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Key factors affecting liver PBDE concentrations in sparrowhawks
(\textit{Accipiter nisus})

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ABSTRACT

High PBDE concentrations have been detected in the eggs of the sexually dimorphic Eurasian sparrowhawk (*Accipiter nisus*) but little is known about contamination levels in adult birds and how this may vary with age and sex. We characterised liver PBDE concentrations in 59 sparrowhawks that had died in central Britain between 1998 and 2009 and determined how concentrations varied with sex, age, body condition and breeding status. Five BDE congeners (99>153>47>100>154) predominated and ΣPBDE concentrations were 10-15 fold and 2-3 fold higher in starved than non-starved adult and juvenile sparrowhawks, respectively. This was likely due to a combination of remobilisation of residues from other tissues and liver wastage. Liver ΣPBDE concentrations did not vary with sex but were greater in adults than juveniles, suggestive of accumulation with age. Overall, liver ΣPBDE concentrations ranged from 43.4 to 68,040 ng/g lipid weight, amongst the highest concentrations reported in birds anywhere.

Keywords: polybrominated diphenyl ethers, sparrowhawk, body condition, penta-BDE, starvation, bioaccumulation, age class

Capsule: Liver PBDE concentrations in UK sparrowhawks are amongst the highest reported anywhere but vary markedly with body condition and age class.
1. Introduction

Polybrominated diphenyl ethers (PBDEs) are flame retardants that have been used globally in a variety of products since the 1970s (Prevedouros et al., 2004; Rahman et al., 2001). There were principally three types of technical formulations, Penta- (PeBDE), Octa- (OBDE) and Deca- (DeBDE). The PeBDE and OBDE mixtures are no longer used in the European Union and North America but environmental releases from in-use products still occur, particularly through dust and vapour release (Batterman et al., 2009). PBDEs are readily assimilated into food webs and there have been numerous studies of contamination in people and wildlife; these have been reviewed by Chen and Hale, (2010); Hites (2004); Law et al., (2006).

Birds have been widely used as monitors or sentinels of environmental contaminants, including PBDEs. Measurement of PBDE concentrations in tissues and eggs has been carried out to characterise the extent of contamination (and associated potential toxicity) and both temporal and spatial trends in contamination (Chen and Hale, 2010; Marteinson et al., 2010; Newsome et al., 2010). These studies have demonstrated that, in European aquatic systems, PBDE contamination in piscivorous birds rose during the 1980s, peaked in the 1990s, and then fell sharply (Crosse et al., 2012a; Sellstrom et al., 2003), largely reflecting modelled usage of PeBDE formulations (Prevedouros et al., 2004). However, the nature of long-term time trends in PBDE concentrations in terrestrial-feeding birds in Europe is equivocal, with decreases in recent years reported in some studies, but not others (Bustnes et al., 2011; Leslie et al., 2011; Johansson et al., 2011). Variation between studies in observed trends over time may be due to a number of factors, such as differences in the range of PBDEs that were monitored, geographical variation in the extent of usage of PBDEs, inter-specific differences
in accumulation and metabolism, and differences in the pharmacokinetic partitioning of PBDEs between different tissues that are then sampled for analysis.

Long term trends in contaminant concentration in terrestrial UK habitats have been tracked previously by measuring concentrations in the eggs and body tissues of the Eurasian sparrowhawk (*Accipter nisus*), a terrestrial species found throughout most of Britain and which mostly preys on small birds (Newton, 1986). Previous studies have focussed on determining temporal and spatial variation in organochlorine insecticides, polychlorinated biphenyls, mercury and arsenic (Newton 1986; Newton et al., 1993; Erry et al., 1999; Broughton et al. 2003) but a recent study has also reported UK long-term trends in PBDE concentrations in sparrowhawks eggs (Crosse et al., 2012b). Sum PBDE (ΣPBDE) concentrations were some of the highest concentrations ever reported in bird eggs or tissues from Europe and were of a magnitude associated with adverse reproductive effects. Unlike trends reported in the majority of studies from the rest of Europe, concentrations did not decline after reaching peak levels in the late 1990s, despite the phasing out of PeBDE and OBDE in the European Union.

Contaminant concentrations in the eggs of investment breeders (Drent and Daan, 1980) are thought largely to provide a snapshot of exposure in females in the days before egg production, although female sparrowhawks can also eliminate bioaccumulated persistent organic contaminants into eggs (Newton et al., 1981), presumably from retained fat deposits laid down earlier. Eggs are therefore a readily available and homogeneous biomonitor of exposure in females that can be directly related to reprotoxic effects, but the time period of exposure may be uncertain. Egg concentrations do not provide direct information on body residues in females or necessarily on exposure in males. The latter may be particularly true for sexually dimorphic species such as the sparrowhawk where males and females specialise
on different sized prey, although male sparrowhawks feed females during the period when
eggs are developing (Newton.1986). Overall, egg residues may provide little or no
information on either the extent of bioaccumulation or the magnitude of residues [and
associated toxicity] in body tissues. The overall objective of the present paper was to more
fully characterise the large-scale PBDE contamination in sparrowhawks in Britain that was
revealed by the earlier analysis of eggs (Crosse et al., 2012b). The specific aims were to
characterise and quantify current PBDE concentrations in the sparrowhawk livers and
determine how concentrations varied with age class and sex. As part of this analysis, we also
examined whether liver PBDE concentrations were affected by body condition at the time of
death, as this has been shown to markedly influence the magnitude of liver concentrations of
other persistent organic pollutants (Wienburg and Shore, 2004).

2. Materials and methods

2.1. Sample collection

Dead sparrowhawks from throughout Britain were collected by volunteers and
submitted to the Predatory Bird Monitoring Scheme (http://pbms.ceh.ac.uk/; Walker et al.,
2008). Provenance, collection date, age, sex, body weight and body condition (assessed
visually using a six point scoring system) were recorded and a necropsy was performed
during which a putative cause of death was determined. Various body tissues were collected
from each carcass, weighed and archived at -20°C. However, whole liver and body weights
were not obtained for all birds, including some used in the present study, usually because
carcasses had been partly damaged through trauma or scavenging, or organs were provided
by taxidermists who had not recorded the body weight of the bird.
Archived livers from birds that had died between 1998 and 2009 from central England, directly east and within 250 km of the Welsh border (S.I. Figure 1), were selected for the present study. Sample selection was restricted in this way to minimise potential confounding temporal and spatial variation; previous analysis of sparrowhawk eggs suggested that exposure in females was largely constant across this time period and geographical region (Crosse et al., 2012b). Selection of birds was further stratified such that individuals were representative of one of eight groups characterised by sex (male/female), age class (adult/juvenile) and body condition (starved/non-starved birds). Juveniles were defined as birds that hatched in the current or previous calendar year while starved birds were those which, at post-mortem inspection, had a complete lack of fat deposits or at most trace amounts of fat typically around the heart but nowhere else. The numbers of birds in each of the eight groups varied between five and 11 and the total number of birds analysed was 59.

2.2. Determination of PBDE concentrations in livers

For each bird, approximately 1 g wet weight of liver (mean ± SD: 0.97 ± 0.22 g) was excised from various parts of the whole liver to obtain a representative sample, and was then homogenised. Homogenates were weighed accurately, extracted and cleaned up, and lipid content determined gravimetrically as described by Crosse et al. (2012a); the mean (± SD) % lipid in livers was 6.88 ± 4.86 %. The cleaned-up extract was analysed by Gas Chromatography Mass Spectrometry (GC-MS, Thermo-Finnigan Trace) fitted with a ThermoQuest AS2000 autosampler and using a 30m CPSIL-8 CB pesticide column (0.25 mm diameter, 0.12 µm internal diameter) and calibrated using seven PBDE standards in a linear range 2.5-250 pg/ul. Livers were analysed for a suite of 30 PBDE tri-Octa BDE congeners (17, 28, 32, 35, 37, 47, 49, 51, 66, 71, 75, 77, 85, 99, 100, 118, 119, 126, 128, 138, 153, 154, 166, 183, 190, 196, 197, 201, 202, 203) as described by Crosse et al. (2012b). BDE209 was
not quantified as the above method was not amenable to its determination, returning poor recovery figures.

The instrument Limit of Detection (LoD) was defined as the lowest observable calibration standard (2.5 pg/ul for tri-hexa BDEs and BDE183 to 5 pg/ul for Octa BDEs) which was equivalent to 0.25 ng and 0.5 ng, respectively, in the liver samples that were analysed. Eight procedural blanks were run alongside the samples and these demonstrated that there was no background contamination. Mean recoveries for $^{13}$C$_{12}$ labelled BDE congeners 28, 47, 99, 100, 153, 154 and 183 (Wellington Laboratories, Guelph, Ontario, Canada) ranged between 74.4 and 88.2% across homologue groups and concentrations were recovery corrected using these data as described by Crosse et al. (2012a). To ensure precision, a quality control (QC) standard, consisting of five PBDEs that encompassed tri-hepta homologue groups at concentrations of 2.5-250 pg/ul, was analysed alongside unknowns. Batches of samples were only fit if QC concentrations were +/- 10% of expected values.

2.3. Statistical analyses

All statistical analysis was performed using Minitab 16.0. General linear models (GLM) were used to determine whether age, sex, body condition and breeding status significantly explained variation in the concentrations of individual PBDE congeners, $\Sigma$PBDEs or physiological characteristics of the liver, such as liver mass and liver % lipid. Because of the biologically plausible complex triple interactive effects of body condition, age and sex on liver residues, we conducted analysis of the effects of age and body condition on liver BDE concentrations in males and females separately. PBDE concentrations and % lipid data were log and arcsine square-root transformed, respectively, so that the underlying
assumptions of equal variance and normality of residuals in the GLM were met. The majority
of congener data sets had some values recorded as below the LoD and, for congeners where
the percentage of values below the LoD was less than 80%, the below LoD values were
assigned an interpolated value following the method described by Hesel, (1990, 2006).

3. Results

The data associated with this study are available from the CEH Information Gateway
(https://gateway.ceh.ac.uk/) and can be identified from their digital object identifier:

http://dx.doi.org/10.5285/1c4f835c-d243-4593-a9b4-71410b9b4bf0

3.1. Congener profiles and concentrations.

A total of 26 congeners were detected in one or more livers. BDEs 47, 99, 100, 153
and 154 were detected in the livers of all the birds, BDEs 138 and 183 in >80%, and BDEs
66, 118, 119, 196, 197, 201, 202 in >50% of birds. Only BDEs 32, 128, 166, and 190 were
not detected in any of the livers. The PeBDE-associated congeners BDEs 99, 153, 47, 100
and 154 dominated the congener profile, comprising almost 90% of the ΣPBDE concentration
(Figure 1). The geometric mean concentrations of these congeners varied between 103 and
945 ng/g lipid weight (lwt) and were generally an order of magnitude higher than those of all
other detected congeners (Table 1 and S.I. Table 1). The two other most frequently occurring
congeners, the hepta-BDE 183 and the hexa-BDE 138, made lesser contributions to the
overall congener profile (Table 1, Figure 1). The concentrations of all seven congeners were
highly correlated with each other and with that of the ΣPBDEs (r ≥ 0.887, P<0.001 in all
cases). The octa-brominated BDEs 197, 201, 202 and 203 occurred in fewer livers but, when
present, were detected in similar amounts to BDE183; the geometric mean concentrations of
the other congeners, when detected, ranged from 4.42-31.5 ng/g lwt (S.I. Table 1). Overall, the geometric mean ΣPBDE concentration was two-three fold higher than that of BDE 99, the most abundant congener, and approximately at least an order of magnitude greater than the concentrations of all other congeners (Table 1 and SI Table 1).

3.2 Factors associated with variation in liver PBDE concentrations

In male sparrowhawks, body condition and age class between them explained 51.3% of the variation in liver ΣPBDE concentrations. Residues were higher in starved than in non-starved birds and in adults compared with juveniles ($F_{(1,21)} \geq 5.28, \ P<0.05$ in both cases; Figure 2). The interaction term between age and body condition was also significant ($F_{(1,21)} = 4.77, \ P<0.05$) as the difference in liver concentrations between starved and non-starved birds was 15-fold in adults but only two-fold in juveniles (Figure 2). In female sparrowhawks, body condition explained 23.3% of variation in liver ΣPBDE concentration, residues again being greater in starved than non-starved birds ($F_{(1,30)} = 8.87, \ P<0.01$, Figure 2). However, unlike in males, age class was not a significant factor in females nor was the interaction term between age class and body condition ($F_{(1,30)} \leq 1.03, \ P>0.05$ in both cases), even though starvation was associated with an average elevation of liver ΣPBDE of 10 fold in adult females but only three fold in juveniles (Figure 2). Unsurprisingly, given the high degree of correlation between the concentrations of the individual main congeners and the ΣPBDE, the effects of body condition and of age class (males only) on each of the individual main congeners were similar to those on ΣPBDE concentrations (data not shown).

Starvation can affect liver concentrations of persistent organic pollutants potentially by altering the lipid content of the liver, through liver wastage associated with starvation, and through remobilisation of contaminants from fat depots and other tissues that subsequently leads to increased accumulation of residues in the liver. We analysed whether starvation, as
measured by body condition, was associated with either altered liver lipid content or a
decrease in liver mass in all birds, and included age class and sex as additional factors in the
analysis. There was no effect of body condition, nor of sex or age class, on % liver lipid
content (F(1, 44) ≤ 1.93, P > 0.05 for all factors/interaction terms; Figure 3), whereas both body
condition and sex were significantly associated with variation in liver mass (F(1, 44) > 7.97,
P < 0.01 in both cases; Figure 3). Liver mass, on average, was approximately 20% less in
starved than non-starved birds of the same sex and age class, and was also approximately
25% lower in males than females, reflecting sexual dimorphism in body weight (Figure 3).

One possible explanation why age class was a statistically significant predictor of
liver ΣPBDE concentrations in male but not female sparrowhawks may be because adult
breeding females transfer a proportion of their maternal PBDE burden into eggs. To test this
hypothesis, we examined whether liver PBDE concentrations in adult sparrowhawks that died
within the breeding season (April-September) were lower than in those collected outside the
breeding season (October-March). We included males in the analysis, as they effectively
acted as controls against which to test the hypothesis; body condition, sex, and season were
factors in the model. There was no effect of season, sex, nor any interaction between sex and
season, on liver ΣPBDE concentrations (F(1, 19) < 0.39, P > 0.05 in all cases; S.I, Figure 2). The
only significant factor affecting liver BDE concentration was body condition and
concentrations were greater in starved than non-starved birds (F(1, 19) = 21.0, P < 0.001; S.I.
Figure 2). There were likewise no significant effects of season on liver concentrations of any
of the major congeners (data not shown).

The above model indicated that sex did not significantly explain variation in liver
ΣPBDE concentrations in adult sparrowhawks. Analysis of data for juvenile birds showed
that there was likewise no effect of sex on liver ΣPBDEs in this age class (F(1, 28) = 0.25,
P > 0.05).
4. Discussion

4.1. Congener profile

The seven congeners that dominated the BDE congener profile in sparrowhawk livers (99>153>47>100>154>183>138) occurred in similar relative proportions in most birds. Concentrations were also in broadly similar proportions to those in the PeBDE technical mixtures DE-71 and Bromkal 70-5DE (Figure 1). This suggests the PeBDE mixture is the most important source of PBDE contamination in sparrowhawks, although the detection of octa-brominated congeners also indicates some contribution of the OBDE and/or DeBDE mixture, of which these congeners are either components or potential degradation products. This congener profile in livers was consistent with that detected in sparrowhawk eggs from the same area (Crosse et al., 2012b) and demonstrates that the congeners associated with the PeBDE technical mixture remain a major source of contamination, despite the banning or phasing out the technical products in the European Union.

4.2. The effect of condition and age on liver PBDE concentrations

The concentrations of BDEs that were detected varied with a number of factors. Starvation was clearly the most important, with concentrations of the major individual BDE congeners and ΣPBDEs elevated in birds in poor body condition. This was, in part, due to a reduction in liver size, presumably a result of liver glycogen being depleted during starvation. However, the elevation in ΣPBDE concentrations in starved birds (10-15 fold in adults and 2-3 fold in juveniles) was disproportionate to the degree of liver wastage (25% reduction in mass). This strongly indicates that liver BDE residues are elevated during periods of starvation because of remobilisation of residues from fat stores and possibly other biological
compartments. Starvation has been found similarly to elevate liver PCB residues in raptors (Wienburg & Shore, 2004) and to affect the concentrations of persistent organic pollutants, including PBDEs, in the eggs of tawny owls (*Strix aluco*) (Bustnes et al., 2011).

The presence of greater liver ΣPBDE concentrations in adult than juvenile males, and the difference between adults and juveniles in the impact that starvation had on liver residues, are both consistent with bioaccumulation of BDEs with age, although differences in dietary exposure between adults and juveniles cannot be ruled out. Adult birds, because they are older, have longer than juveniles to bioaccumulate residues in fat and other tissues and so larger residues are subsequently remobilised during starvation. Such bioaccumulation is likely to vary to some extent between congeners and, in the present study, was most readily detectable for the hexa-brominated BDEs 138, 153 and 154 in males; age class alone was a significant factor (P≤0.01; data not shown) in the statistical models for these congeners. All three have been reported to have long biological half-lives and/or high biomagnification factors (BMFs) in birds (Drouillard et al., 2007; Lindberg et al., 2004; Voorspoels et al., 2007), likely due to their high Log _kow_ values (Voorspoels et al., 2007). BDE183 has been reported to have an even higher BMF (Voorspoels et al., 2007). Although age class alone was not statistically significant in our model that examined which factors explained variation in liver BDE183 residues in males, the interaction between age class and body condition was significant (P<0.05; data not shown). This indicated that residues were more elevated in starved adults than juveniles. This is again consistent with accumulation with age.

Liver PBDE concentrations in female sparrowhawks did not differ from those in males, suggesting that exposure of males and females to BDEs is similar, despite females taking different, typically larger, prey species than males (Newton, 1986). The effect of starvation in elevating liver residues was also the same in females as males. Although there was no statistically significant evidence that liver BDE residues in females increased with age
class, liver ΣPBDE concentrations did not differ between adult males and females. Such a
difference might be expected if males bioaccumulated residues but females did not.
Furthermore, starvation had a much bigger impact on liver residues in adult females than in
juveniles, just as in males. This is also consistent with the concept that both males and
females bioaccumulate PBDEs with age.

Analysis of the factors associated with variation in liver PBDE residues in females
may be confounded by maternal transfer of PBDE burdens into eggs. Such transfer clearly
occurs as PBDEs have been detected in sparrowhawk eggs (Jaspers et al., 2006; Chen et al.,
2007; Crosse et al., 2012b), but it is unknown to what extent egg PBDE concentrations are
derived from maternal diet or from the female’s body burden. Altricial or semi-altricial birds,
such as raptors, are thought to use less maternal lipids and proteins in the formation of eggs
compared to precocial species (Drouillard & Norstrom, 2001; Verreault et al., 2006). It has
been estimated that, in chickens, some 1-20% of maternal body burdens of some
organohalogen compounds are transferred to eggs (Bargar et al., 2001) although this can
further vary with physiological and chemical factors (Van den Steen et al., 2009). Thus,
transfer of maternal PBDE burden into eggs in sparrowhawks may be relatively small. In the
present study, liver PBDE concentrations of adult females that died between April and
September (a period covering the breeding season) were not lower than those outside of this
period, nor did they differ from concentrations in males. This suggests that maternal transfer
of PBDEs into eggs does not result in significant depletion of female liver BDE residues in
sparrowhawks. However, it was not known whether birds that had died between April and
September had laid eggs and so the reported liver concentrations may be representative of a
mixture of pre and post laying females. Thus, our ability to detect significant transfer of
PBDEs from females to eggs from analysis of liver concentrations in this way may be
limited.
4.3 Comparisons with PBDE contamination in birds elsewhere

Overall, liver ΣPBDE concentrations ranged from 43.4 – 68,040 ng/g lwt (equivalent to 7.93 to 7,447 ng/g wet wt). To the best of our knowledge, 68,000 ng/g lw is currently the highest (tri – octa) ΣPBDE concentration recorded in birds anywhere (Guerra et al., 2012) and is only exceeded by the (tetra – deca) ΣPBDE reported in the egg of a peregrine falcon (Falco peregrinus) from the north-eastern USA (Chen et al., 2008). Geometric mean liver concentrations in sparrowhawks in the present study (2440 ng/g lwt) are within the range of terrestrial bird liver concentrations reported by Chen and Hale (2010) in a global review of PBDEs in birds. When compared with data for other sparrowhawk species elsewhere, ΣPBDE concentrations in this study were of a similar magnitude to those reported in birds from mainland Europe (Jaspers et al., 2006; Voorspoels et al., 2006), but exceeded mean liver ΣPBDE concentrations in Japanese sparrowhawks (Accipiter gularis) from China by roughly five-fold (Chen et al, 2007). The similarities in ΣPBDE liver concentrations between those reported in this study and other sparrowhawks from mainland Europe contrasts with the observations by Crosse et al. (2012) that ΣPBDE concentrations in the eggs of UK sparrowhawks were considerably higher than those of other European birds. This apparent anomaly may be related to differences between studies in the body condition of birds which has a major impact on the magnitude of liver residues.

The toxicological significance of the liver PBDE residues in the present study is unknown. This is because, in contrast to studies on PBDEs and other organohalogen compounds in eggs (Chen et al., 2010; Fernie et al., 2009; Harrris and Elliott, 2011; Henny et al., 2009; Marteinson et al., 2010), there is a lack of data that relates the potential toxicity of PBDEs in avian livers to adverse effects. This is an area that merits further investigation.
5. **Conclusions**

The present study has demonstrated that sparrowhawks in Britain accumulate some of the highest PBDE residues reported for terrestrial-feeding birds anywhere. Although this species is sexually dimorphic, there was no evidence that accumulation differed between males and females but it was higher in adults than juveniles. Starvation resulted in massive elevation of liver residues, caused primarily by remobilisation of residues (from body fat and potentially other organs) and partly from liver wastage. It seems likely therefore, that adult birds are likely to have the highest circulating liver PBDE concentrations, particularly during periods of starvation when they are unable to catch sufficient prey to maintain body reserves, and so may be most at risk from any toxic effects of PBDEs. The key role that body condition plays in mediating liver PBDE concentrations highlights the need to account for nutritional status when utilising raptor livers as a biomonitoring tool for PBDEs.

**Acknowledgements**

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Figure 1. PBDE congener profile in sparrowhawk livers from birds that died between 1998 and 2009, and in the DE-71 and 70-5DE PeBDE technical formulations (La Guardia et al 2006). Relative abundance data for each congener in livers was the % contribution to the ΣPBDE concentration and the average for all livers within the age and sex category was taken.
Figure 2. Geometric mean (95% Confidence Interval) liver ΣPBDE concentrations (ng/g lwt) in male (upper graph) and female (lower graph) sparrowhawks characterised by age and body condition. Numbers in columns indicate number of birds in each group.
Figure 3. Mean (± SEM) % lipid liver, liver mass (g) and body weight (g) in sparrowhawks characterised by sex, age and body condition. Numbers in columns indicate number of birds in each group.
Table 1 Geometric mean and range (ng/g lwt) of concentrations for ΣPBDEs and the seven PBDE congeners detected in ≥ 80% of the 59 sparrowhawks analysed. Geometric mean values for concentrations calculated on a wet wt basis are also given for ease of comparison with other studies.

<table>
<thead>
<tr>
<th>Geometric mean (ng/g lipid)</th>
<th>Range</th>
<th>Geometric mean (ng/g wet wt)</th>
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<tbody>
<tr>
<td>BDE 47</td>
<td>368</td>
<td>22.1-14400</td>
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<tr>
<td>BDE 99</td>
<td>945</td>
<td>44.4-28700</td>
</tr>
<tr>
<td>BDE 100</td>
<td>255</td>
<td>12.1-8600</td>
</tr>
<tr>
<td>BDE 138</td>
<td>24.0</td>
<td>1.79-473</td>
</tr>
<tr>
<td>BDE 153</td>
<td>452</td>
<td>12.6-16100</td>
</tr>
<tr>
<td>BDE 154</td>
<td>103</td>
<td>4.34-4150</td>
</tr>
<tr>
<td>BDE 183</td>
<td>63.8</td>
<td>1.36-2100</td>
</tr>
<tr>
<td>ΣPBDE</td>
<td>2440</td>
<td>117-68000</td>
</tr>
</tbody>
</table>

1 Median (range) % lipid content in livers was 5.64 % (1.45-26.9%)
S.I. Figure 1: Map of locations where dead sparrowhawks were found.
S.I. Figure 2: Geometric mean (and 95% Confidence Interval) in liver $\Sigma$PBDE concentrations (ng/g lw) in adult sparrowhawks grouped by sex, body condition, and month of death. Numbers in columns indicate number of birds in each group.
S.I. Table 1  Geometric mean, and range (ng/g lipid) of the liver concentrations of PBDE congeners (17, 28, 35, 37, 49, 51, 66, 71, 75, 118, 119, 126, 196, 197, 201, 202, 203) that were present at detectable levels in less than 80% of sparrowhawks. Mean values are only for those livers that had detectable residues

<table>
<thead>
<tr>
<th>BDE</th>
<th>Number of samples &lt; LoD</th>
<th>Geometric mean in livers with detected residues (ng/g lipid)</th>
<th>Range</th>
</tr>
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<tbody>
<tr>
<td>BDE 17</td>
<td>4</td>
<td>4.42</td>
<td>1.19-11.7</td>
</tr>
<tr>
<td>BDE 28</td>
<td>11</td>
<td>10.1</td>
<td>3.57-30.8</td>
</tr>
<tr>
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