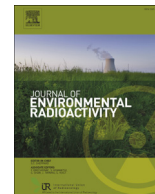




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## Transfer parameters for ICRP's Reference Animals and Plants in a terrestrial Mediterranean ecosystem

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## ABSTRACT

A system for the radiological protection of the environment (or wildlife) based on Reference Animals and Plants (RAPs) has been suggested by the International Commission on Radiological Protection (ICRP). To assess whole-body activity concentrations for RAPs and the resultant internal dose rates, transfer parameters are required. However, transfer values specifically for the taxonomic families defined for the RAPs are often sparse and furthermore can be extremely site dependent. There is also a considerable geographical bias within available transfer data, with few data for Mediterranean ecosystems. In the present work, stable element concentrations (I, Li, Be, B, Na, Mg, Al, P, S, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Mo, Ag, Cd, Cs, Ba, Tl, Pb and U) in terrestrial RAPs, and the corresponding whole-body concentration ratios,  $CR_{wo}$ , were determined in two different Mediterranean ecosystems: a Pinewood and a Dehesa (grassland with disperse tree cover). The RAPs considered in the Pinewood ecosystem were Pine Tree and Wild Grass; whereas in the Dehesa ecosystem those considered were Deer, Rat, Earthworm, Bee, Frog, Duck and Wild Grass. The  $CR_{wo}$  values estimated from these data are compared to those reported in international compilations and databases.

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### 1. Introduction

Radiological protection of the environment has evolved from an anthropogenic perspective ('if man is adequately protected, so is the environment') (ICRP, 1997; 1991) to recommendations that the environment is assessed in its own right (ICRP, 2008a). The concept of Reference Animals and Plants (RAPs) has been proposed by the ICRP (ICRP, 2008b) to provide a methodology similar to that used in human radiological protection (i.e. Reference Man). According to the ICRP definition (ICRP, 2008b), a RAP is 'a hypothetical entity, with the assumed basic biological characteristics of a particular type of animal or plant, as described to the generality of the taxonomic level of family, with defined anatomical, physiological, and life-history properties, that can be used for the purposes of relating exposure to dose, and dose to effects, for that type of living organism'. Various models

are available to quantify exposure (usually as dose rate) of animals and plants (wildlife). Most of these models use a quasi-equilibrium approach to estimate the activity concentration in organisms and consequently their internal dose rate (e.g. the ERICA Tool (Brown et al., 2008, 2016); RESRAD-BIOTA (USDoE, 2002) and R&D128/SP1a (Copplestone et al., 2001, 2003)).

Concentration ratios,  $CR_{wo}$ , are often used in such models (Beresford et al., 2008a) to predict activity concentrations in wildlife assuming that there is equilibrium between the whole organism (RAP) and the appropriate medium (i.e. usually soil in the case of terrestrial ecosystems). Table 1 shows the existing  $CR_{wo}$  values available for the selected RAPs as reported in ICRP 114 (Annex A.1) for terrestrial ecosystems (ICRP, 2009);  $CR_{wo}$  values are generally summarized by element (not specific radioisotope). It can be seen that there are many gaps, and that there are only available data for about 37% of the 200 element-RAP combinations considered in ICRP (2009). Data are also lacking for some radiologically significant elements (e.g. iodine). Data reported in ICRP (2009) were derived from the online database described by (Copplestone et al., 2013).

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**Table 1**  
Availability of CR<sub>wo</sub> values for RAP in terrestrial ecosystem. Adapted from ICRP 114 (ICRP, 2009).

Element	Earthworm	Bee	Rat	Frog	Deer	Duck	Wild Grass	Pine Tree
Am	X		X	X	X	X	X	
Ba								X
Cd	X			X			X	
Ce	X							X
Cl	X						X	X
Co			X					X
Cr								X
Cs	X		X	X	X	X	X	X
Eu	X							X
I	X							
La								X
Mn	X							
Nb	X							
Ni	X						X	
Pb	X		X	X			X	X
Po	X		X				X	X
Pu			X		X	X	X	
Ra			X			X	X	X
Sb	X						X	
Se	X						X	
Sr	X		X	X	X	X	X	X
Tc						X	X	
Th			X				X	X
U	X		X				X	X
Zn	X						X	X

Although this database has been updated since its use in the ICRP publication (see Brown et al., 2016), data remain sparse or lacking for many RAP-element combinations (see <http://www.wildlifetransferdatabase.org/>). CR<sub>wo</sub> values are also likely to be highly site specific which contributes to the large variation observed within the available data (Wood et al., 2009; Beresford et al., 2016; Johansen et al., 2012; Hirth et al., 2017), and there are also biases in the available data (Wood et al., 2013; Beresford et al., 2013). The data included for RAPs in the on-line database (Coppstone et al., 2013) are predominantly from Europe, Japan, North America and Australasia, and mainly in temperate and arctic ecosystems (Howard et al., 2013). To address the lack of data, ICRP (2009) suggested the identification of sites from which all RAPs for a given generic ecosystem could be sampled.

The goal of this study was to determine CR<sub>wo</sub> values for terrestrial RAPs (Earthworm, Bee, Rat, Frog, Deer, Duck, Wild Grass and Pine Tree) collected in Mediterranean ecosystems for 32 elements (Ag, Al, As, B, Ba, Be, Ca, Cd, Co, Cr, Cs, Cu, Fe, I, K, Li, Mg, Mn, Mo, Na, Ni, P, Pb, Rb, S, Se, Sr, Ti, Tl, U, V and Zn). The main sampling site was a Dehesa, which is a typical Mediterranean semi-natural grassland with disperse tree cover, mainly holm oaks (*Quercus ilex*). As there was no pine tree at this location, a Pinewood located in the vicinity was also selected. Pine Tree (wood (trunk), bark, needles and branches) and Wild Grass were collected from this second site. The CR<sub>wo</sub> values for these Mediterranean ecosystems are compared with values reported in temperate climates and international databases (Barnett et al., 2013, 2014; ICRP, 2009; Coppstone et al., 2013). Ratios of elemental concentrations in the RAPs are also discussed.

## 2. Material and methods

### 2.1. Sampling sites

Two locations were selected for sampling terrestrial RAPs in the province of Cáceres, western Spain, in the surroundings of Monfragüe National Park: a Dehesa and a Pinewood. Fig. 1 shows the approximate location of the sampling sites. The climate is dry sub-

humid ('Csa' in Köppen classification), with an annual average temperature of 16 °C and hot summers (Kottek et al., 2006). Fig. 3 shows the daily temperature, humidity and accumulated rainfall in the surroundings of Monfragüe.

The Valero Dehesa is privately owned and extends over more than 4600 ha; 1330 ha are within the National Park Monfragüe. It serves as a hunting reserve, mainly for red deer (*Cervus elaphus*) and wild boar (*Sus scrofa*). Its management is traditional for a dehesa, based on an annually rotating quarter system. A quarter of the site is used for growing cereals (wheat, barley or oats), another for legumes (mainly lupin (*Lupinus albus*)), in another the soil is turned over and kept as fallow land, and the last one is left for wildlife. This rotation prevents soil from depletion, and allows better control of weeds, pests and diseases. At the Dehesa, two different sampling sites (see Fig. 2) were selected at which different representative species of RAPs could be sampled as follows:

- 'Pond area' (c. 5000 m<sup>2</sup>): Earthworms, Frogs, Rat, Deer, Wild Grass and Duck RAPs and soil.
- 'Rat sampling area' (c. 9500 m<sup>2</sup>): Bee, Rat, Deer and Wild Grass RAPs and soil, (approximately 4 km from the 'Pond area').

Soil texture was silt-loam with a pH of 6.5 at the Dehesa. As no pine trees were present in the selected Dehesa, additional sampling was undertaken at Bazagona Pinewood. This unmanaged natural pinewood is approximately 16 km from Valero Dehesa. Wild grass and pine tree were sampled at this location. The soil texture of Pinewood site was loamy-sand with a pH of 5.2.

### 2.2. RAPs sampled

RAPs are defined at the taxonomic level of Family (ICRP, 2009) and Table 2 lists the representative species of RAPs sampled in the Dehesa and Pinewood sites. The following sample types were collected:

- Earthworms (*Lumbricidae* spp.): nineteen individuals were collected by digging in the 'Pond area' in July 2014. After rinsing in distilled water the worms were placed in aerated containers for three days with damp tissue paper to allow gut evacuation. Six composite samples were created with 3–4 individuals in each.
- Bees (*Apis mellifera*): twenty individuals were collected from a hive using smoke whilst wearing protective clothing on November 2014 in the 'Rat sampling area'. The hives present in the area are mobile, so that they can be transported to a new location when food is scarce. In the case of this particular hive, it was placed in June on a mountain area in the north of Cáceres province and brought back to Valero at the end of summer (late September).
- Frogs (*Pelophylax perezi*): three adult individuals were collected in the pond area in July 2014. These were skinned and the gut, liver, kidney, bone and muscle were separated. As the thyroid was too small to easily separate, an area around it was selected and classified as the 'thyroid sample'.
- Rats (*Apodemus sylvaticus*): were sampled from two sites within the Dehesa (as requested by the wardens in order not to disturb hunting preparations). Three individuals were collected at the 'Pond area' (summer 2014), and nine in the 'Rat sampling area' (three each in autumn 2014, winter 2014/15 and spring 2015) using Sherman humane traps. Animals were skinned and the same tissues as for the frogs were removed.
- Deer (*Cervus elaphus*): were shot by hunters and sampled when they were gathered for veterinary examination. We were unable to record the exact place of the hunting or weigh the animals.

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