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Occurrence and distribution of antifouling biocide Irgarol-1051 in coral reef ecosystems, Zanzibar

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ABSTRACT

2-methythiol-4-*tert*-butylamino-6-cyclopropylamino-*s*-triazine (Irgarol-1051) has been widely used as effective alternative antifouling paint in marine structures including ships. However, it has been causing deleterious effects to marine organisms including reef building corals. The main objective of this study was to establish baseline levels of Irgarol-1051 around coral reefs and nearby ecosystems along coastline of Zanzibar Island. The levels of Irgarol-1051 ranged from 1.35 ng/L around coral reefs to 15.44 ng/L around harbor with average concentration of 4.11 (mean) ± 0.57 (SD) ng/L. This is below Environmental Risk Limit of 24 ng/L as proposed by Dutch Authorities which suggests that the contamination is not alarming especially for coral reef ecosystem health. The main possible sources of the contamination are from shipping activities. This paper provides important baseline information of Irgarol-1051 around the coral reef ecosystems within the Western Indian Ocean (WIO) region and may be useful for formulation of marine conservation strategies and policies.

The chemical compound 2-methythiol-4-*tert*-butylamino-6-cyclopropylamino-*s*-triazine (Irgarol-1051) is booster biocide that has been used to prevent biofouling on submerged surfaces such as boats, navigational buoys, underwater equipment and ships in marine environment. The biofoulings are associated with various problems including vessel friction which reduces the speed of a vessel thereby increasing fuel consumption, reducing desalination and performance of power plants fixed in sea water.

Different types of material and techniques used to combat fouling varied from place to place and time. Unfortunately, most of the developed methods were found to be inefficient in controlling the fouling and consequently the last century witnessed significant advancements in the development of new antifouling agents. In the 19th century, Tributyltins (TBTs) have been most often used as antifouling agents and are very effective against both soft and hard fouling organisms. In spite of their performance, these chemicals are associated with negative detrimental impacts on the marine environment and long half-life in the environment. The main sources of contamination of Irgarol-1051 in aquatic ecosystems such as water, sediments and organisms are by leaching and painting of ships and boats (Okamura et al., 2003; Mohr et al., 2008; Balakrishnan et al., 2012).

Due to its toxic nature to marine ecosystems Irgarol-1051 has been used as an alternatives antifouling biocide to replace Tributyltin (TBT) which was banned by International Maritime Organization (Gatidou et al., 2007). The main sources of contamination of Irgarol-1051 in aquatic ecosystems such as water, sediments and organisms are by leaching and

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painting of ships and boats (Okamura et al., 2003; Mohr et al., 2008; Balakrishnan et al., 2012).

Although Irgarol-1051 was used as an alternative to the extreme contamination of TBT, there are also some concerns that this compound this compound poses some threats to aquatic ecosystem (Okamura et al., 2003; Mohr et al., 2008; Balakrishnan et al., 2012). Contamination of Irgarol has been widely reported worldwide for example United States, the United Kingdom, the Netherlands, Singapore, Japan, France and Malaysia (Readman et al., 1993; Okamura et al., 2000; Thomas et al., 2001; Lamoree et al., 2002; Sheikh et al., 2009a; Ali et al., 2013). The highest concentration of Irgarol-1051 reported in marine environment so far was (4200 ng/L) detected in Singapore coastal waters (Basheer et al., 2002).

Irgarol-1051 is known as photosystem II compound (*PSII*) herbicide which inhibits photosynthesis and block conversion of excitation energy into chemical energy (Jones, 2005). Several studies have reported that Irgarol-1051 interferes non-targeted photosynthetic aquatic organisms such as periphyton, plankton and sea grasses (Owen et al., 2002; Cheswortha et al., 2004; Mohr et al., 2008; Zhang et al., 2008; Buma et al., 2009). The detection of Irgarol 1051 in marine ecosystems raises serious scientific concerns for the ecosystem health.

Coral reef ecosystems face a variety of threats from land and marine based anthropogenic activities (Peter et al., 2014; Ali et al., 2013; Balakrishnan et al., 2012; Sheikh et al., 2007; Sheikh et al., 2009b; ISRS, 2004; Konstantinou and Albanis, 2004, Lamoree et al., 2002; Biselli et al., 2000), global warming (Peter et al., 2014) as well as competition for survival (Ferrier-Pages et al., 2011; Amar et al., 2008; Dizon and Yap, 2005) which cause deterioration of coral reefs and other marine resources.

Ecotoxicological laboratory based studies revealed that corals may be affected by even ambient levels of Irgarol-1051. For example, the photosynthesis and calcification rates for *Galaxea fascicularis* have been significantly reduced when exposed to 1000 ng/L of Irgarol (Sheikh et al., 2012) and reduction of incorporation of ^{14}C *Madracis mirabilis* when exposed to 60 ng/L and reduction of net photosynthesis of intact corals reduced by 63 ng/L (Owen et al., 2002). Due to toxic behaviors of Irgarol-1051, especially to non-targeted photosynthetic marine organisms, the countries like the United Kingdom, Sweden and Denmark have imposed restrictions on the utilization of Irgarol-1051 as antifouling paint to recreational boats <25 m long (Thomas et al., 2002).

Zanzibar is a strategic Western Indian Ocean (WIO) semi-autonomous Archipelago within United Republic of Tanzania. Zanzibar depends on marine transportation, tourism and fisheries industries as the key economic players. The Islands are surrounded by fringing reef in eastern, northern and southern corridors (Muthiga et al., 1998). The reefs around Zanzibar have been recently degraded due to developmental activities such as mushrooming of tourist resorts, snorkeling and boating activities. Direct discharge of municipal untreated sewage and shipping activities are among the challenges of conservation strategies of coastal resources in the Island (Sheikh et al., 2007).

As the Zanzibar coral reef ecosystem health faces a numerous threats of pollutions of hazardous chemicals, very scarce is known on occurrences of antifouling biocide Irgarol-1051 in Zanzibar and WIO region at large. This study therefore reports baseline data on occurrence and distribution of Irgarol-1051 in coral reef waters around Zanzibar Island.

A total of 26 seawater samples were collected from 13 sampling locations (Fig. 1). The sites include Malindi harbor, Bwawani area, and Mtoni port (clustered as harbor/docyard). The seawater samples were also collected on small Islets and sand dunes of Bawe, Chapwani, Chumbe, Nyange, Pange, Mnemba and Kwale (Islands). In the coastal area seawater were collected from Kizimkazi and Sheni (coasts) and other samples collected from Murogo reefs and chapwani reefs (coral

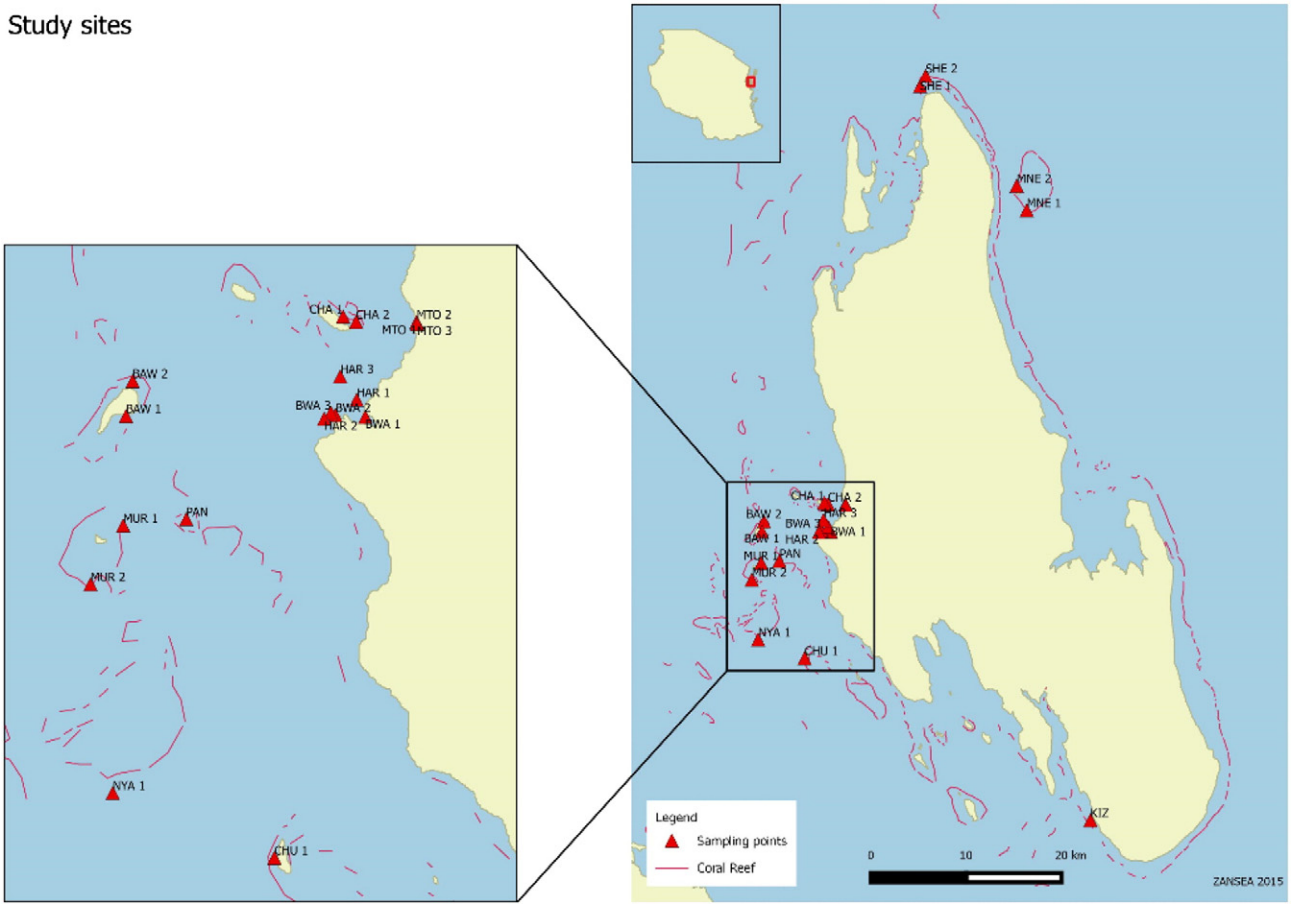

Fig. 1. Location of sampling sites.