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Genetic diversity of the giant tiger prawn *Penaeus monodon* in relation to trace metal pollution at the Tanzanian coast

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ABSTRACT

The genetic diversity of giant tiger prawns in relation to trace metals (TMs) pollution was analysed using 159 individuals from eight sites at the Tanzanian coast. The seven microsatellites analysed showed high degree of polymorphism (4–44 alleles). The measured genetic diversity ($H_o = 0.592 \pm 0.047$) was comparable to that of populations in the Western Indian Ocean. Apart from that, correlation analysis revealed significant negative associations between genetic diversity and TMs pollution ($p < 0.05$), supporting the genetic erosion hypothesis. Limited gene flow was indicated by a significant genetic differentiation ($F_{ST} = 0.059$, $p < 0.05$). The Mantel test rejected the isolation-by-distance hypothesis, but revealed that gene flow along the Tanzanian coast is limited by TMs pollution. This suggests that TMs affect larvae settlement and it may account for the measured deficiency of heterozygosity. This calls for strengthened pollution control measures in order to conserve this commercially important species.

1. Introduction

Pollution of coastal ecosystems is currently a worldwide problem and it is inevitable in developing countries such as Tanzania that largely depend on extractive industries from natural resources for economic development. In general, the extractive industries contribute about 12.4% of the total fiscal revenue (BDO East Afica, 2015). The importance of the manufacturing industries to the national economy has varied across different periods since independence, however, in recent years its contribution to the national income and hence its importance has been on the rise (Wangwe et al., 2014). Due to limited expertise, facilities, and financial capability for the treatment of industrial wastes, most of the wastes and by-products from such industries are discharged without treatment (Masalu, 2000). Such wastes may contain toxic metals such as Cd, Cr, Hg, and Pb, which can enter coastal ecosystems through streams and rivers. Due to the inefficiency of waste treatment facilities to contain harmful trace metals, wastewater from residential, institutions and industrial sources is another source of trace metals to coastal areas. For example, although the collected sewage in Dar es Salaam is treated in waste stabilisation ponds, the disposed sewage is still contaminated with trace metals (Kihampa, 2013). The same situation prevails in many coastal towns and urban centres in the country. Due to this, the expanding coastal urban population (Mmochi and Francis, 2003) is likely to increase the intensity of land based activities and aggravate the contamination of coastal ecosystems. Runoff with residues from inorganic pesticides such as zinc phosphide, copper sulphate, copper hydroxide and copper oxychloride, which are used by farmers in northern Tanzania (Ngowi et al., 2007) and other parts of the country, is another potential source of trace metals in coastal ecosystems. Levels of trace metals above background concentrations were reported in Dar es Salaam (Mtanga and Machiwa, 2007; Rumisha et al., 2012). High levels of trace metals in mangrove sediments were also reported in Dar es Salaam and Rufiji (Kruitwagen et al., 2008). Moderate to significant enrichment of Cr and Ni, was measured in the Pangani river basin (Hellar-Kihampa et al., 2012), while moderate to extreme enrichment of As, Cd, Cr, Hg, Ni, Pb, and Zn was measured in mangrove sediments from Tanga, Kilwa Masoko, Lindi and Mtwara (Rumisha et al., 2016). Marine pollution due to land based activities along the Tanzanian coast, has also been reported in other studies (Mmochi and Francis, 2003; Mohammed, 2002; Yhdego, 1995). Trace metals can accumulate in tissues of fauna and cause damage at several levels of biological organisation. Although the original damage is at the molecular level, there

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are emergent effects at the level of populations, such as the alteration of genetic diversity, that are not predictable based solely on knowledge of the mechanism of toxicity of the contaminants (Bickham, 2000). Toxicants can alter genetic diversity by increasing mutation rates, directional selection of tolerant genotypes, induction of bottleneck effects or by altering the level of gene flow (van Straalen and Timmermans, 2002; Mussali-Galante et al., 2014). Increased mutation rates can lead to increased genetic variation due to new mutations induced directly by the toxicants. Bottleneck effects and directional selection of tolerant genotypes lead to decreased genetic variation in natural populations, as long as there is limited gene flow between impacted and non-impacted populations (Bach and Dahllöf, 2012; Bickham, 2000). The bottleneck effects can be reinforced by contaminants if the size of the population is significantly reduced, leaving a small proportion of genotypes as founder for recovery and expansion (van Straalen and Timmermans, 2002). Decline in genetic diversity can result into long-term biological consequences as populations with reduced genetic diversity have reduced evolutionary potential to respond to environmental changes (Toro and Caballero, 2005). Given the importance of giant tiger prawns to prawn fisheries and the reported levels of trace metals, this study was conducted to assess the genetic variability of giant tiger prawns in relation to trace metal pollution along the Tanzanian coast.

2. Materials and methods

2.1. Study area

The study was conducted along the coastline of the Western Indian Ocean, Tanzania, which extends to over 800 km. Eight sampling sites were selected based on the availability of giant tiger prawns (Fig. 1). Selection of sites was also based on the level of industrialisation and population density. Sites 1, 4, and 8 are the most industrialised areas on the coastline, with a population density ranging from 76 to 3133 persons per square kilometres (77, 76, 3133 persons per square km for sites 1, 2, and 3, respectively (URT, 2013)). Sewage treatment systems in these areas are either not present or accessible to a very small proportion of the inhabitants. For example, municipal sewage is released into a mangrove forest at site 1 without any treatment. In areas where the sewage system is present, the collected sewage is discharged to coastal areas with minimum treatment. These sites are also frequently visited by several ferries and ships, because the largest harbours occur in these areas. Wastes from ships and municipal sewage are likely to contaminate coastal ecosystem. Although the level of industrialisation and population density at sites 2, 5, 6, and 7 is low, agricultural activities are concentrated in these areas. Residues from organic and inorganic pesticides used in agriculture are likely to enter coastal ecosystems and threaten fauna. Site 3 was located in the Saadani fishing village, which is a very small village located in the Saadani national park. The area was expected to be relatively pristine not only because it is found in a national park, which is under protection and that very few people live there (about 8585 inhabitants, (URT, 2013)), but also because it has a limited number of industries. A salt extraction and processing industry is the only industry in the area.

2.2. Sampling

Sampling of giant tiger prawns (*Penaeus monodon*) and sediments was conducted between March and July 2014. Sediments were collected in mangrove forests at low tide. Twenty sediment samples were collected using a plastic spoon and mixed thoroughly in a plastic bucket. Three subsamples were collected from the sampled sediments and stored in a freezer at −20 °C for further analysis. A total of 20 individual prawns were collected from each site with a help of local fishermen. Two pleopods were collected from each individual and preserved in 95% ethanol for molecular analysis. About 50 g of the muscle tissue was collected from the tail muscle of each animal and stored frozen in plastic bags for analysis of trace metals. The geographical coordinates of each site were recorded with a GPS receiver and it is reported in Table S1.

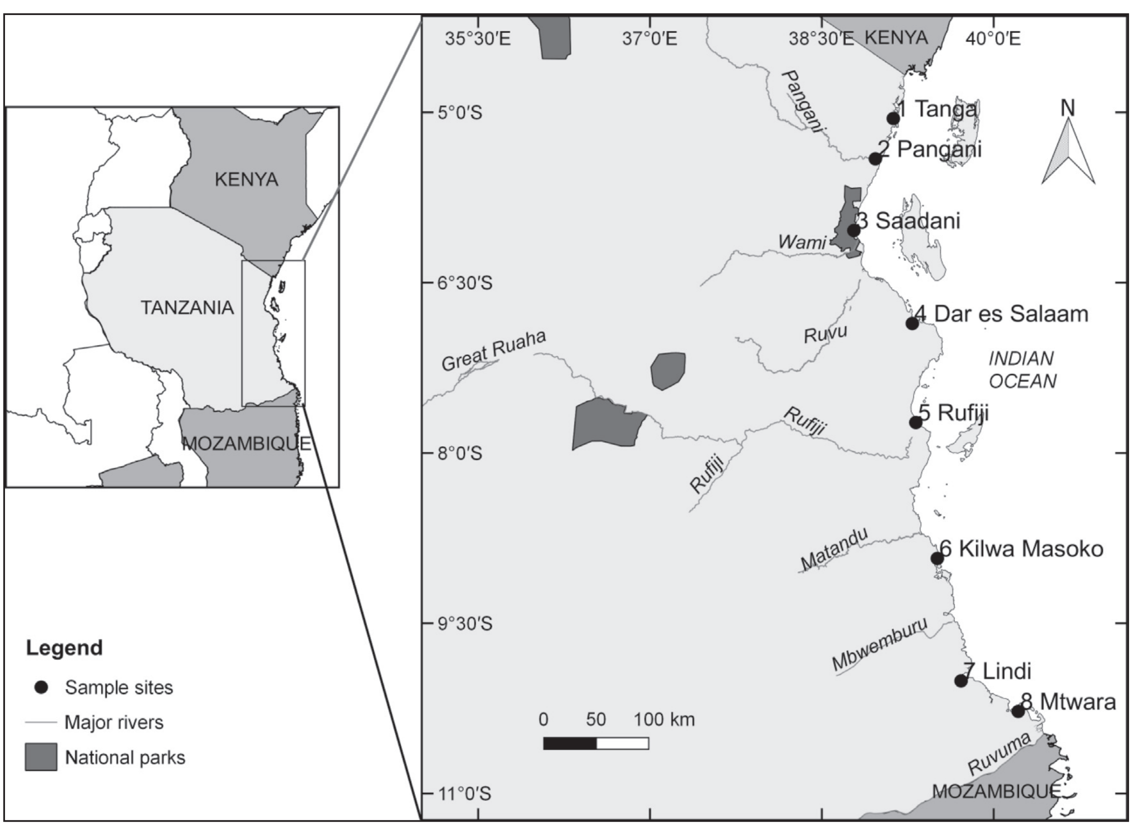

Fig. 1. Map of the Tanzanian coast showing the sample sites.

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