Conference or Workshop Item

Yankovich, Tamara L.; Carr, James; Robertson, Erin; King-Sharp, K.; Killey, R.W. Doug; Beresford, Nicholas A.; Wood, Michael D. 2014. **Spatial distribution and dynamics of carbon-14 in a wetland ecosystem**. [Poster] In: *3rd International Conference on Radioecology and Environmental Radioactivity, Barcelona, 7-12 Sept 2014*.

# Spatial Distribution and Dynamics of Carbon-14 in a Wetland Ecosystem

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## INTRODUCTION

There is significant interest in assessing the potential impact of $^{14}C$ releases from nuclear facilities, radioactive waste management areas, and geologic disposal facilities. As a result, there is a general need to gain understanding of $^{14}C$ dynamics, including in complex interface ecosystems, such as wetlands (Stark *et al.*, 2014; Yankovich *et al.*, 2013, 2014).

Due to physical transport processes (e.g., via groundwater), radionuclides, such as $^{14}C$, can show localized spatial distributions in natural systems, such as wetlands. As a result, a key question from the perspective of environmental impact assessment (EIA) and monitoring is: *how do localized distributions of radionuclides in the environment influence the radiological doses to organisms?* To address this question, studies have been undertaken in Duke Swamp, a 0.1 km$^2$ wetland, consisting of marsh, fen and swamp habitats, on the Atomic Energy of Canada Limited (AECL)'s Chalk River Laboratories (CRL) Site. The swamp receives radionuclides, including $^{14}C$, from an up-gradient waste management area (WMA) (Killey *et al.*, 1998), and $^{14}C$ modelling results suggest that it represents >90% of total dose to resident animals (Zach *et al.*, 1998). An initial study was conducted involving an extensive field sampling campaign to measure $^{14}C$ specific activity in surface vegetation across the swamp to evaluate the spatial distribution of $^{14}C$ (Yankovich *et al*., 2014). Representative receptor plants and animals, and corresponding environmental media (including air, soil, and plant) samples were subsequently collected at a subset of six locations with $^{14}C$ specific activities that spanned the range present in Duke Swamp and which represented the different wetland habitats occurring there (Yankovich *et al.*, 2013).

The objective of this paper is to predict doses to resident biota from $^{14}C$ based on measurements of wildlife collected in Duke Swamp.

## MATERIALS AND METHODS

A detailed field campaign was carried out in summer 2001 to characterize the spatial distribution and areal coverage of $^{14}C$ in Duke Swamp (Killey et al., 1998).

Surface vegetation (predominantly *Sphagnum* moss) was sampled in the summer of 2001 at 69 locations on a 50 m x 50 m grid, with complementary sampling in 2002 of air, soil, fungi, aerial insects, ground-dwelling insects, amphibians, snakes and mammals at a subset of six locations with varying $^{14}C$ concentrations (Yankovich *et al.*, 2013, 2014). Samples were analyzed to characterize $^{14}C$ specific activities (Table 1). Dose rates to resident biota from $^{14}C$ were then estimated based on measured data using the ERICA (Environmental Risk from Ionising Contaminants: Assessment and Management) software tool (http://www.erica-tool.com/). Tier 2 of the tool was used since site-specific $^{14}C$ measurements were available for Duke Swamp environmental media and wildlife species. ERICA default parameters were used for the screening level (10 μGy/h) and radiation weighting factors.

**RESULTS AND CONCLUSIONS**

The highest specific activities in surface vegetation were in a highly localized area of Duke Swamp (Site 35 in Table 1) where groundwater contaminated by the up-gradient WMA reaches the surface. This area of localised high specific activities has been estimated to be about 150 $m^2$ only (Yankovich *et al.*, 2014). In general, it was found that specific activities of $^{14}C$ in biota tissues reflected those measured in air and surface vegetation collected from the same sampling location (Yankovich *et al.*, 2013). There was a tendency for the specific activities in amphibians and reptiles to be higher than those in mammals and insects. This may be due to the increased exposure of reptiles and amphibians to groundwater. Additionally the specific activity in the muscle of white-tailed collected from the site road immediately adjacent to Duke Swamp was determined to be 199 $^{14}C$ Bq $kg^{-1}$ C.

For the purposes of this assessment, predictions of radiological dose rates to relevant reference organisms, including Lichens and Bryophytes (to represent *Sphagnum* moss in the swamp), Flying insects (to represent aerial insects), Detritivorous invertebrates (to represent ground beetles), Amphibians (to represent resident frog species), Reptiles (to represent garter snakes), Mammal (Rat) (to represent small mammals), and Mammal (Deer) (to represent white-tailed deer), were conducted. The assessment was conducted using the maximum measure specific activity for each organism group. Carbon-14 specific activities (in Bq/kg C) were converted to activity concentrations (in Bq/kg fresh mass) assuming: (i) 95%, 50 %, 18% and 33 % carbon for moss, vertebrates, aerial insects and ground beetles on a dry mass basis, respectively; and (ii) 85%, 80%, 70% and 60% water contents for moss, vertebrates, aerial insects and ground beetles, respectively. These conversion data were based upon measurements made in Duke Swamp.The estimated activity concentrations in the organisms were then input into the ERICA tool to estimate dose rates. Based on this assessment, it was determined that predicted total dose rates for Duke Swamp biota fell below the screening dose rate of 10 μGy/hour, with risk quotients ranging from $5.9 \times 10^{-5}$ for white-tailed deer to 0.019 for *Sphagnum* moss (Table 2). The external dose rate for all species was estimated to be 0 μGy/hour.

Dose rates were similar to those reported by Stark et al. (2014), which presented results generated by different international dose models, as part of the International Atomic Energy Agency (IAEA)'s Environmental Modelling for Radiation Safety (EMRAS) II program (http://www-ns.iaea.org/projects/emras/emras2/default.asp?s=8&l=63).

**Table 1:** Summary results of $^{14}C$ analyses of environmental media and resident animals collected in Duke Swamp in 2001-2002.

| Sample Type | Year of Collection | [a] Mean $^{14}C$ Specific Activity (Bq/kg C dry mass) ± Standard Error [n] (Minimum – Maximum) | | | | | |
|---|---|---|---|---|---|---|---|
| | | **Site 9** | **Site 24** | **Site 27** | **Site 29** | **Site 35** | **Site 56** |
| Soil | 2001 | n.a. | n.a. | 38,247 [1] | 1,546 [1] | n.a. | n.a. |
| | 2002 | 714 [1] | 560 [1] | 22,145 [1] | 2,363 [1] | 84,900 (estimated using moss-to-soil relationship) | 7,279 [1] |
| *Sphagnum* moss | 2001 | 1,607 [1] | n.d. | 17,337 [1] | 3,465 [1] | 46,684 [1] | 2,809 [1] |
| | 2002 | n.a. | n.a. | n.a. | n.a. | 48,152 ± 4.927 [5] (30,371 - 56,811) | n.a. |
| Aerial insects | 2002 | 679 [n = 1 composite] | n.a. | n.a. | n.a. | n.a. | n.a. |
| Ground beetles | 2002 | n.a. | n.a. | n.a. | n.a. | n.a. | 1,201 (n = 1 composite) |
| Amphibians (adult) | 2001 | n.a. | n.a. | n.a. | n.a. | [b] 49,681 [1] | n.a. |
| | 2002 | 2,406 ± 561 [6] (731 – 3,869) | 453 ± 25.5 [4] (385 – 503) | 38,854 [1] | 5,193 ± 32.0 [2] (5,161 – 5,225) | 106,515 [1] | 6,750 ± 1,562 [3] (4,455 – 9,734) |
| Small mammals (carcass) | 2001 | n.a. | n.a. | n.a. | n.a. | 5,713 ± 1,696 [6] (1,649 – 11,620) | n.a. |
| Small mammals (carcass) | 2002 | n.a. | n.a. | 3,694 ± 1,012 [3] (2,446 – 5,698) | 2,015 ± 119 [2] (1,896 – 2,133) | 16,554 [1] | n.a. |
| Snakes (carcass) | 2002 | 1,798 [1] | n.a. | n.a. | n.a. | 39,863 ± 488 [2] (38,969 – 40,538) | n.a. |

[a] n.a. – data are not available; n.d. – not detectable ; n – number of samples analyzed for $^{14}C$; n.a. – not available;

[b] Leopard frog captured between Site 27 and Site 35.

**Table 2:** Predicted dose rates for Duke Swamp wildlife species based upon maximum measured activity concentrations in biota.

| Reference Organism | Species | Total Dose Rate (μGy/hour) |
|---|---|---|
| Lichen and Bryophyte | *Sphagnum* spp. | 0.19 |
| Flying insects | Aerial insects | 0.0011 |
| Detritivorous insects | Ground beetle | 0.0041 |
| Amphibian | *Rana pipiens, Rana catesbeiana* | 0.14 |
| Reptile | *Thamnophis sirtalis* | 0.12 |
| Mammal (Rat) | *Blarina brevicauda, Peromyscus leucopus, Microtus pennsylvanicus* | 0.034 |
| Mammal (Deer) | *Odocoileus virginianus* | 0.00059 |


## ACKNOWLEDGEMENT

The authors would like to acknowledge Atomic Energy of Canada Limited (AECL) for their support of this work.


## REFERENCES


Armstrong, W.E. and E.L. Young. 2000. White-tailed deer management in Texas Hill Country. Texas Parks and Wildlife. http://www.tpwd.state.tx.us/publications/pwdpubs/media/pwd_rp_w7000_0828.pdf.

Kilpatrick, H.J., S.M. Spohr, and K.K. Lima. 2001. Effects of population reduction on home ranges of female white-tailed deer at high densities. Canadian Journal Zoology, 79(6): 949-954.

Killey, R.W.D., R.R. Rao and S. Eyvindson. 1998. Radiocarbon speciation and distribution in an aquifer plume and groundwater discharge area, Chalk River, Ontario. Applied Geochemistry, 13: 3-16.

Stark, K., P. Andersson, N.A. Beresford, T.L. Yankovich, M.D. Wood, M.P. Johansen, J. Vives i Batlle, J. Twining, D-K. Keum, A. Bollhöfer, C. Doering, B. Ryan, M. Grzechnik, and H. Vandenhove. 2014. Predicting exposure of wildlife in radionuclide contaminated wetland ecosystems: An international biota dose model inter-comparison. Submitted to *Environmental Pollution*.

Yankovich, T.L., K.J. King-Sharp, M.L. Benz, J. Carr, R.W.D. Killey, N.A. Beresford and M.D. Wood. 2013. Do site–specific radiocarbon measurements reflect localized distributions of 14C in biota inhabiting a wetland with point contamination sources. Journal of Environmental Radioactivity, 126: 352-366.

Yankovich, T.L., K.J. King-Sharp, J. Carr, E. Robertson, R.W.D. Killey, N.A. Beresford and M.D. Wood. 2014. Spatial analysis of Carbon-14 dynamics in a wetland ecosystem (Duke Swamp, Chalk River Laboratories, Canada). Journal of Environmental Radioactivity, In press.

Zach, R., J.H. Rowat, G.M. Dolinar, S.C. Sheppard and R.W.D. Killey. 1998. Ecological risk assessment for the proposed IRUS low level waste disposal facility at AECL's Chalk River Laboratories. Atomic Energy of Canada Limited Technical Record, AECL-TR-791.