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Partitioning and bioaccumulation of PCBs and PBDEs in marine plankton from the Strait of Georgia, British Columbia, Canada

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ABSTRACT

The Strait of Georgia is a large, deep, fjord-like estuary on the southern coast of British Columbia which is subject to local and atmospheric inputs of persistent environmental contaminants. We measured 204 polychlorinated biphenyls (PCBs) and 61 polybrominated diphenyl ethers (PBDEs) seasonally in water (two depths; dissolved and particle-bound) and plankton (vertical tow) samples collected at two stations. Principal components analysis clearly distinguished the dissolved and particulate water fractions and plankton samples, with the latter two compartments associated more with heavier congeners. Bioaccumulation factors (log BAFs) for PCBs and PBDEs in plankton were best described by parabolic relationships against octanol–water partitioning coefficients ($\log K_{ow}$), peaking at a $\log K_{ow}$ of 5–7, underscoring the important role of physico-chemical properties in driving the uptake of these persistent contaminants by plankton from water. The estimated total quantity of PCBs (annual average of 0.61 ± SEM 0.12 kg) and PBDEs (annual average of 0.64 ± 0.19 kg) in Strait of Georgia plankton biomass were remarkably similar, highlighting the emergence of currently-used PBDEs as a priority concern. The estimated total of 52.1 ± 8.41 kg of PCBs in water (dissolved + particle-bound) was higher than the estimated 26.8 ± 5.20 kg of PBDEs (dissolved + particle-bound), reflecting the dichotomous use histories for these two contaminant classes. Results provide insight into the biological availability of PCBs and PBDEs to the Strait of Georgia food web, and describe an important initial partitioning process by which the region's endangered killer whales have become highly contaminated.

1. Introduction

The Strait of Georgia (Fig. 1) is a large, semi-enclosed, fjord-like estuary on the southern coast of British Columbia, Canada (Tully and Dodimead, 1957; Waldichuck, 1957; LeBlond, 1983; Thomson, 1994; Masson, 2002). The Strait is approximately 222 km long, 20–40 km wide, 155 m average depth, and covers an area of 6800 km^2, while containing a volume of 1050 km^3. Exchange with water from the Pacific Ocean, which occurs through the shallow and narrow passages to the north (Johnstone Strait) and south (Haro and Rosario Straits) of the Strait, is controlled by three main factors: tides, runoff from the Fraser River, and wind. Because the northern channel is much more constricted, most of the estuarine exchange occurs through the southern passages to Juan de Fuca Strait. There are two major sill areas: the Victoria sill extending across Juan de Fuca south of Victoria, and Boundary Passage (Masson, 2002).

Polychlorinated biphenyls (PCBs) are well studied persistent organic pollutants (POPs) which, although banned in most countries in the 1970s, are found in biota all over the world, including remote locations far removed from sources. The very high levels of PCBs reported in killer whales from the NE Pacific Ocean have been described as a significant conservation concern (Ross et al., 2000), and raise questions about the source, transport and fate of this important legacy contaminant in the region's food webs.

Polybrominated diphenyl ethers (PBDEs) have been extensively used as flame retardants around the world since the 1980s (Alaee et al., 2003). They share many physico-chemical properties with the PCBs but their transport, fate and effects are less understood (Ross et al., 2009). Concern about the endocrine-disrupting properties of the PBDEs (Darnerud et al., 2001) has led to heightened regulatory scrutiny over recent years (Debruyn et al., 2009).

Owing to their persistence, PCBs and PBDEs have become widely distributed in air, water and sediments (De Wit, 2002; Watanabe and Sakai, 2003; Noël et al., 2009). Because of their hydrophobic properties, PCBs and PBDEs preferentially bind to particles in the aquatic environment and lipids in aquatic biota (De Wit, 2002). Aquatic organisms are exposed to PCBs and PBDEs both through direct partitioning from the surrounding water (i.e.,

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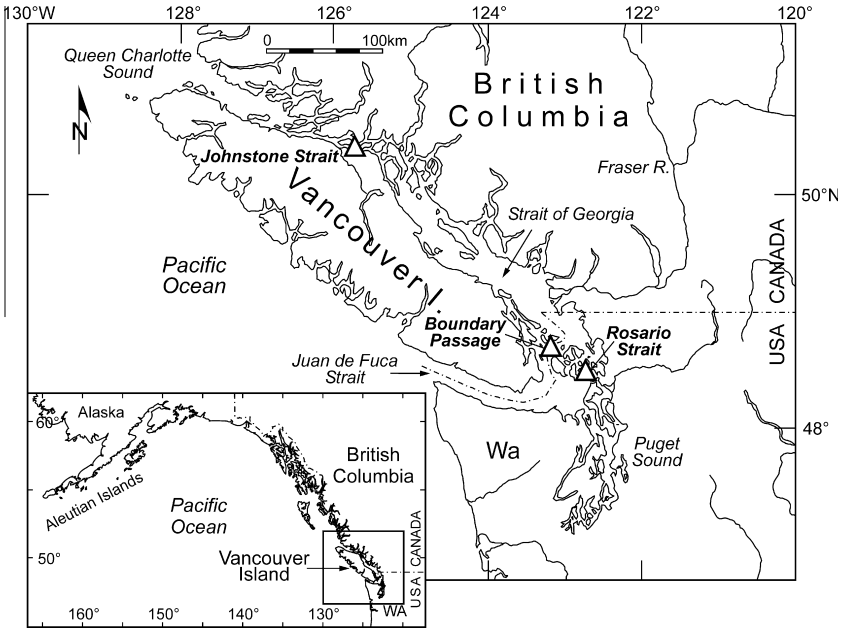

Fig. 1. Water and plankton samples were collected from three sites (indicated as triangles) in 2005–2006 in the Strait of Georgia. The Strait of Georgia is a large, deep, and fjord-like estuary that straddles the Canada–USA boundary but lies primarily in British Columbia, Canada.

bioconcentration), and via the food web, through which both fugacity and concentration are amplified (i.e. biomagnification) (Macdonald et al., 2002).

The lower trophic levels in the marine environment, including plankton, are important points of entry for water-borne POPs into the food web (Swackhamer and Skoglund, 1993; Chiuchiolo et al., 2004). Phytoplankton is exposed to contaminants only via water. Given the high surface area: volume ratio, bioaccumulation in phytoplankton is thought to be governed primarily by equilibrium partitioning between the cells and the surrounding water. Zooplankton, on the other hand, accumulate POPs both from water and from food; it is therefore possible for these compounds to be biomagnified in zooplankton. However, results from previous studies have revealed that POP concentrations in zooplankton may be similar to, or even lower, than in phytoplankton (Harding et al., 1997; Berglund et al., 2000; Sobek et al., 2006). While these studies suggest that POPs in zooplankton may predominantly reflect uptake via water, more recent studies have demonstrated that bioaccumulation of POPs in zooplankton occurs mainly through diet (Borgå et al., 2002; Magnusson et al., 2007; Hallanger et al., 2011).

Relatively few studies have investigated the partitioning of POPs between water and plankton in marine ecosystems, and there exist no studies from the NE Pacific Ocean. Here, we aimed to measure congener-specific PCB and PBDE concentrations in coastal seawater (dissolved and particulate fractions) and plankton samples from two locations in the Strait of Georgia, British Columbia, over the course of a year. The aim is to use these measurements to (i) estimate total loads of these two priority contaminants in the Strait of Georgia, and (ii) garner insight into their uptake by plankton from the water column, a critical pathway which delivers these contaminants to the upper trophic levels in aquatic food webs.

2. Material and methods

2.1. Sample collection

Plankton and water samples were collected at two stations in the southern Strait of Georgia (Fig. 1; Boundary Passage in British Columbia (BC), Canada: 48°43N, 123°15W; Rosario Strait in Washington State, USA: 48°35N, 122°46W). Water samples were collected at a third station in the passage at the northern end of the Strait (Johnstone Strait in BC, Canada: 50°27N, 126°01W) on one occasion (fall; September 9–10, 2005). Water samples at two depths were collected seasonally at Boundary Passage and Rosario Strait during four cruises: June 11–12, September 17–18 and November 23–26 in 2005, and April 21–23 in 2006.

Plankton samples were collected seasonally at Boundary Passage during the same four cruises as the water samples but only for two of the periods (November 2005 and April 2006) in Rosario Strait. No plankton samples were collected at Johnstone Strait. Deep and near-surface water property data were determined by vertical conductivity–temperature–depth (CTD) profiles obtained during sampling cruises. Physical and biological properties of water and plankton from the Strait of Georgia are given in the Supplementary material (Tables S1A and S1B).

2.2. Water sampling techniques

Water was sampled using Infiltrex 100 (Axys Technologies, Sidney, Canada) in situ pumps. Water was drawn through the Infiltrex sampler through an inline filter and then onto the head of the resin column using a gear pump. Filters consisted of either a stainless steel multi-disk holder with two 142 mm glass fiber filters (GF/F 0.7 μm pore, Whatman, Clifton, USA) in parallel or a Teflon holder with GF/F in series with a 125 mm, 2.7 μm pore GF/D depth filter to prevent premature clogging of the GF/F. GF filters were previously baked for two hours at 450 °C. Infiltrex flow rate was 200 mL/min. Teflon columns (310 by 20 mm) were packed with cleaned and proofed Amberlite® XAD-2 (Axys Analytical, Sidney, Canada). Prior to deployment, the head of XAD-column was spiked with PBDE and PCB field surrogate solutions containing ^{13}C standards to assess the possible loss of contaminants during sampling. For every eight columns deployed, one field blank was also collected to account for any possible background adsorption by the XAD sampling matrix.

A minimum of 188 L of seawater was pumped through the columns at each station depth. Sampling was performed aboard the Canadian Coast Guard Ship Vector. During the first deployment at the two southern stations (June 2005), two Infiltrex 100