Chemosphere 85 (2011) 432–440

Contents lists available at SciVerse ScienceDirect

Chemosphere

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

Geographic and trophic patterns of OCs in pelagic seabirds from the NE Atlantic and the Mediterranean: A multi-species/multi-locality approach

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ARTICLE INFO

Article history:
Received 1 March 2011
Received in revised form 8 July 2011
Accepted 29 July 2011
Available online 8 September 2011

Keywords:
Organochlorinated compounds
Procellariiformes
Nitrogen stable isotopes
Trophic ecology
Marine pollution
Pollution monitoring

ABSTRACT

Trophic ecology and geographic location are crucial factors explaining OC levels in marine vertebrates, but these factors are often difficult to disentangle. To examine their relative influence, we analyzed PCBs, DDTs and stable-nitrogen isotope signatures (δ^{15}N) in the blood of 10 pelagic seabird species across 7 breeding localities from the northeast Atlantic and western Mediterranean. Large scale geographic patterns emerged due to the confined character and greater historical OC inputs in the Mediterranean compared to the Atlantic basin. Spatial patterns also emerged at the regional scale within the Atlantic basin, probably associated with long-range pollutant transport. Trophic ecology, however, was also a major factor explaining OC levels. We found clear and consistent OC differences among species regardless of the sampled locality. However, species δ^{15}N and blood OC levels were not correlated within most breeding localities. Petrel species showed significantly greater OC burdens than most shearwater species but similar trophic positions, as indicated by their similar δ^{15}N signatures. This pattern probably results from Petrel species feeding on mesopelagic fish and squid that migrate close to the sea surface at night, whereas shearwater species mainly feed on epipelagic diurnal prey. In sum, this study illustrates the lasting and unequal influence of past human activities such as PCB and DDT usage across different marine regions. In addition, our results suggest that multi-species designs are powerful tools to monitor geographic patterns of OCs and potentially useful to assess their vertical dynamics in the marine environment.

1. Introduction

Organochlorine contaminants (OCs), such as polychlorinated biphenyls (PCBs) and dichlorodiphenil trichloroethane (DDT), are globally found in marine food chains and are known to have a wide array of adverse effects (Walker and Livingstone, 1992). These contaminants bioaccumulate and biomagnify throughout marine food webs due to their persistent and lipophilic properties (Hop et al., 2002). As a result, significant concentrations of OCs have been reported among marine organisms at high trophic positions, potentially resulting in toxicological effects, but also providing opportunities for monitoring marine pollution (Walker, 1992; Jones and Voogt, 1999). Among marine predators, seabirds have been proposed as useful bioindicators for OCs, mainly because many of them are placed at high trophic positions, breed at specific locations and show large-scale distributions (Burger and Gochfeld, 2004). Despite the potential of seabirds to monitor contamination from different ocean habitats, most studies concerning OC levels in seabirds focus on coastal species, and few of them have dealt with species from pelagic ecosystems. This is unfortunate because pelagic seabirds can integrate contaminant levels of areas relatively unexploited by fisheries (Karpouzi et al., 2007), and therefore, poorly explored and difficult to monitor for contaminants.

The limited data on OCs with respect to pelagic seabirds is probably related to the ethical and technical limitations of the sampling strategies (Elliott, 2005; Yamashita et al., 2007), because common tissues for OC analysis (e.g., fat, liver or muscle) involve animal killing or unpractical sampling procedures, such as carcass collection. Nevertheless, thanks to the improvements in analytical skills, we can now survey a wide array of organic contaminants using small blood quantities obtained with negligible impact on the birds. Previous studies have validated the use of blood to evaluate OC levels in seabirds and have successfully used this tissue to evaluate recent exposure to marine contamination (Bustnes et al., 2005b; Finkelstein et al., 2006; Yamashita et al., 2007). In addition, blood can also be used to decipher seabird trophic ecology by means of stable isotope analysis. Specifically, the stable-nitrogen isotope ratio (^{15}N/^{14}N; δ^{15}N) has been widely used to delineate the trophic position of seabirds (Kelly, 2000) and previous studies have

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0045-6535/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.chemosphere.2011.07.070

reported significant positive relationships between blood OC levels and δ^{15}N, reflecting the biomagnification processes (Elliott et al., 2009; Roscales et al., 2010). However, because the accumulation of OCs is not determined by trophic level alone, partial upsets between δ^{15}N and OC levels in seabirds have been reported, suggesting that migratory movements, specific dietary habits or metabolic capabilities can also play a significant role in seabird pollution burdens (Fisk et al., 2001; Elliott, 2005; Ricca et al., 2008). In this regard, multi-species and multi-locality approaches can help to better understand the different contributions of the trophic level compared to other factors on OC burdens.

The present study focuses on OCs in pelagic seabirds (O. Procellariiformes) breeding across the northeast Atlantic and the Mediterranean Sea. Some seabirds are considered vulnerable or threatened, and previous studies have pointed out the need to improve our knowledge about their ecology and contaminant status in these regions (Monteiro and Furness, 1997; Forero and Hobson, 2003). Moreover, several species feed mostly on prey that are also consumed by humans, such as several epipelagic fish and squid species, which makes them potentially useful as sentinels of marine contamination. However, few studies dealing with organochlorine contamination in pelagic vertebrates have been conducted within these regions, even when the Mediterranean basin is known to be strongly affected by marine pollution (Jiménez et al., 2000; Albaigés, 2005). In this study, organochlorine levels and stable isotope signatures of nitrogen were analyzed in blood from 10 species of pelagic seabirds at seven breeding localities across the NE Atlantic and W Mediterranean archipelagos. We aimed (1) to evaluate the relative influence of geographic location and feeding ecology over OCs in pelagic seabirds; (2) to validate OC geographic patterns and sources previously assessed through a single-species approach (Roscales et al., 2010); (3) to understand the biomagnification process of OCs by relating PCB and DDT levels from different species to their feeding ecology.

2. Material and methods

2.1. Species, study area and sampling procedure

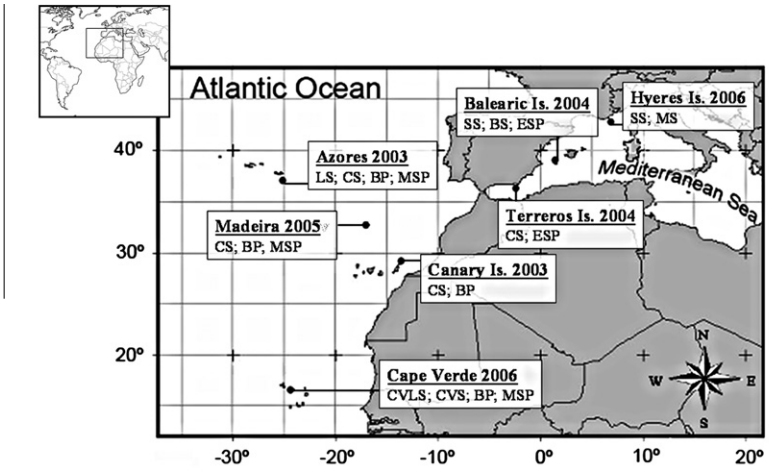
We sampled most petrels and shearwaters (10 species) breeding in the NE Atlantic Ocean and the west Mediterranean archipelagos (Fig. 1). Some groups of species included in this study are parapatric species. That is, their range does not significantly overlap, but are immediately adjacent to each other and show similar morphology and ecology (Table 1). This is the case with three superspecies of shearwaters, each including several paraspecies: the Cory's shearwater (*Calonectris diomedea*, *Calonectris borealis* and *Calonectris edwardsii*), the little shearwater (*Puffinus baroli* and *Puffinus boydi*, among others) and the Manx shearwater (*Puffinus yelkouan* and *Puffinus mauretanicus*, among others) superspecies. These species are closely related forms, and until recently, long considered subspecies of the same species and in some cases their taxonomic status is still being debated (e.g., *Calonectris* shearwaters) (Heidrich et al., 1998; Austin, 2004; Gómez-Díaz et al., 2009). Therefore, regarding contamination, we will consider each superspecies as a single statistical unit and not a different species.

Adult seabirds were sampled during their breeding season from 2003 to 2006 (Fig. 1), particularly during incubation and chick rearing periods. Species from the same breeding locality were sampled within a single year. Previous analysis on Cory's shearwater species complex suggested a negligible influence of sex as well as sampling year (period 2003–2006) over shearwater OC levels (Roscales et al., 2010). Depending on the size of the species, about 0.2–0.5 mL of blood was sampled from the brachial vein. Blood was transferred into vials with 1 mL of absolute ethanol and preserved at −24 °C until analysis.

2.2. Chemical analysis

A sub-sample of the blood fixed with absolute ethanol was used for stable isotope analysis. About 0.36–0.40 mg of dried blood (weighed to the nearest μg) were placed into tin buckets for combustion. Isotopic analyses were carried out by elemental analysis-isotope ratio mass spectrometry (EA–IRMS), and stable isotope ratios were expressed in conventional notation as parts per thousand (‰).

From 0.02 to 0.2 g (depending on the species) of dried blood was used for OC determination. High-resolution gas chromatography coupled to micro-electron capture detection was used for the analysis of organochlorinated compounds: *ortho* PCB congeners #28, #52, #95, #101, #123, #149, #118, #114, #153, #132, #105, #138, #167, #156, #157, #180, #183, #170, #189, #194 and DDTs, including *p,p′*-DDT and its two main metabolites, *p,p′*-DDD and *p,p′*-DDE. Further details of the sample treatment and



Species abbreviations
Cory's shearwater complex: CVS, Cape Verde shearwater; **CS**, Cory's shearwater; **SS**, Scopoli's shearwater
Little shearwater complex: CVLS, Cape Verde little shearwater;**LS**, Little shearwater
Manx shearwater complex: BS, Balearic shearwater; **MS**, Mediterranean shearwater
Petrel & storm-petrel species: BP, Bulwer's petrel; **MSP**, Madeiran storm-petrel; **ESP**, European storm-petrel

Fig. 1. Geographic distribution of the studied seabirds. Black points indicate the localities where seabirds were sampled, including the species and the sampling year.