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First report of bioaccumulation and bioconcentration of aliphatic hydrocarbons (AHs) and persistent organic pollutants (PAHs, PCBs and PCNs) and their effects on alcyonacea and scleractinian corals and their endosymbiotic algae from the Persian Gulf, Iran: Inter and intra-species differences

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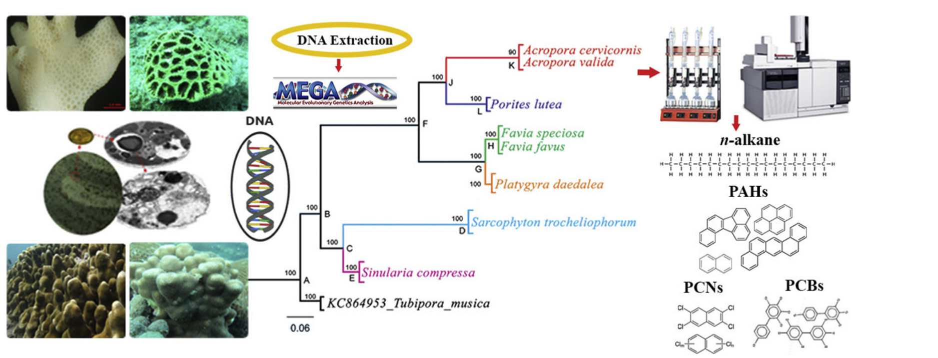
HIGHLIGHTS

- The first report on the bioaccumulation and biocencentration of PCNs in coral species.
- The first report on the bioaccumulation of AHs, PAHs, PCBs and PCNs in zooxanthellae.
- Kharg coral reef demonstrated higher concentrations of AHCs and POPs in all samples compared to Lark.
- LMW-PAHs and AHCs, tri and –tetra-PCBs and PCNs were dominant in coral tissues and zooxanthellae.
- The results disclosed that main source of AHs and POPs is oil/industrial activities in this area.

GRAPHICAL ABSTRACT



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ABSTRACT

The coral reefs of the Persian Gulf are the most diverse systems of life in the marine environment of the Middle East. Unfortunately, they are highly threatened by local and global stressors, particularly oil pollutants. This is the first quantitative and qualitative study aimed at assessing the concentration and sources of *n*-alkanes and POPs (PAHs, PCBs and PCNs) in coral tissues, symbiotic algae (zooxanthellae), reef sediments and seawaters in coral reefs of Lark and Kharg in the Persian Gulf, Iran. This work was conducted on eight species of six genera and three families of hard corals and one family of soft coral. A significant variation in the concentration of $\sum$30*n*-alkanes and POPs ($\sum$40PAHs, $\sum$22PCBs and 20PCNs) was found in the decreasing order: zooxanthellae > coral tissue > skeleton > reef sediment > seawater. The bioaccumulation of these compounds was 2-times higher in ahermatypic than in hermatypic corals, among which significant variations were observed in both sites. In Kharg, *Porites lutea* had the highest mean concentration of $\sum$30*n*-alkanes and $\sum$40PAHs in soft tissue, whereas

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DNA Barcoding
AHs
POPs
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the lowest values were in *Platygyra daedalea*. A contrasting trend was documented for ∑22PCBs and 20PCNs, with the highest level reported in soft tissue of *P. daedalea* and the lowest in *P. lutea* at Kharg. Compositional pattern of AHs and PAHs demonstrated the predominance of LMW-PAHs and *n*-alkanes. In skeleton and reef sediments, tetra, penta and tri-CBs were the most abundant PCBs congeners followed by di-CB > hexa-CB > hepta-CB > octa-CB,whiletri-CB > di-CB > tetra-CB > penta-CB > hexa-CB > hepta-CB > octa-CB was observed for soft tissue, zooxanthellae and seawater. The results of RAD test indicated significantly negative correlation between total concentration of these compounds with zooxanthellae density, the chlorophyll-a and C_2 in corals at both reefs. This is the first report on levels, health assessment and source apportionments of POPs in zooxanthellae and a first step in the implementation of specific coral reef management measures.

1. Introduction

Coral reefs are the most productive and varied ecosystems in the world (Ko et al., 2014; Moberg and Folke, 1999; Reaka-Kudla, 1997; Roberts et al., 2002), providing goods and services for values from $172 to $375 billion per year (Fischlin et al., 2007; Martinez et al., 2007; Veron et al., 2009). Coral reefs are being threatened at a global scale by anthropogenic reasons (Ranjbar Jafarabadi et al., 2017a, 2017b, 2017c), that could lead to their decline and extinction (Hughes et al., 2003; Knowlton, 2001). Ten percent of the world's reefs are already seriously spoiled (Knowlton and Jackson, 2008; Schutte et al., 2010; Tamelander and Rajasuriya, 2008) due to human-associated activities (Goreau et al., 2000; Hoegh-Guldberg, 1999; Wilkinson et al., 1999), and 60% are predicted to display serious damages within the next 20–40 years. Recently, there has been increasing concern over petroleum hydrocarbon pollution in the environment due to its toxicity to biota, corals and other life forms, including humans (Cappello et al., 2017; Cetin, 2016; Elgershuizen and De Kruijf, 1976; Fasulo et al., 2012; Maisano et al., 2017; Tkachenko, 2017; Varjani et al., 2015; Varjani and Upasani, 2016).

Oil pollution is one of the main threats for corals worldwide due to industries along with oil exploration and transportation of metals and other pollutants (Reddy et al., 2007; Pasha et al., 2012; Abdullah et al., 2013). Two important groups belonging to the hydrocarbons (HCs) are aliphatic hydrocarbons (AHs) and polycyclic aromatic hydrocarbons (PAHs). AHs are the major fraction of most crude oils and deposit in sediments (Reitner and Thiel, 2011; Varjani and Upasani, 2017). PAHs are a group of complex mixture compounds of great concern due to their toxicity, carcinogenicity, mutagenicity, low volatility, resistance to microbial degradation, and high affinity for sediments and persistency (Abdel-Shafy and Mansour, 2016; Lamichhane et al., 2016; Ranjbar Jafarabadi et al., 2017a, 2017b, 2017c; Varjani and Upasani, 2016, 2017). PAHs originate from natural and anthropogenic sources, including incomplete combustions (Moon et al., 2006), industrial incinerations (Christensen and Bzdusek, 2005; Ghosh et al., 2015), transport or uncontrolled spills (Nácher-Mestre et al., 2010) wood and coal burning (Lin and Zhu, 2004) and metal smelting. Marine life is sensitive to PAHs, which toxicity increases generally with their molecular weight. PAHs can be metabolized in aquatic fauna to active and potent carcinogenic forms (Bonner et al., 2005; Hardin et al., 1992). Persistent organ halogen compounds (POHCs), such as polychlorinated naphthalenes (PCNs) and polychlorinated biphenyls (PCBs), which belong to persistent organic pollutants (POPs), are well-known environmental contaminants (Castells et al., 2008). PCNs show similar properties as PCBs, and are both included in the Stockholm Convention on POPs (Stockholm Convention, 2014). Among PCBs and PCNs, numerous congeners can adopt a planar configuration, associated with a potential to elicit a dioxin-like toxicity (Ahlborg et al., 1994; Engwall et al., 1994; Hanberg et al., 1990; Villeneuve et al., 2000; Blankenship et al., 2000), which has been reported in some investigations (Brack et al., 2003; Falandysz, 1998; Falandysz, 2003; Hayward, 1998; Persson et al., 2005; Sprovieri et al., 2007; Villeneuve et al., 2000; Yusa et al., 2006). PCNs and PCBs are mainly released into the environment due to the improper use and disposal after intended production (Ishaq et al., 2003), or by municipal solid waste incinerators, accidental spills and leaks and other industrial processes (Abad et al., 1999; Castells et al., 2008). Due to similar physical properties and chemical structures, PCBs and PCNs have been used in similar applications, such as dielectric fluids, insulators, additives and preservatives, and because of their environmental persistence and lipophilic properties, they bioaccumulate in various organisms, from plankton, bivalves, fish, reptiles, birds to terrestrial and marine mammals.

Despite a wealth of information on the effects of petroleum pollutants on corals through laboratory studies, there is a scarcity of information on the levels of petroleum pollutant on corals in the field, and the works realized in Taiwan (Ko et al., 2014), Gulf of Mexico (Sabourin et al., 2013), southwest Puerto Rico (Pait et al., 2009) and Kaneohe Bay in Oahu, Hawaii (Thomas and Li, 2000), constitutes the only background information we currently possess. Oil pollutants are extremely dangerous for coral health and survival by altering the coral photo-physiological capacities (Meehan and Ostrander, 1997) often characterized by zooxanthellae expulsion (Neff and Anderson, 1981; Peters et al., 1981) or decrease of zooxanthellae primary production (Cook and Knap, 1983; Neff and Anderson, 1981; Rinkevich and Loya, 1983), by impairing sediment clearance ability (Bak and Elgershuizen, 1976) or coral fertilization (Negri and Heyward, 2001), and may lead to tissue death (Neff and Anderson, 1981; Wyers et al., 1986).

Considering the threats that oil pollution represents worldwide for corals and the paucity of field works investigation, this study aims to fill these gaps by assessing the environmental risk of pollution by petroleum and POPs in the Persian Gulf. The aim was to provide new data on the spatial variation of the level of hydrophobic organic pollutants (*n*-alkanes, PAHs, PCBs and PCNs) in eight species of hard and soft corals belonging to Acroporidae, Faviidae, Poritidae and Alcyoniidae (in tissues, zooxanthellae, skeleton when possible), as well as in their ambient reef sediments and seawater from Kharg and Lark coral Islands in the Persian Gulf. In addition, zooxanthella density and chlorophyll concentrations in corals were also measured to determine whether the degree of pollution may alter coral health. Overall, the objective of this study was to highlight which coral species, coral compartment, site, abiotic compartment is the most impacted by oil pollution. These findings will definitely help our understanding on the distribution and origins of pollutants in the Iranian coral Islands, and consequent impacts on coral health.

2. Materials and methods

2.1. Study site

The Persian Gulf is one of the most critical water-bodies in the world (Ranjbar Jafarabadi et al., 2017a, 2017b, 2017c), and numerous studies documented the impacts of contaminations (Kazemi et al., 2012; Pejman et al., 2015). Two islands were chosen for the present study, Kharg and Lark (29.235481°N 50.31°E; 26°51′12″ N 56°21′20″ E, respectively). Lark Island (49 km^2) is an area off the coast of Iran and has been one of Iran's major oil export points since 1987. It is located in the