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The transfer of ^{137}Cs, Pu isotopes and ^{90}Sr to bird, bat and ground-dwelling small mammal species within the Chernobyl exclusion zone

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Protected species are the focus of many radiological environmental assessments. However, the lack of radioecological data for many protected species presents a significant international challenge. Furthermore, there are legislative restrictions on destructive sampling of protected species to obtain such data. Where data are not available, extrapolations are often made from 'similar' species but there has been little attempt to validate this approach.

In this paper we present what, to our knowledge, is the first study purposefully designed to test the hypothesis that radioecological data for unprotected species can be used to estimate conservative radioecolgical parameters for protected species; conservatism being necessary to ensure that there is no significant impact.

The study was conducted in the Chernobyl Exclusion Zone. Consequently, we are able to present data for Pu isotopes in terrestrial wildlife. There has been limited research on Pu transfer to terrestrial wildlife which contrasts with the need to assess radiation exposure of wildlife to Pu isotopes around many nuclear facilities internationally.

Our results provide overall support for the hypothesis that data for unprotected species can be used to adequately assess the impacts for ionising radiation on protected species. This is demonstrated for a range of mammalian and avian species. However, we identify one case, the shrew, for which data from other ground-dwelling small mammals would not lead to an appropriately conservative assessment of radiation impact. This indicates the need to further test our hypothesis across a range of species and ecosystems, and/or ensure adequate conservatism within assessments.

The data presented are of value to those trying to more accurately estimate the radiation dose to wildlife in the Chernobyl Exclusion Zone, helping to reduce the considerable uncertainty in studies reporting dose-effect relationships for wildlife.

A video abstract for this paper is available from: http://bit.ly/1JesKPc.

1. Introduction

A necessary component of the tools (e.g. Brown et al., 2008; Copplestone et al., 2001, 2003; USDoE, 2002) now established to estimate the exposure of wildlife to ionising radiations is an ability to predict wholebody activity concentrations of radionuclides in a wide range of biota. Although there are alternative approaches to predict transfer to wildlife in development, such as the use of taxonomic relationships (e.g. Beresford et al., 2013, 2015), most of the available tools use concentration ratios ($CR_{wo\text{-}media}$) relating the activity concentrations in plants and animals to those in the appropriate environmental media (soil, air or water) (Beresford et al., 2008a). Whilst databases of $CR_{wo\text{-}media}$ values for wild species have been collated (e.g. Beresford et al., 2008b; Copplestone et al., 2013; Hosseini et al., 2008; Howard et al., 2013; Yankovich et al., 2013), data for many radionuclide-organism combinations are sparse or not available. Where data are unavailable, assumptions such as applying data for a 'similar organism' (e.g. mammal data for birds) are often made to provide default $CR_{wo\text{-}media}$ values

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for use in dose assessment tools (Beresford et al., 2008b; Brown et al., 2013).

Protected species are the focus of many assessments (e.g. Copplestone et al., 2005; Wood et al., 2008). For many protected species, transfer data are lacking and there are legislative restrictions on destructive sampling to obtain data (Wood et al., 2011). For some protected species, there are very few data for the overall taxonomic group appropriate to that species. A good example of this is chiroptera (bats), all species of which are protected in the European Union (HMSO, 1994). For some radionuclides there are many $CR_{wo\text{-}soil}$ data for other animals within the class mammalia and the extent to which these data are applicable to bats needs to be established. Similarly, at many ecologically important sites requiring assessment (e.g. Natura 2000 sites), the most prevalent protected organisms are aves (bird) species (Copplestone et al., 2003). However, there are very few $CR_{wo\text{-}media}$ values for birds (e.g. ICRP, 2009).

Previously, we have published data on the transfer of ^{137}Cs and ^{90}Sr to a range of bat species sampled from a variety of sites within the Chernobyl Exclusion Zone (CEZ) (Gaschak et al., 2010). The CEZ, which is the area established around the Chernobyl nuclear complex following the 1986 accident, is increasingly viewed as a natural laboratory, and more recently as a radioecological observatory (https://wiki.ceh.ac.uk/x/NoFsD). It provides an opportunity to study the transfer of radionuclides to different species of wildlife across different taxonomic groups (e.g. Beresford et al., 2005). In this paper we present a study where species of birds, bats and ground-dwelling small mammals were sampled from a site within the CEZ and analysed for ^{137}Cs, Pu isotopes and ^{90}Sr. To our knowledge, this is the first study purposefully designed to test the hypothesis that radioecological modelling parameters derived from the sampling and analysis of unprotected species (i.e. ground-dwelling small mammals) result in a conservative dose assessment for protected species inhabiting the same site. The paper also makes an important contribution to the available database of Pu isotope data for terrestrial wildlife, few studies having been published previously (e.g. Johansen et al., 2014, 2015).

2. Materials and methods

2.1. Study sites

In Beresford et al. (2008c) we report a study to determine the exposure of small mammal species at three forest sites within the CEZ conducted during the summer of 2005. The sites were initially selected to have a range in radionuclide activity concentrations; animal samples from each site were collected within a 100 × 100 m area. In the present study, samples have been collected from one of these sites (termed the '*Medium* site' in Beresford et al., 2008c).

The *Medium* site was approximately 8 km to the west of the Chernobyl power plant complex. The woodland at the *Medium* site consisted mainly of *Pinus sylvestris* (Scots pine) and *Quercus robur* (Oak), with some *Sorbus aucuparia* (Rowan) and *Tilia platyphyllos* (Large leaved lime). The sparse understorey vegetation included *Pteridium aquilinum* (Bracken). The site had soddy pseudopodzolic sandy and boggy soils on modern alluvial deposits.

Beresford et al. (2008c) describes the collection and analyses of soils (n = 23) from the *Medium* site; soils were collected from an area extended to 50 m beyond the animal sampling area to encompass the likely home ranges of the animal species being trapped (i.e. soils were collected from an area of 200 m × 200 m or 40000 m^2). Soil activity concentrations were reported in Beresford et al. (2008c) as: 43.3 ± 25.7, 0.83 ± 1.49, 18.6 ± 14.9 kBq kg^{-1} dry mass for ^{137}Cs, ^{238,239,240}Pu and ^{90}Sr respectively. Whilst variable, there was no spatial pattern in soil activity concentrations across the sampling site.

2.2. Biota samples

2.2.1. Bird samples

A range of passerine species were collected by mist net at the *Medium* site during June 2005, euthanised and retained frozen. Species, sample numbers and information on feeding and home range are presented in Table 1.

2.2.2. Bat samples

Three species of bats were collected from the site during the period May–June 2008 using mist nets (Table 1). After being euthanised the samples were stored frozen whilst awaiting analyses.

2.2.3. Ground-dwelling small mammals

In Beresford et al., 2008c, live-monitoring (see approach of Bondarkov et al. (2011) outlined below) results for ^{90}Sr and ^{137}Cs in *Apodemus flavicollis*, *Myodes glareolus* and *Microtus* spp. are

Table 1
Species samples at the study site in the Chernobyl Exclusion Zone.

Species	n	Approximate home range (m^2)	Diet
Birds			
Erithacus rubecula	7	6000 m^2	Ground & flying invertebrates, some fruit
Ficedula albicollis	1	6000 m^2	Flying & ground invertebrates
Ficedula hypoleuca	3	<3000 m^2	Flying & ground invertebrates, some fruit
Fringilla coelebs	4	7000 m^2	Seeds, insects (especially caterpillars)
Parus major	2	<20000 m^2	Insects (especially caterpillars)
Sylvia atricapilla	2	11000 m^2	Flying & ground invertebrates
Turdus merula	2	Minimum 2000 m^2	Ground invertebrates, some fruit
Bats			
Nyctalus leisleri	4	Travel up to 13 km from roosts to foraging sites	Flying insects
Pipistrellus pipistrellus	3	May travel up to 5.1 km from roosts	Flying insects
Plecotus auritus	3	Forage close to the roost (usually within 1.5 km)	Flying insects
Ground-dwelling small mammals			
Myodes glareolus	14	400 – 700 m^2	Plants (including seeds & fruit), some ground invertebrates
Sorex araneus	4	370 – 630 m^2	Ground invertebrates, carrion
Sylvaemus flavicollis	4	5000 m^2	Plants (including seeds & fruit), fungi, ground insects

Data sources: Arnold (2004); Holden and Cleeves (2014); Lindblom (2008); Voyinstvenskyy (1960); http://www.jstor.org/stable/1934734?seq=6#page_scan_tab_contents; http://www.snh.gov.uk/docs/C208532.pdf; http://en.wikipedia.org/wiki/Common_shrew; http://www.mammal.org.uk/species-factsheets/Yellow-necked%20mouse