FAO REGIONAL OFFICE FOR AFRICA

Salinity fluctuations in mangrove forest of Gazi bay, Kenya: lessons for future research

Elisabeth Robert[1,2,], Nele Schmitz[1,2,*], Hamisi Ali Kirauni[3] and Nico Koedam[1]*

Summary

Studies on mangrove ecosystems that deal with the interaction of organisms and their environment very often draw conclusions based on only a restricted number of soil water salinity measurements. As inundation by salty water is the most typical characteristic of the mangrove environment, the authors addressed the temporal and spatial fluctuation of soil water salinity at seven locations in the mangrove forest of Gazi Bay, Kenya. As a pilot study, the research team measured soil water salinity twice a month, at neap tide and at spring tide, during one year. It can be concluded that the soil water salinity in mangrove forests can be highly variable in time as well as in space and depends on a complex interaction between inundation frequency, canopy closure, fresh water input and soil texture. Mangrove researchers should therefore pay attention to the differences in local site conditions inside the mangrove forest and conduct salinity measurements that cover the temporal and spatial fluctuations before drawing conclusions on the relationship to this environmental condition.

Introduction

As mangrove ecosystems are ecologically and economically of high importance but fast disappearing and degrading (Duke, *et al.*, 2007), it is important to conduct scientific studies - fundamental as well as management based – to obtain the necessary knowledge to preserve, to protect and to restore mangrove forests. Ideally, such studies should not only deal with the organisms of the mangrove ecosystem – fauna as well as flora - but also with the interaction between these organisms and their environment. The most characteristic elements of the mangrove environment are a frequent inundation and saline water (Tomlinson, 1994), both not only strongly determining the life of the mangrove inhabitants (e.g. Fratini, *et al.*, 2004, Schmitz, 2008, Robert, *et al.*, 2009) but also, by selection, nature's diversity and assemblage composition.

Studies dealing with the relationship between organisms and their environment often generate conclusions from a restricted dataset – spatially and/or temporally – of environmental parameters. The purpose of this research is to study the variability of the soil water salinity on a spatial as well as on a temporal scale in the mangrove forest of Gazi Bay, Kenya, a well studied site as concerns mangrove research. The results of the study are intended to evaluate the fluctuation of one of the key parameters of the mangrove environment on an intra-annual scale and this for different study sites situated relatively close to each other.

[1] Laboratory of Plant Biology and Nature Management (APNA), Vrije Universiteit Brussel (VUB), Pleinlaan 2, B-1050 Brussels, Belgium, Tel.: +32 2 629 34 14, Fax: +32 2 629 34 13. E-mail: erobert@vub.ac.be (E.M.R.R. – PhD student); nschmitz@vub.ac.be (N.S. – postdoctoral researcher); nikoedam@vub.ac.be (N.K. – professor)
[2] Laboratory for Wood Biology and Xylarium, Royal Museum for Central Africa (RMCA), Leuvensesteenweg 13, B-3080 Tervuren, Belgium, Tel.: +32 2 769 56 13.
[3] Kenya Marine and Fisheries Research Institute (KMFRI), PO Box 81651, Mombasa, Kenya, Tel.: +254 414 75 15 14. E-mail: hamisikirauni@yahoo.com (H.A.K. – scientific employee)
[*] The first two authors have equal contribution on this work.

Study area

Study sites

The study area is situated in Kenya, in the mangrove forest of Gazi Bay (39°30'E, 4°25'S), which covers about 600 ha (UNEP, 2001, Neukermans, *et al.*, 2008) and is situated approximately 50 km south of Mombasa. The mangrove forest has a tidal amplitude of about 3.8 m with a maximum of 4.1 m (Kenya Ports Authority tide tables for Kilindini, Mombasa) and is characterized by a sloping topography (Matthijs, *et al.*, 1999). Seven sites spread over the mangrove forest (Figure 1) were studied with as common characteristic the occurrence of the mangrove tree species *Avicennia marina*.

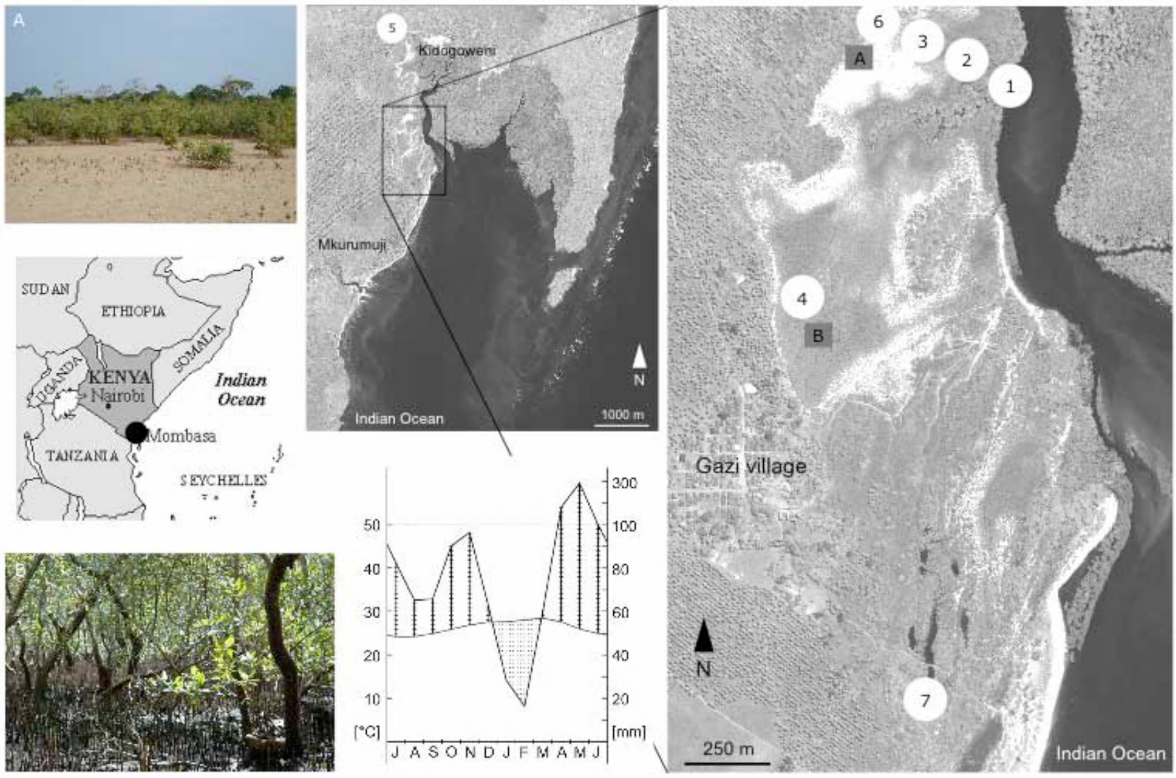

Figure 1: Description of the study area. Map of east Africa (left middle) *showing the location of Gazi Bay on the Kenyan east coast (black dot) and two QuickBird satellite images of Gazi Bay (Kenya) (middle up and right), acquired in 2002 (Neukermans, et al., 2008) situating the seven study sites in the mangrove forest of Gazi Bay and the location the pictures A and B (left up and left down) have been taken. The two seasonal rivers that provide freshwater to the mangrove forest are indicated on the satellite image in the middle. Climate diagram (middle down) of Mombasa (adapted from Lieth, et al., 1999) representing the climate of the African east coast. Temperature (°C) is shown on the left and precipitation (mm) on the right vertical axe. Precipitation scale is reduced to 1/10 above the horizontal line. Pictures: Nele Schmitz and Elisabeth Robert.*

Climate description

The climate along the Kenyan coast is characterized by a bimodal distribution of the precipitation (Figure 1). A distinct dry season (January - February) is followed by a long (April - July) and a short (October - November) rainy season (Figure 1). During the wet season, the rivers Mkurumuji and Kidogoweni (Figure 1) provide an important freshwater source for the mangroves of Gazi Bay. The average temperature at the Kenyan coast ranges from 22 to 30°C, with a mean relative humidity of 65% to 81% (annual averages of minimal and maximal values for Mombasa for the period 1972 - 2001, data from the Kenyan Meteorological Department, Mombasa, Kenya).

Material and methods

Environmental data collection

For each of the seven sites (i) soil texture was determined by standard field characterization methods (GLOBE, 2005) and (ii) height above sea level and inundation frequency were calculated based on the Kilindini Harbour tide tables (Kenya, 39°39'E, 4°04'S). The local flooding level was measured with tracing paper impregnated with ecoline dye. For study site seven the exact height above datum and inundation frequency could not be determined. Here, the mangrove trees grow in a basin and are disconnected from the rest of the basin type forest by a raised road. Consequently, the inundation frequency differs in rainy and dry season since the water level reaches more frequently the height of the road during the former.

From April 2007 to February 2008, the salinity was measured at each site with a hand-held refractometer (ATAGO, Tokyo, Japan / 0 – 100 ‰). Here for, soil water was sampled two times a month, once during neap tide and once during spring tide, at approximately 25 cm depth and at three positions scattered over each of the seven study sites. This was done with a punctured plastic tube connected to a vacuum pump or by digging a hole of the same depth when fine soil particles clogged the filtering tissue wrapped around the punctured plastic tube. Soil water salinity has only been measured at 25 cm depth so that the variation in soil water salinity with depth is not within the scope of this study.

Data analysis

To show the variation in soil water salinity, median, minimum and maximum values were calculated. However, at three of the seven sites no soil water could be extracted at certain dates (Figure 2, black stars). In these cases, the highest soil water salinity measured during fieldwork expeditions in the rainy season of 2005 and 2006 and the dry season of 2007 and 2009 was taken. For the basin forest the highest salinity of the water in the puddle was taken. Monthly rainfall data were averaged for the period 1966-2006 and are from the Kenyan Meteorological Department, Mombasa, Kenya.

Results

The seven study sites, although situated in one mangrove forest, differed seriously in environmental conditions (soil texture – height above sea level – inundation frequency) (Table 1). The annual average salinity as well as the pattern of variation of the soil water salinity over the year was different in different study sites (Figure 2).

Discussion

The study could not indicate one factor as being the main environmental characteristic determining soil water salinity. Instead, different environmental factors contribute to the annual average salinity as well as to the pattern of variation of the soil water salinity over the year. But although no clear-cut relationships between soil water salinity and environmental characteristics could be deducted from Figure 2, some trends were observed.

Table 1. Environmental description of the seven study sites in the mangrove forest of Gazi Bay, Kenya.

Location	Soil Texture	H_{asl} (m) †	Inundation frequency ‡ (days/month)
site 1	silty clay	2.18	30
site 2	sandy loam	2.84	23
site 3	loamy sand	3.25	14
site 4	clay loam	3.35	12
site 5	clay loam – loamy sand	3.49	8
site 6	sandy loam – loamy sand	3.63	5
site 7	loamy sand – sandy loam	3.66-3.80*	5-3*

† Height above sea level.
‡ Inundation frequency based on the Kilindini Harbour tide tables of 2009.
* See 'Material and methods – Environmental data collection' for more information.

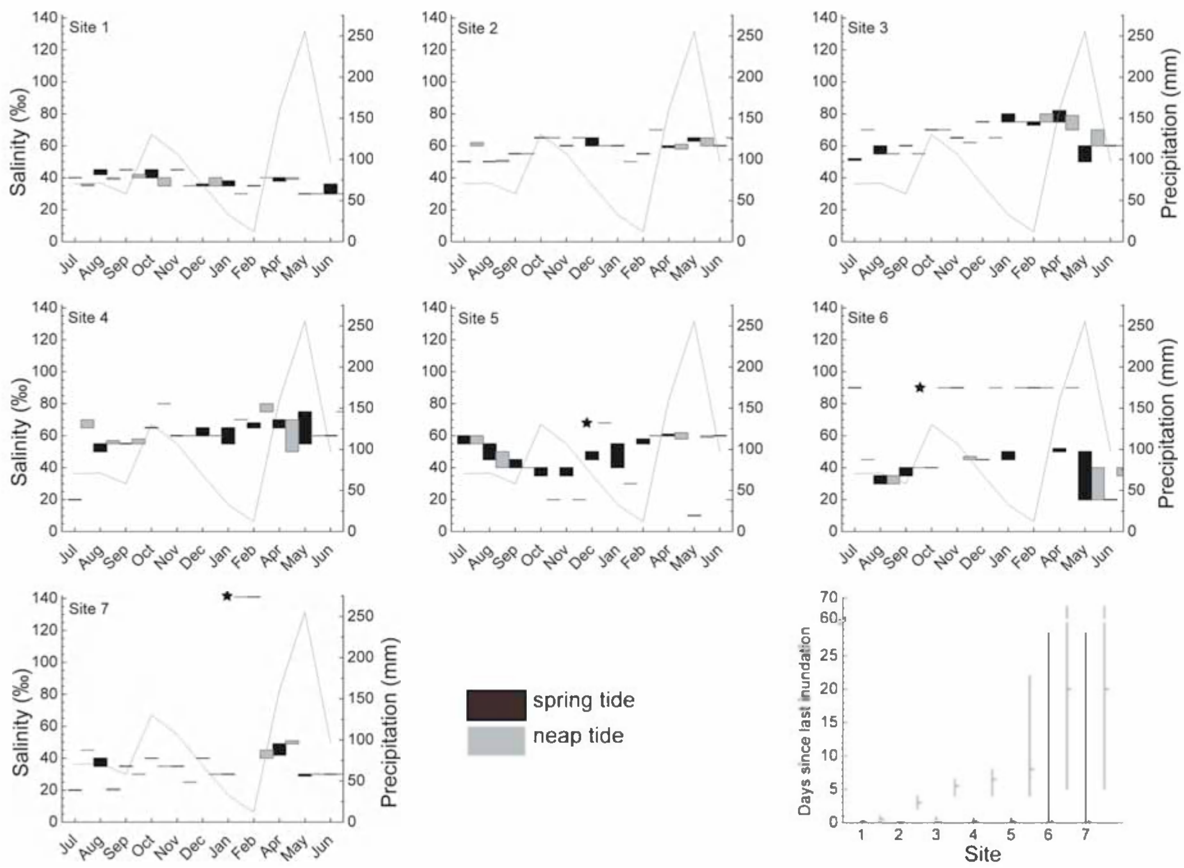

Figure 2: Spatial and temporal variation in soil water salinity in the mangrove forest of Gazi Bay, Kenya. *Bars represent the salinity range of three measurements on the day when the high tide was highest during spring tide or lowest during neap tide. Black stars indicate moments when no soil water could be extracted and the highest soil water salinity measured in the period 2005-2009 was plotted (see also 'Material and methods – Data analysis'). The number of days since the last inundation on the day of measurement was plotted for each site as a monthly average (min-median-max).*

First, study sites that are daily inundated have a rather constant soil water salinity compared to study sites that are inundated only a few days a month (Figure 2, site 4-7 *vs.* 1-3). Non-frequent inundation implies longer dry periods during which the soil water evaporates leading to an increase in soil water salinity as alternating with periods of dilution by rainwater and salinity decrease. In contrast, frequent inundation permanently saturates the soil with water of seawater salt content. A similar effect was expected from the monthly tidal rhythm. At neap tide, study sites experience a drought period for one day up to more than two months (Figure 2). At spring tide, all sites are flooded at least once a day except for the most landward site and the site that is disconnected from the sea by a road (Figure 1 and 2, site 6-7) which experience drought periods of maximum one month. However, no link was found between tidal period and soil water salinity.

Second, the annual average salinity increased with decreasing inundation frequency in the seaward study sites (Figure 1 and 2, site 1-3). Further landward this trend broke down for the annual average but not for the maximum salinity, with study site 5 as an exception. In general, the disrupted trend with inundation frequency in site 4 to 7 could be related to changes in fresh water influence, canopy closure and soil texture. While site 3 is an open forest (Leaf Area Index of 0.23) with small trees (mean tree height: 2m) (Schmitz, *et al.*, 2008), the mangrove forest at study site 4 has comparably a closed canopy (Leaf Area Index of 1.18) (Schmitz, *et al.*, 2008) and a muddy soil (Table 1), both counteracting evaporation and thus also counteracting increase of soil water salinity. In study sites 5 and 6 fresh water input affects the soil water salinity. Site 5 is situated upstream the Kidogoweni river causing soil water salinity to match the precipitation curve. Site 6 is located at the border of the mangrove forest experiencing high amounts of freshwater run-off during the rainy season, leaching the sandy soil (Table 1). Due to the sandy soil in combination with an open canopy (Leaf Area Index of 0.62) (Schmitz, *et al.*, 2008), it is also study site 6 in which drought has the biggest impact. In study site 7 the main factor determining soil water salinity is the topography, which is like a basin. Seawater is thus standing and the salinity in the puddle gradually increased from the surface to the bottom. Stratification of the puddle water can thus explain why evaporation or fresh water input did not directly affect soil water salinity. Only in the middle of the dry season - around February - values up to 140 ‰ were measured in the last bit of water before the basin dried out completely.

Soil water salinity has a direct effect on the water relations in trees as high and fluctuating soil water salinity makes high demands on the water transport system by creating high risk of air blocking the water transporting canals (Cochard, 2006, Naidoo, 2006). This is especially true for mangrove trees inundated by saline water regularly to twice a day. Spatial differences in soil water salinity influence the species distribution of the mangrove forest due to differences in the ability to support high and fluctuating salinity between mangrove trees (Verheyden *et al.*, 2005, Schmitz, 2008, Robert *et al.*, 2009). Tree species distribution on its turn influences *e.g.* seedling dispersal (different root complexes act differently in propagule dispersal and establishment – Di Nitto *et al.*, 2008) and mangrove fauna (*e.g.* Smith, 1987), so that we can conclude that salinity is one of the major factors influencing and structuring life in the mangrove ecosystem.

Conclusion

The variability of the mangrove forest in terms of soil water salinity as observed in the mangrove forest of Gazi bay (Kenya) should alert all those involved in mangrove studies. The factors contributing to this dynamism in time as well as in space, their interactions and the magnitude of the resulting fluctuations will vary between mangrove forests all over the world. Nevertheless, the message learnt from this study is of general importance. Soil water salinity cannot be predicted from inundation frequency alone and the additional influencing factors such as canopy closure, topography, fresh water input and soil texture can vary significantly within only a few hundred meters. The great number of micro-environments a mangrove forest can consist of should be taken into account to get better understanding of the functioning of the mangrove ecosystem and to be able to make high-impact conclusions that go beyond specific mangrove sites.

Recommendations

Soil water salinity, inundation frequency and soil texture can be determined with cheap and fast methods. The authors recommend that it should be standard practice for mangrove researchers to carefully compare different locations of a mangrove forest for these environmental parameters given their importance to obtaining a reliable reflection of the variation in soil water salinity. Moreover adequate number of measurements has to be carried out to cover the local variation not only in space but also in time. In the event that this is not possible, the limitations of the soil water sampling strategy should be reported and considered when drawing conclusions.

Acknowledgements

We thank James Gitundu Kairo of KMFRI for his assistance during fieldwork. The postdoctoral researcher is supported by the National Fund for Scientific Research (FWO, Belgium), but during this study she was supported by the Institute for the Promotion of Innovation through Science and Technology in Flanders (IWT-Vlaanderen) as is the PhD student (E.M.R.R). This research was further sponsored by travel grants from the FWO, the Schure-Beijerinck-Popping Fonds (Koninklijke Nederlandse Akademie van Wetenschappen, Nederland) and the Flemish Interuniversity Council (VLIR).

References

Cochard H. 2006 Cavitation in trees. *Comptes Rendus Physique* 7: 1018-1026.

Di Nitto D., Dahdouh-Guebas F., Kairo J. G., Decleir H., Koedam N. 2008. Digital terrain modelling to investigate the effects of sea level rise on mangrove propagule establishment. *Marine Ecology-Progress Series* 356:175-188.

Duke N. C., Meynecke J. O., Dittmann S., Ellison A. M., Anger K., Berger U., Cannicci S., Diele K., Ewel K. C., Field C. D., Koedam N., Lee S. Y., Marchand C., Nordhaus I. & Dahdouh-Guebas F. (2007) A world without mangroves? *Science* 317: 41-42.

Fratini S., Vigiani V., Vannini M. & Cannicci S. (2004) *Terebralia palustris* (Gastropoda; Potamididae) in a Kenyan mangal: size structure, distribution and impact on the consumption of leaf litter. *Marine Biology* 144: 1173-1182.

GLOBE (2005) *Soil Characterisation Protocol. Field Guide.* GLOBE website at http://www.globe.gov/.

Lieth H., Berlekamp J., Fuest S. & Riediger S. (1999) *CD 1 - Climate Diagram World Atlas*. Backhuys Publishers, Leiden.

Matthijs S., Tack J., van Speybroeck D. & Koedam N. (1999) Mangrove species zonation and soil redox state, sulphide concentration and salinity in Gazi Bay (Kenya), a preliminary study. *Mangroves and Salt Marshes* 3: 243-249.

Naidoo G. (2006) Factors contributing to dwarfing in the mangrove *Avicennia marina*. *Annals of Botany* 97: 1095-1101.

Neukermans G., Dahdouh-Guebas F., Kairo J. G. & Koedam N. (2008) Mangrove Species and Stand Mapping in Gazi bay (Kenya) using Quickbird Satellite Imagery. *Spatial Science* 53: 75-86.

Robert E. M. R., Koedam N., Beeckman H. & Schmitz N. (2009) A safe hydraulic architecture as wood anatomical explanation for the difference in distribution of the mangroves *Avicennia* and *Rhizophora*. *Functional Ecology* 23: 649-657.

Schmitz N. (2008) *Growing on the edge: hydraulic architecture of mangroves: ecological plasticity and functional significance of water conducting tissue in* Rhizophora mucronata *and* Avicennia marina. PhD Thesis, Vrije Universiteit Brussel, Brussels, Belgium. 135 p.

Schmitz N., Robert E. M. R., Verheyden A., Kairo J. G., Beeckman H. & Koedam N. (2008) A patchy growth via successive and simultaneous cambia: key to success of the most widespread mangrove species *Avicennia marina*? *Annals of Botany* 101: 49-58.

Smith T. J. III. (1987) Seed predation in relation to tree dominance and distribution in mangrove forests. *Ecology* 68: 266–273.

Tomlinson P. B. (1994) *The Botany of Mangroves*. Cambridge University Press, Cambridge. 433 p.

UNEP. (2001) *Eastern African Database and Atlas Project (EAF/14). The Eastern African Coastal Resources Atlas: Kenya*. United Nations Environmental Program.

Verheyden A., De Ridder F., Schmitz N., Beeckman H. & Koedam N. (2005) High-resolution time series of vessel density in Kenyan mangrove trees reveal link with climate. *New Phytologist* 167: 425-435.