Environmental Pollution 220 (2017) 1090–1099

Contents lists available at ScienceDirect

Environmental Pollution

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

Linking pollutant exposure of humpback whales breeding in the Indian Ocean to their feeding habits and feeding areas off Antarctica☆

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ARTICLE INFO

Article history:
Received 30 July 2016
Received in revised form
10 November 2016
Accepted 10 November 2016
Available online 22 November 2016

Keywords:
Baleen whale
Persistent organic pollutants
Stable isotopes
Reunion Island
Indian Ocean

ABSTRACT

Humpback whales, *Megaptera novaeangliae*, breeding off la Reunion Island (Indian Ocean) undergo large-scale seasonal migrations between summer feeding grounds near Antarctica and their reproductive winter grounds in the Indian Ocean. The main scope of the current study was to investigate chemical exposure of humpback whales breeding in the Indian Ocean by providing the first published data on this breeding stock concerning persistent organic pollutants (POPs), namely polychlorinated biphenyls (PCBs), hexachlorobenzene (HCB), hexachlorocyclohexanes (HCHs), DDT and its metabolites (DDTs), chlordane compounds (CHLs), polybrominated diphenyl ethers (PBDEs), and methoxylated PBDEs (MeO-PBDEs). Analyses of stable isotopes $\delta^{13}C$ and $\delta^{15}N$ in skin resulted in further insight in their feeding ecology, which was in agreement with a diet focused mainly on low trophic level prey species, such as krill from Antarctica. POPs were measured in all humpback whales in the order of HCB > DDTs > CHLs > HCHs > PCBs > PBDEs > MeO-BDEs. HCB (median: 24 ng g^{-1} lw) and DDTs (median: 7.7 ng g^{-1} lw) were the predominant compounds in all whale biopsies. Among DDT compounds, *p,p′*-DDE was the major organohalogenated pollutant, reflecting its long-term accumulation in humpback whales. Significantly lower concentrations of HCB and DDTs were found in females than in males ($p < 0.001$). Other compounds were similar between the two genders ($p > 0.05$). Differences in the HCB and DDTs suggested gender-specific transfer of some compounds to the offspring. POP concentrations were lower than previously reported results for humpback whales sampled near the Antarctic Peninsula, suggesting potential influence of their nutritional status and may indicate different exposures of the whales according to their feeding zones. Further investigations are required to assess exposure of southern humpback whales throughout their feeding zones.

1. Introduction

Southern Hemisphere humpback whales (*Megaptera novaeangliae)* feed mainly on krill in circumpolar waters around Antarctica and migrate to specific breeding grounds in tropical waters where they reproduce during the austral winter (Clapham, 2009). For management purposes, the International Whaling Commission (IWC) separated the Southern Hemisphere in 7 breeding stocks designated by the letters A-G (International Whaling Commission, 1998), which link to 6 putative feeding areas, designated as Areas I-VI (Fig. 1). In the south-western Indian Ocean, three main breeding sub-regions within the breeding region C (C1 to C3) have been described by the IWC based on historical whaling data and contemporary surveys, genetic studies, and photo-identification (Fleming and Jackson, 2011; Fossette et al., 2014; Jackson et al., 2014). A fourth breeding region C4 (Mascarene Islands) has been recently suggested, following the increase in the number of whales wintering around Reunion island (International Whaling Commission, 2011). Humpback whales wintering in the south-western Indian Ocean are presumed to feed mainly in Feeding

☆ This paper has been recommended for acceptance by Maria Cristina Fossi.

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http://dx.doi.org/10.1016/j.envpol.2016.11.032
0269-7491/

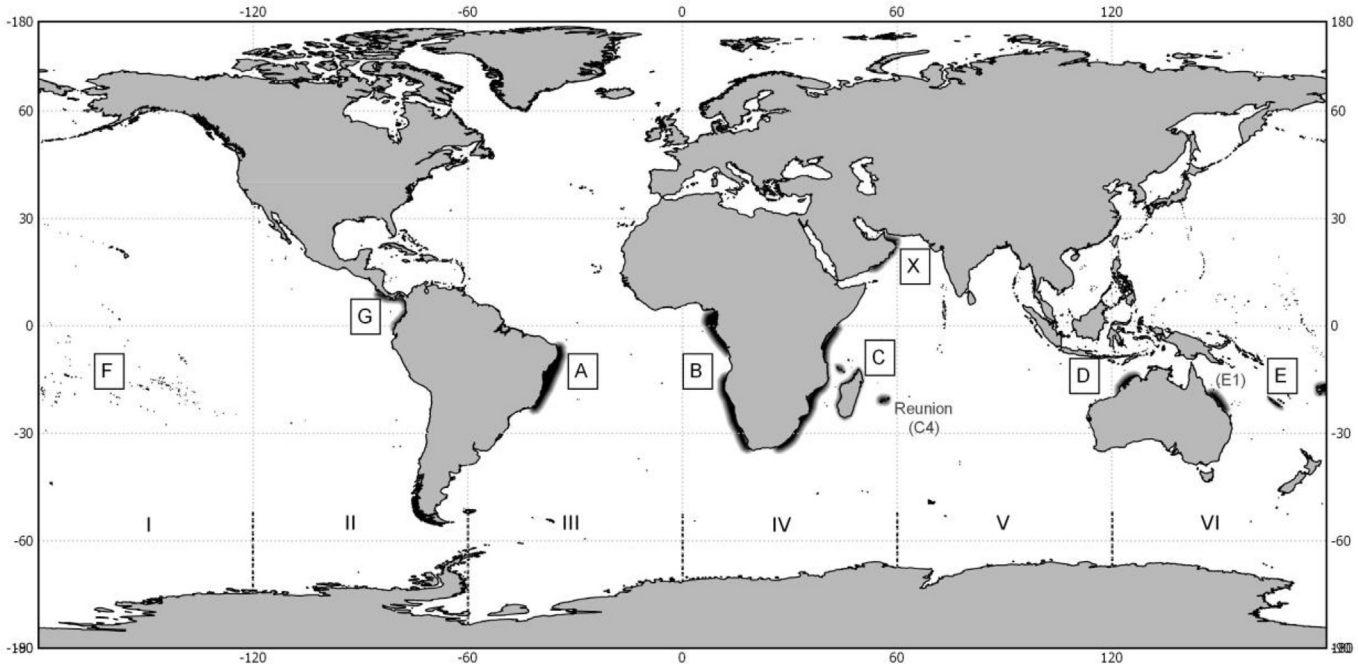

Fig. 1. Stocks and feeding grounds of humpback whales breeding off la Reunion Island (Stock C), off Australia (stock E), off Ecuador (stock G). Other stocks (A, B, X, D and F) as defined by the International Whaling commission are also presented. (International Whaling Commission, 1998).

Area III as confirmed by recent satellite tagging (Cerchio et al., 2013; Fossette et al., 2014). During their north- and southbound migration and on the breeding grounds, humpback whales, like most baleen whales, feed at a reduced rate and opportunistically (Cerchio et al., 2013; Fossette et al., 2014; Silva et al., 2013). The extensive fat accumulated during the summer feeding season in Antarctica support their reproduction and their migratory journeys (Silva et al., 2013). However, whales, and marine mammals in general, experience a high risk of accumulating toxic levels of highly lipophilic chemicals because of their metabolic requirements, extensive fat store and long life span (Bossart, 2011). Effects of migration and fasting on pollutant concentrations in humpback whales is poorly known, but seasonal mobilization of blubber fractions of pollutants during prolonged periods of lipid depletion may place humpback whales in a higher risk category than attributed by exposure alone (Bengtson Nash et al., 2013).

Persistent organic pollutants (POPs) are widely distributed compounds that can be transported to remote areas away from their production sites via long-range environmental transport (Wania and Mackay, 1993). The atmosphere is the dominant pathway for transport of POPs to polar regions, which act as environmental storage for such chemicals (Corsolini et al., 2006). First reports of POPs in Antarctic biota go back to the 1960s (George and Frear, 1966; Sladen et al., 1966; Tatton and Ruzicka, 1967). Current literature further documents the ubiquitous distribution of POPs throughout the Southern Ocean food webs (Bengtson Nash et al., 2008; Corsolini et al., 2006), including in the Antarctic krill *Euphausia superba*, which forms the base diet of several marine mammal species (Chiuchiolo et al., 2004; Corsolini et al., 2002).

For conservation purposes, it is of prime importance to better understand the feeding ecology of humpback whales and their current exposure to organic and inorganic pollutants. Over the past decade, stable isotope (SI) ratios ($^{13}C/^{12}C$ and $^{15}N/^{14}N$ reported as $\delta^{13}C$ and $\delta^{15}N$, respectively) have been widely used to study trophic ecology of marine mammals, allowing the assessment of their trophic position in the food web and their foraging habitat (Newsome et al., 2010). The combined use of SI and POPs may also be used to trace feeding habits and thus to provide further insights into population structure and movement pattern of migratory species (Witteveen et al., 2009). Research efforts should further investigate the feeding strategies and ecology of Southern Hemisphere humpback whales, in order to boost the scarce information about the connection between populations, their dependency on local prey stocks as well as their exposure to contaminants.

The principal objective of the current study was to document the chemical exposure of humpback whales breeding in the Indian Ocean by providing the first quantitative data on POP concentrations in this breeding population. POPs measured in the blubber include polychlorinated biphenyls (ΣPCBs), hexachlorobenzene (HCB), hexachlorocyclohexanes (HCHs), DDT and its metabolites (ΣDDX), chlordane compounds (CHLs), polybrominated diphenyl ethers (PBDEs), and methoxylated PBDEs (MeO-PBDEs). $\delta^{13}C$ and $\delta^{15}N$ values measured in skin of humpback whales were used to describe feeding habits of humpback whales presumably on their feeding ground in Antarctica. Unless whales undertook migratory feeding, $\delta^{13}C$ and $\delta^{15}N$ values are expected to reflect accumulated energy stores from Antarctica.

2. Methodology

2.1. Sampling location

Reunion Island is a small oceanic island (2511 km^2) located in the south-western Indian Ocean, 700 km east of Madagascar (Fig. 2) and 250 km west of Mauritius. The humpback whale is the cetacean species most frequently observed in shallow waters from June to November and is involved in breeding activity (Dulau-Drouot et al., 2012).

2.2. Sample collection

Skin and blubber biopsy samples from female ($n = 14$) and male