Distribution, Sources and Risk Assessment of Polychlorinated Biphenyls in Soils from the Midway Atoll, North Pacific Ocean

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Abstract

Concentrations of 28 polychlorinated biphenyls (PCBs) were assessed in soils from the Midway Atoll in the central North Pacific Ocean. The analytical procedure involved the application of accelerated solvent extraction (ASE) and gas chromatography coupled with ion trap mass spectrometric detection (GC/ITMS) for identification and quantification. Among the 28 PCB congeners studied, 26 of them, except CB195 and CB209, were detected in the analyzed samples at different frequencies. The total concentrations of 28 indicator PCBs (ΣPCBs) ranged from 2.6 to 148.8 ng g⁻¹ with an average value of 50.7 ng g⁻¹ and median of 39.5 ng g⁻¹. Sources and congeners' pattern of PCB were investigated in the soil of Midway Atoll. The principal component analysis indicated that the compositions of PCBs in most of the soil samples were similar. The total concentrations of PCBs were used to assess the cancer risk probabilities in humans via ingestion, dermal contact and inhalation of soil particles. Very low cancer risk was found in all soil samples caused by ΣPCBs.

Introduction

Persistent organic pollutants (POPs), as PCBs and OCPs are synthetic compounds with great chemical stability. Due to the wide use throughout the world since the middle of the past century, these compounds are ubiquitous in the environment and pose an environmental and human risk [1,2]. Some of these pollutants are highly toxic and have a large variety of chronic effects, including endocrine dysfunction, mutagenesis and carcinogenesis. PCBs are hydrophobic and have considerable accumulation potential in organisms and magnification through the food chain [3]. PCBs are components of transformers, capacitors, hydraulic and heat exchange fluids [4], and the dismantling and burning activities promote its leakage into the surrounding soils. PCBs are believed to act as endocrine disruptors that affect hormone regulation [5]. Significant correlations between biochemical parameters (serum hormone concentrations and cytochrome P450 enzyme activities) and residues of endocrine disrupting chemicals were found in some marine animal species, which indicates that these chemicals may impose toxic effects in animals even at the current levels of exposure. In general, water birds and marine mammals accumulated the dioxin-like compounds with much higher concentrations than humans, implying higher risk from exposure in wildlife [6].

The Midway Atoll (178°W, 28°N) is in the North Pacific Ocean 1100 miles northwest of Honolulu, Hawaii. The Midway atoll consists of two main islands, Sand and Eastern, surrounded by a fringing coral reef [7]. The Midway Atoll was under the Navy jurisdiction from 1903 to 1996. There are many environment contaminants that resulted from 90 years of military operations. Contaminants included PCBs, polycyclic aromatic hydrocarbons (PAHs), petroleum hydrocarbons, pesticides such as dichlorodiphenyltrichloroethane (DDT) and dichlorodiphenyl dichloroethane (DDE), and numerous metals. During World War II, several aircraft carriers and hundreds of aircraft were sunk near the Midway. PCBs have been released from the generators, capacitors, etc. of the sunken aircraft carriers and aircraft. These compounds have been accumulating in the soils and marine life surrounding these sunken vessels.

Even though heavily modified by human activity nearly hundred years, the islands provide breeding and feeding habitats for 17 species of seabirds with an aggregate population of nearly 2 million. The Midway Atoll is also a habitat for threatened green sea turtles and Hawaiian monk seals [8]. In order to limit the exposure by ecological receptors, remedies have been implemented. However, those contaminants are not easily degraded. The bulk of POPs in the environment resides in soils and sediments where they primarily partition into organic matter. Small changes in the mass of soils/sediments would have a major impact on concentrations in ‘adjacent’ media, such as air or water [2]. Many organochlorine POPs have high affinity for soil and are retained in this environment medium for a long time. Such POPs maybe taken by crops or by grazing animals and hence reach the human
food chain. They may also be washed in run-off from the land into watercourses.

The objectives of the study were to determine the concentrations of PCBs in the soil of the Midway Atoll, and analyze the potential sources of PCBs in this area. The study also conducted a human health risk assessment on cancer, in order to evaluate the potential carcinogenic risk based on the concentrations of PCBs in soil.

**Materials and Methods**

**Study Area and Sample Collection**

Midway Atoll is located at the northwest end of the Hawaiian Islands archipelago, at 28.208°N latitude and −177.379°W longitude (Fig. 1). This is approximately 2,000 km from Honolulu, Hawaii and 4,900 km from Portland, Oregon. The atoll is comprised of two main islands, Sand and Eastern, and one smaller islet, enclosed within a reef approximately 8 km. As part of the Midway Atoll, Sand Island has a long history of use for communications, commercial and military purposes. Midway was a base for military operations between 1941 and the early 1990’s. As such, portions of Sand Island were, and continue to be occupied by an airfield, buildings and other structures to support operations and staff that live on the island. One hundred and eleven soil samples were collected from the Sand Island and Eastern islands in Midway Atoll, the North Pacific Ocean.

One hundred and eleven surface soil samples (0–15 cm) were collected in 2006 from different station on Midway Atoll. The samples were immediately transferred to the laboratory and frozen at −20°C until processed for analysis. All samples were collected under the permit of the U.S. Fish and Wildlife Service.

**Analytes**

The 28 PCBs indicators were studied including di-CBs (PCB 8), tri-CBs (PCB18, 28), tetra-CBs (PCB 44, 52, 66, 77, 81), penta-CBs (PCB 101, 105, 114, 118, 123, 126), hexa-CBs (PCB 128, 138, 153, 156, 157, 167, 169), hepta-CBs (PCB 170, 180, 187,189), octa-CBs (PCB 195), nona-CBs (PCB 206) and deca-CBs (PCB 209). 13C-PCBs 28, 123, 169 and 170 were used as surrogate standards, and pentachloronitrobenzene (PCNB) was used as an internal standard. The basic PCB structure is shown in Fig. 2.

**Sample Preparation, Extraction and Cleanup**

Soil samples were freeze-dried for 24 h, pulverized and sieved through 80-mesh stainless steel. The sample cell (about 6–12 g) was loaded into an accelerated solvent extractor (ASE) 200 system (Dionex, Sunnyvale, CA, USA). The extraction was performed with a mixture of acetone and methylene chloride (1:1, v/v) at a pressure of 1500 psi and temperature of 100°C for three static cycles, a flush volume of 60% of the cell volume and a N2 purge time of 5 s. A mixture of Ottawa sand and Na2SO4 was extracted in the same manner as the sample blank. All samples were extracted in triplicate. After the extract was dried with 30 g of anhydrous sodium sulfate and rinsed with hexane (2 mL), it was concentrated to approximately 2 mL by using a rotary evaporator. The concentrated extract in hexane was cleaned up on an 8 mm i.d. aluminum/silica column. The column was packed, from the bottom to the top, with neutral silica (4 g, 3% deactivated), neutral alumina (2.0 g, 6% deactivated), and anhydrous sodium sulfate.
Gas Chromatography and Ion Trap MS (GC/ITMS) Analysis

The samples were analyzed on a Varian Saturn 2000 (Palo Alto, CA) gas chromatograph with mass spectrometric (ion trap) detection (GC/ITMS). The column was a capillary column DB-5MS (J&W Scientific, Inc., 30 m × 0.25 mm i.d. × 0.25 μm). Helium was used as the carrier gas. The oven temperature started at 100°C for 1 min, increased to 170°C at a rate of 30°C min⁻¹ and held for 5 min, increased to 270°C at a rate of 5°C min⁻¹ and held for 2 min, and finally increased to 300°C at a rate of 5°C min⁻¹ and held for 15 min. The injector temperature was set at 300°C. The detector was 320°C. The injection volume was 2 μL. The injection mode was splitless. The purge time was 1.2 min. The ion trap temperature was 200°C, manifold 80°C, and the transfer line 210°C. The determination was performed by using selected ion monitoring (SIM) mode. Concentrations were calculated from external standards with the MS.

Quality Assurance and Quality Control (QA/QC)

Average PCB recoveries and relative standard deviations (RSDs) were first obtained to evaluate the method performance by multiple analyses of 10 replicate spiked soil samples with a concentration of 5 ng g⁻¹ for each PCB congener. The extraction and cleanup methods according to the procedure described above. A solvent blank and matrix blank were processed through the entire procedure and analyzed prior to and after every 10 samples. Working standard solutions of PCBs were run at the beginning of sample analysis to determine the relative response factors and evaluate peak resolution. Each sample was analyzed in triplicate unless otherwise stated. The limit of detection (LOD) was determined as signal-to-noise ratio of 3:1. Ranges of average PCB recoveries and RSDs in 10 replicate spiked soil samples were from 70% to 104% and 10% to 15%, respectively. LODs for PCBs ranged from 1–50 pg g⁻¹ dependent upon the degree of chlorination of different congeners and were approximately 5 pg g⁻¹ for most congeners. The average recoveries of the surrogate standard ¹³C-PCBs 28, 123, 169 and 170 ranged from 72% to 96%. Reported PCB concentrations were not corrected according to the recoveries of the surrogate.

Statistical Analysis

Principal component analysis (PCA) was carried out in SPSS for the available samples to identify the possible source of PCBs and the distribution of PCBs congeners in Midway Atoll. The PCA component matrix was rotated using a Varimax rotation to the axes, which maximized the variance of the components.

Cancer Risk Assessment

Cancer risks via ingestion, dermal contact and inhalation of soil particles were estimated on the following Eqs. (1), (2) and (3), which were adapted from two documents from the U.S. Environmental Protection Agency (U.S. EPA) [9,10].

\[
CR_{\text{ingest}} = \frac{C_{\text{soil}} \times \text{IngR} \times EF \times ED \times BW \times AT}{CF \times SF_{\text{oral}}} \quad (1)
\]

where CR_{ingest} is the cancer risk via accidental ingestion of soil, \(C_{\text{soil}}\) is the concentration of the contaminant in soil (mg kg⁻¹), IngR is the ingestion rate of soil (mg d⁻¹), EF is the exposure frequency (d a⁻¹), ED is the exposure duration (a), BW is the average body weight (kg), AT is the averaging time (d), CF is the conversion factor (1×10⁻¹⁰ kg mg⁻¹), SF_{oral} is the oral slope factor (2.0×10⁻³ mg kg⁻¹ d⁻¹⁻¹).

### Table 1. The concentrations of PCB congeners in soils from the Midway Atoll.

| PCB congeners | Concentrations (ng g⁻¹) | PCB congeners | Concentrations (ng g⁻¹) |
|---------------|-------------------------|---------------|-------------------------|
|               | Range | Average | Median | Range | Average | Median |
| CB-8          | nd-8.78 | 3.20 | 3.03 | CB-153 | nd-10.2 | 3.13 | 2.79 |
| CB-18         | nd-3.43 | 0.46 | 0.28 | CB-138 | nd-10.4 | 3.12 | 2.88 |
| CB-28         | nd-3.48 | 0.58 | 0.16 | CB-128 | nd-11.9 | 0.44 | 0.00 |
| CB-52         | nd-4.12 | 0.54 | 0.19 | CB-167 | nd-11.5 | 0.06 | 0.00 |
| CB-44         | nd-4.86 | 0.57 | 0.37 | CB-156 | nd-0.70 | 0.03 | 0.00 |
| CB-66         | nd-7.96 | 1.40 | 1.01 | CB-157 | nd-1.55 | 0.04 | 0.00 |
| CB-81         | nd-59.5 | 12.0 | 1.35 | CB-169 | nd-2.01 | 0.12 | 0.00 |
| CB-77         | nd-62.8 | 14.1 | 8.27 | CB-187 | nd-5.32 | 1.28 | 1.03 |
| CB-101        | nd-3.10 | 0.91 | 0.79 | CB-180 | nd-7.01 | 2.05 | 1.74 |
| CB-123        | nd-6.66 | 2.02 | 1.58 | CB-170 | nd-2.68 | 0.37 | 0.00 |
| CB-118        | nd-6.26 | 1.58 | 1.29 | CB-189 | nd-5.14 | 0.30 | 0.00 |
| CB-114        | nd-2.95 | 0.46 | 0.00 | CB-195 | nd-0.89 | 0.01 | 0.00 |
| CB-105        | nd-20.6 | 1.21 | 0.60 | CB-206 | nd-1.18 | 0.03 | 0.00 |
| CB-126        | nd-12.2 | 0.67 | 0.19 | CB-209 | Nd | Nd | Nd |

Note: nd denotes not detected.

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Figure 3. The composition of PCB homologues in soil, black-footed albatross, surface water and marine sediment of the Midway Atoll.
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Figure 4. Composition of PCB homologues (average %) in the soil samples and in reference Aroclors 1016, 1242, 1248, 1254 and 1260.
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ingestion rate (IngR) of 100 mg d

The total concentrations of the 28 indicator PCBs (ΣPCBs) ranged from 2.6 to 148.8 ng g

1) [14], Azerbaijan (0.4–0.7 ng g

As to the profile of PCBs homologues (Fig. 3.), the dominant congeners were tetra-chlorobiphenyls (tetra-CBs) (mean: 45%), followed by hexa-CBs (mean: 18%) and penta-CBs (mean: 16%), accounting for more than 79% of the total PCBs concentration.
The degradation [25]. Hexa-CBs are easily accumulated in albatross.
adsorb readily to sediments and are more resistant to microbial
levels in the aquatic environment because they are less volatile,
moderately and highly chlorinated PCBs may remain at constant
volatilization and possibly microbial degradation [23,24]. While
PCBs, like mono-CBs, are more susceptible to losses through
while nona- and deca-CBs were only found in marine sediment
the biggest contributions. Mono-CBs was only found in albatross,
dominated in albatross, while tetra-CBs contributed the most in
matrices. The results illustrate that penta, hexa and hepta-CBs
comprised large proportion in all of the matrices. Hexa-CBs
congeners from other areas could contribute some of the pollution
too.

The composition of PCBs in soil from our study was also
compared to the studies of Caccamise et al. [22] and Hope et al.
[7] in black-footed albatross and marine sediment in this area.
Fig. 3 shows that the PCBs patterns varied largely among different
matrices. The results illustrate that penta, hexa and hepta-CBs
concentrations obtained from any of these in the technical
mixtures 1016, 1242, 1248, 1254 and 1260 (Fig 4), which could
be attributed to weathering and changes during bioaccumulation.
From Fig. 4, we can conclude that there was no Aroclors 1260
used in this area because no octa-CBs was detected in the soil
samples. However, the data was not sufficient to draw further
conclusions about the original Aroclors of PCBs in the soils of the
Midway Atoll. Since Midway Atoll is a tiny island located in the
middle of North Pacific Ocean and which was only for military
use, moreover, 9000 tons of soil was shipped to this area from
Oahu and Guam [8], so PCBs could be transported to this place at
the same time. The long-range transmission of low chlorinated
congeners from other areas could contribute some of the pollution

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Fig. 3 shows that the PCBs patterns varied largely among different
matrices. The results illustrate that penta, hexa and hepta-CBs
comprised large proportion in all of the matrices. Hexa-CBs
dominated in albatross, while tetra-CBs contributed the most in
soils. In the surface water and marine sediment, hepta-CBs made
the biggest contributions. Mono-CBs was only found in albatross,
while nona- and deca-CBs were only found in marine sediment
and water. None of these three was found in soils. Low chlorinated
PCBs, like mono-CBs, are more susceptible to losses through
volatilization and possibly microbial degradation [23,24]. While
moderately and highly chlorinated PCBs may remain at constant
levels in the aquatic environment because they are less volatile,
adsorb readily to sediments and are more resistant to microbial
degradation [25]. Hexa-CBs are easily accumulated in albatross.

PCBs Congeners' Pattern in Soil
The patterns and relationships between congeners and sample
locations were further investigated using principal component
analysis (PCA), performed with SPSS software. PCA describes the
statistical relationship between the variables and simplifies the data
set converting it into an easily visualized graphical form [26],
which has been widely used to identify the potential source of
pollutants in the environment [27]. Concentrations obtained from
chemical analysis for the 28 congeners were divided into 9 groups
based on the chlorination level, however, PCB 209 (CL-10) was not
detected in any of the samples, thus 8 groups were used for the
analysis. Individual congeners that were below the estimated
analytical detection limit were set at one-half the detection limit.
The eigenvalue for the first three principal components (PCs)
accounted for 66% of the total variance of the 8 groups. Component 1 (PC1) was characterized by high chlorinated
homologues (hexa-CBs, hepta-CBs and octa-CBs), whereas
component 2 (PC2) was characterized by low chlorinated
genogers (di-CBs, tri-CBs, tetra-CBs and penta-CBs), and
component 3 (PC3) was characterized as nona-CBs. As shown in
Fig. 5, it is possible to observe the presence of clusters in all
samples based on the PCB chlorination level. The principal
component plot indicated that the compositions of PCBs in most
of the soil samples were similar, which probably originated from
the same source. Among the 111 available soil samples, 106 of
them could be classified into one group that was dominated by
tetra-, hexa- and penta-CBs.

Cancer Risk Assessment
Human risk assessment was evaluated via inhalation of soil
particles, dermal contact and ingestion according to the equations
described in 2.6. Taking into the low level of PCB concentrations
in this study, the results were only used to assess the potential
impact of these measured PCBs on humans. As shown in Table 2,
the risks of PCBs of different exposure pathway are far below
10⁻¹⁰, suggesting negligible adverse effects of those compounds.
The total cancer risk is at the low cancer risks rank even at the 95th
percentile according to ATSDR standard. For different exposure
pathways, the increasing trend in risks of cancer for PCBs was as
follows: inhalation<dermal contact<ingestion.

Conclusion
PCBs residual levels in the soils of the Midway Atoll were
investigated. The results show that the concentrations of PCBs in
this area were at the medium level compared with several different
places around the world. According to the principal component
analysis, the compositions of PCBs in most of the soil samples were
similar, which indicated that the pollution of PCBs probably
originated from the same source. Furthermore, risk assessments via
ingestion, dermal and inhalation were evaluated based on the data
obtained. The cancer risk of PCBs in the soils fell into very low
range. It is noteworthy that Midway Atoll is contaminated with a
number of pollutants such as PAHs and heavy metals. This study
focused on PCBs cancer risk assessment. A comprehensive risk
assessment is required for all significant pollutants for the area.

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Author Contributions
Conceived and designed the experiments: JG LW QL JW. Performed the
experiments: JG JW. Analyzed the data: JG JW. Contributed reagents/
materials/analysis tools: JG JW. Wrote the paper: JG. Collecting samples:
LW.

References
1. Ben Hassine S, Ben Ameur W, Gandoura N, Driss MR (2012) Determination of
chlorinated pesticides, polychlorinated biphenyls, and polybrominated diphenyl
ethers in human milk from Bizerte (Tunisia) in 2010. Chemosphere 89: 369–
377.
2. Jones K, Vooget P (1999) Persistent organic pollutants (POPs): state of the science
Environmental pollution 100: 209–221.
3. U.S EPA (1999) Polychlorinated Biphenyls (PCBs): Basic information. In:
Environmental Protection Agency W, editor.
4. U.S EPA (2009) Polychlorinated Biphenyls (PCBs), Basic information. In:
Environmental Protection Agency W, editor.
5. de Boer J, Weser P, Klammer H, Lewis W, Boon J (1998) Do flame retardants
threaten ocean life? Nature 394: 28–29.
6. Tanabe S (2002) Contamination and toxic effects of persistent endocrine
disrupters in marine mammals and birds. Marine Pollution Bulletin 45: 69–77.
7. Hope B, Scatolini S, Titus E, Cotrer J (1997) Distribution Patterns of Polychlorinated Biphenyl Congeners in Water, Sediment and Biota from Midway Atoll (North Pacific Ocean). Marine Pollution Bulletin 34: 548–563.
8. USFWS (2010) Combined preliminary assessment/site inspection report. Department of interior U.S. FISH & WILDLIFE SERVICE.
9. U.S EPA (1997) Exposure Factors Handbook. EPA/600/P-95/002F. In: Agency USEPA, editor. Environmental Protection Agency, Washington.
10. U.S EPA (2009) Risk Assessment Guidance for Superfund, Vol. I: Human Health Evaluation Manual (F, Supplemental Guidance for Inhalation Risk Assessment) EPA/540/R/070/002. In: Agency USEPA, editor. Environmental Protection Agency, Washington.
11. U.S EPA (1989) Risk Assessment Guidance for Superfund, Vol. I: Human Health Evaluation Manual, EPA/340/1-89/002. In: Environmental Protection Agency, Washington, editor: Environmental Protection Agency.
12. ATSDR (1995) Public Health Assessment. Johnstown City Landfill, Johnstown, Fulton County, (CERCLIS NO. NYD980506927). In: Department of Health and Human Services HHS, Atlanta, editor: New York State Department of Health under cooperative agreement with the Agency for Toxic Substances and Disease Registry.
13. Safe S (1990) Polychlorinated biphenyls (PCBs), dibenzo-p-dioxins (PCDDs), dibenzofurans (PCDFs), and related compounds: environmental and mechanistic considerations which support the development of toxic equivalency factors (TEFs). Critical Reviews in Toxicology 21: 51–88.
14. Wilcke W, Krauss M, Safroinov G, Fokin AD, Kaupenjohann M (2006) Polychlorinated biphenyls (PCBs) in soils of the Moscow region: Concentrations and small-scaled distribution along an urban–rural transect. Environmental Pollution 141: 327–335.
15. Aliyeva G, Kurkova R, Hveorkova I, Klanova J, Halsall C (2012) Organochlorine pesticides and polychlorinated biphenyls in air and soil across Azerbaijan. Environmental Science and Pollution Research 19: 1953–1962.
16. Liao C, Lv J, Fu J, Zhao Z, Liu F, et al. (2012) Occurrence and profiles of polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and organochlorine pesticides (OCPs) in soils from a typical e-waste recycling area in Southeast China. International Journal of Environmental Health Research 22: 317–330.
17. Klanova J, Matykiewiczo N, Macka Z, Prosek P, Laska K, et al. (2008) Persistent organic pollutants in soils and sediments from James Ross Island, Antarctica. Environ Pollut 152: 416–423.
18. Motelay-Massei A, Ollivon D, Garban B, Teil M, Blanchard M, et al. (2004) Distribution and spatial trends of PAHs and PCBs in soils in the Seine River Basin. Chemosphere 55: 555–565.
19. Falandy A, Buadnovski B, Kawano M (2001) Polychlorinated biphenyls and organochlorine pesticides in soils from the southern part of Poland. Archives of Environmental Contamination and Toxicology 40: 173–178.
20. Meijer S, Ockenden W, Sweetman A, Breivik K, Grimalt J, et al. (2003) Global distribution and budget of PCBs and HCB in background surface soils: Implications or sources and environmental processes. Environmental Science & Technology 37: 677–672.
21. Brown J (1994) Determination of PCB metabolic, excretion, and accumulation rates for use as indicators of biological responses and relative risk. Environmental Science & Technology 28: 2295–2303.
22. Caccamisea S, Wang J, Wu L, Woodard L, Li Q (2012) Accumulation and toxicity assessment of polychlorinated biphenyls in black-footed albatross (Diomedea nigripes) from Midway Atoll, North Pacific Ocean. Ecological Indicators 20: 75–81.
23. Quensen J, Tiedje J, Boyd S (1988) Reductive dechlorination of polychlorinated biphenyls by anaerobic microorganisms from sediments. Science 242: 732–734.
24. Brown J, Bedard D, Breunm B, Carnahan J, Feng H, et al. (1987) Polychlorinated biphenyl dechlorination in aquatic sediments. Science 236: 769–772.
25. Connell D (1988) Bioaccumulation behavior of persistent organic chemicals with aquatic organisms. Review of Environmental Contamination and Toxicology 14: 587–594.
26. Manz M, Wenzel K, Dietze U, Schuermann G (2001) Persistent organic pollutants in agricultural soils of central Germany. The Science of the Total Environment 27: 187–198.
27. Cachada A, Lopes L, Hursthouse A, Biasioli M, Gremen H, et al. (2009) The variability of polychlorinated biphenyl levels in urban soils from five European cities. Environmental Pollution 157: 511–518.