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# Biomagnification of persistent organic pollutants in a deep-sea, temperate food web

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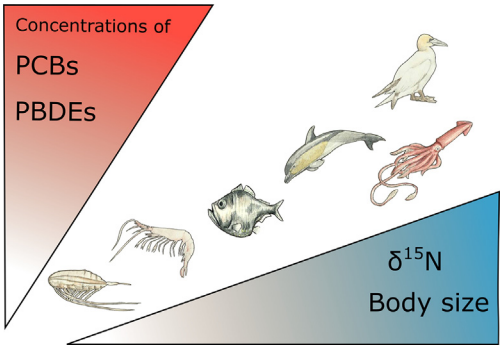
## HIGHLIGHTS

- POP concentrations in the Avilés Canyon fauna are comparable to other food webs.
- PCBs and PBDEs biomagnify in the AC pelagic food web.
- The TMF was higher when homeotherm top predators were included in the estimations.
- The benthic food web did not show any trophic magnification.
- Body size can be used as a proxy to estimate trophic magnification.

## GRAPHICAL ABSTRACT

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## ABSTRACT

Polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs) and polychlorinated dibenzo-*p*-dioxins and -furans (PCDD/Fs) were measured in a temperate, deep-sea ecosystem, the Avilés submarine Canyon (AC; Cantabrian Sea, Southern Bay of Biscay). There was an increase of contaminant concentration with the trophic level of the organisms, as calculated from stable nitrogen isotope data ($\delta^{15}N$). Such biomagnification was only significant for the pelagic food web and its magnitude was highly dependent on the type of top predators included in the analysis. The trophic magnification factor (TMF) for PCB-153 in the pelagic food web (spanning four trophic levels) was 6.2 or 2.2, depending on whether homeotherm top predators (cetaceans and seabirds) were included or not in the analysis, respectively. Since body size is significantly correlated with $\delta^{15}N$, it can be used as a proxy to estimate trophic magnification, what can potentially lead to a simple and convenient method to calculate the TMF. In spite of their lower biomagnification, deep-sea fishes showed higher concentrations than their shallower counterparts, although those differences were not significant. In summary, the AC fauna exhibits contaminant levels comparable or lower than those reported in other systems.



## 1. Introduction

Persistent organic pollutants (POPs) are ubiquitous in the environment (*i.e.* soils, sediments, air, water or biota) and persist for decades (Jones and De Voogt, 1999; Lohmann et al., 2007). Due to their lipophilic and refractory nature they tend to bioaccumulate in food webs. Hence organisms achieve high concentrations of the contaminants relative to the environment, causing adverse reproductive effects, endocrine disruption or immune dysfunction (Vasseur and Cossu-Leguille, 2006). As a result, the 2001 Stockholm Convention aimed at halting or reducing the emissions of polychlorinated biphenyls (PCBs), polybrominated

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diphenyl ethers (PBDEs; included in the Stockholm Convention in 2009) and polychlorinated dibenzo-*p*-dioxins and -furans (PCDD/Fs), among others. All these substances have been included in the OSPAR List of Chemicals for Priority Action (OSPAR, 2013), within the framework of its Hazardous Substances Strategy.

In spite of reduction efforts, there are still high concentrations of these pollutants in the marine environment, with inputs through river run-off, air-water exchange (Totten et al., 2001) or soot carbon (Lohmann et al., 2006). They have been detected in the deep sea (Jamieson et al., 2017; Storelli et al., 2009), sometimes at higher concentrations than those of shallow waters (Covaci et al., 2008; Froescheis et al., 2000), pointing to a role of the abyssal depths of the ocean as a sink for these pollutants. They enter the deep ocean by vertical transport of sinking particles (Dachs et al., 2002; Jurado et al., 2007) to be subsequently distributed globally by deep circulation of water masses originated in polar regions (Lohmann et al., 2006), where higher POP concentrations are commonly measured (Froescheis et al., 2000; Wania and Mackay, 1996). Transport of deep POPs back to the surface by vertical advection may well become the main source of POPs when policies to limit terrestrial inputs reach their targets. Clearly, there is a need to quantify POP in deep waters, their fate and their effects on the marine biota.

POPs accumulate in the organisms (*i.e.* bioaccumulation) *via* uptake of the chemical directly from the environment (*i.e.* bioconcentration) or by ingestion of other organisms containing the pollutants. Once they have entered a food web, their concentrations tend to increase with trophic level (*i.e.* biomagnification), leading to highest concentrations in the top predator (Broman et al., 1992). Concerns about the impact in food webs are usually centered on top predators (Jones and De Voogt, 1999), but biomagnification may be due not only to a food web effect, but also to larger bodies and lipid contents (Gray, 2002; Leblanc, 1995) and higher metabolic activities (*i.e.* homeotherm *vs.* poikilotherm; Fisk et al., 2001; Hop et al., 2002). Most evidence of biomagnification originates from Arctic ecosystems (Letcher et al., 2010), with comparatively fewer studies from temperate food webs (*e.g.* Byun et al., 2013; Nfon et al., 2008) and none from a deep-sea ecosystem.

The Avilés submarine Canyon (AC) supports vulnerable cold-water coral communities (Louzao et al., 2010), top predators such as cetaceans and giant squid (*Architeuthis dux*) and the contiguous continental shelf hosts important fisheries (*e.g.* hake, monkfish). For all these reasons, the AC System has been recently declared a Site of Community Importance (SCI) within the European Natura 2000 network of marine protected areas. In spite of its conservation value, monitoring of human impacts in such important deep environments is still incipient (OSPAR, 2010).

The objective of this study is to quantify PCB, PBDE and PCDD/F contamination in the AC deep sea ecosystem. Analysis of the correlation between POP concentrations and $\delta^{15}N$ in the tissues of organisms as an indicator of their trophic position (Minagawa and Wada, 1984) allowed us to confirm the existence of biomagnification in the AC food web and surroundings.

## 2. Material and methods

### 2.1. Study area and sampling procedure

The AC is situated in the Central Cantabrian and its head is located 12 km off the Avilés coast with a depth range from 128 m at its head, down to 4766 m when it reaches the abyssal plain of the Bay of Biscay (Gómez-Ballesteros et al., 2014; Fig. 1). We analyzed 41 tissue samples of 10 taxonomic groups from the AC. Samples of mesozooplankton (0.2–2 mm), pelagic crustaceans, echinoderms and fishes were collected during two oceanic cruises which took place between the 27th September and the 6th October 2012 (BIOCANT 2) and between the 24th April and the 4th May 2013 (BIOCANT 3). Most of the samples used in this study were caught in stations P3 and TP (1200 and 1500 m depth, respectively; Fig. 1), situated on the slope adjacent to the AC. Further details of the sampling methods are described in Romero-Romero et al. (2016a). In addition, muscle tissue samples of the cetaceans *Delphinus delphis*, *Stenella coeruleoalba* and *Physeter macrocephalus*, the sea birds *Morus bassanus* and the giant squid *Architeuthis dux* were obtained from individuals stranded on the coast. We also analyzed 9 more fish samples collected on the shelf between 35 and 70 m depth recovered from the bycatch of a trammel net (Fig. 1). Organisms were weighed on board using Pesola Micro-Line spring scales, models 20010, 20030, 20060, 20100, 20300, and 40600, which measured up to 10, 30, 60, 100, 300, and 600 g with precisions of 0.10, 0.25, 0.50, 1, 2, and 5 g, respectively. For specimens heavier than 600 g, we used a hanging scale. Samples of mesozooplankton and pelagic fishes were obtained by pooling several individuals and were assigned a mean individual weight. Mesozooplankton samples were pooled and transferred onto glass-fiber GF/A filters, while all the others were wrapped individually in aluminum foil. All samples were stored frozen at −20 °C until analysis. One sub-sample of around 0.5 g was employed for the stable isotope analyses and the remaining was used for POP quantification. Whole

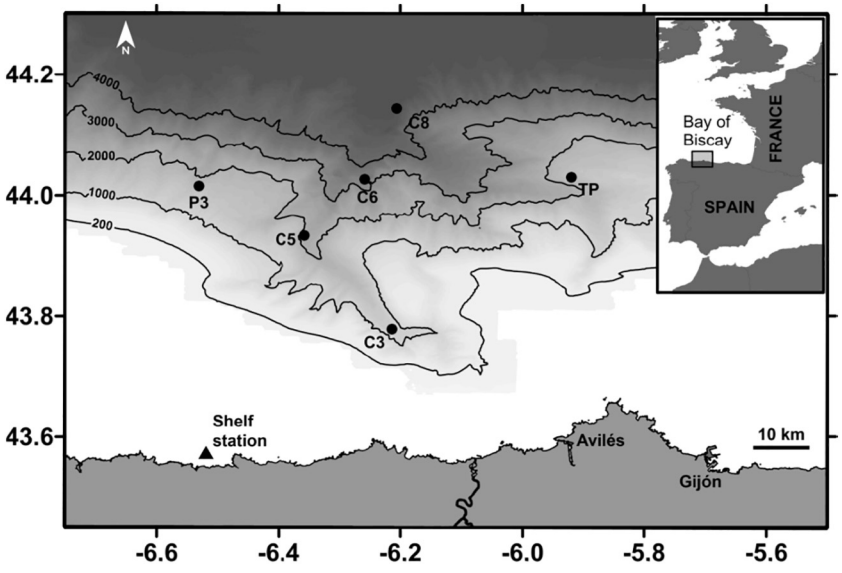


**Fig. 1.** Map of the study area, the Avilés Canyon (AC). Dots indicate sampling stations in the AC and the triangle points the sampling location for shelf fishes.