Science of the Total Environment 649 (2019) 186–200

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Prospective biomonitor and sentinel bivalve species for pollution monitoring and ecosystem health disturbance assessment in mangrove–lined Nicaraguan coasts

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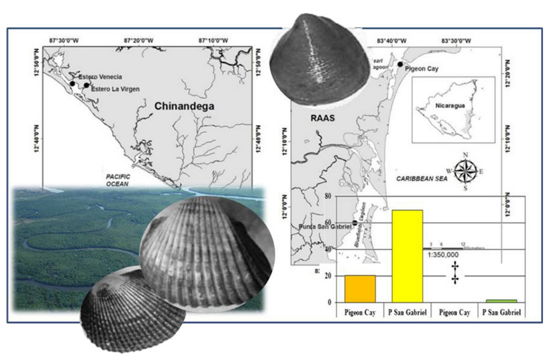
HIGHLIGHTS

- *P. arctata*, *A. tuberculosa* and *L. grandis* bioaccumulate metals, PAHs and POPs.
- Their health status can be assessed by low-cost and effortless effect biomarkers.
- They are suitable for biomonitoring as alternative/complementary to *C. rhizophorae*.
- This species assortment is suitable for regional monitoring in Mesoamerica.
- This monitoring strategy may be useful for mangrove-lined ecosystems worldwide.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 10 April 2018
Received in revised form 30 July 2018
Accepted 20 August 2018
Available online 23 August 2018

Editor: Daniel Wunderlin

Keywords:
Mangrove
Bioaccumulation
Biomarkers
Ecosystem health
Monitoring

ABSTRACT

This research aims at contributing to the use of *Polymesoda arctata*, *Anadara tuberculosa*, and *Larkinia grandis* as prospective biomonitors and sentinels, surrogate of *Crassostrea rhizophorae* for pollution biomonitoring in mangrove-lined coastal systems. Localities were selected along the Nicaraguan coastline in the rainy and dry seasons during 2012–2013: *A. tuberculosa* and *L. grandis* were collected in the Pacific, and *P. arctata* in the Caribbean. The tissue concentration of metals, polycyclic aromatic hydrocarbons (PAHs) and persistent organic pollutants (POPs) were integrated into pollution indices (chemical pollution index -CPI- and pollution load index -PLI-) and biological endpoints (flesh-condition, reproduction, histopathology and stress-on-stress) were determined as biomarkers of ecosystem health disturbance. In the Caribbean, contaminant tissue concentration was low in *P. arctata*, with some exceptions. Ag, As, Cd, Hg, Ni and V were mainly recorded during dry season, and PAHs and POPs (HCHs, DDTs, AHTN, PCBs and BDE85) during rainy season. Metals and PAHs were not a major threat in the study area; in contrast, high levels of HCHs and DDTs and low-to-moderate levels of musk fragrances and PBDEs were recorded. Minor differences were found in biological parameters albeit during the rainy season the LT50 values were low and seemingly associated to high PLI and CPI values. In the Pacific, the main pollutants recorded in *A. tuberculosa* and *L. grandis* were HCHs, DDTs, AHTN and PDBEs in rainy season and Cd in dry season. Although basic research is needed to understand the general biology, ecology and diseases in these Pacific

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https://doi.org/10.1016/j.scitotenv.2018.08.269

species, biological endpoints comparable to those used in other sentinel bivalves are seemingly suitable biomarkers of health disturbance. Overall, Caribbean *P. arctata* and Pacific *A. tuberculosa* and *L. grandis* seem to be potential target species for pollution monitoring and ecosystem health disturbance assessment in mangrove-lined Nicaraguan coastal systems. Their use together with *C. rhizophorae* would provide opportunities for common approaches to be applied in inter-ocean countries of the Mesoamerican region.

1. Introduction

The mangrove forest from Nicaragua extends throughout 69,050 ha and represents a main coastal ecosystem that is quite equally distributed between the Pacific and the Caribbean coasts (Jiménez, 1999; FAO, 2007). Overall, mangrove ecosystems are threatened by a combination of natural disasters, tourism, aquaculture, deforestation and chemical pollution (Ellison, 2004; Defew et al., 2005; Fernandez et al., 2007; Polidoro et al., 2010; Lewis et al., 2011; Bayen, 2012). Concretely, Nicaraguan mangroves are influenced by 21 watersheds: 13 drain in the Caribbean coast and 8 in the Pacific coast (González, 1997). Thus, the Caribbean coast is a major sink for contaminants transported along the watersheds that receives the 90% of the Nicaragua's territory catchment (UNEP, 2002). In the Pacific coast, maritime traffic and ports, urban settlements, shellfish farming and intensive agriculture are potential sources of pollutants (Spongberg and Davies, 1998; Gener et al., 2009; Spongberg and Witter, 2008; Vargas et al., 2015). Within this context, pollution monitoring programmes are needed for environmental management and protection in the region. The most relevant biomonitoring programmes world-wide are based on the Mussel-Watch approach and use bivalve molluscs as biomonitors and sentinels (Goldberg, 1975; Sericano et al., 1995; Monirith et al., 2003; Kimbrough et al., 2008, 2009; Garmendia et al., 2011; ICES, 2011; Marigómez et al., 2013). Alas, in Nicaragua and the majority of Mesoamerican countries, pollution biomonitoring activities are, to our knowledge, based on sporadic studies carried out by academics and research groups (GEF-REPCar, 2011; Ebanks-Mongalo et al., 2013; Aguirre-Rubí et al., 2018a,b) or by international organisations such as the International Mussel Watch and the UNEP Caribbean Environment Programme (Farrington and Tripp, 1995; Siung-Chang, 1997; UNEP, 2006).

The mangrove cupped oyster (*Crassostrea rhizophorae*) is a major candidate as biomonitor and sentinel for pollution monitoring programmes in mangrove ecosystems (Nascimento et al., 1998; Wallner-Kersanach et al., 2000; Rebelo et al., 2005; Silva et al., 2003, 2006; da Silva et al., 2005; Zanette et al., 2006; Valdez Domingos et al., 2007; Torres et al., 2012; Aguirre-Rubí et al., 2018a,b). However, its distribution in Nicaragua is restricted to the Caribbean coast and therefore it cannot be used in pollution monitoring programmes in the Pacific Coast. In consequence, additional potential biomonitor and sentinel species are needed, both in the Caribbean and in the Pacific Coasts. This multi-species approach is a common practice in pollution monitoring programmes carried out from North to South America, which regularly use more than one biomonitor/sentinel species (mussels, oysters, clams and cockles) depending on their availability at each particular sampling locality (Farrington and Tripp, 1995; Sericano et al., 1995; Kimbrough et al., 2008). Besides, pollution biomonitoring often includes the simultaneous use of more than one species because the susceptibility against pollutants may vary amongst species (Fernández-Tajes et al., 2011; Pereira et al., 2011). Within this framework, the slender marsh clam, *Polymesoda artacta* from the Caribbean Sea, and mangrove cockles, *Anadara tuberculosa* and *Larkinia grandis* from the Pacific coast were selected as potential biomonitor/sentinel species for Nicaraguan mangrove ecosystems to be used either in parallel or as alternative to mangrove cupped oysters. These three species had been used as biomonitors in previous reports (Farrington and Tripp, 1995; Pérez-Cruz et al., 2013; Ziarrusta et al., 2015) but to our knowledge, biological effects studies are lacking.

P. artacta (syn., *P. solida*) is a benthic mollusc with a biogeographical range extending from Belize to the Orinoco River in Venezuela (Severeyn et al., 1994). It inhabits fine, sandy sediments of the low-to-medium salinity estuarine zone (high organic content, salinity: 3–20 ppt; Severeyn et al., 1994). In Nicaragua, this species has been recorded in the Caribbean coast from Pearl Lagoon (North) to Monkey Point (South), as *P. solida*, *Polymesoda* sp. or simply marsh clam (Mackenzie and Stehlik, 2001; MARENA, 2004; GTR-K, 2007; Ziarrusta et al., 2015). Mangrove cockles, *A. tuberculosa* and *L. grandis*, (syn., *A. grandis*) are found along an ample biogeographical range from Baja California in Mexico to Bahia de Tumbes in Perú (Mora Sanchez, 1990; Cruz and Jimenez, 1994). In general, the pustulose ark, *A. tuberculosa* is more abundant than the ark shell clam, *L. grandis* (Mackenzie, 2001). Pustulose arks inhabit mud sediments (up to 15 cm depth) in mangrove swamps, amongst the aerial prop roots and under the canopies of the mangrove trees (Mackenzie, 2001; Stern-Pirlot and Wolff, 2006). In Nicaragua, this species (commonly named “black shell”) has been recorded along the Pacific coast (Pérez et al., 2003; Gener et al., 2009; USAID, 2012). Ark shell clams live in intertidal mudflats and some subtidal areas beyond the edges of mangrove swamps (Mackenzie, 2001). Unlike in neighbouring countries such as Honduras and El Salvador where it is commercially exploited (Galdamez Castillo et al., 2007), in Nicaragua this species (commonly known as “casco de burro” -donkey's hoof-) is endangered by overharvest (Gener et al., 2009), except in the Padre Ramos reserve, where it is under community management for recovery.

The present research aims at contributing, on the basis of the experience and toolbox developed previously for mangrove cupped oysters in the same region (Aguirre-Rubí et al., 2018a,b), to the use of *P. arctata*, *A. tuberculosa* and *L. grandis* as potential biomonitors and sentinels species for pollution biomonitoring in mangrove-lined coastal systems. For this purpose, a pilot field study was carried out in 5 localities (2 in the Caribbean and 3 in the Pacific coast) subjected to different types and levels of pollution, in two sampling campaigns during 2012–2013. Samples were collected in the rainy and dry seasons and the tissue concentration of metals, polycyclic aromatic hydrocarbons (PAHs) and persistent organic pollutants (POPs), and relatively effortless effect biomarkers (i.e., histopathology) were recorded in the three species.

2. Material and methods

2.1. Sampling sites and sample collection

Sampling was carried out along one year (2012—2013) in the rainy season (October) and in the dry season (March). Seawater surface temperature was in the range of 30–32 °C at both seasons in all the studied localities. Slender marsh clams (*Polymesoda arctata*) were collected from two (subtidal; <1 m depth) localities of the Caribbean coast (Fig. 1): Punta San Gabriel at Bluefields and Pigeon Cay at Pearl Lagoon. Punta San Gabriel was considered as presumptive reference site (far away from urban settlements, ~6 km) whilst Pigeon Cay was selected as potentially polluted due to the influence of aquatic transport and urban discharges (GEF-REPCar, 2011; Ebanks-Mongalo et al., 2013). Pustulose arks (*Anadara tuberculosa*) were collected from two intertidal mangrove swamps in the Pacific coast (Fig. 2): Isla de Machuca (Puerto Corinto) and Estero La Virgen (Padre Ramos Natural Reserve). Isla de