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The response of the red mangrove *Rhizophora mucronata* Lam. to salinity and inundation in South Africa

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ABSTRACT

Salinity and water level fluctuations are important factors that influence mangrove species distribution, zonation patterns and succession. Increases in salinity and prolonged inundation are predicted along the south eastern African coast associated with sea level rise due to climate change. This study investigated the response of red mangrove seedlings (*Rhizophora mucronata* Lam.) to these factors in controlled laboratory experiments. Seedlings were exposed to five salinity treatments (0, 8, 18, 35 and 45 PSU) and a semi-diurnal tidal cycle in an experimental tank set-up. In a separate experiment the effects of different inundation treatments: no inundation, 3, 6, 9 h tidal cycles and continuous inundation (24 h) were investigated. Both morphological and physiological responses of *R. mucronata* seedlings were measured. There was a decrease in growth (plant height, biomass and leaf production) with increasing salinity. Seedlings in the seawater, hypersaline and no inundation treatments showed symptoms of stress such as increased leaf necrosis ('burn marks'). The highest seedling growth occurred in the low salinity (8 PSU) treatment, but the highest photosynthetic performance and stomatal conductance occurred in the freshwater treatment (0 PSU). The typical response of stem elongation with increasing inundation was observed in the 24 h inundation treatment. Seedlings in the no inundation treatment had significantly lower seedling height compared to the other treatments.

1. Introduction

Understanding the response of mangroves to climate change is important as these habitats are rapidly disappearing due to natural and human impacts (Nicholls et al., 2007). Sea level rise will increase salinity when tides push up further into estuaries, there will be longer inundation cycles and changes in the intertidal region. Modeling by McFadden et al. (2007) suggests that as much as 33–44% of mangrove ecosystems may be lost from 2000 to 2080 due to an increase of 36–72 cm in sea level. These losses would however be site-specific. It is therefore necessary to understand the effects of these changes on mangrove growth.

A study on *Rhizophora mucronata* trees showed that they responded to high salinity by increasing their vessel density to facilitate increased and better water transport in hypersaline environments (Schmitz et al., 2006). *R. mucronata* is also a salt excluder that accumulates salt in the more mature leaves which are then shed to rid the plant of salt (Steinke, 1999).

Aziz and Khan (2001) showed that *R. mucronata* seedlings had optimum growth at 17.5 PSU while another study by Jayatissa et al. (2008) found that *R. mucronata* seedlings flourished at 26 PSU, hence the specific tolerance range of this species to salinity has not been fully understood. South Africa is a semi-arid country where the high demand for freshwater places stresses on our aquatic environments. The closure of estuaries to the sea is a threat and this leads to loss of mangroves. An understanding of the responses of mangroves to these local changes is necessary to ensure the conservation and management of these unique ecosystems particularly at their southern limit in Africa. Additionally, in South Africa, *R. mucronata* is a protected tree species and predict the local responses of this species an greater understanding of plant ecophysiology is needed.

Although mangroves are adapted to periodic waterlogging, different species respond differently to the duration of inundation (Luzhen et al., 2005). Prolonged inundation can cause mangrove die-back. This occurred in the Kosi Estuary in KwaZulu Natal, South Africa when the mouth closed and water level increased. Large areas experienced mass die offs of mangroves (Branch and Branch, 1995). Mouth closure in such systems is normally a rare event, but may result from heavy storms or freshwater abstraction in the catchment. Mangroves have modified roots to cope with low sediment oxygen conditions. These roots are mostly made up of aerenchyma tissue where the air spaces provide rapid diffusion of oxygen through the lenticels

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to the rest of the submerged root system (Lovelock et al., 2006a,b).

The red mangrove *R. mucronata* Lam. is found worldwide from East Africa and India through Asia as well as Indonesia to the western Pacific, wet tropical regions of Australia (Duke, 2006) and in Mozambique and South Africa, where it is distributed from Kosi Bay in KwaZulu-Natal to the southern limit in Pondoland (MacNae, 1963; Steinke, 1999). However, some individuals of *R. mucronata* have been found further south at Wavecrest at the Nxaxo Estuary, Eastern Cape (32°35′S; 28°31′E) (Adams et al., 2004). In South Africa *R. mucronata* occurs along channels and fringing estuary habitats and is not as abundant as *Avicennia marina* or *Bruguiera gymnorrhiza* (Steinke, 1999). Because of the limited distribution of *R. mucronata* in South Africa, this species is in the Protected Tree List of South Africa in the Department of Water Affairs and Forestry (National Forest Act of 1998, Act 84 of 1998, of South Africa).

The aim of this study was to determine the growth responses of *R. mucronata* seedlings to different inundation cycles and salinity concentrations. This species was chosen for the study as it typically occurs in the lower intertidal zone, fringing rivers and lagoons (Duke, 2006) which are considered susceptible to changing climate.

2. Materials and methods

2.1. Propagule collection prior to the study

Mature propagules of the species *R. mucronata* were collected from the Mngazana Estuary (31°42′S, 29°25′E) in the Eastern Cape Province, South Africa. Five propagules were planted in each plastic pot (2 l) containing sediment collected in the same area. Pots were kept under natural light in a glasshouse, watered with 50% seawater once a day and air temperature in the greenhouse was between 27 and 35 °C. Propagules were allowed to germinate and grow for ±3 months prior to the experiments. Then all established seedlings within the pots were moved from the Nelson Mandela Metropolitan University's glasshouse to a through-flow seawater system at Bayworld's Research Laboratory.

2.2. Tank set-up

The research laboratory had natural light (transparent corrugated roofing and large windows). The average light within the research laboratory was 850 + 67 μE m^{-2} s^{-1} at midday. The experiment was conducted during May to August 2008, during the autumn and winter months, when day length was 11–13 h. Moderate temperatures (22–30 °C) were maintained using a manual extractor fan (Xpelair model 90012 AW) and monitored with a data logger.

Salinity treatments of 0, 8, 18, 35 and 45 PSU were used, where 35 PSU was undiluted seawater while 45 PSU represented hypersalinity. These treatments all had a semi-diurnal tidal cycle. Different tidal cycles were used for the inundation experiment. For the no inundation treatment (0 h) the pots stood in 5 cm deep water and were never inundated at any time. The continuous inundation treatment (24 h) was standing water with a water level of approximately 30 cm from the base of the propagules. The other three treatments were 3, 6 and 9 h tidal cycles. These treatments all had the same salinity concentration of 18 PSU.

Tidal regimes were simulated using a tidal tank set-up similar to that used by Luzhen et al. (2005). Two custom made glass tanks (length 2.64 m, width 0.52 m and height 0.60 m) were set up next to each other. One tank was used for the salinity treatments and the other for the inundation treatments. Each tank had five equally sized compartments (0.52 m × 0.6 m × 0.52 m) with a capacity of 162 l. The compartments had an inlet and an outlet pipe, a siphon on the outlet pipe, thermostats, air tubes and air stones to create water circulation and provide aeration. Compartments also contained crates for pots to stand on.

A flow-through and recycling system was designed to simulate natural tidal cycles. The system consisted of four 1000 l storage batch containers, a custom-built programmable unidirectional liquid multiplexer that consisted of four input and twelve output points which provided the correct treatment water to the tank. The rotating arm of the multiplexer was connected to a motor and encoder which were in turn connected to a Programmic Logic Controller (PLC) (Allen-Bradley Micrologix-1000) which determined the mixing process and was programmed according to the needs of the experiment. Water supply was programmed on the PLC that ran as a time based sequencer, running in 15 min intervals. For example, to make up a 12 h tidal cycle there were 48 steps in total. For each step the program had the compartment number, representing the different treatments, as well as the number of parts that were required to make up these treatments, from each of the three sources coming from the 1000 l storage batch containers.

Fresh seawater was pumped from the sea and fed to the storage containers. The water passed through the tanks only once and went to waste thereafter. However, the hypersaline water supply was recirculated between the treatment and 1000 l storage batch container. The batch was replaced twice during the 14 week study period. Hypersaline water was produced by dissolving ready to use aquarium salt (aQuality Research grade Synthetic Reef Salt, Cape Town, South Africa) in seawater.

For tidal simulation each compartment had a siphon pipe which allowed the tanks to drain to the low water mark (LWM) (low tide just covered the bottom of the tank with 5 cm of water) when the compartments were overfilled. The simulated high tide caused all seedlings to be flooded with only the upper foliage exposed. Overfilling the compartments triggered the siphoning that created a low tide.

2.3. Measurements for salinity and inundation experiments

There were five seedlings in each pot and the different salinity and inundation treatments had five replicate pots where each pot was considered a replicate. It would have been nice to have replicate tidal compartments but this was not possible because of infrastructure constraints. The plants were acclimatized to the different salinity concentrations for five weeks. They were then placed into the representative treatment compartments. The two experiments, salinity and inundation, ran parallel for a 14 week period. From May to August plant height and number of leaves of each seedling were measured and morphological changes noted.

Leaf stomatal conductance and leaf chlorophyll fluorescence (Fv/Fm) were measured using a Leaf Porometer (Decagon Device, US/Canada) and a Hansatech Plant Efficiency Analyser (Hansatech Instruments, Norfolk, England). Before measuring fluorescence the seedlings were dark-adapted for 30 min. The unit automatically calculated the Fv/Fm parameter which represents the "quantum yield or efficiency of photochemistry in PS II" (Björkman et al., 1988). Measurements were done at the start of each experiment and every two weeks thereafter for a total of 14 weeks. Each seedling was tagged with a number and these were secured to the stem of the seedling with plastic cable ties. One mature leaf of each seedling was chosen and tagged with a thin piece of thread. In both cases care was taken not to break the leaves or secure the materials too tightly so that growth would be inhibited. Stomatal conductance and fluorescence measurements were made on the abaxial surface of fully expanded, mature leaves. The same tagged leaves were measured every 2nd week. Following harvesting, leaf water content was measured by first recording the wet weight (WW) of the leaves and then oven-drying these at 60 °C for a week.