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Fish assemblages in Tanzanian mangrove creek systems influenced by solar salt farm constructions

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ABSTRACT

Deforestation of mangrove forests is common occurrence worldwide. We examined fish assemblage composition in three mangrove creek systems in Tanzania (East Africa), including two creeks where the upper parts were partly clear-cut of mangrove forest due to the construction of solar salt farms, and one creek with undisturbed mangrove forest. Fish were caught monthly for one year using a seine net (each haul covering 170 m^2) within three locations in each creek, i.e. at the upper, intermediate and lower reaches. Density, biomass and species number of fish were lower in the upper deforested sites compared to the mangrove-fringed sites at the intermediate and lower parts in the two creeks affected by deforestation, whereas there were no differences among the three sites in the undisturbed mangrove creek system. In addition, multivariate analyses showed that the structure of fish assemblages varied between forested and clear-cut sites within the two disturbed creeks, but not within the undisturbed creek. Across the season, we found no significant differences except for a tendency of a minor increase in fish densities during the rainy season. At least 75% of the fishes were juveniles and of commercial interest for coastal fisheries and/or aquaculture. *Mugil cephalus*, *Gerres oyena* and *Chanos chanos* were the most abundant species in the forested sites. The dominant species in the clear-cut areas were *M. cephalus* and *Elops machnata*, which were both found in relatively low abundances compared to the undisturbed areas. The conversion of mangrove forests into solar salt farms not only altered fish assemblage composition, but also water and sediment conditions. In comparison with undisturbed areas, the clear-cut sites showed higher salinity, water temperature as well as organic matter and chlorophyll *a* in the sediments. Our results suggest that mangrove habitat loss and changes in environmental conditions caused by salt farm developments will decrease fish densities, biomass and species numbers as well as alter the overall fish assemblage composition in the salt farm area but not downstream in the creek.

1. Introduction

Mangroves and associated creek systems provide breeding, feeding and recruitment areas for a wide variety of marine fish species, and are hence critical habitats sustaining productivity in coastal fisheries (Beck et al., 2001; Nagelkerken et al., 2008). The structure of mangrove trees, trunks and prop roots provide fishes with protection from predation while at the same time they enhance sedimentation rate and lateral trapping of suspended particles, which is important for settling of fish larvae (Kathiresan and Bingham, 2001; Manson et al., 2005). Leaves and epiphytes form the basis of the food web within mangrove systems and support a high primary production and production of leaf litter (Rönnbäck et al., 1999; Kathiresan and Bingham, 2001). This high productivity increases prey density and is the reason why mangrove areas are assumed as important feeding areas for fish, especially juveniles (Robertson and Blaber, 1992; Heck et al., 2003; Manson et al., 2005). As the mangrove habitat comprises an important part of the coastal context it may also have strong influences on the fish assemblage composition of other adjacent shallow-water systems such as coral reefs (Nagelkerken and van der Velde, 2002; Dorenbosch et al., 2007) and seagrass beds (Gullström et al., 2008). For instance, Mumby et al. (2004) showed that fish biomass of several commercially important species was higher on coral reefs that were in close proximity to mangroves than in areas without mangrove forest.

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During the last decades deforestation of mangrove forest has been extensive throughout the world (Primavera, 1997; Semesi, 1998; Alongi, 2002; Barbier and Cox, 2002; Thu and Populus, 2007), and various studies have shown that losses of mangrove habitats have had negative effects on the abundance and diversity of fish (e.g. Whitfield and Elliott, 2002; Shervette et al., 2007). Nevertheless, the response of fishes to mangrove deforestation may depend on the type of disturbance (Huxham et al., 2004; Manson et al., 2005).

One of the main threats to mangrove systems in the East African region is the conversion of mangrove areas into other economic activities like solar salt farms and aquaculture ponds (Linden and Lundin, 1996; Semesi, 1998; UNEP/GPA and WIOMSA, 2004). Solar salt farms need large space and depend on mangrove creeks for water access. The construction of such salt farms not only leads to habitat loss, with subsequent reduction of habitat complexity and potential refuges for fish, but it also alters drainage patterns and surface runoff. Because subsistence fishing and fish production in many areas depend directly or indirectly on mangrove forests (e.g. Jiddawi and Öhman, 2002; Islam and Haque, 2004), loss of this habitat may threaten the livelihood of artisanal fishers (Gunawardena and Rowan, 2005). However, very few studies have investigated the effects of mangrove deforestation for construction of solar salt farms on fish communities.

The present study examined the composition of fish assemblages in mangrove creek systems in Tanzania, East Africa. We specifically investigated whether there were spatial and seasonal differences in fish assemblage composition among sites naturally fringed by mangrove forest and sites located in areas deforested for salt farms.

2. Materials and methods

2.1. Sites description

This study was carried out in three mangrove creeks; Mbegani, Nunge and Manyema, which are situated along the Tanzanian coastline (Fig. 1). The climate of this region is influenced by monsoon winds and two pronounced rainy seasons, i.e. the south-east monsoon (March–May) and the north-east monsoon (October–December) (McClanahan, 1988). The annual water temperature ranges from 20 to 30 °C and the annual rainfall from 750 to 1500 mm (Richmond, 2002). Ocean salinity ranges between 35 and 36 throughout the year (Richmond, 2002), while the salinity in mangrove creeks may vary depending on freshwater input and tidal patterns (from approximately 5 to 36; Lugendo et al., 2007; this study). The entire study area is influenced by a strong semi-diurnal tidal rhythm where the mean tidal range is approximately 3.5 m. The major part of the mangrove area is exposed at low tide (for about 4–6 h depending on tidal period; A.W. Mwandya pers. comm.), although the three creek systems retain water even during the low spring tide. The landward forest, including the upstream margins of all three creeks, is dominated by the two mangrove species *Avicennia marina* and *Xylocarpus granatum*.

A major part of the upstream mangrove areas of Nunge and Manyema creeks has been cleared for solar salt farms (>10 years ago), while the creek at Mbegani has not been affected by deforestation and salt farm constructions. The clear-cut sites consisted of soft muddy bottom covered by a layer of benthic microflora. The forested sites downstream in all three creeks as well as the upper part of Mbegani creek were also dominated by mud- and sandflats, although some sites were partly covered by patches of seagrass (i.e. the lower sites in Manyema and Mbegani creeks) (Table 1).

A typical salt farm consists of a series of earthen ponds of varying sizes between 0.25 and 1 m depth, and a reservoir as a back-up area for sea water. The salt farm in Nunge occupies an area of approximately 120 ha with a reservoir covering about 4 ha, while the salt farm of Manyema covers approximately 50 ha with a reservoir of about 3 ha. The salt production areas are isolated from the forested mangrove creek systems downstream by dikes. The water flow along the creeks is diverted and only a certain amount of water is allowed to enter the reservoirs through the gates. Refilling of the reservoirs is mainly performed during the high spring tide that normally occurs twice a month.

2.2. Field methods and sampling design

Field sampling was conducted monthly in daytime at low spring tide (±2 h) from January to December 2005 (except in September). Within each mangrove creek, sampling was performed in the lower, intermediate and upper reaches during one day. The three creeks were repeatedly sampled in three consecutive days. Samples in Nunge and Manyema creeks were taken from the lower and intermediate undisturbed sites and from the reservoirs of the salt farms within the two clear-cut sites in the upstream part. In Mbegani creek, the three sampling sites were all fringed by natural mangrove forest.

Salinity and water temperature were measured alongside with fish sampling at each site throughout the study period. Determination of salinity and water temperature was conducted *in situ* using a hand refractometer and an oxygen meter (oxyguard), respectively. Samples for estimation of sediment organic matter (OM) content were collected from March to November, while those for estimation of sediment chlorophyll *a* (chl *a*) concentrations were sampled from March to August. On every sampling occasion, two replicate samples of sediment (each about 50 and 10 g wet weight for OM and chl *a*, respectively) were obtained by scooping the upper layer of sediment (about 1 cm). All sediment samples were put on ice in closed plastic containers and transported to the laboratory for further analyses. For estimation of OM, the sediments were homogenized and oven-dried at 65 °C to constant weight. Thereafter, the samples were burnt in the furnace for 24 h in 450 °C and expressed as percentage of sediment dry weight. The concentration of chl *a* was determined using a spectrophotometer and expressed as μg chl *a* per g sediment dry weight (Parsons et al., 1984).

A seine net measuring 17 m in length and 2 m in height with a mesh size of 1.9 cm was employed for collection of fish samples. Two hauls covering an area of about 170 m^2 each were performed at every site each sampling day (i.e. once a month; see above). Collected fish samples were kept in ice-boxes prior to analysis in the laboratory. Fish total length and body weight (biomass) were measured to the nearest 0.1 cm and 0.1 g, respectively. All individuals were counted and identified to the lowest taxonomic level possible according to Smith and Heemstra (1991) and Froese and Pauly (2007). Life stage for each individual of all fish species was decided according to the methodology used by Nagelkerken and van der Velde (2002) that grouped fishes into three size categories (juveniles, subadults and adults) based on the maximum lengths of each fish species (after Froese and Pauly, 2007).

2.3. Data analysis

Differences in fish densities, biomass and species numbers as well as environmental parameters (salinity, water temperature, sediment OM and sediment chl *a*) were analysed using nested ANOVAs with Creek (1 level) as a fixed factor and Site (3 levels) as

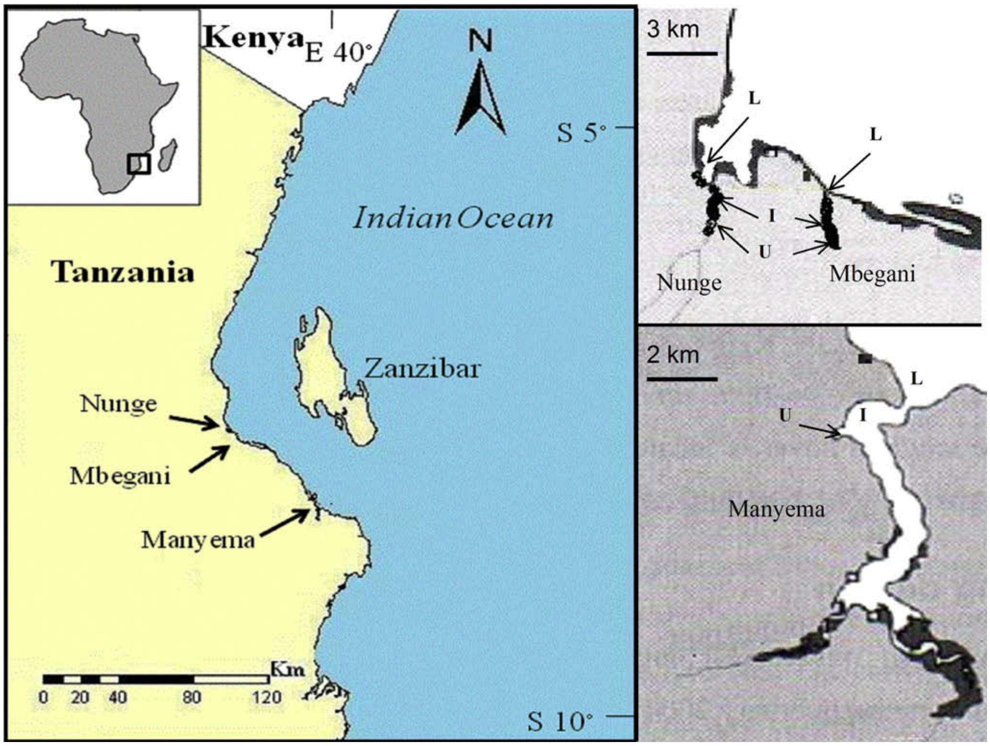

Fig. 1. Map of the coastal region of Tanzania and the locations of the studied creeks (Nunge and Mbegani creeks in Bagamoyo mangrove area and Manyema creek in Kunduchi mangrove forest). L = lower sites, I = intermediate sites, U = upper sites.

a fixed factor nested within Creek. Since all nested ANOVAs showed significant differences among the three creeks, we excluded the factor Creek and carried out analyses using two-way ANOVAs for each creek with Site (3 levels) and Season (2 levels) treated as orthogonal fixed factors. Prior to all analyses, Levene's test was applied to check the assumption of homogeneity of variances. When necessary, the data were transformed using square root or $\ln + 1$, and if the data remained heteroscedastic despite transformations, hypotheses were rejected at alpha levels lower than the p-values of the Levene's test (Underwood, 1981). *A posteriori* pairwise comparisons of means were carried out using Tukey's HSD test.

Differences in fish assemblage structure among sites in each creek were analysed for density and biomass data using multivariate two-way crossed analysis of similarities (ANOSIM) based on Bray–Curtis similarity measures (Clarke, 1993). To reduce the weight of dominant values, the data were square root-transformed. Non-metric multidimensional scaling (nMDS) ordinations were used to visualize the patterns of similarities among sites. The similarity of percentages (SIMPER) was performed in order to examine the fish taxa that contributed most to the dissimilarity among sites in each creek (Clarke, 1993).

3. Results

3.1. Environmental parameters

In Nunge and Manyema creeks, i.e. those with salt farms, salinity and water temperature were higher in the clear-cut sites compared to the forested sites, whereas there were no differences among sampling sites in Mbegani creek in absence of salt farms (Fig. 2a, b, Table 2a, Tukey's test at $p < 0.05$). Sediment OM and chl *a* were higher in all three creeks at the upper sites compared to the lower and intermediate sites, except in Mbegani where there was no difference between the upper and intermediate sites (Fig. 2c, d, Table 2a, Tukey's test at $p < 0.05$). Additionally, in Manyema the sediment OM was higher in the intermediate site than in the lower site, whereas in Nunge the sediment chl *a* was higher in the intermediate site compared to the lower site (Fig. 2c, d, Table 2a, Tukey's test at $p < 0.05$).

Table 1
Habitat characteristics at each sampling site within the three mangrove creeks.

Creek	Site	State of the site	Dominant bottom characteristics	Water depth at low tide (m)
Mbegani	Lower	Fringed mangrove	Sand (65%), patches of seagrass (25%)	1.3
	Intermediate	Fringed mangrove	Mud (75%), sand (25%)	0.8
	Upper	Fringed mangrove	Mud (60%), sand (35%)	0.8
Nunge	Lower	Fringed mangrove	Mud (70%), sand (30%)	1.5
	Intermediate	Fringed mangrove	Mud (70%), sand (30%)	1.0
	Upper	Clear-cut mangrove and salt farm	Mud with benthic microflora (95%)	0.5
Manyema	Lower	Fringed mangrove	Sand (40%), patches of seagrass (45%)	1.5
	Intermediate	Fringed mangrove	Mud (60%), sand (30%)	1.0
	Upper	Clear-cut mangrove and salt farm	Mud with benthic microflora (75%)	0.5

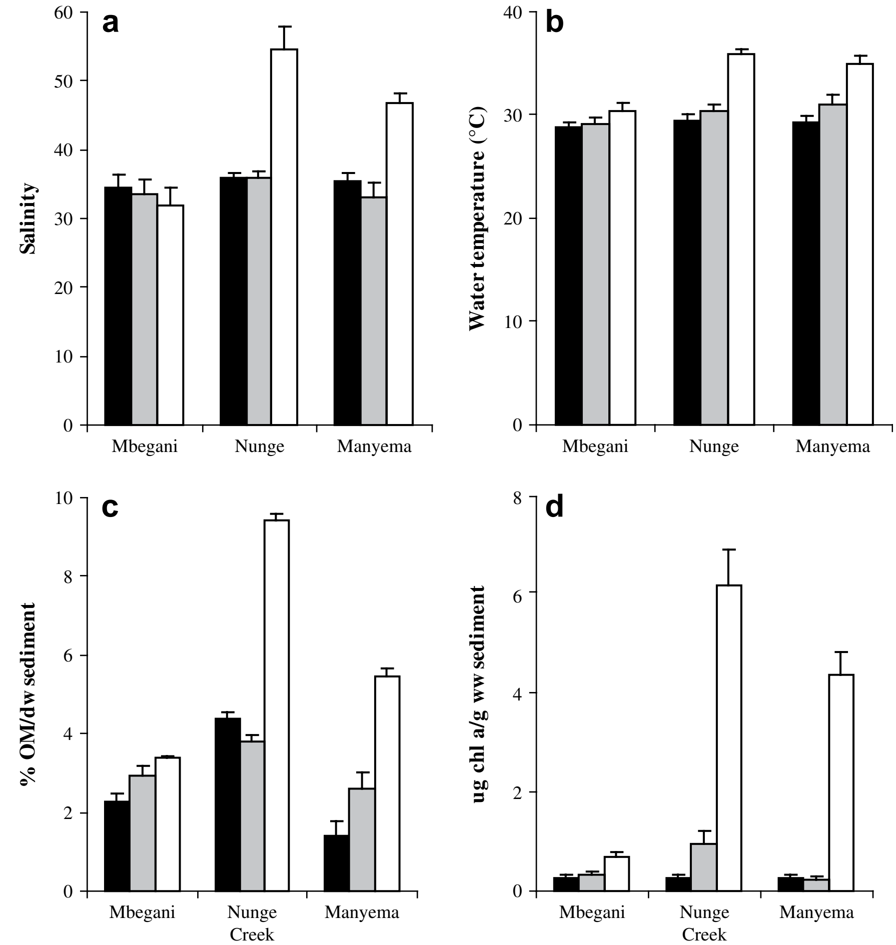

Fig. 2. Mean estimates of (a) salinity, (b) water temperature, (c) sediment organic matter (OM) and (d) sediment chlorophyll *a* (chl *a*) measured in lower (black bars), intermediate (grey bars) and upper (white bars) sites of the three mangrove creek. White bars of Nunge and Manyema creeks represent clear-cut sites, while all other bars represent mangrove-fringed sites. Error bars denote SE.

In terms of seasonality, the salinity and water temperature appeared stable with little within-site variability. Though, a significant interaction between site and season was found for water temperature in Nunge (Table 2a). Sediment variables showed strong seasonal patterns with significant variability in all three creeks, except for sediment OM in Nunge and for sediment chl *a* in Mbegani (Table 2a). Moreover, significant interactions between site and season were detected for the sediment variables in all three creeks, and only sediment chl *a* in Manyema showed no significant effect (Table 2a). The highest values of sediment OM were recorded during the rainy seasons, while sediment chl *a* concentrations showed the opposite pattern with highest values during the dry seasons.

3.2. *Taxonomic composition of fish*

A total of 65, 61 and 62 fish taxa were collected in Mbegani, Nunge and Manyema creeks, respectively (Appendix 1). In terms of

Table 2a
Results of two-way ANOVAs of environmental variables in the three mangrove creeks. Significant values ($p < 0.05$) are shown in bold.

Creek	Source of variation	df	Salinity			Temperature			Sediment OM			Sediment chl *a*		
			MS	F	p	MS	F	p	MS	F	p	MS	F	p
Mbegani	Site	2	19.5	0.33	0.722	6.14	1.55	0.233	2.55	13.3	**<0.001**	0.60	19.7	**<0.001**
	Season	1	200	3.38	0.078	0.63	0.16	0.694	7.66	39.8	**<0.001**	0.04	1.36	0.253
	Site × Season	2	4.15	0.07	0.932	7.36	1.86	0.178	0.83	4.29	**0.030**	0.22	7.27	**0.003**
	Residual	24	59.2			3.97			0.19			0.03		
Nunge	Site	2	6.06	25.9	**<0.001**	72.1	13.8	**<0.001**	76.9	248	**<0.001**	124	553	**<0.001**
	Season	1	0.29	1.24	0.276	8.37	1.60	0.217	0.49	1.57	0.226	11.5	51.5	**<0.001**
	Site × Season	2	0.17	0.73	0.493	22.9	4.39	**0.024**	3.89	12.5	**<0.001**	9.28	41.5	**<0.001**
	Residual	24	0.23			5.22			0.31			0.22		
Manyema	Site	2	526	18.4	**<0.001**	103	30.1	**<0.001**	2.01	387	**<0.001**	10.2	524	**<0.001**
	Season	1	5.42	0.19	0.667	0.01	0.002	0.969	0.12	22.1	**<0.001**	0.56	29.1	**<0.001**
	Site × Season	2	31.1	1.09	0.354	6.39	1.87	0.176	0.02	3.67	**0.046**	0.05	2.36	0.112
	Residual	24	28.6			3.42			0.01			0.02		

number of species per family, Gobiidae (6 species), Tetraodontidae (4 species), Mugilidae and Gerreidae (3 species each) were the most diverse fish families at the clear-cut sites in Manyema and Nunge, while in the mangrove-fringed sites of the same creeks, Gobiidae (9 species), Carangidae (8 species) and Lutjanidae (5 species) had the highest number of species. The most diverse families in the undisturbed Mbegani creek were Lutjanidae (4 species) and Gerreidae (3 species) at the lower site, Gobiidae (4 species) at the intermediate site, and Gobidae (5 species), Lutjanidae and Carangidae (4 species each) at the upper site (Appendix 1). In terms of species dominance, *Mugil cephalus*, *Gerres oyena* and *Chanos chanos* were the most abundant species within forested sites, while the clear-cut sites were dominated by *M. cephalus* and *Elops machnata* (Appendix 1).

Fish density, biomass and species number were higher in mangrove-fringed areas (i.e. lower and intermediate sites) compared to the clear-cut sites upstream at Nunge and Manyema creeks (Fig. 3, Table 2b, Tukey's test at $p < 0.05$). Comparing lower and intermediate sites, we found no significant differences for any fish variable in Nunge, but in Manyema density and biomass differed while the species number did not (Fig. 3, Table 2b, Tukey's test at $p < 0.05$). In Mbegani creek, there were no differences among sampling sites for neither fish density nor fish biomass (Fig. 3a, b, Table 2b), but species number was found to be higher at the upper and intermediate sites compared to the lower site (Fig. 3c; Table 2b, Tukey's test at $p < 0.05$). All three fish variables remained stable across the seasons in Nunge and Mbegani (Table 2b). In Manyema, fish density and species number were higher during the rainy seasons compared to the dry seasons, while there was no seasonal effect on fish biomass (Table 2b). Some important species (*Siganus sutor*, *Siganus canaliculatus*, *Acanthurus blochii* and *Sillago sihama*), however, disappeared or were relatively few in numbers of individuals during the heavy rains from April to May.

3.3. Fish assemblage structure

Multivariate analysis showed significant separation in fish assemblage structure based on density data among sites in all three creeks (two-way ANOSIM; global $R = 0.20–0.56$, $p < 0.01$, Table 3). Similar patterns of separation as for the density-based analyses were found for fish biomass (two-way ANOSIM; global $R = 0.24–0.55$, $p < 0.001$, Table 3). Pairwise comparisons, however, revealed no significant differences (based on either density or biomass data) between the intermediate and upper sites in Mbegani and between the lower and intermediate sites of Nunge, respectively (Table 3). Multivariate patterns on density data were visually supported in nMDS ordination plots (Fig. 4). A SIMPER analysis indicated that significant differences in fish assemblage structure among sites of Mbegani creek were mainly driven by species of the families Gerreidae (*G. oyena* and *Gerres filamentosus*), Mugilidae (*M. cephalus*) and Tetraodontidae (*Arothron immaculatus* and *Arothron hispides*). The dissimilarities in Nunge creek were primarily caused by Chanidae (*C. chanos*) and Mugilidae (*M. cephalus*), whereas families like Chanidae (*C. chanos*), Gerreidae (*G. oyena*) and Mugilidae (*M. cephalus*) were responsible for differences in Manyema creek.

An analysis of the relative abundance of fish grouped into life stages showed that the numbers of juveniles in all sites were much higher compared to the numbers of subadults and adults (Fig. 5). The subadult and adult categories were dominated by small-sized species with a total length of less than 40 cm when fully grown (e.g. *Ambassis natalensis*, *Ambassis gymnocephalus*, *Amblygobius albimaculatus*, *Hippichthys spicifer* and *Chelonodon laticeps*), with the majority being of minor or non-commercial value. In contrast, most of the juveniles composed of taxa of economic importance for fisheries and/or of interest for marine aquaculture (Appendix 1).

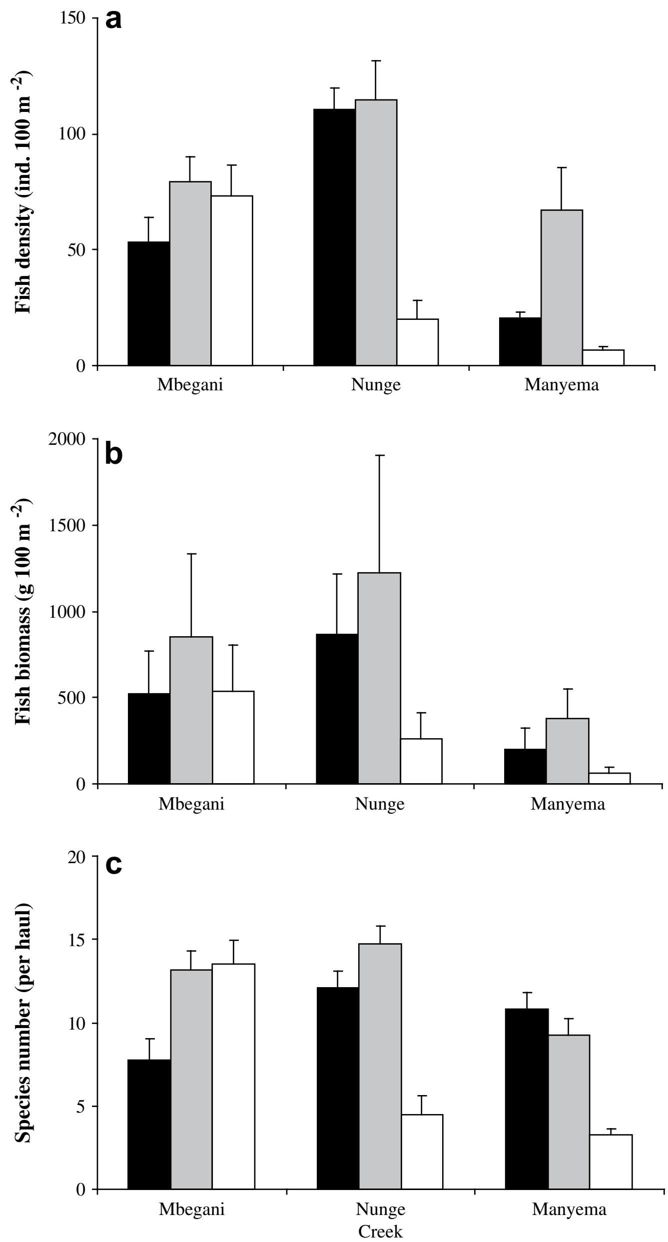

Fig. 3. Mean density (a), biomass (b) and species number (c) of fish measured in lower (black bars), intermediate (grey bars) and upper (white bars) sites of the three mangrove creeks. White bars of Nunge and Manyema creeks represent clear-cut sites, while all other bars represent mangrove-fringed sites. Error bars denote SE.

4. Discussion

Solar salt farm constructions require surface area and effective water exchange systems. If these constructions are made in mangrove areas deforestation is a necessity which will have a profound effect on fish habitat characteristics. We examined fish numbers and community composition in mangrove areas that were affected by solar salt farm development and compared with forested areas. Results showed that in areas affected by mangrove

Table 2b
Results of two-way ANOVAs of fish variables in the three mangrove creeks. Significant values ($p < 0.05$) are shown in bold.

Creek	Source of variation	df	Fish density			Fish biomass			Species number		
			MS	*F*	*p*	MS	*F*	*p*	MS	*F*	*p*
Mbegani	Site	2	9.83	1.48	0.248	77.3	1.13	0.341	102	5.35	**0.012**
	Season	1	2.10	0.32	0.580	73.6	1.07	0.310	1.20	0.06	0.804
	Site × Season	2	3.74	0.56	0.578	32.8	0.48	0.626	22.5	1.18	0.326
	Residual	24	6.66			68.6			19.2		
Nunge	Site	2	28,322	20.8	**<0.001**	9.99	12.7	**0.002**	323	24.3	**<0.001**
	Season	1	4015	2.95	0.099	0.02	0.02	0.886	2.70	0.20	0.657
	Site × Season	2	4199	3.08	0.064	0.97	1.23	0.311	19.2	1.44	0.256
	Residual	24	1363			0.79			13.3		
Manyema	Site	2	13.4	75.5	**<0.001**	7.92	29.3	**<0.001**	5.88	30.1	**<0.001**
	Season	1	0.77	4.33	**0.048**	0.33	1.23	0.279	1.30	6.67	**0.016**
	Site × Season	2	0.15	0.87	0.434	0.48	1.78	0.190	0.05	0.24	0.785
	Residual	24	0.18			0.27			0.20		

deforestation fish assemblages were different, and fish densities, biomass and species numbers were lower compared to areas with standing mangrove forest. Factors contributing to these patterns seemed to be a combination of changes in habitat structure (especially the removal of mangrove trees and prop roots), water conditions and substratum characteristics.

Our results revealed higher salinity, water temperature, sediment organic matter and sediment chlorophyll *a* concentration at the clear-cut sites compared to the forested sites in the two disturbed creek systems (i.e. Nunge and Manyema) and the undisturbed mangrove-fringed Mbegani creek. Persistently higher salinity and water temperature could act as a physiological barrier to fish due to osmoregulatory stress or reduced foraging efficiency, which is often reflected by lower number of fish species and changes in fish assemblage composition (Robertson and Duke, 1990a; Faunce et al., 2004; Vega-Cendejas and Santillana, 2004; Shervette et al., 2007). Results from the present study showed that fish taxa with high tolerance to salinity and water temperature fluctuations, such as *M. cephalus* and *C. chanos*, dominated in the deforested sites, while other taxa were found in very low numbers (less than one individual per 100 m^2). The dominance of these two species in deforested sites could be due to a high abundance of benthic microalgae on the unvegetated soft bottom (as revealed by the high sediment chlorophyll *a* concentration), especially since juveniles of mugilids and chanids often consume benthic microflora and sediment particles (Oren, 1981; Sanchez Rueda, 2002). The predominance of benthic microflora was most likely a response to light availability due to exposure, shallowness and the suitable soft substratum.

Table 3
Pairwise comparisons of two-way ANOSIM *R* values and significance (*p*) values for fish assemblage structure based on density and biomass data between sites in each of the mangrove creeks. Prior to analyses, all data were square root-transformed. L = lower sites, I = intermediate sites, U = upper sites. ns = not significant.

Creek	Sites	Fish density		Fish biomass	
		R	*p*	*R*	*p*
Mbegani	L vs I	0.266	0.008	0.259	0.004
	L vs U	0.324	0.002	0.311	0.004
	I vs U	0.059	ns	0.173	ns
Nunge	L vs I	−0.091	ns	−0.022	ns
	L vs U	0.264	0.002	0.401	0.001
	I vs U	0.339	0.001	0.421	0.001
Manyema	L vs I	0.651	0.001	0.698	0.001
	L vs U	0.586	0.001	0.566	0.001
	I vs U	0.461	0.001	0.418	0.001

It has been demonstrated that recruits of marine fishes show preference to shallower upstream areas relative to deeper ones downstream (Robertson and Duke, 1990b; Sedberry and Carter, 1993). This high abundance of juveniles upstream is likely driven by several factors including temporal searching for food and predator avoidance (Robertson and Duke, 1990b; Sedberry and Carter, 1993). However, studies have shown that physical obstruction of fish movement upstream tends to exclude fish from potential habitats, which results in alterations of the fish community composition (see Lucas and Frear, 1997; Ovidio and Philippart, 2002). In this study, fish movement could have been partially affected by physical obstructions as part of the salt farm constructions. Water conditions may change for natural reasons, due to seasonal weather patterns, which could influence fish distributions (Vega-Cendejas and Santillana, 2004; Barletta et al., 2005). In the present study, we found no seasonality in either fish assemblage composition or abiotic attributes except that the sediment organic matter was higher during the wet season and the sediment chlorophyll *a* was higher during the dry season. This lack of seasonal variations in density, biomass and species number of fish and most abiotic factors is consistent with the findings by Richmond (2002) and Lugendo et al. (2005), who found that environmental parameters (Richmond, 2002) and fish community compositions (Lugendo et al., 2005) in mangrove systems in East Africa often remained unchanged across seasons despite changes in surface runoff due to rainfall. On the other hand, the higher organic matter content in the forested sites during the wet season could be explained by its allochthonous origin due to increased surface runoff, while in the clear-cut sites it might be a result of eroding banks of the reservoirs. The high chlorophyll *a* concentration during the dry season could be caused by active photosynthetic processes by benthic microflora.

Substratum characteristics (i.e. sediment texture and bottom macrophyte coverage) seemed to be an important regulator in terms of fish abundance and species number. This was clearly shown in the naturally fringed mangrove areas. In the undisturbed Mbegani creek, for instance, species of the most diverse fish families – Gobiidae, Carangidae and Mugilidae – were found in large numbers at the intermediate and upper sites that comprised mud and fine-sand bottom substrata, while they were either few or not represented in the lower site dominated by coarse sand and patches of seagrass. Many species of these families prefer mudflats and fine sediment where they can feed and hide by burrowing in the sediment (Ikejima et al., 2003, 2006; Jaafar et al., 2004). In addition to the physical condition of the substratum, the high rate of organic matter and the abundant benthic microflora in the sediment together with decreasing water depth upstream could

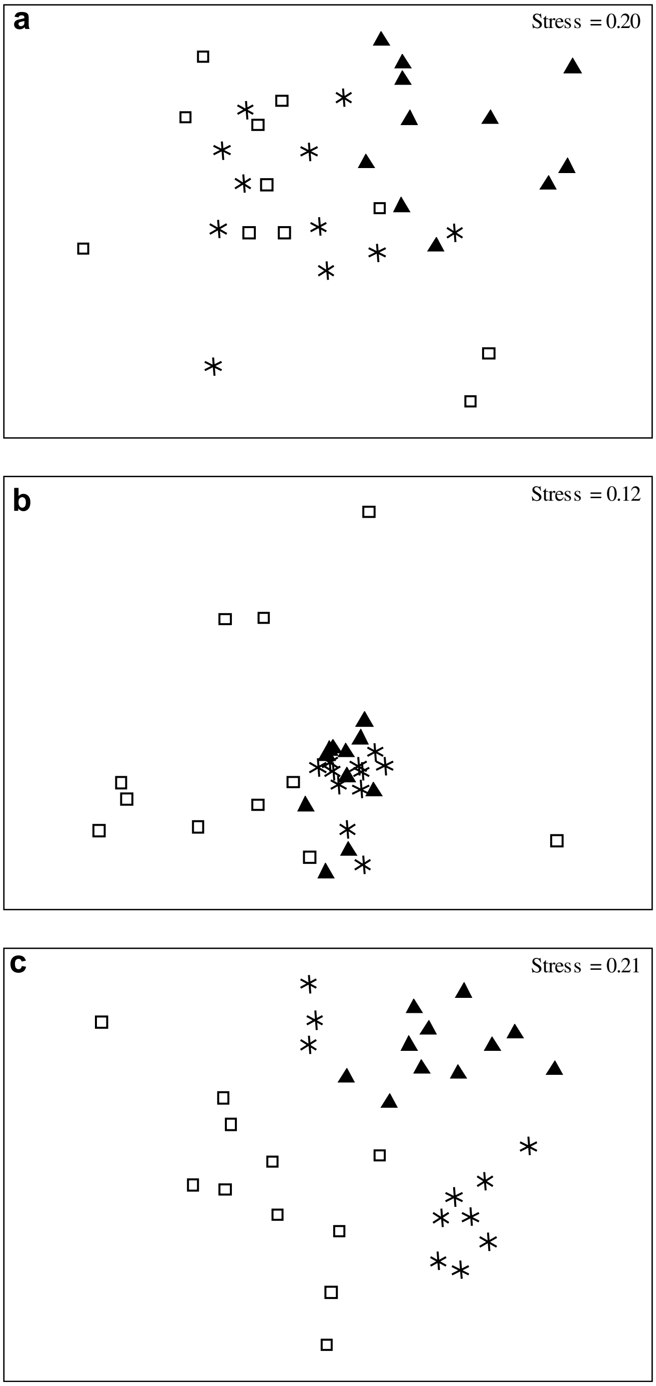

Fig. 4. Non-parametric multidimensional scaling (nMDS) ordinations of fish assemblage structure in mangrove creeks of (a) Mbegani, (b) Nunge and (c) Manyema. Plots are based on the Bray–Curtis similarities index using square root-transformed density data. ▲ = lower sites, * = intermediate sites, □ = upper sites.

attract many fish species as most of them were juveniles (Nagelkerken et al., 2008). This observation could be an explanation for lower fish species numbers in the lower sites compared to the intermediate and upper sites. Similarly, the prevalence of mudflats at the intermediate site in Manyema creek could be the reason for higher fish densities compared to the lower site with coarse sand and patches of seagrass. The higher abundance at the intermediate site was primarily due to higher catches of schooling individuals of species belonging to Chanidae, Mugilidae and Gobiidae, which are able to forage successfully on sediment particles (Froese and Pauly, 2007). Furthermore, the likeness in substrate types at the lower and intermediate sites in Nunge creek could be the reason for similarity in fish community variables (i.e. density, biomass and species number). Submerged macrophytes like seagrasses and macroalgae, which often attract fishes by provision of food and shelter (Laegdsgaard and Johnson, 2001; Lugendo et al., 2007; Gullström et al., 2008), should have had a minor effect in this study since they were only observed in low proportions in two of our study sites.

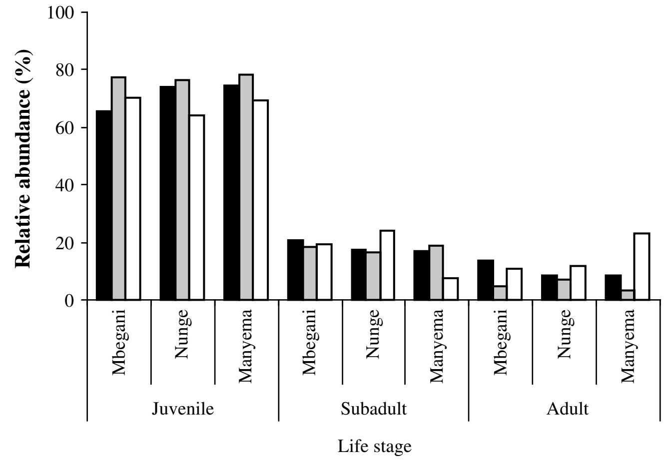

Fig. 5. Relative abundance (%) in number of individuals of juvenile, subadult and adult life stages (size classes) of fish in lower (black bars), intermediate (grey bars) and upper (white bars) sites of the three mangrove creeks. White bars of Nunge and Manyema creeks represent clear-cut sites, while all other bars represent mangrove-fringed sites.

5. Concluding remarks

During the last two decades, more than one third of the mangroves in Tanzania have been cleared due to salt production (Semesi, 1991, 1998). The results from this study suggest that solar salt farm constructions will have profound influences on mangrove-associated fish as density and diversity will be reduced and fish community structure will change within the actual area of the salt farm (in this case the upper part of the creek). This has implications for management as lowered fish numbers could influence a range of the services the mangrove ecosystem provides, including fishery resources. It is desirable that the land use change is included in an integrated management scheme in which necessary protective measures should be taken. Other resource opportunities like fish farming should also be considered. In this study it was observed that some species, such as *M. cephalus* and *C. chanos*, seemed to have a competitive advantage to other species in the deforested sites, most likely as they are adapted to live in a stressed environment, characterising not only salt farms but also fish farming systems. Hence, the integration of salt production and marine fish farming could be an option for maximizing the economical use of deforested areas which are currently mainly used for salt production.

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Appendix. Supplementary data

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ecss.2008.12.010.

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