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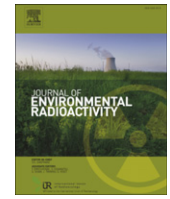

Derivation of hazardous doses for amphibians acutely exposed to ionising radiation

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ABSTRACT

Derivation of effect benchmark values for each taxonomic group, which has been difficult due to lack of experimental effects data, is required for more adequate protection of the environment from ionising radiation. Estimation of effects doses from nuclear DNA mass and subsequent species sensitivity distribution (SSD) analysis were proposed as a method for such a derivation in acute irradiation situations for assumed nuclear accident scenarios. As a case study, 5% hazardous doses (HD_5s), at which only 5% of species are acutely affected at 50% or higher lethality, were estimated on a global scale. After nuclear DNA mass data were obtained from a database, 50% lethal doses (LD_{50}s) for 4.8 and 36% of the global Anura and Caudata species, respectively, were estimated by correlative equations between nuclear DNA mass and LD_{50}s. Differences between estimated and experimental LD_{50}s were within a factor of three. The HD_5s obtained by the SSD analysis of these estimated LD_{50}s data were 5.0 and 3.1 Gy for Anura and Caudata, respectively. This approach was also applied to the derivation of regional HD_5s. The respective HD_5s were 6.5 and 3.2 Gy for Anura and Caudata inhabiting Japan. This HD_5 value for the Japanese Anura was significantly higher than the global value, while Caudata had no significant difference in global and Japanese HD_5s. These results suggest that this approach is also useful for derivation of regional benchmark values, some of which are likely different from the global values.

1. Introduction

In the last decade, there have been a number of international initiatives to develop frameworks to provide criteria and a methodological approach for the protection of the environment from ionising radiation (IAEA, 2002; ICRP, 2003, 2008; OECD/NEA, 2007). Frameworks for environmental protection have also been developed on national and regional scales, e.g., in Europe (Howard et al., 2010) and North America (US DOE, 2002). In such frameworks, the risk level is judged by comparing dose rates to non-human biota with effect benchmark values. Therefore, a number of approaches or tools have been developed to estimate dose rates to non-human biota, and intercomparison exercises have been carried out (e.g., Vives i Batlle et al., 2011).

Some trials have been also made for estimation of benchmark values for ionising radiation (Andersson et al., 2009; Garnier-Laplace et al., 2006, 2008, 2010). These trials have been based on the species sensitivity distribution (SSD) approach. It has been used to estimate 5% hazardous concentrations of chemicals (HC_5s), at which only 5% of species are affected and the other 95% of species are protected in an environment.

However, most of the estimated benchmark values, i.e., 5% hazardous dose rates (HDR_5s) for ionising radiation, are generic, e.g., for the whole ecosystem (terrestrial + freshwater + marine ecosystems) (Garnier-Laplace et al., 2008, 2010), terrestrial or freshwater ecosystems (Garnier-Laplace et al., 2006) and vertebrates or invertebrates (Andersson et al., 2009). Currently it is difficult to estimate HDR_5 specific to each taxonomic group by SSD, because only limited effect data are available for each group (Andersson et al., 2009; Garnier-Laplace et al., 2008). Since there is a large difference in radiosensitivity among taxonomic groups (UNSCEAR, 2011), generic benchmark values are too strict for radioresistant groups and too lax for radiosensitive groups. As Garnier-Laplace et al. (2010) pointed out, it is necessary to derive benchmark values specific to each taxonomic group such as family or class, in correspondence to each ICRP Reference Animal and Plant (ICRP, 2008).

It is difficult experimentally to obtain sufficient effects data in each taxonomic group; appropriate extrapolation methods are required. It is well known that radiosensitivity increases almost

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Table 1
Estimated and experimental LD_{50} for Anura and Caudata.

Species	LD_{50}, Gy		Ratio (A/B)	Reference for experimental LD_{50}
	Estimated[a] (A)	Experimental (B)		
Anura				
Bufo fowleri	10.9	17.8	0.61	Landreth et al., 1974
Bufo melanostictus	9.3	7.5	1.2	Guha and De, 1974
Limnodynastes tasmaniensis	33.2	18.7	1.8	Panter, 1986
Rana pipiens	8.2	6.6	1.2	Stearner, 1950
Caudata				
Taricha granulosa	4.3	2	2.2	Willis, 1980

[a] From equations (1) or (2) and nuclear DNA mass.

linearly with nuclear size parameters such as nuclear DNA mass. This is because DNA is a target of ionising radiation. This relationship holds for viruses, bacteria and multi-cellular organisms such as plants and amphibians (Sparrow et al., 1967). It is expected to be much easier to estimate radiosensitivity from this relationship than to investigate radiation effects experimentally, because nuclear DNA mass can be determined easily by flow cytometry or other techniques from which a lot of DNA mass data have been accumulated for various taxonomic groups.

Watanabe et al. (manuscript in preparation) have modified a regression equation between nuclear size parameter and 100% lethal dose rate (LDR_{100}) for woody plants, which was originally determined by Sparrow et al. (1976). Watanabe et al. estimated the LDR_{100} values for approximately 4600 species from the modified regression equation and nuclear size parameter data accumulated in a database; then, HDR_5s for woody gymnosperms and angiosperms were derived from applying the SSD approach to the resulting LDR_{100} data.

Amphibians are relatively radiosensitive (UNSCEAR, 2011) and one of the ICRP Reference Animals and Plants (ICRP, 2008); they were studied in this paper and their 50% lethal doses (LD_{50}s) in acute irradiation scenarios were estimated from nuclear DNA mass data on a global scale. Furthermore, 5% hazardous doses (HD_5s), at which only 5% of species are acutely affected at 50% or higher lethality, were estimated by the SSD approach for initial demonstration of the usefulness of this extrapolation method to derive benchmark values specific for each taxonomic group. Then, HD_5s were estimated for amphibians inhabiting Japan, which as an eastern Asian country has some differences in ecological characteristics from Europe and North America, and the resulting HD_5 values were compared with the global values to discuss regional differences in benchmark values to be proposed. The HD_5 estimated in this study will be useful for risk assessment in the event of nuclear accidents, for which criteria and guidance are still lacking.

2. Methods

2.1. Validation of LD_{50} estimation

The class Amphibia consists of the following three orders: Anura (frogs and toads), Caudata (newts and salamanders) and Gymnophiona (caecilians) (Frost, 2010). Anura and Caudata can be described by the following regression equations between nuclear DNA mass (in pg) and LD_{50} (in roentgen) (Conger and Clinton, 1973):

$$\text{Anura}: \log LD_{50} = 4.493 - 1.387 \log(\text{nuclear DNA mass}) \quad (1)$$

- Data size (n): 4

Xenopus laevis, Hyla squirella, Rana pipiens and Rana temporaria

- Correlation coefficient (r^2): 0.9819
- 95% confidence intervals

Intercept: $\pm$0.064.
Slope: $\pm$0.571

$$\text{Caudata}: \log LD_{50} = 3.622 - 0.526 \log(\text{nuclear DNA mass}) \quad (2)$$

- Data size (n): 4

Necturus maculosus, Ambystoma mexicanum, Notophthalmus viridescens and Desmognathus fuscus

- Correlation coefficient (r^2): 0.7442
- 95% confidence intervals

Intercept: $\pm$0.246.
Slope: $\pm$0.937.

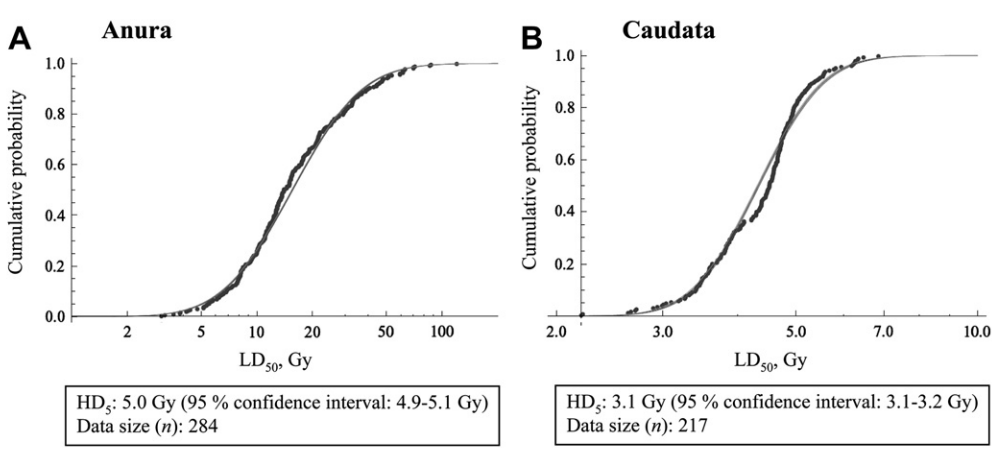

Fig. 1. SSDs of LD_{50}s for the global Anura (A) and Caudata (B). Shaded areas represent 95% confidence intervals.