## Electronic supplementary material

# Persistent organic pollutants and mercury in a colony of Antarctic seabirds: Higher concentrations in 1998, 2001, and 2003 compared to 2014 to 2016

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## *Calculation of embryonic ages*

Embryonic ages were calculated following the formula evaluated by Ricklefs (2010):

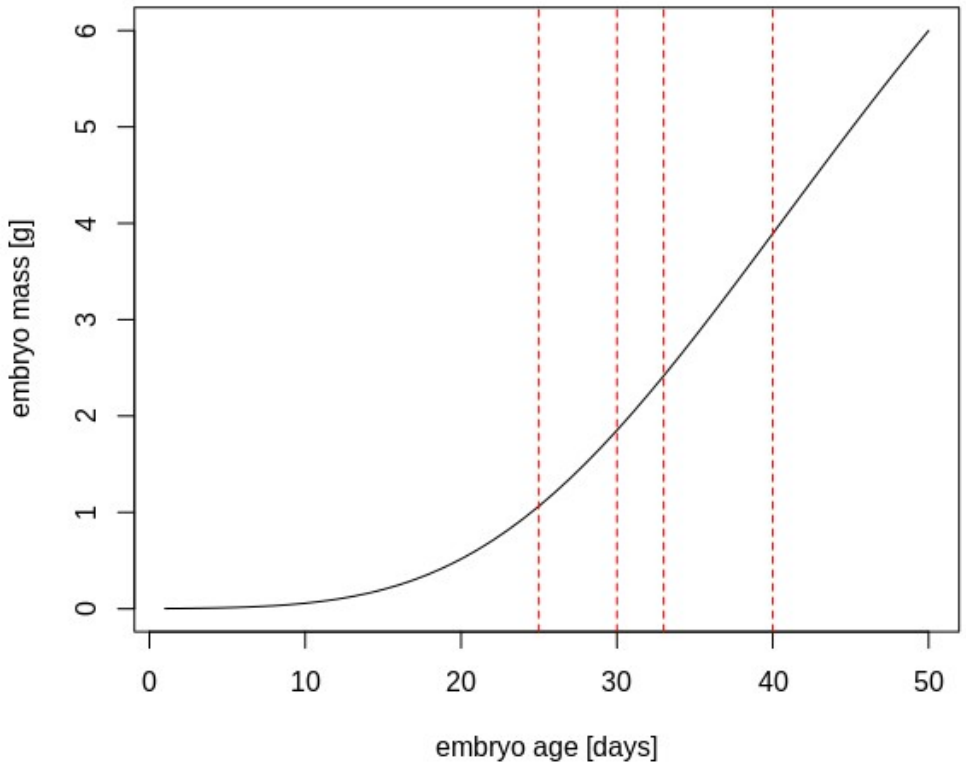
$$\frac{\ln(b) - \ln\left(\ln\left(\frac{A}{M}\right)\right)}{k} = t$$

where: *b* is the scaling parameter for the exponent of the Gompertz function; A is the fitted asymptote (g); *M* is the embryo's mass (g); *k* is the embryo's Gompertz growth rate ($days^{-1}$); *t* is the embryo age (days). To match our species, we used values for the related species, the Leach's storm-petrel (*Oceanodroma leucorhoa*, Ricklefs, 2010) and adjusted the values to fit *Oceanites oceanicus* based on own data (Online Resource 1).

**Online Resource 1** Parameters used for embryo age determination in *Oceanodroma leucorhoa* (Ricklefs, 2010) and *Oceanites oceanicus*

| Species | ln*A* | *k* | $M_0$ | Adult | IP | IEM |
|---|---|---|---|---|---|---|
| *Oceanodroma leucorhoa* | 2.225 | 0.066 | 0.00133 | 39.8 | 41.8 | 11.2 |
| *Oceanites oceanicus* | 2.394 | 0.054 | 0.00133 | 38 | 50 | 11.8 |

ln*A* = natural log of the fitted asymptote (g); *k* = Gompertz growth rate of embryo ($days^{-1}$); $M_0$ = fitted initial embryo mass at age 0 (g); Adult = adult mass (g), primarily from Dunning (1993); IP = incubation period (days), from various sources; IEM = initial egg mass (g).




**Online Resource 2** Approximate mass growth curve for *Oceanites oceanicus* embryos adjusted analogue to Ricklefs (2010). Dashed red lines show separation of age groups

As preliminary trails with material from other bird species suggested POP concentrations <LOD for individual samples, several embryos of similar ages were pooled together to one sample (Online Resource 3).

**Online Resource 3** Defined age groups, their according dw, estimated ww equivalents, and embryonic age estimates (altered after Ricklefs, 2010) for embryos from 2001 and 2003 (N = 40), and 2014 to 2016 (N = 23)

| Age group | Dry weight (g) | Wet weight (g) | Age (days) |
|---|---|---|---|
| 1 | 0-0.25 | 0.0-1.2 | 0-25 |
| 2 | 0.25-0.40 | 1.2-2.0 | 26-30 |
| 3 | 0.40-0.50 | 2.0-2.5 | 31-33 |
| 4 | 0.50-0.80 | 2.5-4.0 | 34-40 |
| 5 | > 0.80 | > 4.0 | > 40 |

## *Parameters of POP analysis*

**Online Resource 4** Temperature program of the GC oven

| Rate (°C $min^{-1}$) | Temperature (°C) | Hold (min) |
|---|---|---|
| - | 60 | 3 |
| 10 | 200 | 0 |
| 2 | 270 | 0 |
| 40 | 290 | 17.5 |

**Online Resource 5** Parameters of test substances for MS detection

| Substance | Function | Structure | CAS RN | Molar mass (g $mol^{-1}$) | Retention time (min) | Target ions (amu)[a] |
|---|---|---|---|---|---|---|
| PCB 28 | Analyte | $C_{12}H_7Cl_3$ | 7012-37-5 | 257.54 | 27.56 | 186, **256** |
| PCB 52 | Analyte | $C_{12}H_6Cl_4$ | 35693-99-3 | 291.99 | 29.05 | 220, 257, **292** |
| PCB 49 | Analyte | $C_{12}H_6Cl_4$ | 41464-40-8 | 291.99 | 29.35 | 220, 257, **292** |
| TCN | IS | $C_{12}H_6Cl_4$ | 20020-02-04 | 265.95 | 30.70 | 194, **266** |
| 2,4'-DDE | Analyte | $C_{14}H_8Cl_4$ | 3424-82-6 | 318.03 | 34.02 | **246**, 318 |
| PCB 101 | Analyte | $C_{12}H_5Cl_5$ | 37680-73-2 | 326.43 | 34.67 | 256, 291, **326** |
| PCB 99 | Analyte | $C_{12}H_5Cl_5$ | 38380-01-7 | 326.43 | 35.06 | 256, 291, **326** |
| 4,4'-DDE | Analyte | $C_{14}H_8Cl_4$ | 72-55-9 | 318.03 | 36.72 | 246, **318** |
| 2,4'-DDD | Analyte | $C_{14}H_{10}Cl_4$ | 53-19-0 | 320.04 | 37.37 | 165, **235** |
| PCB 110 | Analyte | $C_{12}H_5Cl_5$ | 38380-03-9 | 326.43 | 37.40 | 256, 291, **326** |
| PCB 77 | Analyte | $C_{12}H_6Cl_4$ | 32598-13-3 | 291.99 | 38.42 | 220, **292** |
| 2,4'-DDT | Analyte | $C_{14}H_9Cl_5$ | 789-02-6 | 354.49 | 39.66 | 165, **235** |
| PCB 118 | Analyte | $C_{12}H_5Cl_5$ | 31508-00-6 | 326.43 | 39.84 | 256, 291, **326** |
| 4,4'-DDD | Analyte | $C_{14}H_{10}Cl_4$ | 72-54-8 | 320.04 | 40.72 | 165, **235** |
| PCB 153 | Analyte | $C_{12}H_4Cl_6$ | 35065-27-1 | 360.88 | 40.94 | 290, 325, **360** |
| PCB 132 | Analyte | $C_{12}H_4Cl_6$ | 38380-05-1 | 360.88 | 41.05 | 290, 325, **360** |
| PCB 105 | Analyte | $C_{12}H_5Cl_5$ | 32598-14-4 | 326.43 | 41.89 | 256, 291, **326** |
| 4,4'-DDT | Analyte | $C_{14}H_9Cl_5$ | 50-29-3 | 354.49 | 43.10 | 165, **235** |
| PCB 138 | Analyte | $C_{12}H_4Cl_6$ | 35065-28-2 | 360.88 | 43.20 | 290, 325, **360** |
| PCB 187 | Analyte | $C_{12}H_3Cl_7$ | 52663-68-0 | 395.32 | 44.05 | 324, 359, **394** |
| PCB 183 | Analyte | $C_{12}H_5Cl_5$ | 52663-69-1 | 395.32 | 44.51 | 324, 359, **394** |
| PCB 156 | Analyte | $C_{12}H_4Cl_6$ | 38380-08-4 | 360.88 | 47.91 | 290, **360** |
| PCB 180 | Analyte | $C_{12}H_5Cl_5$ | 35065-29-3 | 395.32 | 48.57 | 324, 359, **394** |
| PCB 170 | Analyte | $C_{12}H_5Cl_5$ | 35065-30-6 | 395.32 | 50.97 | 324, 359, **394** |

[a] bold: masses used for quantification

**Online Resource 6** Calculated LOD and LOQ values for all test substances in ng $g^{-1}$ ww. Used numerical factors are $k$ = 3 (LOD), and $k$ = 10 (LOQ)

| Analyte | LOD | LOQ |
|---|---|---|
| PCB 28[b] | 27.0 | 83.1 |
| PCB 52 | 0.3 | 0.8 |
| PCB 49 | 0.4 | 1.1 |
| 2,4'-DDE | 0.1 | 0.2 |
| PCB 101 | 0.4 | 0.9 |
| PCB 99 | 0.3 | 0.7 |
| 4,4'-DDE | 0.1 | 0.2 |
| 2,4'-DDD | 0.2 | 0.5 |
| PCB 110 | 2.7 | 8.3 |
| PCB 77 | 0.1 | 0.4 |
| 2,4'-DDT | 0.2 | 0.3 |
| PCB 118 | 0.4 | 0.9 |
| 4,4'-DDD | 0.2 | 0.6 |
| PCB 153 | 0.6 | 1.6 |
| PCB 132 | 1.0 | 2.8 |
| PCB 105 | 0.3 | 0.7 |
| 4,4'-DDT | 0.2 | 0.4 |
| PCB 138 | 0.2 | 0.4 |
| PCB 187 | 0.1 | 0.3 |
| PCB 183 | 0.1 | 0.2 |
| PCB 171 | 0.1 | 0.3 |
| PCB 156 | 0.2 | 0.5 |
| PCB 180 | 0.1 | 0.3 |
| PCB 170 | 0.1 | 0.2 |

[b] high background noise levels at RT for PCB 28

## *Statistical comparisons between individual PCB concentrations*

**Online Resource 7** results of pairwise Dunn's post-hoc testing of concentrations differences between all possible pairs of PCB congeners with the test statistic Z, the unadjusted *p* value, the adjusted *p* value after Bonferroni correction, and the significance indication by asterisks: *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$

| **Comparison** | Z | *p* | adjusted *p* | significance |
|---|---|---|---|---|
| PCB 99 vs. PCB 105 | -0.8 | 0.411 | 1 | |
| PCB 99 vs. PCB 118 | -1.9 | 0.059 | 1 | |
| PCB 105 vs. PCB 118 | -1.1 | 0.288 | 1 | |
| PCB 99 vs. PCB 138 | -1.6 | 0.105 | 1 | |
| PCB 105 vs. PCB 138 | -0.8 | 0.425 | 1 | |
| PCB 118 vs. PCB 138 | 0.3 | 0.79 | 1 | |
| PCB 99 vs. PCB 153 | -3.4 | < 0.001 | 0.016 | * |
| PCB 105 vs. PCB 153 | -2.6 | 0.009 | 0.246 | |
| PCB 118 vs. PCB 153 | -1.6 | 0.119 | 1 | |
| PCB 138 vs. PCB 153 | -1.8 | 0.068 | 1 | |
| PCB 99 vs. PCB 170 | -1.8 | 0.074 | 1 | |
| PCB 105 vs. PCB 170 | -1.4 | 0.155 | 1 | |
| PCB 118 vs. PCB 170 | -0.9 | 0.344 | 1 | |
| PCB 138 vs. PCB 170 | -1.1 | 0.287 | 1 | |
| PCB 153 vs. PCB 170 | -0.2 | 0.803 | 1 | |
| PCB 99 vs. PCB 180 | -1.5 | 0.132 | 1 | |
| PCB 105 vs. PCB 180 | -0.7 | 0.494 | 1 | |
| PCB 118 vs. PCB 180 | 0.4 | 0.704 | 1 | |
| PCB 138 vs. PCB 180 | 0.1 | 0.909 | 1 | |
| PCB 153 vs. PCB 180 | 1.9 | 0.053 | 1 | |
| PCB 170 vs. PCB 180 | 1.1 | 0.265 | 1 | |
| PCB 99 vs. PCB 183 | 1.1 | 0.26 | 1 | |
| PCB 105 vs. PCB 183 | 1.9 | 0.051 | 1 | |
| PCB 118 vs. PCB 183 | 3 | 0.003 | 0.072 | |
| PCB 138 vs. PCB 183 | 2.7 | 0.006 | 0.168 | |
| PCB 153 vs. PCB 183 | 4.6 | < 0.001 | < 0.001 | *** |

| | | | |
|---|---|---|---|
| PCB 170 vs. PCB 183 | 2.3 | 0.022 | 0.612 |
| PCB 180 vs. PCB 183 | 2.6 | 0.008 | 0.237 |

## *Overview of pollutant levels found in other studies*

**Online Resource 8** Overview of PCB and DDT concentrations in eggs of different bird species across the Antarctic Peninsula. Congener numbers refer to the considered number of congeners, year of sampling indicates breeding season when eggs were collected

| pollutant group | scientific name | common name | number congeners | Σconcentration, (range) (ng $g^{-1}$ ww) | References (year of sampling) |
|---|---|---|---|---|---|
| PCB | *Sterna vittata* | Antarctic tern | 51 | 133 | Cipro et al. 2013 (2004/05, 2005/06) |
| PCB | *Pygoscelis adeliae* | Adélie penguin | 27 | 32.5 (2.53–41.9) | Cipro et al. 2010 (2004/05, 2005/06) |
| PCB | *Pygoscelis antarcticus* | Chinstrap penguin | 27 | 37.3 (3.11–78.7) | Cipro et al. 2010 (2004/05, 2005/06) |
| PCB | *Pygoscelis papua* | Gentoo penguin | 27 | 26.0 (4.58–42.2) | Cipro et al. 2010 (2004/05, 2005/06) |
| PCB | *Stercorarius* spp. | skuas | 51 | 228 (11.2–649) | Cipro et al. 2013 (2004/05, 2005/06) |
| PCB | *Daption capense* | Cape petrel | 51 | 19.6 (13.7–25.4) | Cipro et al. 2013 (2004/05, 2005/06) |
| PCB | *Larus dominicanus* | Kelp gull | 51 | 79.9 (64.5–95.3) | Cipro et al. 2013 (2004/05, 2005/06) |
| PCB | *Stercorarius antarcticus lonnbergi* | Brown Skua | 54 | 53.41±19.61 (31.28-68.62) | Corsolini et al. 2011 (2003/04, 2004/05) |
| PCB | *Pygoscelis adeliae* | Adélie penguin | 54 | 12.03±3.91 (7.26-16.81) | Corsolini et al. 2011 (2003/04, 2004/05) |
| DDX | *Sterna vittata* | Antarctic tern | 6 | 76.6 | Cipro et al. 2013 (2004/05, 2005/06) |
| DDX | *Pygoscelis adeliae* | Adélie penguin | 6 | 6.29 (2.07–8.93) | Cipro et al. 2010 (2004/05, 2005/06) |
| DDX | *Pygoscelis* | Chinstrap penguin | 6 | 15.8 | Cipro et al. 2010 |

| | | | | | |
|---|---|---|---|---|---|
| | *antarcticus* | | | (2.67–38.0) | (2004/05, 2005/06) |
| DDX | *Pygoscelis papua* | Gentoo penguin | 6 | 5.47 (3.10–9.95) | Cipro et al. 2010 (2004/05, 2005/06) |
| DDX | *Stercorarius* spp. | skuas | 6 | 26.3 (13.2–37.7) | Cipro et al. 2013 (2004/05, 2005/06) |
| DDX | *Daption capense* | Cape petrel | 6 | 9.68 (6.42–12.9) | Cipro et al. 2013 (2004/05, 2005/06) |
| DDX | *Larus dominicanus* | Kelp gull | 6 | 94.3 (52.4–136) | Cipro et al. 2013 (2004/05, 2005/06) |
| DDX | *Larus dominicanus* | Kelp gull | N.A. | no unit | Lukowski 1983 (1977/78) |
| DDX | *Macronectes giganteus* | southern giant petrel | N.A. | no unit | Lukowski 1983 (1977/78) |

## *Literature*


Cipro CVZ, Colabuono FI, Taniguchi S, Montone RC (2013) Persistent organic pollutants in bird, fish and invertebrate samples from King George Island, Antarctica. Antarct Sci 25:545–552. https://doi.org/10.1017/S0954102012001149

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Corsolini S, Borghesi N, Ademollo N, Focardi S (2011) Chlorinated biphenyls and pesticides in migrating and resident seabirds from East and West Antarctica. Environ Int 37:1329–35. https://doi.org/10.1016/j.envint.2011.05.017

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