ABSTRACT

Are Peri-urban Mangroves Viable? Effects of Sewage Pollution and Wood Exploitation on the Structure and Development of the Mangroves of Mombassa (Kenya).

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PREFACE

Acknowledging the increasingly prominent urban character of many ecosystems globally, mangroves being no exception, and possible associated impediments to the viability of these ecosystems (i.e. the inherent capacity or ability to grow, develop or recover after disturbances) under urban conditions. We adapt a system approach to establish the viability of the peri-urban mangrove of Tudor creek in Mombasa, Kenya. Three important aspects of the peri-urban mangroves are assessed. These include (i) structural aspects (vegetation structure and regeneration), (ii) functional aspects (productivity) and (iii) human aspects (socioeconomics).

Chapter 1 and 2 introduce the study, outlining the objectives and the study area. The chapters lay down an overview of the mangrove trees physiological adaptations and the ecological attributes that make the mangrove ecosystems unique and highly adaptable to a harsh and dynamic intertidal environment. The chapters further outline the extent andstatus of mangroves in Kenya, their socioeconomic importance, and the legislation that governs their management and conservation.

Chapters 3 and 6 describe the structural attributes and regeneration status of the peri-urban mangroves of Tudor creek. Based on species importance values the dominant mangrove species were *Rhizophora mucronata* Lam. (Rhizophoraceae) and *Avicennia marina* (Forssk.) Vierh. (Acanthaceae)[♣]. *Lumnitzera racemosa* Willd. (Combretaceae), reported in an earlier floristic survey, was not encountered. Tree density varied between 1,264 trees ha^{-1} and 1,301 trees ha^{-1}, which is within the range of values reported for similar forests globally. However, the size-class structure showed the numerical dominance of small trees over larger trees. The

[♣] Nomenclature according to Angiosperm Phylogeny Group, 2003 spatial distribution pattern of adults and juveniles varied greatly between sites had a close to uniform pattern (Morisita's Index $I_\delta << 1$) for adult trees, but a tendency for clustered distribution ($I_\delta >> 1$) for juveniles. This pattern of distribution is not expected for a healthy forest. The distribution of regenerating seedlings was mainly impacted by canopy gap sizes. This chapter shows that unmanaged but exploited peri-urban mangroves are structurally degraded, having enlarged canopy gaps, characterised by spatial and temporal heterogeneity in edaphic conditions that influences regeneration. This enlarged gaps and edaphic heterogeneity imposes longer periods for canopy closure by lowering regeneration and promoting mortality of seedlings. Larger gaps (> $60m^2$) had lower regeneration levels and intermediate gaps ($20-50m^2$) had adequate regeneration. The occurrence of *R. mucronata* seedlings and saplings in the understorey under all cover types and inundation, confers advantages to this species under the current disturbance regime. Disturbances include sewage pollution, unregulated harvesting and siltation. The current status of the forest is reminiscent of a recovery phase, a multiphase species succession stage, after a major disturbance event, accompanied by recurrent anthropogenic pressure. This study shows that species composition and thus recovery of a mangrove forest after disturbance depends in part on the balance between subsequent large-scale natural and recurrent small-scale human disturbances.

Chapter 4 assesses the human dependence on the peri-urban mangrove. Through questionnaires and field surveys, the study demonstrates the challenges of questionnaire surveys targeting respondents involved in exploitation of sensitive resource. This potentially limits if not inhibit information flow. Firewood is the ubiquitous form of mangrove wood utilisation, exploited at both subsistence and commercial scales. Forest assessments indicate the lack of preferred or specific harvesting sites, with *R. mucronata* being the most harvested, probably due to its distribution range and ease of access. Sewage pollution was viewed with mixed feelings. Many appreciate the nutrient enrichment of the sewage rather than the filtration capacity of mangroves, resulting in the usage of sewage for irrigating small plots of subsistence farms. The study shows that resource exploitation is intense in an urban setting due to an economic drive and an increasing demand. The rural setting on the other hand, utilisation included both subsistence and commercial charcoal production. The limited range of means of livelihoods in a rural setting, coupled with poverty and the need for cheap domestic energy, necessitates dependence on mangrove resources. This has promoted more efficient, destructive and unsustainable exploitation levels. Associated benefits of these activities grossly under-value the ecosystem goods and services in addition to degrading the ecosystem. Our observations, consistent with other studies, shows that management of mangroves for wood extraction in urban areas may not be a viable and/or sustainable option, as it conflicts with the essential '***filtration***' and '***habitat provisioning***' functions and services of mangrove ecosystems. These functions and services, otherwise increasingly important in a "diminishing" urban environment. This arises out of the lack of adequate alternatives and conflicting interests in growing urban areas. It is recommended that '*adaptive*' and '*participatory management*' based on multiple uses and users, with specific legislative, education and institutional interventions. Integrating local ecological knowledge, may further expedite the formulation of sustainable management plans for peri-urban mangroves.

Chapter 5 presents insights on the productivity of an under-valued, over-exploited and sewage polluted peri-urban mangrove through litter fall studies on three common mangrove species, *R. mucronata*, *A. marina* and *S. alba.* The study covers a period of two years. The mean annual litter fall was estimated at 12 ± 3 t $ha^{-1}yr^{-1}$ for the whole stand, which is within the range of values reported for similar forests occupying the same latitudinal range. Litter fall, in both content and quantity was highly seasonal, with high rates occurring in the dry North Easterly Monsoon (NEM) season, January-April (ca. 5 ± 1 g DW m^{-2} day^{-1}) and lower rates in the cool and wet South Easterly Monsoon (SEM) season, June-October (ca. 3 ± 0.5 g DW m^{-2} day^{-1}). *R. mucronata* recorded the highest annual rate of 15 ± 3 t $ha^{-1}yr^{-1}$, with no significant differences between *A. marina* and *S. alba*, (11 ± 3 and 10 ± 5 t $ha^{-1}yr^{-1}$ respectively). Sewage exposure levels did not appear to influence litter production rates despite higher nutrient levels in completely exposed sites. $\delta^{15}N$ varied with species, *A. marina* (6.48 ± 0.03‰) and *S. alba* (6.76 ± 0.24‰) having higher composition than *R. mucronata* (3.88 ± 0.64‰). This implies the forest has a more open N cycle, favouring $\delta^{15}N$ accumulation within the system. This study shows that sewage exposure may not necessarily translate into elevated productivity in mangroves, but may alter leaf total nitrogen content, possibly altering the decay of litter and nutrient cycling.

Chapter 7 presents a synthesis linking the findings to possible implications on the general status of the mangrove ecosystem. The major disturbances observed for the peri-urban mangroves of Tudor creek include (i) domestic sewage pollution, (ii) recurrent unregulated harvesting; and (iii) recurrent annual siltation during the rainy season. Our observations indicate that

(i) Raw domestic sewage pollution may not be harmful to the mangrove vegetation, but may affect edaphic conditions through nutrients enrichment. Sewage pollution effects, though not qualitatively proven in our study, enhances growth of mangrove trees. This is due to increase in amounts of nutrients available for biomass formation, observed as leaf nitrates resorption efficiencies. However, the raw domestic sewage is reported to alter the general healthy decomposing aerobic-anaerobic mangrove system to a complete anaerobic system. This tends to lower efficiencies in nutrient cycling, and cause accumulation of nutrients in the sediments. Observations within the same site and other East African mangroves (under the PUMPSEA project) indicate negative effects of sewage on the sediment cyanobacterial diversity, with an increase in microalgal abundance. Furthermore, within Mikindani (Sewage impacted site in Tudor creek), high rates of sediment $\sum CO_2$ production indicate a system under stress due to the presence of easily degradable organic matter.

(ii) Un-regulated harvesting creates and enlarges canopy gaps, lowering availability of seed bearing trees, altering species composition and stem size distribution due to its selective nature, and lowers regeneration under the enlarged canopy gaps. This strongly lowers recovery rates after major disturbances.

(iii) Siltation stands out as a major cause of degradation. Siltation is extrinsic in nature, a result of poor land use practices. This probably makes it a major issue of concern due to its impact on regeneration. A major siltation event, associated with the 1997-1998 ENSO, is widely identified as a cause of enlarged canopy gaps. Little recovery has occurred 10 years after the event due to recurrent anthropogenic pressure.

The combined effects of these factors have important implications on growth, productivity and recovery of the mangrove ecosystem. The effects include shifts or changes in mangrove tree species distribution. This has lowered the system *functional diversity* and *response diversity*, and therefore ecosystem resilience - viability of the ecosystem. It is recommended that *integrated adaptive management*, based on sound knowledge of the system is the best approach. The participation of stakeholders (government institutions, the private sector and local communities) is crucial for managing peri-urban mangroves for sustainability. Not intervening may only result in a worst case scenario. Especially with the current global financial crisis, more locals will turn to '*cheap*' mangrove firewood.