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Diatom communities on commercial biocidal fouling control coatings after one year of immersion in the marine environment

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ABSTRACT

Little is known about the effect of commercial biocidal fouling control coatings on fouling diatom communities and their growth forms after long periods of exposure in the marine tropical environment. The current study investigated the abundance and composition of fouling diatom communities developed on 11 commercially available biocidal antifouling coatings, covering the three main technology types in recent historic use (Self-Polishing Copolymers, Self-Polishing Hybrid and Controlled Depletion Polymers) after one year of static immersion at two locations in Muscat, Oman (Marina Shangri La and Marina Bandar Rowdha). Light microscopy demonstrated that the total abundance of diatoms and the relative abundance of growth forms were significantly affected by the choice of biocidal antifouling coating and experimental location. Using scanning electron microscopy, a total of 21 diatom genera were identified which were grouped into adnate, motile, plocon and erect growth forms. The adnate growth forms, mainly the genera *Amphora*, *Cocconeis* and *Mastogloia*, dominated the other growth forms in terms of their relative abundance. Current results revealed the importance of exposure location and choice of biocidal antifouling coating on the relative abundance of diatom growth forms.

1. Introduction

Ecological niche refers to the position of an organism within an ecosystem depending on its morphological, physiological and behavioural adaptations to the surroundings (Vandermeer, 1972). In regard to diatoms, several studies have reported that their diverse growth forms (Round and Crawford, 1981) and their habitat occupancy (planktonic or benthic) significantly approximate a diatom's ecological niche (Hoagland et al., 1982; Hoagland, 1983; Round et al., 1990; McCormick and Stevenson, 1991; Johnson et al., 1997; Yokota and Sterner, 2010). The type of the diatom growth form was shown to partially influence the availability of light and nutrients to the cells within a stratified environment such as microbial biofilms on biotic surfaces (Yokota and Sterner, 2010). Although microbial biofilms are composed of various microorganisms including bacteria, diatoms, dinoflagellates, fungi and protozoa (Lewandowski, 2000; Wahl et al., 2012), benthic diatoms are considered to be one of the primary colonizers (Mieszkin et al., 2013).

Benthic diatoms form biofilms on any surface immersed in the marine environment (Cooksey and Wigglesworth-Cooksey, 2001; Molino and Wetherbee, 2008; Cooksey et al., 2009; Zargiel et al., 2011). The accumulation of fouling on ships' hulls impacts on operational efficiency by reducing ship speed and/or increases fuel consumption (Evans et al., 2000; Lewthwaite et al., 1985; Bohlander, 1991; Candries et al., 2001; Swain et al., 2007; Schultz et al., 2011). The most common method to control fouling on marine vessels is the application of fouling control coatings (Cassé and Swain, 2006; Molino et al., 2009; Briand et al., 2012; Hunsucker

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et al., 2014; Hunsucker and Swain, 2015). Although it is reasonable to expect the market share of non-biocidal foul release coatings to increase in future years, biocidal antifouling coatings currently remain the dominant technology, reportedly accounting for almost 94% of global sales (Lindholdt et al., 2015). However, it is recognised that even the best fouling control coating is unlikely to prevent all fouling on all ship types under all conceivable operational profiles (Kidd et al., 2016).

To date, 38 diatom genera have been identified within the biofilms developed on two types of commercial biocidal coatings *viz.* Self-Polishing Copolymers (SPC) and Controlled Depletion Polymers (CDP). The most common fouling diatoms included the genera *Amphora, Nitzschia*, *Navicula*, *Fragilaria*, *Cylindrotheca* and *Synedra* (Callow, 1986; Cassé and Swain, 2006; Molino et al., 2009; Fay et al., 2011; Briand et al., 2012). Apart from taxonomical information, knowledge of the morphological or physiological aspects of fouling diatoms on biocidal coatings were reported only in two studies (Hunsucker et al., 2014; Zargiel and Swain, 2014), which did not reveal any information regarding the diatom growth forms. Furthermore, the influence of location on the composition of fouling diatom communities on biocidal coatings had previously been tested for periods of only two weeks exposure in marine environments (Molino et al., 2009; Briand et al., 2012).

Light microscopy has been the most commonly used technique to study diatom communities in biofilms developed on biocidal coatings (Cassé and Swain, 2006; Molino et al., 2009; Zargiel et al., 2011; Briand et al., 2012; Hunsucker et al., 2014). This technique allows the quantitative analysis of diatom communities on a relatively large surface area on the antifouling coating for a given amount of time. The identification of some diatoms at the genus level is feasible due to the availability of a large collection of microscopic images in diatom and algae databases worldwide (ANSP Algae Image Database from the Phycology Section, USA; Diatom Image Database from ADIAC Project, UK; Diatom Image Database, FCE LTER, USA). However, for the identification of diatoms at the species level and the observation of species of smaller cell sizes, it is mandatory to use scanning electron microscopy (SEM) (Bishop et al., 1974; Daniel et al., 1980; Robinson et al., 1985; Totti et al., 2007; Molino et al., 2009; Céliavillac et al., 2013). SEM has been commonly used to study benthic diatom assemblages on various marine substrata including turtles (Majewska et al., 2015), hydroids (Round et al., 1961; Di Camillo et al., 2005; Romagnoli et al., 2007, 2014), sponges (Cerrano et al., 2004a; b; Totti et al., 2005), bryozoans (Wuchter et al., 2003), macroalgae (Majewska and De Stefano, 2015; Majewska et al., 2016), seagrasses (Pennesi et al., 2011, 2012, 2013), rocks (Colak Sabanci and Koray, 2010), quartzite and marble (Totti et al., 2007) in the marine environment. Only few studies have reported the use of the SEM technique to investigate the diatom communities within marine biofilms developed on antifouling coatings (Dempsey, 1981a, b; Molino et al., 2009).

In this study, the abundance and diversity of fouling diatom communities developed on three types of commercial biocidal coatings were investigated after static immersion for a period of one year at a depth of 1 m in Marina Shangri La and Marina Bandar Rowdha, Oman using light and scanning electron microscopy. The aims of this study were as follows:

1. To estimate the total abundance of fouling diatoms and relative abundance of diatom growth forms using light microscopy;
2. To identify fouling diatoms at the genus and species level using light and scanning electron microscopy;
3. To assess the effects of the type of biocidal coating and location on the total abundance and composition of fouling diatom communities.

2. Materials and methods

2.1. Description of experimental locations

The two locations selected for this study were Marina Shangri La (23°32′55″N 58°39′23″E) and Marina Bandar Rowdha (23°35′07″N 58°36′48″E) in Muscat, Oman (Fig. 1). Marina Shangri La is part of a resort that was established in 2005 and provided more than 50 berths for recreational boats and yachts (www.shangri-la.com/muscat/barraljissahresort/sports-recreation/sea-sports/Accessed on 30 April 2015). The shoreline is formed mainly by Paleocene-Eocene limestone rocks (Searle, 2014) and the water and sediments showed minimal heavy metal and hydrocarbon pollution. On the other hand, Marina Bandar Rowdha was established in 1996 as a semi-enclosed bay providing more than 200 berths for various fishing vessels, recreational boats and yachts (www.marinaoman.net/about.html/Accessed on 30 April 2015). The shoreline is mostly composed of eroded ophiolite rocks (Searle, 2014) and waters at the marina are polluted by hydrocarbons due to the presence of the petrol station, while sediments at this location contained tributyltin (TBT) and high concentrations of heavy metals. There were no differences between the locations in terms of temperature (24–34 °C), pH (8.17–8.33) and salinity (37–38 ppt) throughout the study. The *in situ* turbidity measurement of the waters at Marina Shangri La was 5–7 NTU (Nephelometric

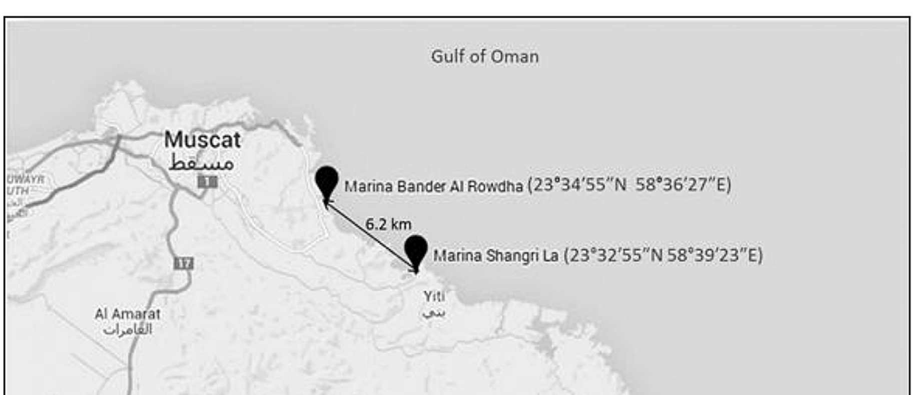

Fig. 1. Locations of the 2 experimental sites; Marina Shangri La and Marina Bander Al Rowdha at Muscat, Oman (Image was taken from Map data ©2014 Google Lite mode and modified to show latitude and longitude of each location and distance between the locations).