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# Mangrove's response to cyclone Eline (2000): What is happening 14 years later

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This study assesses the impact of severe cyclones on a mangrove forest and the response over a 14 year period. SPOT images from pre- and post-cyclone years were used to assess changes in area and in the Normalized Difference Vegetation Index (NDVI) in a cyclone impacted mangrove forest in central Mozambique. Forest structure and condition were evaluated in the field 11 years after the cyclone, sampling both the protected creek and exposed seaward mangroves. Transects perpendicular to the coast line were set across impact zones, covering high-, mid- and less-impacted zones. Quadrats ($10 \times 10$ m) were set along each transect, and adult trees within were identified to species, Diameter at Breast Height (DBH) measured, height estimated, and life condition (living or dead) indicated. Regeneration was assessed in $5 \times 5$ m quadrats. Cyclone Eline impacted on 47.8% of the mangrove forest area, as shown by reduced NDVI in 2000 after the cyclone. Field sampling results indicate substantial recovery in creek forests; while seaward mangroves had 100% mortality in *Rhizophora mucronata* dominated areas. This species is sensitive to defoliation and sedimentation and unable to sprout. Only mid- and less-impacted zones had high densities of juveniles. Species with high regenerating success were *R. mucronata*, *Ceriops tagal* and *Avicennia marina*. Sheltered creek mangroves were able to recover but changes in sedimentation prevented recovery in the exposed seaward sites. This study highlights the need to understand the response of mangroves to cyclones, considering increased frequency with climate changes. Higher frequency of cyclones might prevent recovery, threatening the forest and associated coastal protection. However increased forest resilience can be gained with proper management.



## 1. Introduction

Globally, there are 7 main tropical cyclone areas, which are the North Atlantic Ocean, Eastern and Western parts of the North Pacific, Southwestern Pacific, Southwestern and Southeastern Indian Ocean, and the Northern Indian Ocean (Gray, 1968). The most active areas are the Western North Pacific with an average of 26 tropical storms each year and the North Atlantic Basin, where on average 6 of the 10 annual tropical storms reach the hurricane strength (Henderson-Sellers et al., 1998). In the southern hemisphere, the Southeastern Indian Ocean is the most active area, with an average of 9 cyclones per year (Henderson-Sellers et al., 1998).

In South Eastern Africa and Western Indian Ocean, the long coastlines of Mozambique and Madagascar are amongst the most affected by cyclones. Particularly to Mozambique, in the last 65 years its coast has been affected by at least 20 cyclones (Mavume et al., 2014), three of which were very severe and made landfall in the south-central region between 2000 and 2007: Tropical cyclone Eline in 2000, which was the longest-lasting (29 days) tropical cyclone in the Indian Ocean (Reason and Keibel, 2004); Tropical cyclone Japhet in 2003 and Tropical Cyclone Favio in 2007 (Mavume et al., 2014). All cyclones were very damaging in terms of human lives and infrastructure. Impacts on natural habitats are also likely to have occurred (Furze and Preble, 2003; Ohara and Falvey, 2007; Massuanganhe et al., 2015).

Understanding the impacts of cyclones on natural habitats, and the habitat's response and recovery mechanisms is particularly important in the current scenario of climatic changes exacerbated by an increasing trend in the frequency and intensity of cyclones

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worldwide (Webster et al., 2005). Mangroves in particular are key ecosystems in this matter, considering their role in coastal protection, carbon sequestration and the high vulnerability and susceptibility to impacts during such events (Alongi, 2008; Gilman et al., 2008).

Mangroves can be impacted in several ways, such as land-use changes, conversion to bare soils, physical damages to plants, defoliation and uprooting, changes in population structure (including in regeneration), sedimentation, erosion (Smith et al., 2009) and changes in soil characteristics (Cahoon et al., 2003). The duration and intensity of such impacts will depend on numerous factors (Sherman et al., 2001), including site-specific biophysical characteristics, species composition and species ability to cope with inflicted damages (Baldwin et al., 2001; Sherman et al., 2001). Healthy resilient forests will be in a better condition to recover after a major disturbance, and the least frequent the disturbance, the greater the chance for a full recovery (Alongi, 2008).

Studies on the impact of cyclones (and associated floods) and climate change on mangroves were documented in parts of the world, including Australia and Micronesia, United States of America, Nicaragua, India, Bangladesh, Myanmar, and many more (Paling et al., 2008; Kauffman and Cole, 2010; Aung et al., 2011). Most studies rely on remote sense techniques to asses land use changes and changes in forest area (Paling et al., 2008; Bhowmik and Cabral, 2013), while others focus on physical damages caused by winds and storm surges on the mangrove trees (Doyle et al., 1995; Houston, 1999), changes in the forest structure and regeneration patterns (Roth, 1992; Kauffman and Cole, 2010) and forest recovery after cyclone impact with and without human intervention (Harun-or-Rashid et al., 2009; Aung et al., 2011, 2013).

In Africa, and the Eastern African region in particular, studies on the impacts of cyclones and climate change related events are uncommon, and rarely isolate climate-related events from human interference (Bosire et al., 2014). To our knowledge, documented studies of cyclone impact on mangrove structural dynamics in the Western Indian Ocean are scarce, except for the study that describes die back of *Heritiera littoralis* in Rufiji Delta (Tanzania) after El Niño related floods (Erftemeijer and Hamerlynck, 2005) and the qualitative description of the impacts of the recurrent catastrophic events (cyclones and floods) on human and natural systems in central Mozambique (Massuanganhe et al., 2015).

This study assesses the condition of a mangrove forest in Eastern Africa that has been impacted by three major cyclones and associated floods. Furthermore, it focuses on how impacts and recovery might differ in different mangrove locations setup in the same cyclone impacted estuary (from Save River, a major one in eastern Africa). By combining field sampling and remote sensing techniques (NDVI), the study also documents the forest dynamics, recovery and condition after cyclone impact, highlighting the regeneration process and change detection.

## 2. Material and methods

### 2.1. Description of study site

The study was implemented in Save River Delta, the fourth largest river in south-central Mozambique, and one of the largest in Eastern Africa. Biophysically its river mouth area falls within the muddy coast section, a low lying area with numerous streams discharging into the Indian Ocean. The area is suitable for the growth of well-established mangrove formations, which extend to the Zambezi Delta further north. Two main villages were built along this section of the river (Machanga and Nova Mambone Villages), and according to the 2007 census (http://www.ine.gov.mz), the main economic activities of the local coastal communities are agriculture, cattle and fishing. The climate of the area is tropical humid (annual precipitation 1500 mm), with two seasons. The wet season extends from November to March (peak in January/February), with average temperatures of 33 °C; while the dry cooler season extends from April to September, with average temperature around 18 °C. The wet season is also cyclone prone, and since 2000 the area has been hit by three major cyclones: Eline in 2000 (wind speed between 168 km/h and 212 km/h when crossed the study area); Japhet in 2003 (wind speed of 157 km/h in the study area) and Favio in 2007 (wind speed of 222 km/h in the study area) (Fuze and Preble, 2003; Reason and Keibel, 2004; Ohara and Falvey, 2007). Cyclone Eline was the most devastating to the mangroves in the study area due to the severity of the cyclone when passing the Mozambican coast and proximity of the mangroves to the landfall site. Key ecosystems represented in the area include seagrass beds and mangrove forests, which grow in most river mouths covering the adjacent districts of Govuro and Machanga (Massuanganhe et al., 2015).

### 2.2. Mapping

SPOT data were used to map and analyze the mangrove changes over the time. The images were orthorectified and projected to UTM zone 36 S. For the mapping process, the principles of remote sensing were used by extracteing the Normalized Difference Vegetation Index (NDVI) for further comparison over the time period in analysis. The SPOT images used in this study were taken in 1999 (before the cyclone), 2000 (months after cyclone Eline), 2007 (months after Cyclone Japhet), 2011(field sampling period) and 2014 (present time) covering a time span of 15 years. The SPOT images were aligned one to another as some of them were the same scale as the others. This registration was undertaken as a prerequisite for further comparison by overlapping that data.

A geomorphological approach was used to separate mangrove wetland areas from the upper deltaic plain, which included vegetated dune ridges. The wetland areas assessed were those where mangrove forest has high chances to develop. From this stage, the NDVI was extracted from each image and compared the changes to the subsequent image with the purpose of finding a pattern that may be correlated with the cyclones that affected this region. Therefore, each NDVI map was resample to a 10 m cell size for further comparison and all data were exported to a table containing the attributes of each cell. This allowed the extraction of cell values and to perform the arithmetical operation to find the differences between the different years.

The comparisons between the different years were performed by calculating the difference between the NDVI with the subsequent year. With this operation all the positive values would reflect areas of greenness where the mangrove may have increased allowing in this way to record even smaller changes that could not be accounted when using a visual approach.

### 2.3. Mangrove sampling

Sampling areas were identified based on local knowledge of impacted sites after cyclone Eline in 2000 (the first and most devastating). The sampling took place in 2010 and 2011, and at each time a different impacted area was visited. Two sub-areas were identified in the field: sub-area A with creek protected mangroves and sub-area B with seaward exposed mangroves. In both sub-areas, three blocks were identified: Block I for the mangroves growing along the creeks or sea, highly impacted by the cyclone; Block II of mid-section mangroves, with medium impacts; and Block III for the inner mangrove, with few or no visible impacts of the cyclone (Fig. 1). A variable number of 10 × 10 m quadrats were set in each sub area and blocks along the transect, separated by at least 25 m. The number of quadrats varied with the length of each Block. In