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Can predatory bird feathers be used as a non-destructive biomonitoring tool of organic pollutants?

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The monitoring of different types of pollutants that are released into the environment and that present risks for both humans and wildlife has become increasingly important. In this study, we examined whether feathers of predatory birds can be used as a non-destructive biomonitor of organic pollutants. We demonstrate that polychlorinated biphenyls (PCBs), dichlorodiphenyltrichloroethane (DDT) and polybrominated diphenyl ethers (PBDEs) are measurable in one single tail feather of common buzzards (*Buteo buteo*) and that levels in this feather and internal tissues are significantly related to each other ($0.35 < r < 0.76$ for all 43 buzzards; $0.46 < r < 0.84$ when excluding 17 starved birds). Our findings provide the first indication that feathers of predatory birds could be useful in non-destructive biomonitoring of organic pollutants, although further validation may be necessary.

Keywords: biomonitor; feathers; polybrominated diphenyl ethers; polychlorinated biphenyls; organochlorine pesticides; birds of prey

1. INTRODUCTION

Worldwide, many pollutants, such as heavy metals and persistent organic pollutants (POPs), are released into the environment. POPs, which include polychlorinated biphenyls (PCBs) and organochlorine pesticides (OCPs; e.g. dichlorodiphenyltrichloroethane (DDT)), along with polybrominated diphenyl ethers (PBDEs) are lipophilic pollutants that accumulate within biological tissues and biomagnify through food chains. PCBs and DDT have been shown to disrupt endocrine systems, to cause population declines and to present risks for both humans and wildlife (Jones & De Voogt 1999; Ross *et al.* 2000). Although concentrations have declined since the 1970s, their presence in the environment still remains of concern. PBDEs are intensely used as flame-retardants and have therefore recently emerged as ubiquitous environmental pollutants (Hites 2004). PBDEs have also been associated with endocrine disruption (Darnerud 2003).

Predatory birds have been used extensively in the past as biomonitors of environmental contamination, because they are sensitive to environmental changes and are situated high on the food chain, thus accumulating high levels of POPs (Furness 1993). Moreover, several pollutants with health risks for humans, such as DDT, have been identified following reports of adverse effects in wild bird populations (Ratcliffe 1967). While many studies have measured heavy metals in feathers (Burger 1993), reports on concentrations of organic pollutants in feathers of predatory birds are lacking in literature. Recently, PCBs and DDTs could be quantified in feathers of small passerines, such as the great tit (*Parus major*) (Dauwe *et al.* 2005). However, concentrations were very low and feather sampling could not be considered non-destructive, because a large amount of feather tissue was necessary. Therefore, the present study was performed on a larger predatory bird, occupying a higher position in the food chain.

Here, we report on levels of organic pollutants (PCBs, DDTs and PBDEs) in feathers, muscle and liver tissue of the common buzzard (*Buteo buteo*). We further investigate if there is a correlation between levels of organic pollutants in liver and muscle and levels in the corresponding feathers. The existence of such a relationship would allow future use of feathers of predatory birds in biomonitoring of contamination with organic pollutants. The use of hair, also a keratinous tissue, has recently been established as a successful method for the analysis of POPs (Zupancic-Kralj *et al.* 1992; Dauberschmidt & Wennig 1998; Covaci *et al.* 2002; Altshul *et al.* 2004; D'Havé *et al.* 2005). In contrast to hair, which is continuously growing, feathers grow only for a certain period of time and only during this limited time period are they connected to the blood stream (and its circulating pollutants).

2. MATERIAL AND METHODS

Between October 2003 and June 2004, 43 cadavers of common buzzards (including only two juveniles) were collected in collaboration with Wildlife Rescue Centres in Flanders (Vogelbescherming Vlaanderen vzw, Belgium). The birds had died due to traffic accident, natural causes or starvation ($n = 17$). No birds were killed for the purpose of this study. Liver and pectoral muscle were excised and stored at $-20\,^{\circ}C$ until sample preparation. One outermost tail feather of each bird was removed, stored in a paper envelope and used for further analysis.

Analytical procedures for feathers were similar to the method described by Covaci & Schepens (2001), while procedures for internal tissues are described in detail by Voorspoels *et al.* (2003) and Dauwe *et al.* (2005). Briefly, feathers were washed with distilled water and cut into pieces of approximately 1 mm. Feathers were weighed (~200 mg) and left standing overnight at 40 °C with hydrochloric acid and a mixture of hexane and dichloromethane (4 : 1, v/v). After liquid extraction, clean-up was performed on acidified silica. Approximately 1.5 g of liver or muscle was weighed, mixed with anhydrous Na_2SO_4 and Soxhlet extracted with a mixture of hexane and acetone (3 : 1, v/v). After gravimetric lipid determination on an extract aliquot, the remaining extract was cleaned-up on acidified silica. Analysis was done using a gas chromatograph coupled with a mass spectrometer (GC/MS) operated in electron capture negative ionization mode for PBDEs and OCPs, and using a GC/MS in electron ionization mode for PCBs. In all samples, seven PBDE congeners (28, 47, 99, 100, 153, 154 and 183), bromo biphenyl 153, 25 PCB congeners (18, 28, 52, 74, 95, 99, 101, 105, 110, 118, 128, 132, 138, 149, 153, 156, 167, 170, 177, 180, 183, 187, 194, 196 and 199) and DDT and metabolites (*p*,*p*′-DDT, *p*,*p*′-DDE and *p*,*p*′-DDD, expressed here as DDTs) were analysed.

All statistical analyses were performed using STATISTICA v. 5.5 for Windows (Statsoft 2000, Tulsa, OK, USA) and GRAPHPAD INSTAT v. 3.06 for Windows (GraphPad Software Inc., San Diego, CA, USA). Samples with levels below the limit of quantification (LOQ) were assigned a value of $(1-p) \times \mathrm{LOQ}$, with p the proportion of measurements with levels below the LOQ (Voorspoels

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Table 1. Median concentrations and range of organic pollutants in feathers, muscle and liver of buzzards (*Buteo buteo*) from Belgium ($n=43$). (n.a, not applicable.)

	feather (ng g^{-1})	muscle (ng g^{-1} ww)	liver (ng g^{-1} ww)
mean lipid (%)	n.a.	3.87	4.04
sum of 18 PCBs	26 (5.1–200)	220 (18–2400)	145 (9.0–10 400)
sum of three PBDEs	1.4 (0.5–10)	5.7 (0.4–104)	2.8 (<0.1–310)
sum of DDT and DDE	4.9 (1.6–62)	73 (2.6–820)	34 (2.2–1300)

Table 2. Pearson's correlation coefficients (r) calculated between log concentrations in feathers (ng g^{-1}), muscle (ng g^{-1} ww) and liver (ng g^{-1} ww) of buzzards (*Buteo buteo*). ($^{*}p<0.05$; $^{**}p<0.01$.)

	feather–muscle		feather–liver	
sample size (n)	all buzzards (43)	excl. starved (26)	all buzzards (43)	excl. starved (26)
sum of 18 PCBs	$r=0.76^{**}$	$r=0.84^{**}$	$r=0.60^{**}$	$r=0.62^{**}$
sum of three PBDEs	$r=0.73^{**}$	$r=0.74^{**}$	$r=0.43^{**}$	$r=0.40^{*}$
sum of DDT and DDE	$r=0.53^{**}$	$r=0.56^{**}$	$r=0.35^{*}$	$r=0.46^{*}$

et al. 2002). Compounds with over 50% of the measurements below the LOQ were excluded from the statistical analysis. Data were not normally distributed (Shapiro–Wilk's test) and were log-transformed ($\log(x+1)$) to meet normal distribution requirements. Parametric Pearson correlations were calculated between concentrations of sum PCBs, PBDEs and DDTs in feathers, liver and muscle.

3. RESULTS

In feathers, 18 PCB congeners (range 5.1–200 ng g^{-1}), *p*,*p*′-DDT and its metabolite *p*,*p*′-DDE (range 0.2–6.4 and 1.1–60 ng g^{-1}, respectively), plus the environmentally predominant PBDE congeners 47, 99 and 153 (range 0.5–10 ng g^{-1}) could be quantified with more than 50% of all samples above LOQ. Median concentrations and range of sum PCBs, sum PBDEs and sum DDTs in feathers, muscle and liver, respectively, are listed in table 1, while correlations between concentrations in feathers and muscle or liver are shown in table 2. All correlations were found to be significant (table 2). The highest correlation was found for PCBs between levels in feathers and muscle ($r=0.76$, $p<0.01$; figure 1). When starved birds ($n=17$) were excluded even higher correlations were found ($r=0.84$, $p<0.01$; table 2). In general, higher correlation coefficients were found between feathers and muscle samples than between feathers and liver samples (table 2).

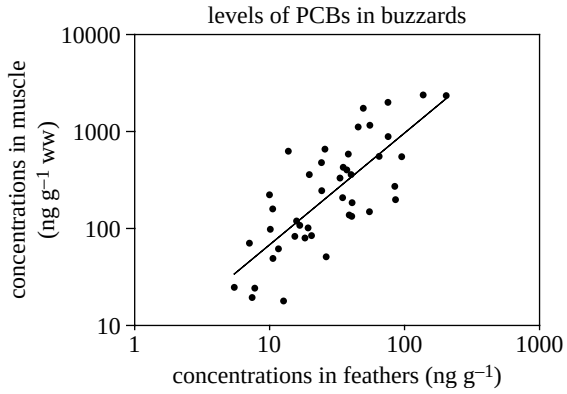

Figure 1. Relation between sum PCB concentrations in feathers and muscle samples of common buzzards ($n=43$) from Belgium ($\log y=1.15 \log x+0.68$; $r=0.76$).

4. DISCUSSION

Our results show that organic pollutants can be measured in a single tail feather of predatory birds and that concentrations in feathers reflect to a certain extent concentrations in internal tissues (table 2). The strongest correlation was found between levels of PCBs in feathers and muscle. Future (experimental) studies should examine whether correlations can improve when potentially confounding variables such as age, sex, condition of birds and season (which may affect external contamination) are being adequately controlled for. When the starved birds were excluded, correlations between concentrations in feathers and internal tissues improved, indicating the importance of controlling for the condition of the birds. It is interesting to note that similar correlation coefficients have been reported for heavy metals between levels in feathers and internal tissues (r ranging from 0.51 to 0.84 between feathers and liver, and from 0.31 to 0.74 between feathers and muscle; Burger 1993). Recently, D'Havé *et al.* (2005) evaluated the use of hair of hedgehogs (*Erinaceus europaeus*) as a non-destructive biomonitor for PBDEs. They observed positive relationships between hair and internal tissues that, after removal of two outliers in their dataset, were in the lower range of correlations found in our study ($0.43<r<0.53$; D'Havé *et al.* 2005).

Higher correlation coefficients were found between feathers and muscle samples than between feathers and liver samples. Assuming that concentrations in feathers reflect circulating concentrations in the body at the time of their formation, feathers may not reflect recent changes in contamination. Since the turnover rate in liver (a highly metabolically active tissue; Voet & Voet 1995) is higher than in muscle, concentrations in liver probably reflect more recent

exposure, which may explain the lower correlation coefficients found between feather and liver samples.

The lower correlation coefficients observed in this study for PBDEs and DDTs in comparison to PCBs could possibly be explained by different degrees of external deposition onto the feather surface or by different metabolization rates. Although for heavy metals, external contamination of feathers has been observed (Burger 1993), Dauwe *et al*. (2005) found no increase of PCBs concentrations with the age of the feather, suggesting little influence of exogenous contamination. Clearly, however, the influence of external contamination needs to be evaluated in more detail.

Given that feathers can be easily preserved and that bird collections in museums and private collections date from the late 1700s, feathers could be useful for retrospective biomonitoring of POPs, as has been successfully done for heavy metals (Burger 1993), and to study regional and temporal trends (Rocque 2005). However, external contamination cannot be completely excluded and should be investigated. While many POP biomonitoring studies have previously focused on bird eggs, feathers have the advantage that they can be collected in any season and from each age or sex class. Moreover, since one feather can easily be removed from a living bird without causing severe damage, non-destructive biomonitoring may be of valuable use with regard to endangered species.

In conclusion, we show for the first time that levels of some organic pollutants in predatory bird feathers and internal tissues are related to each other. At present, our results cannot explain all the variation observed between levels in feathers and internal tissues, but instead show that feathers of predatory birds give a good estimate of contamination levels. While additional studies need to investigate the influence of external contamination and other confounding factors, feathers seem to represent a potential non-destructive biomonitoring tool for organic pollutants in predatory birds.

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