legends must incorporate all the information needed and placed on the same page as the table. Authors are requested to indicate the recommended position of figures and tables in the left-hand margin of the text.

**9.** The international system of units (SI Units) must be used throughout; abbreviations and acronyms should be identified where they first appear; mathematical symbols and formulae should be used only when absolutely necessary and should be clearly defined in the text.

**10.** A complete **Original Article** manuscript must include the following: title page, abstract, keywords, introduction, materials and methods, results, discussion, acknowledgements, references, tables and figures (with figure legends) in that order.

**a. Title Page:** This should contain a concise title and the names of authors followed by affiliations and their complete postal addresses, phone numbers, and email addresses. The corresponding author and email address must be indicated.

**b. Abstract:** The abstract should not exceed 200 words, and should be on a separate page. It should briefly describe the main points of the manuscript, i.e. the topic, the main findings and the conclusions.

**c. Keywords:** four to six key words are required for indexing purposes.

**d. Introduction:** A brief survey of relevant literature and objectives of the work should be given in this section. Thus, the introduction should largely be limited to the scope, purpose and rationale of the study.

**e. Materials and Methods:** In this section, the methodology used should be clearly explained, including relevant references, such that another person can repeat the procedures. It should provide the framework to gain answers to the questions or problems identified.  Sampling methods must be elaborated as well as analytical frameworks and model specifications.

**f. Results:** Make the text as objective and descriptive as possible. Only material pertinent to the subject should be included. Avoid presenting the same information in both graphical and tabular form.

**g. Discussion:** This section could be combined with the above to present "Results and Discussion". It should interpret the results in view of the problems identified in the introduction, as well as in relation to other published work. The final paragraph of this section could include concluding remarks and recommendations for future work.

**h. Citations:** Authors should be cited using their surnames, followed by the year of publication. Two authors should be separated by 'and'. If there are more than two authors, only the first author, followed by "*et al.*", should be given. This and other Latin or foreign terms should be italicized.

**i. Acknowledgement/s:** This section should be brief. Authors are advised to limit acknowledgements to substantial contributions to the scientific and technical aspects of the paper, financial support or improvements in the quality of the manuscript.

**j. References:** The reference section must contain an alphabetical list of all references mentioned in the text of the manuscript. Limit punctuation and special fonts as indicated and give all journal names in full. Examples for citations from periodicals, books and composite works are given below:

- *Periodicals*. Here the following should be sequentially listed: author's name/s, initials, year of publication, full title of paper, periodical (in full), volume, first and last page numbers.

  Example: Richardson K, Beardall J, Raven J (1983) Adaptation of unicellular algae to irradiance: An analysis of strategies. The New Phytologist 93: 157-191

- *Books*. The following should be listed: author's or editor's name, initials, year of publication, full title, publisher, place of publication, total pages.

  Example: Kirk TJO (1983) Light and photosynthesis in aquatic ecosystems. Cambridge University Press, Cambridge. 401 pp

- *Composite works or serials.* The sequence should be as above, but also should include full title of paper followed by In: editor(s) if any, full title of publication, publisher, etc., and the first and last page numbers.

  Example: Sathyendranath S, Platt T (1993a) Remote sensing of water-column primary production. In: Li WKW, Maestrini SY (eds) Measurement of primary production from the molecular to the global Scale. ICES Marine Science Symposia, Vol. 97, Copenhagen. pp 236-243

- *Articles with a Digital Object Identifier (DOI).*

  Example: Gooseff MN, McKnight DM, Lyons HJ, Blum RJ (2002) Weathering reactions and hyporheic exchange controls on stream water chemistry in a glacial meltwater stream in the McMurdo Dry Valleys. Water Resources Bulletin 38 [doi: 10.1029/2001WR000834]

**k. Tables and illustrations:** Each figure/table/photograph should be numbered consecutively, accompanied by a complete caption, and must be cited in the text. Figures should be of high quality to allow reproduction and reduction without loss of information. When accepted for publication the original figure files may be requested to authors in order to eventual standardization and graphical improvement. Photographs should be of excellent quality to maximise contrast and detail during printing (15cm longest edge @300 dpi), be focused and well composed.

**l. Supplementary material:** In case it is found relevant, authors may submit appendices with relevant information of major interest for the interpretation of the manuscript results. This is not applicable for the raw data of normal research. The editors will decide its eventual inclusion as appendices.

**11.** A complete **Review Article** manuscript must include the following: title page, abstract, keywords, introduction, main body text (the central sections vary with specific divisions according to the theme), acknowledgements, references, tables and figures (with figure legends) in that order.

**12.** A complete **Short Communication** manuscript must include the same structure as an Original Article in a shorter format.

The Western Indian Ocean Journal of Marine Sciences is the research
publication of the Western Indian Ocean Marine Science Association (WIOMSA).
It publishes original research papers or other relevant information in all aspects
of marine science and coastal management as articles, reviews,
and short communications (notes).