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Advances in environmental radiation protection: re-thinking animal-environment interaction modelling for wildlife dose assessment

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INTRODUCTION

Current wildlife dose assessment models used in environmental radiation protection adopt simplistic approaches to the representation of animal-environment interaction. The simplest approaches are: (i) to average environmental media activity concentrations over an area approximating to the home range of assessed species; or (ii) to relate organism exposure to activity concentrations in media collected at the point of sampling of the animal. In both cases, the external exposure of the organism is then estimated by defining the geometric relationship between the organism and the medium. For example, an organism within the soil would have a 4π exposure geometry to contamination present within the soil and a reference organism on the soil would have a 2π exposure geometry. At best, the current modelling approaches recognise major spatial differences in media activity concentrations by calculating exposure for different areas of contamination and then estimating the fraction of time that an organism spends in each area (e.g. Johansen *et al*., 2012).

In other fields of pollution ecology, more advanced approaches to modelling animal-environment interaction have been developed (e.g. Hope, 2005; Loos *et al*., 2010). These approaches are being used within ecological risk assessments to assess exposure of wildlife to heterogeneously distributed chemical contamination (Loos *et al*., 2010). In this paper, we provide an overview of some of the alternative modelling approaches that have been developed and outline international research activities to evaluate the applicability of these models for environmental radiation protection.

MODELLING ANIMAL-ENVIRONMENT INTERACTION

Many modelling approaches that have been developed to simulate animal-environment interaction utilise georeferenced data on the spatial distribution of contamination in the area under assessment. The models then simulate the movement of one or more animals through the assessment area and estimate exposure based on the extent of spatial interaction with areas of contamination. Such models have been referred to as individual-based movement models (e.g. Hope, 2005), object-oriented models (e.g. Loos *et al*., 2010) and agent-based models (e.g. Forbes and Calow, 2012).

Although the nomenclature varies, the modelling approach is broadly similar; the assessment area is overlaid with a grid of cells and modelling rules govern the movement of an animal within this grid. At the simplest level, unconstrained simple random walk modelling can be used (Codling *et al*., 2005). In this case, there is an equal probability of the animal moving in any direction so movement within the grid is completely random. The result is a movement pattern akin to Brownian motion. The more advanced modelling approaches attempt to provide more realistic simulations of animal movement by incorporating consideration of the spatial distribution of habitat features. For example, a Habitat Suitability Index (HSI) can be defined (Purucker, 2006). This describes the 'attractiveness' of each grid cell based on evaluation of the quality of the habitat in each cell for the type of animal under assessment. The probability of an animal moving from its current grid cell to each of the eight neighbouring cells is calculated by dividing the HSI value of each grid cell by the sum of all HSI values in the eight grid cells adjacent to the animal's current location. Animals therefore have a higher probability of moving to a grid cell with higher habitat suitability.

A variety of software tools have been developed to facilitate the implementation of these models. Software tools that are freely available include Eco-SpaCE (Loos *et al*., 2010) and Adehabitat (Calenge, 2006). Eco-SpaCE is a spatial modelling tool that is available within the 'Ecopath with Ecosim' modelling suite (http://www.ecopath.org/). Adehabitat is a package that has been written for R (http://cran.r-project.org) and includes the capability to integrate with open source GIS solutions, such as QGIS (http://www.qgis.org/en/site/).

APPLICABILITY OF THESE TOOLS FOR ENVIRONMENTAL RADIATION PROTECTION

Although these more advanced animal-environment interaction modelling approaches are freely available, it is questionable whether these should be adopted for use in environmental radiation protection. The system for radiological protection of wildlife has been evolving over the last two decades and there is no wish to add any unnecessary complexity to that system. However, there is also a need to demonstrate to stakeholders that the impact of ionising radiation on wildlife has been adequately assessed. If more complex exposure assessment approaches are being used within chemicals risk assessment, there is a need to evaluate whether or not they have a role in environmental radiation protection. More specifically: (i) are current approaches suitably conservative; and (ii) would the adoption of spatial animal-environment interaction modelling techniques improve radiation exposure estimates for wildlife?

The IAEA MODARIA Programme

Working group 8 of the International Atomic Energy Agency's MODARIA programme (http://www-ns.iaea.org/projects/modaria/) is focussing on wildlife risk assessment modelling and a sub-group is undertaking a comparison of approaches for modelling radiation exposure of wildlife. The hypothesis being tested is: *that current simplistic assumptions, which ignore* *how animals utilise their environment, ensure wildlife is protected by generating a conservative estimate of exposure (for regulatory purposes*).

A case study of moose (*Alces alces*) in Sweden is being used to test the different modelling approaches, including the current simplistic approach adopted within environmental radiation protection and the more advanced approaches developed for chemical exposure assessment. Geospatial data on ^{137}Cs deposition have been sourced from the Geological Survey of Sweden and collaborators at the Swedish University of Agricultural Sciences are assisting with access to habitat data. This information will be used to inform the application of the various models. Results from each of the modelling approaches will be compared to determine which model provides the highest exposure predictions. The results will also be compared with a 'best estimate' of exposure, calculated for moose that have been fitted with Global Positioning System (GPS) collars and tracked over different seasons by the Swedish University of Agricultural Sciences. These GPS data are freely available from the Wireless Remote Animal Monitoring (WRAM) database (http://www.slu.se/en/collaborative-centres-and-projects/wireless-remote-animal-monitoring-wram/about/).

TRansfer – Exposure – Effects (TREE)

Although the work undertaken within MODARIA WG8 will provide an initial assessment of the effectiveness of different approaches for assessing wildlife radiation exposure based on animal-environment interaction, there are no field measurements of exposure against which model predictions can be compared. To undertake a more comprehensive evaluation of the different modelling approaches, there is a need for a case study that includes georeferenced media activity concentrations and animal movement data coupled with direct measurements of external radiation exposure and whole-body activity concentrations.

TRansfer – Exposure – Effects (TREE) is a 5-year programme of research in the Chernobyl Exclusion Zone (CEZ) that has been funded by four organisations in the United Kingdom, namely the Natural Environment Research Council (NERC), Nuclear Decommissioning Authority (NDA), Environment Agency (EA) and Science & Technology Facilities Council (STFC). Contamination in the CEZ is highly heterogeneous and the TREE project is studying the exposure of large mammals to this contamination. Motion activated trail cameras, known as camera traps, are currently deployed in the CEZ and are providing information on the utilisation of different areas of the CEZ by a range of large mammal species. The data from the camera traps will inform the selection of a large mammal species to study using state-of-the-art satellite navigation technology. Preliminary data suggest that this will most likely be a canid species (*Canis lupus* or *Nyctereutes procyonoides*) due to their abundance within the zone, relatively large range and ease with which they can be trapped and a GPS collar fitted.

The target species will be fitted with GPS collars onto which radiation dose monitoring equipment will be fitted. This includes a thermoluminescent dosimeter (TLD) chip that will provide an integrated measure of exposure over the period that the collar is fitted to the animal and a modified version of the *Instadose2*, provided by Mirion Technologies. In combination with the GPS results, the *Instadose2* will give multiple georeferenced dose measurements each day. Animals will also be live-monitored to determine whole-body radionuclide body burdens and faecal DNA analysis will be used to allow quantification of dietary composition. Coupled with well-characterised contamination and habitat distribution within the CEZ, the TREE research programme will provide an ideal case study for testing the different exposure modelling approaches.

SUMMARY

The current approaches for estimating the exposure of wildlife to ionising radiation are being evaluated against those that have been developed for use in chemicals risk assessment. The purpose is to determine whether, for regulatory assessments, the current approaches are fit-for-purpose. Initial evaluations are being undertaken within the scope of the IAEA MODARIA programme. However, the TREE programme will allow much more comprehensive evaluation by providing field exposure measurements against which model predictions can be compared.

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