Predicting population responses of a freshwater invertebrate after chronic exposure to radionuclides inducing different toxic effects on organisms

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INTRODUCTION

Assessing the ecological risk of radioactive substances requires evaluation of effects of acute and chronic exposure to ionising radiation in representative wildlife species. In this aim, a series of experiments was conducted in recent years with the microcrustacean *Daphnia magna* (Alonzo et al. 2006, 2008a; Gilbin et al., 2008; Zeman et al., 2008). This species is widely-used for investigating toxicity of contaminants in freshwater invertebrates.
Laboratory experiments demonstrated that chronic exposure of daphnids to natural uranium (U), ^{241}americium (Am-241), and ^{137}caesium (Cs-137) caused different perturbations in survival, reproduction, and several other vital functions of organisms (nutrition, respiration, growth and storage of energy reserves). However, these observations were made in laboratory conditions on an individual level, whereas their consequences in a broader ecological context are poorly documented.
In this study, we simulate potential changes in population dynamics in relation to radionuclide effects observed experimentally at the individual level, in order to improve the ecological relevance for risk assessment.

MATERIALS AND METHODS

Experimental dataset

An overview of the biological effects of Am-241, U, and Cs demonstrated at the individual level under controlled laboratory conditions is reported in Table 1. Further details may be found in the corresponding publications.

Table 1. Biological effects observed in daphnids exposed to different radionuclides.

Radionuclide		Am-241	U	Cs-137
Dose rate or concentration range		0.3-15 mGy h^{-1}	10-100 µg L^{-1}	0.4-31 mGy h^{-1}
Observed biological effects	Reduced survival	●	●	
	Reduced reproduction	●	●	●
	Delay in reproduction	●	●	●
	Reduced body growth	●	●	
	Reduced feeding		●	
	Increased respiration	●	●	
References		Alonzo et al., 2006, 2008a	Zeman et al., 2008	Gilbin et al., 2008

Population models

Several models were used to simulate changes in daphnid population size under different scenarios of exposure to radionuclides. Population susceptibility to changes in different individual endpoints was also examined.

Age-structured population model

This model uses Leslie matrices (Leslie, 1945) to calculate the age distribution of a population in relation to age-specific rates of survival and reproduction, as described in Alonzo et al. (2008b). Changes in survival and reproduction rates under toxic stress translate into delay-in-population-growth of exposed populations compared to an unexposed control (Stark et al. 2004).

Physiology-based population model

The model is individual-based and simulates the acquisition of energy from food and its allocation towards important processes for population dynamics (Calow & Sibly, 1990; Calow, 1991). Increasing energy consumption and/or decreasing food acquisition reduce the amount of energy available for organisms and come at the expense of survival, growth and reproduction. In daphnids exposed to Am-241 or U, increasing respiration rates reflected additional energy costs due to coping with toxic stress. Exposure to U also induced a reduction in feeding activity.

RESULTS AND CONCLUSIONS

Radionuclides induce delay in population growth of daphnids

Results from simulations show that radionuclides induce increasing delay in population growth with increasing dose rate (Am-241, Cs-137) or concentration (U). For example, Am-241 induces a delay in population growth ranging from 3d at 0.3 mGy h^{-1} to 8d at 15 mGy h^{-1} (Figure 1). These values represent from 0.3 to 0.8 generation times (e.g. relative to 10 days that daphnids take to grow from eggs to reproducing adults).

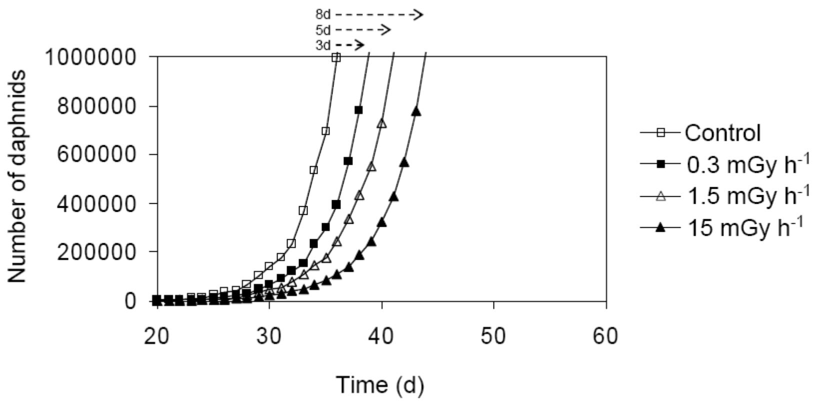

Figure 1. Predicted population growth of daphnids exposed to alpha internal irradiation over a range of dose rates. Arrows indicate delay in growth to 1,000,000 individuals compared to an unexposed control.

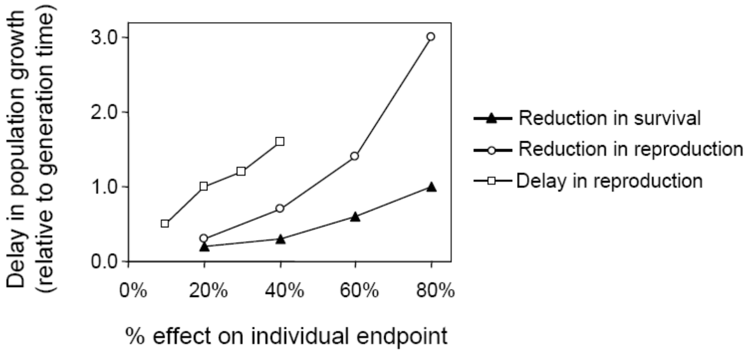

Figure 2. Sensitivity of the delay in population growth to gradual reduction in survival, reduction in reproduction or delay in reproduction.

Different individual endpoints do not show the same importance at the population level

One striking result is that the same level of effect applied to delay in reproduction, reduction in reproduction or reduction in survival does not show the same delay in population growth (Figure 2). Similarly, a delay in population growth of 10d is obtained with 14% delay in reproduction, 50% reduction in reproduction or 80% reduction in survival. The physiological-based model also makes it possible to evaluate the importance of perturbations in feeding activity and respiration for population growth.

Population susceptibility differs between species

Comparing our results with those obtained with the earthworm *Eisenia fetida* (Hertel-Aas et al., 2007) shows that the same effect observed at the individual level might have different consequences for population growth, depending on life-history characteristics of the species. Thus, ecological consequences of toxicity measured at the individual level cannot be considered species-independent.

Perspectives

This work is part of an ongoing study. Further perspectives aim to:

- examine how population-level responses might influence the evaluation of ecological risk associated with ionising radiation.
- evaluate how radionuclide exposure might alter biodiversity (using population performance to predict potential outcomes of natural selection on the physiological characteristics of organisms).

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