



## Baseline

## Distribution and sources of polycyclic aromatic hydrocarbons in surface sediments from the Bering Sea and western Arctic Ocean



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## ABSTRACT

To analyze the distribution and sources of polycyclic aromatic hydrocarbons (PAHs) and evaluate their potential ecological risks, the concentrations of 16 PAHs were measured in 43 surface sediment samples from the Bering Sea and western Arctic Ocean. Total PAH (tPAH) concentrations ranged from 36.95 to 150.21 ng/g (dry weight). In descending order, the surface sediment tPAH concentrations were as follows: Canada Basin > northern Chukchi Sea > Chukchi Basin > southern Chukchi Sea > Aleutian Basin > Makarov Basin > Bering Sea shelf. The Bering Sea and western Arctic Ocean mainly received PAHs of pyrogenic origin due to pollution caused by the incomplete combustion of fossil fuels. The concentrations of PAHs in the sediments of the study areas did not exceed effects range low (ERL) values.

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There is a growing awareness of persistent organic pollutants and the harm they cause to human health and ecosystems (Gschwend and Hites, 1981; Brown et al., 1998; Jones and Devoigt, 1999), and polycyclic aromatic hydrocarbons (PAHs) are among the major persistent organic pollutants that are discharged from the land into the sea (MacDonald et al., 1998; Grebmeier et al., 2010). Due to their chemical stability, PAHs tend to remain in the environment for a long time, and they can migrate globally from areas of human activity through marine biogeochemical processes or settle into high-latitude alpine regions through distillation and condensation (Goldberg, 1975; Friedman and Selin, 2012). Once transported to the marine environment, PAHs can be easily adsorbed by suspended particles and carried into seabed sediments, from which they may be re-released into the water or even biological tissues, resulting in secondary pollution (Stout and Emsbo-Mattingly, 2008; Achten and Hofmann, 2009; Harris et al., 2011). Therefore, marine sediments comprise both a “sink” and a “source” of PAHs. Studies of persistent organic pollutants in marine sediments have great scientific significance, as such research can clarify pollutant levels, distributions, and source characteristics as well as the environmental risks posed by such pollutants (Baumard et al., 1998a, b; Magi et al., 2002; Nakata et al., 2005; Boonyatumanond et al., 2006; Chen et al., 2013; Rahmanpoor et al., 2014).

The Arctic region, which experiences low temperatures throughout the year, is an area that collects materials transported by the atmosphere and ocean currents (Chernyak et al., 1996; Jantunen and

Bidleman, 1998). The harsh Arctic climate and environment create difficulties for sampling, and research on PAHs has mainly been conducted in densely populated areas, estuaries, bays, and coastal zones of developed regions (Melnikov et al., 2003; Ding et al., 2007; Yunker et al., 2014). The natural environment and ecology of the Arctic region are substantially affected by human social interactions and human settlement and industrialization (Jaffrezo et al., 1994; Yunker et al., 1995, 2005; Stein and MacDonald, 2004; Stein, 2008). In the present study, we have quantitatively analyzed PAHs in sediment samples from the Bering Sea and western Arctic Ocean to examine their distribution and sources as well as pollution levels.

Forty-three surface sediment samples (depth: 0–2 cm) were collected from the Bering Sea and western Arctic Ocean using the “Xuelong” ice-breaker during the Fourth Chinese National Arctic Research Expedition (July–August, 2010). Sampling stations were selected from the Aleutian Basin to the north, through the Bering Strait, Chukchi Plateau, Canada Basin, Alpha Ridge, and Makarov Basin (53–89°N; Fig. 1). Sediment samples were sealed in aluminum boxes on site, stored at –20 °C, and, after transportation to the laboratory, lyophilized and milled.

Each of the sediment samples (5.00 g each) was weighed and mixed with 1 g of diatomaceous earth, after which the mixture was placed into an extraction pool and the internal standard was added to extract the PAHs. The PAHs were extracted using an accelerated solvent extraction system (ASE200, Dionex, USA) under the following conditions: *n*-hexane and methylene chloride (1:1 volume ratio) as the extraction solvent, a temperature of 100 °C, a pressure of 1000–1500 psi (6.9–10.3 × 10<sup>6</sup> Pa), two repetitions of a 5-min static extraction, an elution volume of 60%, and a purge time of 8 s.

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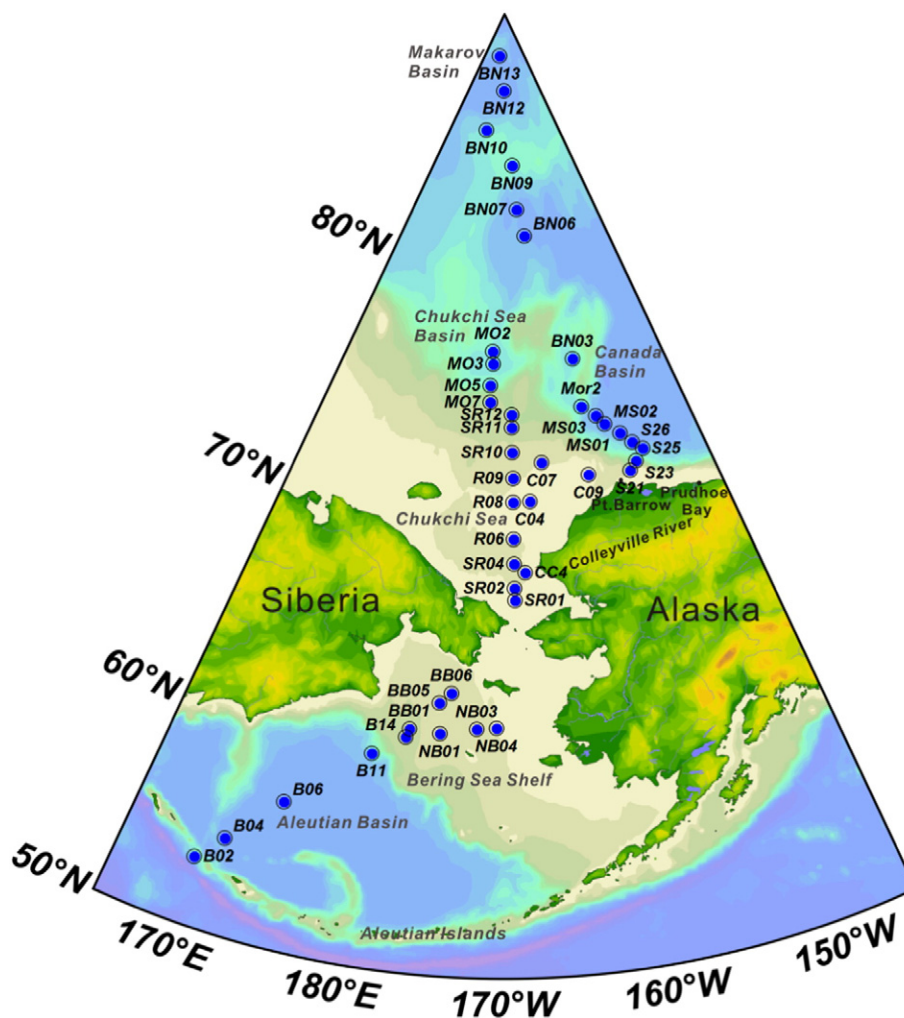


Fig. 1. Location of the sampling stations in the Bering Sea and western Arctic Ocean.

Sixteen PAHs were analyzed using a Shimadzu QP-2010 plus/GC-MS, and the following chromatographic conditions: DB-5 MS capillary column (30 m × 0.25 mm × 0.25 μm), high-purity helium carrier gas, splitless injection (1 μL injection volume), and ion source and quadrupole temperatures of 250 °C and 150 °C, respectively.

The PAH samples were combined with alternative internal standards (naphthalene-d8, acenaphthene-d10, phenanthrene-d10, chrysene-d12, and perylene-d12), while blank samples, duplicate samples, and spiked blank samples were prepared to control for the recovery of the analytical method. Recoveries of the PAH monomer from the spiked blank samples ranged from 86.1%–119.06%. No target contaminants were detected in the blank samples.

Prior to grain size analysis, sediment samples were soaked in 10% H<sub>2</sub>O<sub>2</sub> to remove organic matter, and grain size was determined using the Malvern 2000 laser particle size analyzer (Malvern Instruments Ltd., Worcestershire, UK). Measurements ranged from 0.02–2000 μm. The resolution of the grain size measurements was 0.01 φ, and the relative error of repeated analyses was <3%.

Total organic carbon (TOC) was determined using a Vario EL Cube CN organic elemental analyzer. Sediment samples were dried at a low temperature (50 °C) before being ground, and approximately 0.15 g of the ground samples was weighed and treated with hydrochloric acid to remove carbonate. Following completion of the reaction, each sample was repeatedly washed with deionized water, after which it was centrifuged, and the supernatant was decanted until neutral pH was reached. After drying, 10 mg of each sample was weighed, using a millionth balance, and wrapped with a tin cup.

To delineate the spatial distribution of the PAHs, the study area was divided into seven regions according to geographic location: the Aleutian Basin, Bering Sea shelf, southern Chukchi Sea, northern Chukchi Sea, Chukchi Basin, Canada Basin, and Makarov Basin. The compositions and concentrations of PAHs in the surface sediments of the study area are presented in Table 1, and the distribution of total PAH (tPAH) concentrations is shown in Fig. 2a. Of the 16 typical PAHs under environmental priority control, 15 (anthracene was the exception) were detected in the sediment samples (Table 1).

The mean grain sizes of the surface sediments ranged from 3.7 φ (SR01, southern Chukchi Sea) to 8.03 φ (MS03, Canada Basin) in the Bering Sea and western Arctic Ocean study area. In general, the mean grain sizes of the surface sediments decreased gradually from the Bering Sea to the deep western Arctic Ocean. The TOC percentage in the sediments analyzed ranged from 0.017% (BN13, Makarov Basin) to 2.559% (BB06, Bering Sea shelf), with highest levels corresponding to the Bering Sea shelf (Fig. 2).

PAHs were detected at every station in the study area, and tPAH concentrations (dry weight) ranged from 36.95–150.21 ng/g with a mean value of 70.61 ng/g. The distribution (decreasing) of PAHs in the surface sediments of the study area was as follows: Canada Basin > northern Chukchi Sea > Chukchi Basin > southern Chukchi Sea > Aleutian Basin > Makarov Basin > Bering Sea shelf.

Of the simple components of the PAHs, the phenanthrene content was highest in the study area, and the second highest content was observed for benzo[*g,h,i*]perylene. A comparative analysis of the total contents of low-ring (two- and three-ring) and high-ring (four- to

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