Restoration of Benthic Macro-endofauna after Reforestation of *Rhizophora mucronata* Mangroves in Gazi Bay, Kenya

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Abstract—Recovery of *Rhizophora mucronata* mangrove ecosystems was investigated by assessing the physical characteristics of their sediments and the forest densities, community composition and diversity of macro-endofauna. This was done in 5- and 10-year reforested mangroves and natural and degraded controls. Natural and 10-year reforested sites were characterised by significantly higher TOM and silt/clay. The natural site had significantly higher (ANOVA, $p<0.05$) macrofaunal densities than all the other sites. Oligochaetes dominated the natural and 10-year reforested sites, but in higher densities at the former. Polychaetes and nemertines dominated the 5-year reforested and degraded sites. PCA, MDS and ANOSIM indicated clear differences in physical characteristics of the sediment and macrofaunal composition between the sites. The study showed that, while mangrove degradation leads to drastic changes in sediment characteristics as well as macrofaunal density and community structure, reforested mangroves evolve slowly back to their natural condition. However, the recovery may take more than 10 years before complete in terms of their TOM and macrofaunal densities.

INTRODUCTION

Mangrove ecosystems provide a microhabitat and nutritional base for diverse faunal communities (Macintosh *et al.*, 2002; Lee, 1998). In this way, mangroves increase the biodiversity of estuarine and nearshore areas and act as nurseries and feeding grounds for various marine fauna (Alongi, 2002). Mangroves are also characterised by high organic production and serve as nutrient traps, a function which reduces nutrient loads in ocean waters, fostering the growth of sea grasses and corals. Additionally, mangroves play a role in shoreline stability by reducing coastal erosion (Hogarth, 1999).

Benthos are an important and integral component of mangroves (Ngoile & Shunula, 1992; Macintosh, 1984) and play a significant role in their structure and function (Lee, 1998; Schrijvers *et al.*, 1995). Litter degradation by macrofaunal shredding and the subsequent release of finer faecal material enhances detritus-based food webs (Slim *et al*., 1997).

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Subsequent degradation of the litter by microorganisms contributes to its nutrient enrichment, from which other small burrowing organisms benefit (Skov & Hartnoll, 2002). Additionally, burrowing macrofauna modify the physical and biogeochemical nature of the sediment which, in turn, affects vegetation structure (Fratini *et al.*, 2004). Thus, the structure and diversity of the macro-endofaunal community may reflect the status and functioning of mangrove forest ecosystems, and serve as ecological indicators of habitat condition.

Anthropogenic pressures have reduced the global cover of mangroves from 75% to less than 50% of their original cover (Kairo *et al.*, 2001). Along the Kenyan coast, mangrove degradation has been caused by unrestricted extraction of wood for building materials and as wood for fuel, which has left some areas completely bare (Kairo, 1995). Experimental reforestation started between 1991 and 1994 (Kairo, 1995). Restoration projects have proven successful in some areas as shown by improvements in their vegetation structure (pers. obs.). However, for restoration to be deemed successful, the Society of Ecological Restoration International (SER) suggests that restored ecosystems should have similar attributes to natural reference sites such as the diversity and community structure in their associated fauna and flora, the presence of indigenous species, the presence of functional groups necessary for their long-term stability, and the capacity of the physical environment to sustain reproductive populations (Maria *et al.*, 2005). The recruitment of fauna is rarely quantified in most case studies on mangrove rehabilitation; their focus has been to restore the forests as habitats, with little attention being given to the re-establishment of their ecosystem structure and function (Field, 1999). Therefore, monitoring of associated fauna is of great importance in reforested mangrove plantations as mangrove vegetation contributes to the habitat complexity which enhances the diversity of associated fauna. This biodiversity is especially important in maintaining genetic richness, ecological function and ecosystem resilience (Lee, 1998). Bosire *et al.* (2004) and Fondo and Martens (1998) documented benthic fauna in natural, reforested and degraded mangroves in Gazi Bay. However, they focused mainly on epifauna. This study aimed to identify the extent of ecosystem recovery in *Rhizophora mucronata* mangrove plantations through a comparison of the macro-endofauna in reforested areas of different ages (5 and 10 years old) relative to a natural forest and a fully degraded site in Gazi Bay, Kenya.

MATERIALS AND METHODS

Study area

This study was conducted in Gazi Bay, 50 km south of Mombasa in Kenya, in a natural stand of *R. mucronata*, 5- and 10-year old re-plantings, and a degraded forest (Fig. 1). The natural, the 10-year reforested and the degraded sites fell in inundation class 4 and, therefore, were flooded by tidal water during high spring tides, while the 5-year reforested site fell in inundation class 2 and was covered by water during all medium high tides (Hogarth, 1999).

Sampling and sample analysis

Three sampling plots measuring 25 m^2 each and 50 m apart were randomly selected at each site. In each of these plots, three sediment cores (6.4 cm diameter, 10 cm long) were collected at random for macrofauna, total organic matter (TOM) and grain size analysis, providing nine replicate for each site. Macrofauna were separated from the sediment by sieving through a 0.5 mm sieve with a 2 mm pre-sieve to trap plant debris which hampered the sorting process. Macrofauna were fixed in 5% buffered formalin on collection while TOM samples were kept in a cooler box in the field, and deep frozen on arrival in the laboratory to arrest microbial activity. The macro-endobenthos retained on the 0.5 mm sieve were identified to the highest possible taxonomic level under a dissecting microscope and enumerated. The TOM samples were oven-dried at 80°C for 24 h to remove all moisture. Thereafter, 10 g of the dried samples were ashed at 6000C for 6 h to obtain the ash-free dry weight (AFDW); TOM was calculated as
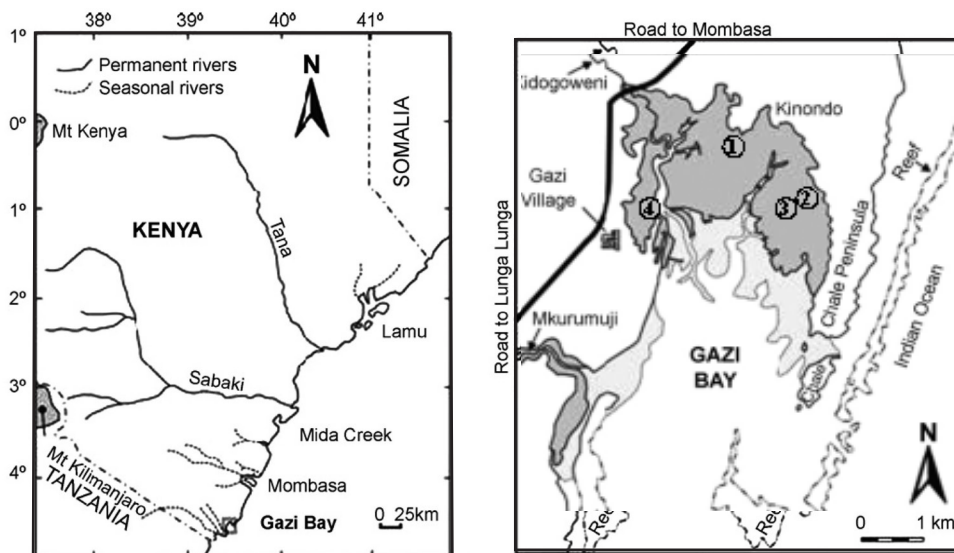
Figure 1. Map of Gazi Bay showing the study sites. 1= degraded site, 2 = natural site, 3= 10-year reforested site and 4 = 5-year reforested site (adapted from Bosire *et al.*, 2004).

the percentage of the ashed material. Sediment grain size was analysed using the method of Buchanan and Kain (1971). Interstitial sediment water samples were collected for measurement of salinity and temperature in a 5-10 cm hole dug in the sediment. Salinity was measured using an Atago optical refractometer. Sampling was undertaken at low tide during the dry season in September 2005.

Statistical analysis

Data on sediment physical characteristics and macrofauna community were analysed using PRIMER (v. 5) and STATISTICA (v. 6). Principal Component Analysis (PCA) ordination using Euclidean distances was used to reveal variation between sites based on physical sediment characteristics. Non-metric multidimensional scaling (MDS) ordination of square root-transformed data using the Bray-Curtis similarity coefficient was used to reveal similarities between the study sites in terms of macro-endofaunal community composition. Variability in macrofaunal density between sites was tested using analysis of similarity (ANOSIM; Clarke & Gorley, 2001). The Shannon diversity index (H') , highest taxonomic richness (S) and species rarefaction (ESn) were calculated using

DIVERSE. SIMPER was used to determine which macrofaunal taxa contributed most to the similarities between sites. Differences in environmental characteristics between sites, their macrofaunal density and diversity indices was analysed using ANOVA, while post hoc analysis was performed using Tukey's Honest Significant Difference test.

RESULTS

Environmental characteristics

All sites had significantly different TOM levels ($p < 0.05$) with the highest mean TOM concentration being recorded at the natural site (Table 1). The highest sand content was recorded at the degraded site, while the silt/clay fraction was highest in the 10-year reforested site. Sand and silt/clay fractions differed significantly between all sites ($p < 0.05$). The highest salinity was recorded at the 5-year reforested site, and the lowest at the natural site; all sites differed significantly ($p < 0.05$). Temperatures differed significantly between all sites ($p < 0.05$) with the degraded site being the warmest and the 10-year reforested site the coolest. Principal Component Analysis between the sites in

Table 1. Mean values (±SE) of parameters measured in sediments at natural, reforested and degraded mangrove sites in Gazi Bay. N=9.

Parameter	Sites			
	Nat	**Refo10**	**Refo5**	**Degr**
Total organic matter (%)	54 ± 6	29 ± 6	18 ± 8	4 ± 1
Silt/clay (%)	57 ± 5	73 ± 9	41 ± 14	21 ± 5
Sand (%)	43 ± 5	27 ± 9	59 ± 14	79 ± 5
Temperature (°C)	29 ± 0.5	28 ± 0.2	31± 1	33 ± 1
Salinity	38 ± 1	39 ± 0.7	48 ± 1	46 ± 1

terms of TOM, silt/clay, salinity and temperature showed a clear separation of the sites (Fig. 2). Principal Components (PC) 1 and 2 explained 99% of the observed variability (PC 1, 87%; PC 2, 11%). The first principal component revealed that the natural and the 10-year reforested sites had high TOM and silt/clay and were separated from the 5-year reforested and degraded sites. Separation along the second principal component was less pronounced, though it revealed differences between the natural site and the 10-year reforested based on TOM.

Macrofaunal density and community composition

A total of 12 macro-endofaunal taxa were recorded at the sites, all being found at the natural site, ten at the 10-year reforested site and seven at the 5-year reforested and degraded sites. Oligochaeta were the most abundant taxon at the natural and 10-year reforested sites, accounting for 59% and 60% of the total densities respectively. Polychaeta and Nemertina were abundant at the 5-year reforested and degraded sites, accounting for 80% and 79% of the total densities respectively. Significantly higher

macrofauna densities were recorded at the natural site (Fig. 3a) than all the other sites, with the 10-year reforested site also exceeding the 5-year reforested site (p<0.05). However, both reforested sites did not differ significantly in macrofaunal density from the degraded site. Figure 3b shows the total macrofaunal densities excluding the nematodes. The natural and 10-year reforested macrofauna included significantly higher oligochaete densities (Fig. 3c) than the 5-year reforested and degraded sites (p<0.05) but with no significant differences between the first two because of high variation in their numbers at the natural site. Polychaete densities were, on average, highest at the natural and both reforested sites and lowest at the degraded site (Fig. 3d). However, variability again precluded the detection of significant differences in this group between sites (p>0.05).
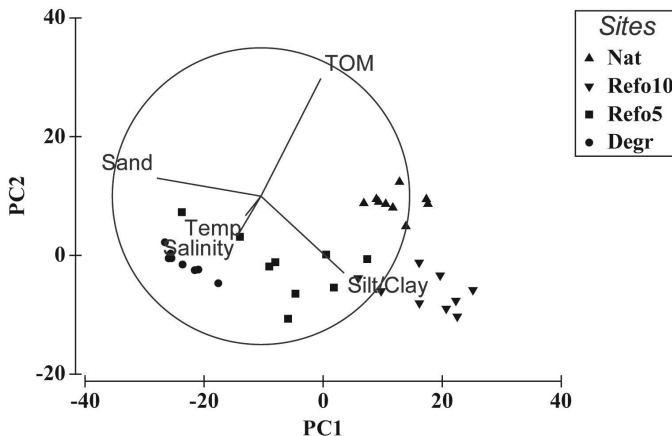

Figure 2. CA ordination showing the separation of natural, reforested and degraded mangrove sites in Gazi Bay in terms of their physical sediment characteristics.
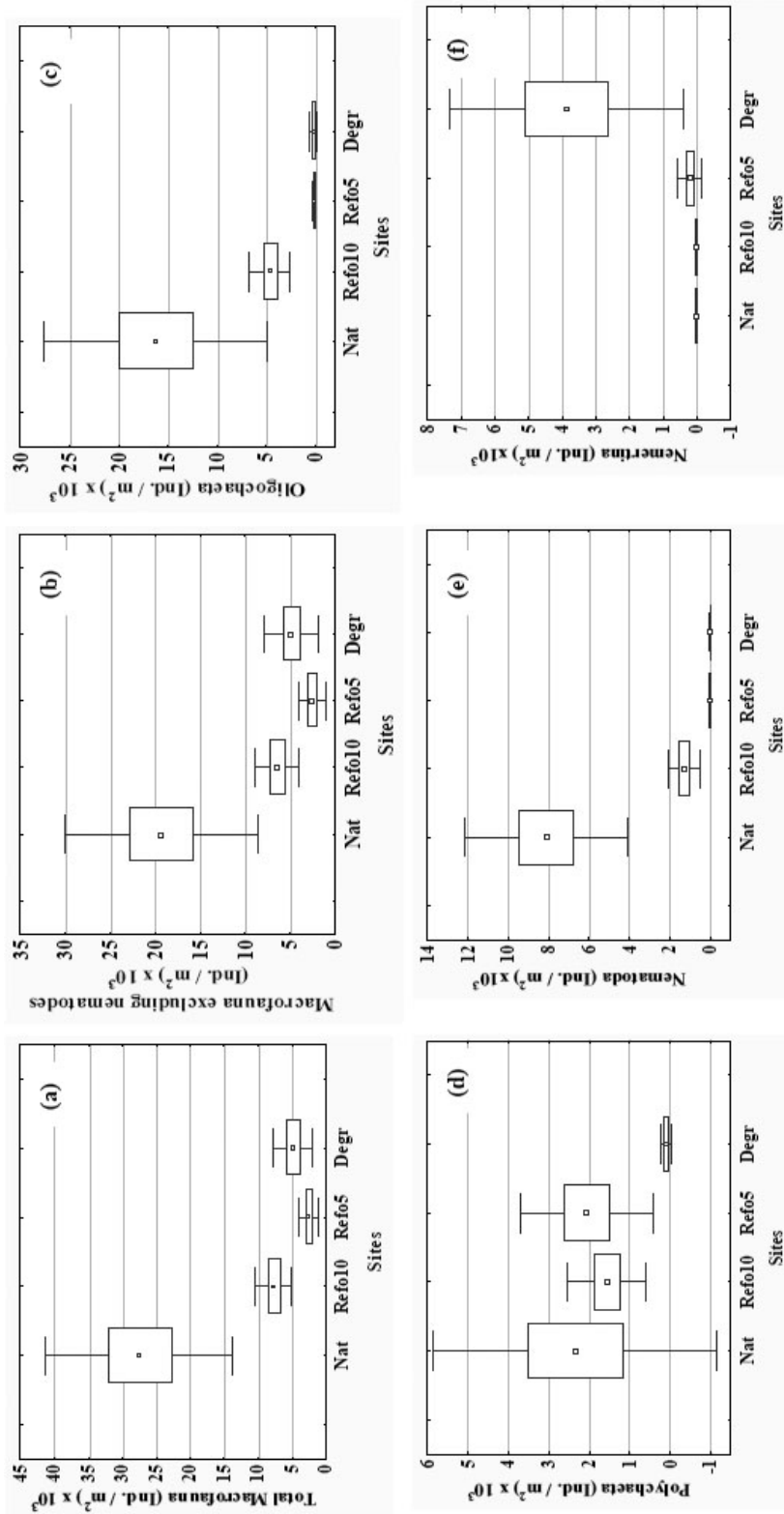
Figure 3a-f. Density (mean±SE) of a) macrofauna, b) macrofauna excluding nematodes, c) Oligochaeta, d) Polychaeta, e) Nematoda and f) Nemertina in the natural, 10-year reforested, 5-year reforested and degraded mangrove sites in Gazi Bay. N=9.

Table 2. Macrofauna taxa diversity measures (mean ± SD; n = 9) at the study sites.

	Taxa richness (S)	Taxa rarefaction (ES_{50})	Shannon Diversity Index (H'$_{loge}$)
Nat	5.9 ± 1.5	3.9 ± 0.6	0.9 ± 0.1
Refo10	4.3 ± 1.2	3.9 ± 0.9	1.0 ± 0.1
Refo5	2.6 ± 1.1	2.5 ± 1.1	0.6 ± 0.4
Degr	3.0 ± 0.7	2.8 ± 0.7	0.5 ± 0.4

Though Nematoda typically constitute meiofauna (<0.5 mm), large nematodes were found in very high densities amongst the sediment macrofauna (>0.5 mm), especially at the natural site (Fig. 3e). Significantly lower densities (p<0.05) were recorded in the 10-year reforested site and they occurred sporadically at both the 5-year reforested and degraded sites. Densities of Nemertines (Fig. 3f) were highest at the degraded site, with lower densities at the 5-year reforested site and lower again in the 10-year reforested and natural sites. There were significant differences in the Nemertea between the degraded site and all the other sites (p<0.05).

Macrofauna diversity

Significantly higher taxonomic richness (S) was recorded at the natural site than all the other sites (p<0.05). Similarly, the 10-year reforested had significantly higher taxonomic richness than the 5-year reforested site (p<0.05). However, the degraded site did not differ significantly from the 5-year reforested site. The natural and 10-year reforested sites had significantly higher Shannon diversity indices than the 5-year reforested

and degraded sites (p<0.05). Similarly, both the natural and 10-year reforested sites had significantly higher (p<0.05) taxonomic rarefaction compared to the 5-year reforested and degraded sites (Table 2).

MDS analysis (Fig. 4) showed that the four sites were separated based on macrofauna community composition. ANOSIM pairwise comparisons further confirmed that all sites were significantly different (Global R = 0.724; all pairwise comparisons R > 0.6). Overall, Oligochaeta, Nematoda, Polychaeta and Nemertina were responsible for the observed dissimilarities between sites (Table 3).

DISCUSSION

Some previous studies have already documented the different community patterns of benthos in natural, reforested and degraded mangroves in Gazi Bay. Bosire *et al.* (2004) found similar crab species diversity and abundance in natural, 5-year old reforested and bare sites of *Rhizophora mucronata*, *Sonneratia alba* and *Avicenia marina*. However, the densities of sediment infauna were found to differ between all

Table 3. Contribution of macrofauna to dissimilarities between natural, reforested and degraded mangrove sites in Gazi Bay.

| Sites	(%) Dissimilarity	Macrofaunal % contribution to dissimilarities
Nat, Refo10	39	Nematoda (30), Oligochaeta (30), Polychaeta (11)
Nat, Refo5	76	Oligochaeta (41), Nematoda (32), Polychaeta (8)
Refo10, Refo5	62	Oligochaeta (44), Nematoda (24), Polychaeta (12)
Nat, Degr	87	Oligochaeta (33), Nematoda (26), Nemertina (15)
Refo10, Degr	80	Oligochaeta (30), Nemertina (24), Nematoda (17), Polychaeta (15)
Refo5, Degr	74	Nemertina (39), Polychaeta (29), Insect Larvae (16)
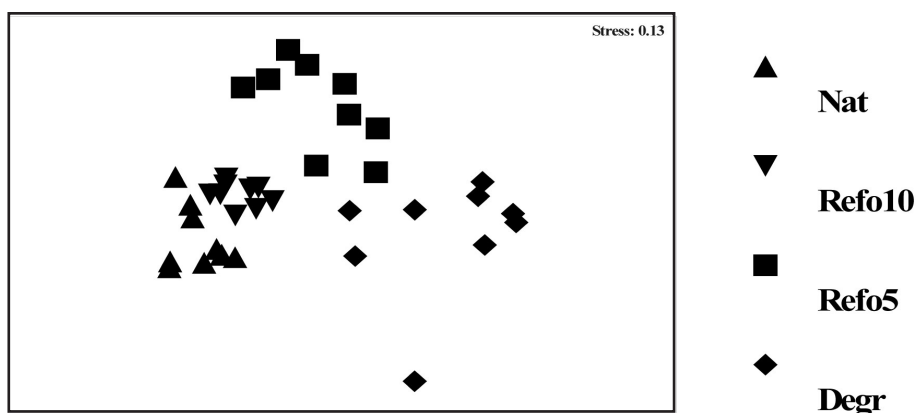
Figure 4. MDS (√-transformed data) of macrofaunal community composition showing affinities between the natural, reforested and degraded sites in Gazi Bay.

sites and mangrove species. The bare sites had the lowest densities of sediment infauna, whereas the natural had the highest. Crona *et al.* (2005) found different shrimp densities in natural, replanted and degraded sites of S. alba in Gazi Bay. Fondo and Martens (1998) examined the effects of mangrove deforestation on macrobenthic densities and identified 13 higher taxa but these were recorded in higher densities in the natural mangrove area. These studies focused mainly on macrobenthic epifauna, giving little attention to the macro-endofauna.

Most of the physical characteristics of the sediment determined during this study differed between the forested and degraded sites and there were also differences between the reforested sites, depending on their age. The natural site differed from the 10-year reforested site, especially in terms of organic matter content. However, the latter site was characterised by the highest silt/clay content, while the 5-year reforested site shared lower TOM, coarser sediments, higher salinity and temperatures with the degraded site. The differences in silt/clay content between the natural and 10-year reforested sites may be linked to the mangrove root mat which plays a crucial role in wave attenuation, slowing down tidal currents and ultimately prevents resuspension and tidal erosion of fine sediments from the mangroves (Wolanski *et al.*, 1992). Roots in the 10-year reforested site were observed to be more dense than in the natural site which was dominated

by mature trees with big prop roots (pers. obs.). These large prop roots may be a less efficient trapping system compared to the smaller, denser root network observed in the 10-year reforested site and may explain the differences observed in silt/clay content between the 10-year reforested and natural sites. The high levels of TOM in the natural site compared to the 10-year reforested site may be related to the high levels of peat which the former has accumulated over the years. Indeed, Bosire *et al.* (2004) and Schrijvers *et al.* (1995) recorded similar levels in organic matter content in natural, reforested and denuded mangrove sites.

In similar vein, denuded mangrove sites are usually more exposed, making them less efficient in slowing down incoming and outgoing tides. This leads to sediment erosion and resuspension of detrital material by tidal currents, resulting in a coarser sediment grain size and reduced organic content. Wolanski *et al.* (1992) noted that trunks and roots of the mangroves obstruct orbital water motion that transmit wave energy through mangrove forests. Wave attenuation is greater the closer the trees are together and, since the ability of water to transport sediment depends on its velocity, slowing down the currents results in settlement of the sediments. Denuded sites lack this protection.

Twelve macro-endobenthic taxa were recorded during this study which is close to numbers recorded in previous studies conducted in the same area (16 taxa, Schrijvers *et al.*, 1995; 13 taxa, Fondo &

Martens, 1998; 13 taxa, Bosire *et al.*, 2004). The density and number of macrofauna were higher in the natural site than the other sites. This trend is similar to that recorded by Bosire *et al.* (2004) in natural, reforested and degraded *R. mucronata*, *S. alba* and *A. marina* sites. The total number of taxa and average densities of macro-endofauna in the 10-year reforested site was also higher than in the 5-years reforested and degraded sites. This shows that restoration of mangrove forests leads to the recolonisation of sediment by macro-endofauna, and suggests a measure of recovery in ecosystem function. However, this recolonisation seems to be forest-age dependent and may take longer than 10 years for a complete to the natural state. A gradual change in macrofaunal epifauna with forest age has also been reported for the Ranong mangrove forest of Thailand (Macintosh *et al.*, 2002) and the Matang mangroves in Malaysia (Sesakumar *et al.*, 1998). Additionally, Morrisey *et al.* (2003) observed substantial differences in the density and community composition between the benthic fauna in young (3-12 yrs) and old (>60 years) mangrove forests in New Zealand. These differences were linked to more leaf litter and higher organic matter content with increasing forest age. Sergio and Gallucci (2003) similarly found that macrofaunal patterns may vary in relation to sediment grain size and organic matter content with highest macrofaunal densities at sites with high organic matter content. These findings again corroborate observations in the current study.

Mangrove-derived detritus has been shown to be of low nutritional value due to its high tannin content and low C/N ratio (Skov & Hartnoll, 2002; Alongi, 1987b). The food value of mangrove detritus is attributable to the detrital food web in which detritivores like oligochaetes and nematodes feed on the microflora associated with decomposing detrital material (Skilletter, 2000; Sergio & Gallucci., 2003). The nutritional value in detritus comes mainly from the surface biofilm which includes bacteria, microalgae, protozoa and fungi (Gwyther, 2003). Additionally, bacteria produce a heavy, slimy layer on leaf litter during the initial stages of decomposition. This acts as a matrix for the further accumulation of detritus, algae, fungal spores and, ultimately, the benthic fauna for which the aforementioned constitute a primary food source (Moens & Vincx, 1997; Fell *et al.*, 1975). Even after intense microbial decomposition, mangrove and marsh-derived detritus remains refractory and is poor in nutrients compared to phytoplankton, microphytobenthos and macroalgae (Alongi, 1987b). Sources of nutrients for invertebrate communities in intertidal mangroves, especially carbon and nitrogen, thus depends on microphytobenthos associated with detritus, a variety of epiflora and tidally imported sources such as phytoplankton and seagrass-derived organic matter (Bouillon *et al.*, 2004a).

Environmental parameters like sediment temperature, salinity and pH have also been shown to influence the abundance of mangrove benthic fauna (Ingole & Parulekar, 1998; McLachlan, 1978; Tietjen, 1969). Degraded mangrove areas are usually exposed to solar radiation due to lack of canopy cover. This exposure increases the sediment temperature and salinity and, consequently, reduces the sediment water content, which negatively affects the benthic fauna by increasing environmental stress (Sesakumar, 1994). This may explain the low densities of macro-endobenthos recorded in the 5-year reforested and degraded sites in which the highest temperatures and salinities were recorded. High salinity and temperature may also negatively affect benthic microphytobenthos which act as fa ood source for benthic fauna.

Nemertines were abundant at the degraded site, which also had the highest sand content and lowest TOM. Most interstitial nemertines have been recorded in intertidal and subtidal zones subject to currents which facilitate sedimentation of relatively coarse sand and shell fragments (Higgins & Thiel, 1992). Nemertines also prefer areas with low organic matter or silt (Higgins & Thiel, 1992). The degraded site had the highest sand content and the lowest silt/clay and TOM. These physical conditions concur with the habitat preferences of nemertines, accounting for their high densities recorded there.

This study has thus shown that degradation in mangrove ecosystems leads to detrimental physical changes in their sediments and declines in their macro-endobenthic densities and community structure. It is also clear that restored mangrove forests gradually revert back to their natural state. However, this may take longer than 10 years as shown by the results presented here. In this regard, the results provide useful information that will improve mangrove management and restoration.

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