Journal of Environmental Radioactivity 211 (2020) 106108

Contents lists available at ScienceDirect

Journal of Environmental Radioactivity

journal homepage: http://www.elsevier.com/locate/jenvrad

Editorial

More than thirty years after the Chernobyl accident: What do we know about the effects of radiation on the environment?

The year 2016 was the 30th anniversary of the world's worst nuclear accident at the Chernobyl nuclear power plant (Ukraine). To mark this anniversary, a workshop was held in Chernihiv (Ukraine) to discuss what we have learnt from studies of the effects of radiation on the environment (i.e. wildlife) in the Chernobyl Exclusion Zone (CEZ), and what questions remain.

The workshop was held because of the lack of consensus on the impacts of radiation on wildlife in the CEZ (e.g. Beresford and Copplestone, 2011; Møller and Mousseau, 2016). There are a comparatively large number of publications, which report observed detrimental effects of radiation on wildlife at comparatively low dose rates. To put these low dose rates into context, some studies report radiation induced effects below natural background exposure rates of wildlife in, for instance, the United Kingdom. A similar debate is beginning to evolve with respect to observations made within the vicinity of Fukushima (e.g. Beresford et al., 2012; Copplestone and Beresford, 2014; UNSCEAR 2106).

Radiation effect studies of wildlife in the CEZ receive relatively high coverage within the media. However, the lack of scientific consensus is difficult to communicate to the public and indeed impacts on the credibility of radioecology. We are aware that the low dose rates at which effects are being reported present 'problems' for regulators/international bodies, as they challenge existing dose rate benchmarks used in radiological environmental impact assessments.

We attempted to achieve a wide spectrum of participation within the workshop with participants, not only from the fields of radioecology/radiation protection, but also from regulatory organisations, nuclear related industries, an NGO (see Sutcliffe, 2019a,b this issue), the media, chemical ecotoxicology (Spurgeon, 2019 this issue) and social sciences and humanities. We also aimed to ensure participation of scientists from Ukraine and Belarus (see papers presenting new studies in this issue (Burdo et al., 2019; Kashparova et al., 2019; Morozova et al., 2019) and Japan. A summary of the workshop discussions and abstracts of all presentations can be found in Barnett and Welch (2016); this issue of *Journal of Environmental Radioactivity* contains papers associated with some of the presentations made at the workshop. Here we will summarise the recommendations of the workshop and link these, where relevant, to the papers in this issue.

Recommendations - improving field studies and there interpretation

1. The results from field studies reporting substantial effects at low dose rates cannot currently be used in the derivation of benchmarks values for use in regulatory assessment (derivation of benchmarks must take a rigorous approach (Real and Garnier-Laplace, 2019 this issue). However, there was agreement that these data should not be dismissed, these 'inconvenient truths' need to be acknowledged (and the hypotheses they propose tested), and not ignored. This highlights the need to provide relevant and robust data for ecological protection (Hanson et al., 2017). Current benchmarks are based predominantly on data from laboratory experiments. However, the extrapolation from laboratory to field data is a current topic of debate (Beaugelin-Seiller et al., 2019b this issue; Smith, 2019 this issue; Beaugelin-Seiller and Garnier-Laplace, 2019 this issue).
2. Studies reporting effects at low dose rates need to be independently investigated (e.g. repeating the studies although it may be difficult to persuade funding agencies of the need to do this).
3. Exposure is often poorly determined. Many studies report (relatively few) dose rate meter results, often in units which are not applicable to wildlife (e.g. Sv) (see discussion in Beresford et al. (2019a) in this issue). Use of dose rate meters may be acceptable as a marker of different contamination levels, but the limitations of their use need to be acknowledged in papers and results should not presented as actual exposure rates. This issue is discussed further in papers within (Beresford et al., 2019a this issue) with recommendations for improvements in field dose estimates being made (Beaugelin-Seiller et al., 2019a this issue). From measurements at a site within the CEZ Beresford et al. (2019b this issue) demonstrate that ambient dose rates (as made by hand-held dosimeters) may underestimate the actual dose rate for some organisms by more than an order of magnitude.
4. Contamination is highly heterogeneous in the Chernobyl Exclusion Zone and often too few measurements are made to even indicate a gradient of exposure with any confidence; there is rarely any error presented for dose rate measurements. Sufficient estimates of contamination, relative to the likely home range of the species being considered, should be made (see Beaugelin-Seiller, 2019a et al. this issue) the error on dose rate should be presented (this is rare in publications).
5. Internal exposure is rarely determined and often not estimated. Internal dose rates could be determined for ^{137}Cs and ^{90}Sr at least by live-monitoring (e.g. see Beresford et al., 2019b this issue). If it is not possible to live-monitor, then transfer values specific to the CEZ are becoming available (e.g. see Beresford et al., 2019b this issue).
6. External dose rates could be better estimated by fitting animals with dosimeters – these could be applicable for animals as small as large bee species. For mammals dosimeters are available which record dose rate as a time series. However, this obviously requires

https://doi.org/10.1016/j.jenvrad.2019.106108

Available online 19 November 2019

recapture of a sufficient number of animals (with dosimeters) or some other means of collecting the dosimeters. Subsequent to the workshop such studies have been conducted and published (Aramrun et al., 2019; Hinton et al., 2019).

7. If application of dosimeters is impractical then better external dose estimates could be made by determining radionuclide activity concentrations in sufficient environmental media samples from an area representing that likely to be utilised by the species of interest and an estimation of dose rate made using a bespoke wildlife assessment model. Such an approach to estimate doses for a range of species at a site in the CEZ is described by Beresford et al. (2019b, this issue).
8. It must be recognised that in some cases any effect observed may be the consequence of much higher dose rates in the past – i.e. the exposure history of the organism or species needs to be considered. With respect to the CEZ, the need to consider site history was highlighted. For instance, the highest exposure rates in most papers must have been determined in the Red Forest, though this is often not acknowledged in papers. Nowhere else in the CEZ is likely to give rise to dose rates >100 μGy h^{-1}). However, the Red Forest is an area that was coniferous forest which was killed by high radiation in 1986. It has slowly been recolonised by less radiosensitive species such as birch along with understorey vegetation and is of poor habitat quality. This is, therefore, a very different habitat to the rest of the CEZ. Furthermore, the Red Forest is relatively close to the Chernobyl NPP and hence some areas are subject to some human disturbance. These issues are explored further in Beresford et al. (2019a this issue). The fact that the Red Forest is a unique ecosystem is not acknowledged in the vast majority of papers that use data from it to derive radiation effect relationships.
9. The often reported statistically 'significant' relationships in the literature do not necessarily demonstrate a causal effect. A significant statistical relationship does not necessarily have real world relevance (many of the reported significant relationships have poor R^2 values). Issues around the statistical interpretation of field effects studies are discussed in Beresford et al. (2019a this issue).
10. Future studies should have appropriate controls (this is not always the case in studies published to date). Control sites may be in or out of the CEZ depending upon the context and purposes of the study.
11. Researchers must publish studies showing no-effects recognising that such studies are unfortunately unlikely to be published in high profile journals (as studies reporting effects often are). However, it is critical that such data are made available so that they can be included in overall evaluations of risk to wildlife from ionising radiation.
12. Working in the CEZ (and Fukushima area) is often a matter of achieving what you can on a limited budget during a limited field visit period. This was recognised as being a 'fact of life', however, when writing-up such studies, authors must be clear about the limitations of their work. This also supports the argument for collaborative fieldwork between research teams from different international institutes (e.g. see Beresford et al. (2019c, this issue) which discusses collaborative programmes in the CEZ).
13. The workshop strongly recommended that data from radiation effects studies are made openly and freely available – there are now a number of mechanisms whereby this can be done using 'data centres' or on-line data repositories. Making data available is a requirement of many journals and funders, though currently is not rigorously adhered to. Two datasets for the CEZ have been published associated with the workshop (Beresford et al., 2018; Gaschak et al., 2018) and more are being made available (e.g. see https://tree.ceh.ac.uk/content/tree-publications-and-datasets). If underpinning data from the field studies are made available a significant step would be made to addressing the disagreement on the magnitude of effects due to exposure to ionising radiation observed in the CEZ/Fukushima areas by enabling its re-evaluation by others.
14. There is a need to be able to link effects observed at the individual level (including molecular and biomarker results) with population level effects, given that populations are usually the endpoint of environmental impact assessments.
15. We need to improve communication on issues around the effects of radiation on the environment with stakeholders including the public and media. As a result of inviting active media participation in the workshop a number of public focused articles were published (e.g. Pearce, 2016; Massey and Stacey, 2017; Stacey, 2017).

Towards solving the scientific controversy

Interpretation of effects studies in the CEZ remains an area of controversy (e.g. see Beaugelin-Seiller et al., 2019b this issue; Smith, 2019 this issue; Beaugelin-Seiller and Garnier-Laplace, 2019 this issue).Subsequent to the workshop discussed above a second, linked, event was held (https://www.ceh.ac.uk/news-and-media/blogs/what-are-effects-radiation-wildlife-discussing-results-chernobyl) for scientists who had been collaborating in studies within the CEZ through the UK funded TREE project (https://tree.ceh.ac.uk/) and activities supported by European Radioecology ALLIANCE (http://www.er-alliance.eu/) members. This resulted in a statement paper outlining research needs (taking forward the above recommendations) with respect to the effects of ionising radiation on the environment which is published in this issue (Beresford et al., 2019c this issue).

Acknowledgements

The workshop in Chernihiv was supported by the EU funded COMET project (contract number: 604974; https://radioecology-exchange.org/content/comet). We would like to thank all attendees for their active participation in the workshop. We would also like to thank Svetlana Chesnokova (Chornobyl Center, Ukraine) for her help in organising and running the workshop, and Cath Barnett and Sam Welch of CEH for producing the meeting report.

References

Aramrun, K., Beresford, N.A., Skuterud, L., Hevroy, T.H., Drefvelin, J., Yurosko, C., Phruksarojanakun, P., Esoa, J., Yongprawat, M., Siegenthaler, A., Fawkes, R., Tumnoi, W., Wood, M.D., 2019. Measuring the radiation exposure of Norwegian reindeer under field conditions. Sci. Total Environ. https://doi.org/10.1016/j.scitotenv.2019.06.177.

Barnett, C.L., Welch, S., 2016. COMET Deliverable (D-N°5.6). COMET Workshop report: thirty years after the Chernobyl accident: what do we know about the effects of radiation on the environment? https://radioecology-exchange.org/sites/default/files/Deliverable_56_COMET_workshop_4_final.pdf.

Beaugelin-Seiller, K., Garnier-Laplace, J., 2019. Answer to comments made by J. Smith on "Is non-human species radiosensitivity in the lab a good indicator of that in the field? making the comparison more robust" by Beaugelin-Seiller et al. (2018). J. Environ. Radioact. (this issue).

Beaugelin-Seiller, K., Garnier-Laplace, J., Beresford, N.A., 2019. Estimating radiological exposure of wildlife in the field. J. Environ. Radioact. (this issue).

Beaugelin-Seiller, K., Della-Vedova, C., Garnier-Laplace, J., 2019. Is non-human species radiosensitivity in the lab a good indicator of that in the field? making the comparison more robust. J. Environ. Radioact. (this issue).

Beresford, N.A., Copplestone, D., 2011. Effects of ionizing radiation on wildlife: what knowledge have we gained between the Chernobyl and Fukushima accidents ? Integr. Environ. Assess. Manag. 7, 371–373.

Beresford, N.A., Adam-Guillermin, C., Bonzom, J.-M., Garnier-Laplace, J., Hinton, T., Lecomte, C., Copplestone, D., Della Vedova, C., Ritz, C., 2012. Response to authors' reply regarding "Abundance of birds in Fukushima as judged from Chernobyl" by Møller et al. (2012). Environ. Pollut. 169, 139–140. https://doi.org/10.1016/j.envpol.2012.05.013.

Beresford, N.A., Gaschak, S., Barnett, C.L., Maksimenko, A., Guliaichenko, E., Wells, C., Chaplow, J.S., 2018. A 'reference site' in the chernobyl exclusion zone: radionuclide and stable element data, and estimated dose rates NERC-environmental information data centre. https://doi.org/10.5285/ae02f4e8-9486-4b47-93ef-e49dd9ddecd4.

Beresford, N.A., Scott, E.M., Copplestone, D., 2019. Field effects studies in the chernobyl exclusion zone: lessons to be learnt. J. Environ. Radioact. (this issue).

Beresford, N.A., Barnett, C.L., Gashchak, S., Maksimenko, A., Guliaichenko, E., Wood, M. D., Izquierdo, M., 2019. Radionuclide transfer to wildlife at a 'reference site' in the chernobyl exclusion zone and resultant radiation exposures. J. Environ. Radioact. (this issue).

Beresford, N.A., Horemans, N., Copplestone, D., Raines, K.E., Orizaola, G., Wood, M.D., Laanen, P., Whitehead, H.C., Burrows, J.E., Tinsley, M.C., Smith, J.T., Bonzom, J.-M., Gagnaire, B., Adam-Guillermin, C., Gashchak, S., Jha, A.N., de Menezes, A., Willey, N., Spurgeon, D., 2019. Towards solving a scientific controversy – the effects of ionising radiation on the environment. J. Environ. Radioact. (this issue).

Burdo, O.O., Lypska, A.I., Riabchenko, N.M., Sova, O.A., 2019. Peculiarities of hematopoiesis in small rodents from the chornobyl exclusion zone on the background of extreme environment. J. Environ. Radioact. (this issue).

Copplestone, D., Beresford, N.A., 2014. Questionable studies won't help identify Fukushima's effects. The Conversation.

Gaschak, S.P., Beresford, N.A., Barnett, C.L., Wells, C., Maksimenko, A., Chaplow, J.S., 2018. Radionuclide data for vertebrates in the chernobyl exclusion zone NERC-environmental information data centre. https://doi.org/10.5285/518f88df-bfe7-442e-97ad-922b5aef003a.

Hanson, M.L., Wolff, B.A., Green, W., Kivi, M., Panter, G.H., Warne, M.S.J., Agerstrand, M., Sumpteri, J.P., 2017. How we can make ecotoxicology more valuable to environmental protection. Sci. Total Environ. 578, 228–235.

Hinton, T.G., Byrne, M.E., Webster, S.C., Love, C.N., Broggio, D., Trompier, F., Shamovich, D., Horloogin, S., Lance, S.L., Brown, J., Dowdall, M., Beasley, J.C., 2019. GPS-coupled contaminant monitors on free-ranging Chernobyl wolves challenge a fundamental assumption in exposure assessments. Environ. Int. 133 https://doi.org/10.1016/j.envint.2019.105152.

Kashparova, E., Levchuk, S., Morozova, V., Kashparov, V., 2019. Dose rate causes no fluctuating asymmetry indexes changes in silver birch (betula pendula (L.) roth.) leaves and Scots pine (pinus sylvestris L.) needles in the Chernobyl exclusion zone. J. Environ. Radioact. (this issue).

Massey, L., Stacey, K., 2017. Back from the brink. Outdoor Photography March.

Møller, A.P., Mousseau, T., 2016. Are organisms adapting to ionizing radiation at Chernobyl? Trends Ecol. Evol. 31 (4), 281–289.

Morozova, V., Kashparova, O., Levchuk, S., Bishchuk, Y., Kashparov, V., 2019. Chronic ionizing radiation at low doses has no effect on the functional state of the cellular antioxidant defence system of shoots, as well as morphometric parameters, of seedlings of Arabidopsis thaliana (L.) Heynh. seeds, exposed in natural conditions of the Chernobyl Exclusion Zone. J. Environ. Radioact. (this issue).

Pearce F, Chernobyl, 2016. BBC Wildlife Magazine, 22 November 2016 (4).

Real, A., Garnier-Laplace, J., 2019. The importance of deriving adequate wildlife benchmark values to optimize radiological protection in various environmental exposure situations. J. Environ. Radioact. (this issue).

Smith, J., 2019. Field evidence of significant effects of radiation on wildlife at chronic low dose rates is weak and often misleading. A comment on "Is non-human species radiosensitivity in the lab a good indicator of that in the field? making the comparison more robust" by beaugelin-seiller et al. J. Environ. Radioact. (this issue).

Spurgeon, D.J., 2019. Higher than … or lower than ….? evidence for the validity of the extrapolation of laboratory toxicity test results to predict the effects of chemicals and ionising radiation in the field. J. Environ. Radioact. (this issue).

Stacey, K., 2017. Out of the Ashes. BBC Earth. March 2017.

Sutcliffe, J., 2019. In: Low Level Radiation and Health Conference 1985-2016. Journal of Environmental Radioactivity (this issue).

Sutcliffe, J., 2019. In: COMET Workshop. Journal of Environmental Radioactivity (this issue).

UNSCEAR, 2016. Developments since the 2013 UNSCEAR Report on the Levels and Effects of Radiation Exposure Due to the Nuclear Accident Following the Great East-Japan Earthquake and Tsunami. A 2016 White Paper to Guide the Scientific Committee's Future Programme of Work. United Nations Scientific Committee UNSCEAR on the Effects of Atomic Radiation. Available from: http://www.unscear.org/docs/publications/2016/UNSCEAR_WP_2016.pdf.

C. Lecomte-Pradines*, C. Adam-Guillermin
IRSN, Centre de Cadarache, 13115 St Paul Lez Durance, France

S. Gashchak
Chornobyl Centre for Nuclear Safety, Radioactive Waste and Radioecology, International Radioecology Laboratory, 77th Gvardiiska Dyviiya Str.11, P. O. Box 151, 07100, Slavutych, Kiev Region, Ukraine

C. Bradshaw
Department of Ecology, Environment and Plant Sciences, Stockholm University, SE-10691, Stockholm, Sweden

D. Copplestone
Faculty of Natural Sciences, University of Stirling, Stirling, FK9 4LA, United Kingdom

N.A. Beresford
UK Centre for Ecology & Hydrology, CEH Lancaster, Lancaster Environment Centre, Library Av., Bailrigg, Lancaster, LA1 4AP, United Kingdom

* Corresponding author.
E-mail address: catherine.lecomte-pradines@irsn.fr (C. Lecomte-Pradines).