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Relationship between metal and polybrominated diphenyl ether (PBDE) body burden and health risks in the barnacle *Balanus amphitrite*

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ABSTRACT

In the present study, we employed the widespread and gregarious barnacle species *Balanus amphitrite* in a biomonitoring program to evaluate coastal pollution around three piers (i.e., Tso Wo Hang, Sai Kung and Hebe Haven) in Hong Kong. An integrated approach was used herein, combining both the chemical determination of contaminant concentrations, including metals and polybrominated diphenyl ethers (PBDEs), and a suite of biological responses across the entire barnacle lifecycle (i.e., adult, nauplius, cyprid and juvenile). The analytical results revealed a distinct geographical distribution of metals and PBDEs. Adult physiological processes and larval behaviors varied significantly among the three piers. Furthermore, a correlation analysis demonstrated a specific suite of biological responses towards metal and PBDE exposure, likely resulting from their distinct modes of action. Overall, the results of this study indicated that the combination of chemical and biological tests provided an integrated measure for the comprehensive assessment of marine pollution.

1. Introduction

The use of sentinel organisms as biomonitors to indicate environmental safety is a well-established approach in the environmental risk assessment of a wide variety of anthropogenic contaminants (Durou et al., 2007; Phillips and Rainbow, 1993; Rainbow et al., 2000). During exposure to environmental pollution, biomonitors are able to accumulate trace aqueous contaminants to a much higher level in their tissues, eventually causing the emergence of physiological disturbances. Working together with chemical monitoring of geographical fluctuations of contaminants, the integrated application of a suite of biological responses can provide early warning signals of environmental disturbances and offer ecotoxicologically relevant tools for the comprehensive evaluation of the combined effects of contaminants (Cheung et al., 2002; Durou et al., 2007; Dionísio et al., 2013). Therefore, serving as an efficient supplement to chemical detection, biomonitoring has become widely applied, and various biomonitors, such as mussels, oysters and barnacles, are generally considered in an attempt to obtain a complete assessment of the risks associated with contaminants (Blackmore, 1998; Blackmore et al., 1998; Morillo et al., 2005; Páez-Osuna et al., 1999).

The barnacle is an intertidal crustacean species and shows a global distribution, playing ecologically important roles in the structure and function of coastal ecosystems (Cheng et al., 2004; Chiang et al., 2003). The lifecycle of the barnacle comprises two stages: one planktonic stage and one sessile stage (Fig. 1). In the planktonic stage, nauplius larvae are released from adult barnacles. After feeding to deposit adequate energy, the nauplii will transform into non-feeding cyprids, which are competent for later settlement. In general, cyprids will search the habitat surface first and then attach onto the chosen site to metamorphose into sessile juvenile barnacles (He et al., 2012).

During their whole lifecycle, barnacles will be subjected to environmental pollution and suffer from adverse effects. As sessile filter-feeders, barnacles tend to ingest large quantities of contaminant-rich particles from ambient water matrices, and thus, they exhibit a high uptake and bioaccumulation of environmental contaminants (Rainbow, 1995; Ramos et al., 2014). The barnacle mostly fulfills the qualifications of an ideal biomonitor and consequently is being widely used as a suitable indicator in programs designed to assess coastal pollution (Rainbow et al., 2000). For example, previous research has employed adult barnacles of various species to indicate the bioavailability of trace metals through measuring the metal concentrations in soft tissues (Blackmore, 1998; Dionísio et al., 2013; Fialkowski and Newman, 1998; Páez-Osuna et al., 1999; Rainbow et al., 2000). In addition, at Quequén Harbor in Argentina, the population recruitment of the barnacle *Balanus*

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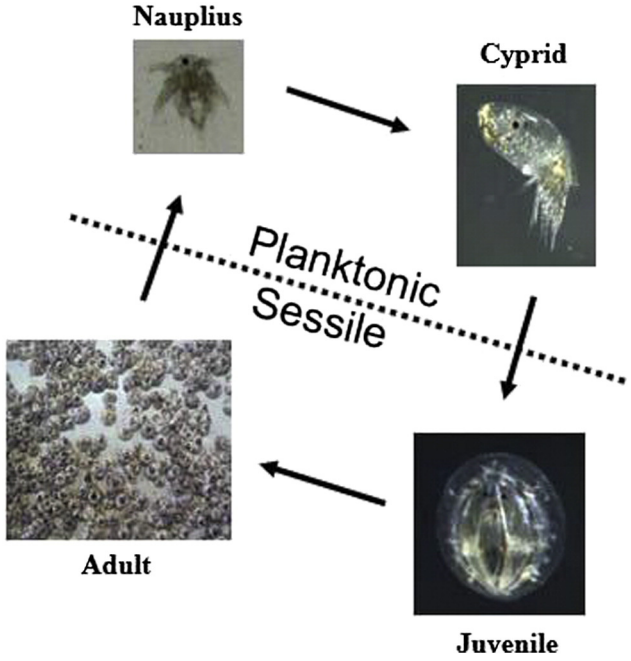

Fig. 1. The lifecycle of the barnacle *B. amphitrite* includes a planktonic stage and a sessile stage. After release from the adult barnacle, the feeding nauplius larvae will transform into the non-feeding cyprid larvae, which is competent for later attachment and metamorphosis into the sessile juvenile barnacle.

amphitrite Darwin is used to assess the environmental quality; recruitment failure as a result of sewage outfall leads to a steady decrease in the population density (Calcagno et al., 1998). Physiological changes involved in oxidative stress and neural signaling, as indicated by sensitive biomarkers with distinct biological meanings, are documented in barnacles as responses to exposure to marine pollution (Niyogi et al., 2001; Ramos et al., 2014; Zanette et al., 2015). Furthermore, the relatively high sensitivities of developmental and behavioral assays, including both phototaxis and settlement tests, allow the extensive incorporation of barnacle nauplii and cyprids into the ecotoxicity assessment battery (Billinghurst et al., 1998; Chiang et al., 2003; Faimali et al., 2006; Greco et al., 2006; Lam et al., 2000; Qiu et al., 2005; Wu et al., 1997a,b).

Therefore, in the present study, the widespread and gregarious barnacle *B. amphitrite* Darwin was used as a convenient, easily accessed biomonitor to evaluate the geographical variation in coastal pollution in Hong Kong. Pollution assessment around three piers (i.e., Tso Wo Hang, Sai Kung and Hebe Haven) was facilitated first by analytical measurements of the concentrations of metals and polybrominated diphenyl ethers (PBDEs). In addition, a wide spectrum of biological responses, including physiological and behavioral assays across the whole lifecycle of *B. amphitrite* (i.e., adult, nauplius, cyprid and juvenile), was also determined to complement the chemical tools for the comprehensive monitoring of marine pollution.

2. Materials and methods

2.1. Study sites and adult barnacle collection

As shown in Fig. 2, adult barnacles were collected from three piers (i.e., Tso Wo Hang, Sai Kung and Hebe Haven) in the eastern Kowloon area of Hong Kong on September 14, 2014. Although the three piers under investigation are closely located geographically, their associated human activities, which are considered the primary sources of marine pollution, are much different. Around Sai Kung pier with a dense population, the heavy domestic discharge and shipping activities are the likely causes of the burden on the marine environment. Hebe Haven, which is a largely enclosed bay with limited water circulation and renewal, has the most intense shipping activities, which range from ship building, traveling and dry dock maintenance, despite not being densely populated like Sai Kung. However, compared with Sai Kung and Hebe Haven, the Tso Wo Hang area lacks a dense residential population and heavy shipping, and thus, it was considered as the reference site. The physiochemical conditions of the seawater at the three piers, including the pH, temperature, salinity and dissolved oxygen, were measured (Table 1). Despite spatial separation and distinct anthropogenic interference, the seawater around the three piers exhibited identical physiochemical properties.

Barnacles were scraped from the intertidal zone of the piers, placed temporarily in polythene bags and stored at −80 °C in the laboratory

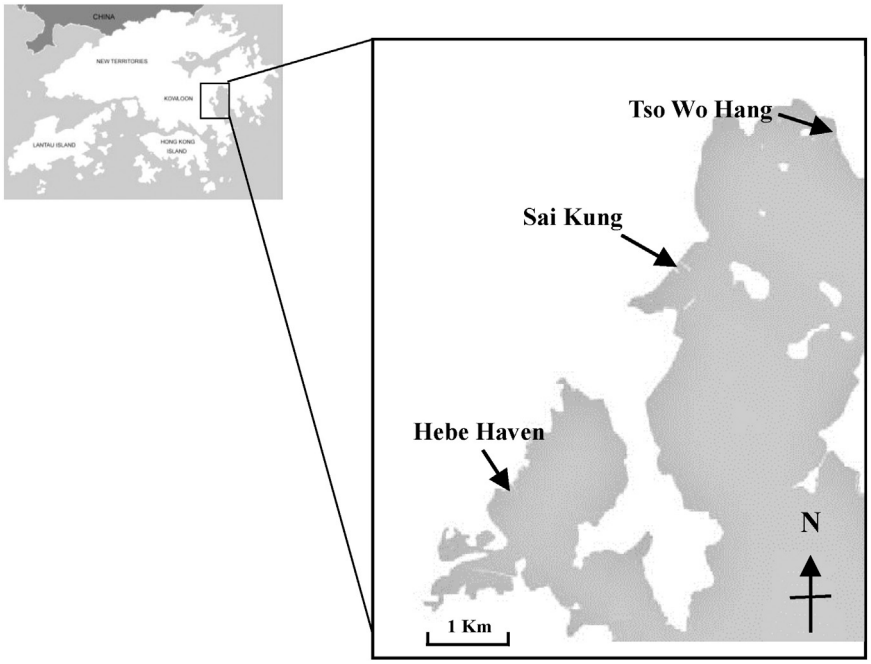

Fig. 2. Location map of the three piers used for barnacle collection in Hong Kong.

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