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Whole organism to tissue concentration ratios derived from an Australian tropical dataset

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ABSTRACT

Whole organism to tissue concentration ratios ($CR_{wo\text{-}tissue}$) were derived for six wildlife groups (freshwater birds, freshwater bivalves, freshwater fishes, freshwater reptiles, freshwater vascular plants and terrestrial mammals). The wildlife groups and data represented species common to tropical northern Australia. Values of $CR_{wo\text{-}tissue}$ were derived for between 6 and 34 elements, depending upon wildlife group. The values were generally similar to international reference values. However, differences for some element-tissue combinations could affect radiation dose estimates for wildlife in certain environmental exposure situations, including uranium mining, where these data are intended to be applied.

1. Introduction

The evolution of the system of radiological protection to explicitly include protection of the environment (ICRP, 2007) has supported international efforts to collate data (Beresford et al., 2015; Copplestone et al., 2013; Howard et al., 2013a; Yankovich et al., 2013) and develop models (Brown et al., 2008, 2016; Vives i Batlle et al., 2008, 2012) for assessing radiation exposures to wildlife. Evaluation of wildlife exposures for environmental protection purposes is currently based on comparing model estimates of whole organism dose rates from internal and external radionuclides to effects-based 'derived consideration reference levels' (ICRP, 2008, 2014) or other benchmarks (Andersson et al., 2009; UNSCEAR, 1996, 2008). In Australia, protection of the environment is now included within the national framework for radiation protection (ARPANSA, 2014), with supplementary guidance on its implementation (ARPANSA, 2015).

Estimates of whole organism internal dose rates require whole organism activity concentrations of radionuclides to be determined. Whole organism radionuclide measurements are generally scarce and it is often necessary to convert tissue-specific data originally collected for human food chain assessments to whole organism data. Such data conversions were used in the derivation of whole organism concentration ratios for the ERICA Tool (Beresford et al., 2008; Hosseini et al., 2008) and by the International Atomic Energy Agency (IAEA) in developing its handbook on radionuclide transfer to wildlife (IAEA, 2014).

In the Alligator Rivers Region in tropical northern Australia, the Ranger uranium mine is proceeding towards a 2021 deadline for the end of its operational life and a 2026 deadline for remediation. Remediation planning for the mine is underway, including assessments of radiation exposures to people (Doering et al., 2017) and wildlife (Doering and Bollhöfer, 2016a) from residual radioactivity in the environment after remediation. Radioecological and environmental chemistry data for wildlife collected during the life of the mine (Doering and Bollhöfer, 2016b) primarily represent radionuclide activity and stable element concentrations in specific tissues consumed by Aboriginal people as bush foods. To be useful for wildlife dose assessments, these data need to be converted to whole organism values. This study uses the tissue concentration data from Doering and Bollhöfer (2016b) and subsequent sample analyses to derive whole organism to tissue concentration ratios ($CR_{wo\text{-}tissue}$). The aims were to: (i) provide ancillary information to support wildlife dose assessments in the context of remediation of the Ranger uranium mine; and (ii) compare the values derived from site-specific data to reference values derived from internationally pooled data. The results of this study may also be useful for wildlife dose assessments at other Australian mining sites.

2. Data and methods

The tissue-specific data used in this study come from an Australian tropical dataset (Doering and Bollhöfer, 2016b) and additional analyses of field samples primarily collected from freshwater and terrestrial ecosystems unaffected by uranium mining. in the Alligator Rivers Region. The data represented radionuclide and stable element

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Table 1
Wildlife groups and broad equivalences with ICRP Reference Animals and Plants.

Ecosystem	Wildlife group	Reference Animal or Plant
Freshwater	Birds	Duck
	Bivalves	–
	Fishes	Trout
	Reptiles[a]	–
	Vascular plants	–
Terrestrial	Mammals	Deer, Rat

[a] Includes species that live in the terrestrial ecosystem but primarily prey on freshwater organisms.

Table 2
Tissue fractional fresh masses for vertebrate organisms.

Tissue	Birds[a]	Fishes[b]	Mammals[c]	Reptiles[d]	
				Turtles	Others
Bone	0.115	0.1346	0.1689	0.420	0.0722
Kidney	0.003	0.0054	0.0057	0.003	0.0030
Liver	0.016	0.0148	0.0278	0.058	0.0475
Muscle	0.866	0.8452	0.7977	0.519	0.8770

[a] Goose data (Murawska, 2013).
[b] Review data for fishes (Yankovich et al., 2010).
[c] Kangaroo and sheep data (Hopwood et al., 1976; Tribe and Peel, 1963).
[d] Review data for reptiles (Wood et al., 2010).

Table 3
Whole organism to tissue concentration ratios for freshwater birds.

Element	Tissue	Mean	s.d.[a]	Min	Max	n
Cd	Liver	1.5E-1	–	–	–	1
	Muscle	1.1E+0	–	–	–	1
Cu	Liver	1.3E+0	3.4E-1	1.1E+0	1.7E+0	3
	Muscle	1.0E+0	3.4E-3	9.9E-1	1.0E+0	3
Fe	Liver	2.5E-1	6.4E-2	2.0E-1	2.9E-1	2
	Muscle	1.1E+0	2.2E-2	1.0E+0	1.1E+0	2
K	Liver	1.6E+0	1.5E-1	1.5E+0	1.8E+0	3
	Muscle	9.9E-1	9.8E-4	9.9E-1	9.9E-1	3
Mg	Liver	1.6E+0	1.1E-1	1.5E+0	1.7E+0	3
	Muscle	9.9E-1	7.7E-4	9.9E-1	9.9E-1	3
Mn	Liver	2.2E-1	3.9E-2	1.8E-1	2.6E-1	3
	Muscle	1.1E+0	1.8E-2	1.1E+0	1.1E+0	3
Pb	Liver	3.9E+0	5.7E+0	5.6E-1	1.0E+1	3
	Muscle	1.0E+0	1.7E-2	9.8E-1	1.0E+0	3
S	Liver	1.1E+0	7.6E-2	1.0E+0	1.1E+0	3
	Muscle	1.0E+0	1.2E-3	1.0E+0	1.0E+0	3
Th	Liver	8.0E-1	5.1E-1	2.6E-1	1.3E+0	3
	Muscle	1.0E+0	3.3E-2	1.0E+0	1.1E+0	3
U	Liver	6.9E-1	2.7E-1	5.2E-1	1.0E+0	3
	Muscle	1.0E+0	9.6E-3	1.0E+0	1.0E+0	3
Zn	Liver	5.3E-1	1.1E-1	4.1E-1	6.3E-1	3
	Muscle	1.0E+0	8.4E-3	1.0E+0	1.0E+0	3

[a] Standard deviation.

concentrations in tissue samples obtained from single organisms or in composite samples of tissue material harvested from several individuals of the same species. Sample preparation and analysis techniques have been described in Doering and Bollhöfer (2016b) and references therein. Radionuclide and stable element concentration data reported as below detection limits were not used in this study.

The data were sorted into six wildlife groups using the groupings of IAEA (2014). The wildlife groups and their broad equivalences with the Reference Animals and Plants of ICRP (2008) are shown in Table 1. Data for vertebrate organisms (freshwater birds, freshwater fishes, freshwater reptiles and terrestrial mammals) focused on four commonly measured tissue types (bone, kidney, liver and muscle). Data for invertebrate organisms (freshwater bivalves) focused on the shell and soft tissue mass. Data for freshwater vascular plants included both the above- and below-sediment tissue components.

Tissue combinations (i.e. the combination of different tissue types

Table 4
Whole organism to tissue concentration ratios for freshwater bivalves.

Element	Tissue	Mean	s.d.[a]	Min	Max	n
Al	Shell	6.1E-1	3.3E-1	4.2E-1	2.1E+0	75
	Soft tissue	4.4E+0	2.8E+0	7.4E-1	1.5E+1	75
As	Shell	5.3E-1	–	–	–	1
	Soft tissue	2.4E+0	–	–	–	1
Ba	Shell	2.0E+0	1.0E+0	6.3E-1	5.5E+0	120
	Soft tissue	8.4E-1	1.8E-1	6.5E-1	1.7E+0	120
Ca	Shell	4.0E-1	2.0E-3	4.0E-1	4.1E-1	120
	Soft tissue	8.6E+1	4.2E+1	2.2E+1	2.2E+2	120
Cd	Shell	8.1E-1	3.8E-1	4.7E-1	1.7E+0	16
	Soft tissue	1.7E+0	8.5E-1	7.8E-1	4.2E+0	16
Ce	Shell	5.4E+0	2.2E+0	2.7E+0	9.6E+0	14
	Soft tissue	6.6E-1	2.3E-2	6.3E-1	7.1E-1	14
Co	Shell	5.7E-1	4.9E-2	4.8E-1	6.9E-1	35
	Soft tissue	2.1E+0	4.3E-1	1.4E+0	3.6E+0	35
Cs	Shell	6.8E-1	5.9E-1	4.1E-1	2.5E+0	13
	Soft tissue	9.2E+0	7.6E+0	7.1E-1	2.3E+1	13
Cu	Shell	4.8E-1	2.9E-2	4.1E-1	5.7E-1	120
	Soft tissue	4.3E+0	3.9E+0	2.0E+0	4.5E+1	120
Fe	Shell	2.8E+0	1.5E+0	1.1E+0	1.1E+1	120
	Soft tissue	7.3E-1	6.3E-2	6.2E-1	9.5E-1	120
Hg	Shell	4.8E-1	–	–	–	1
	Soft tissue	3.7E+0	–	–	–	1
K	Shell	2.6E+0	6.2E-1	1.7E+0	3.6E+0	13
	Soft tissue	7.2E-1	3.4E-2	6.7E-1	7.8E-1	13
La	Shell	1.0E+1	4.1E+0	2.6E+0	1.7E+1	14
	Soft tissue	6.3E-1	2.4E-2	6.1E-1	7.1E-1	14
Lu	Shell	4.6E-1	–	–	–	1
	Soft tissue	4.9E+0	–	–	–	1
Mg	Shell	2.7E+0	1.3E+0	1.3E+0	7.6E+0	114
	Soft tissue	7.3E-1	5.7E-2	6.3E-1	8.8E-1	114
Mn	Shell	7.4E-1	1.3E-1	5.2E-1	1.2E+0	120
	Soft tissue	1.4E+0	3.4E-1	9.0E-1	2.6E+0	120
Na	Shell	4.8E-1	1.8E-2	4.4E-1	5.3E-1	51
	Soft tissue	3.9E+0	7.5E-1	2.5E+0	6.8E+0	51
Nd	Shell	4.5E+0	1.5E+0	2.2E+0	6.6E+0	8
	Soft tissue	6.7E-1	3.2E-2	6.4E-1	7.4E-1	8
Ni	Shell	4.7E-1	2.7E-2	4.3E-1	5.1E-1	12
	Soft tissue	4.3E+0	1.5E+0	2.7E+0	7.7E+0	12
P	Shell	1.1E+1	4.2E+0	5.0E+0	2.5E+1	51
	Soft tissue	6.3E-1	1.1E-2	6.1E-1	6.5E-1	51
Pb	Shell	1.1E+0	7.3E-1	4.8E-1	3.7E+0	29
	Soft tissue	1.4E+0	7.0E-1	6.7E-1	3.5E+0	29
Ra	Shell	6.9E+0	2.7E+0	2.9E+0	1.5E+1	29
	Soft tissue	6.4E-1	2.1E-2	6.2E-1	7.0E-1	29
Rb	Shell	4.3E+0	2.0E+0	1.4E+0	1.1E+1	35
	Soft tissue	6.8E-1	5.4E-2	6.2E-1	8.4E-1	35
Re	Shell	4.3E-1	–	–	–	1
	Soft tissue	7.9E+0	–	–	–	1
S	Shell	9.9E-1	1.7E-1	7.0E-1	1.5E+0	100
	Soft tissue	1.0E+0	1.3E-1	8.2E-1	1.4E+0	100
Sb	Shell	4.1E-1	–	–	–	1
	Soft tissue	1.9E+1	–	–	–	1
Se	Shell	5.3E-1	8.3E-2	4.4E-1	7.0E-1	12
	Soft tissue	3.5E+0	2.0E+0	1.4E+0	7.0E+0	12
Sr	Shell	4.2E-1	9.8E-3	4.0E-1	4.5E-1	120
	Soft tissue	2.0E+1	1.2E+1	5.1E+0	7.6E+1	120
Ta	Shell	6.5E-1	–	–	–	1
	Soft tissue	1.6E+0	–	–	–	1
Th	Shell	7.0E-1	6.7E-1	4.0E-1	5.2E+0	66
	Soft tissue	1.3E+1	2.9E+1	6.5E-1	1.6E+2	66
Ti	Shell	4.6E-1	4.4E-2	4.0E-1	5.3E-1	6
	Soft tissue	2.8E+1	5.3E+1	2.5E+0	1.4E+2	6
U	Shell	8.3E-1	3.5E-1	4.2E-1	2.4E+0	77
	Soft tissue	2.0E+0	1.9E+0	7.2E-1	1.1E+1	77
W	Shell	5.3E-1	–	–	–	1
	Soft tissue	2.5E+0	–	–	–	1
Zn	Shell	2.3E+0	1.0E+0	9.1E-1	7.5E+0	120
	Soft tissue	7.7E-1	9.1E-2	6.3E-1	1.1E+0	120

[a] Standard deviation.