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Does Chernobyl-derived radiation impact the developmental stability of *Asellus aquaticus* 30 years on?

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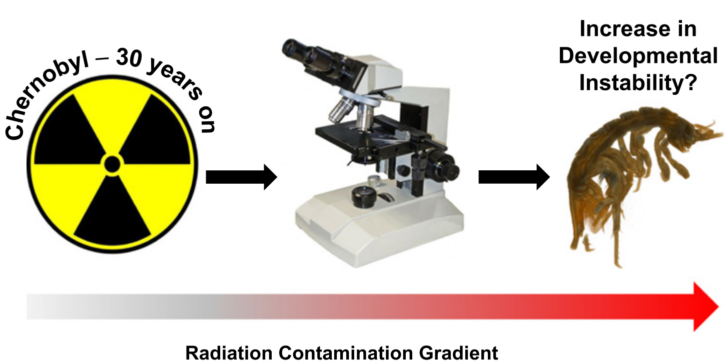
HIGHLIGHTS

- 30 year impacts of Chernobyl on development of *Asellus aquaticus* assessed
- Fluctuating asymmetry (FA) used as measure of developmental stability
- No increase in developmental stability along gradient of radioactive contamination
- Findings suggest resilience of aquatic invertebrate populations to radionuclides.
- Helps to understand the impacts of chronic exposures to radiation on ecosystems

GRAPHICAL ABSTRACT



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ABSTRACT

Effects of long-term, environmentally relevant doses of radiation on biota remain unclear due to a lack of studies following chronic exposure in contaminated environments. The 1986 Chernobyl accident dispersed vast amounts of radioactivity into the environment which persists to date. Despite three decades of research, impacts of the incident on non-human organisms continues to be contested within the scientific literature. The present study assessed the impact of chronic radiation exposure from Chernobyl on the developmental stability of the model aquatic isopod, *Asellus aquaticus* using fluctuating asymmetry (FA) as an indicator. Fluctuating asymmetry, defined as random deviations from the expected perfect bilateral symmetry of an organism, has gained prominence as an indicator of developmental stability in ecotoxicology. Organisms were collected from six lakes along a gradient of radionuclide contamination in Belarus and the Ukraine. Calculated total dose rates ranged from 0.06–27.1 μGy/h. Fluctuating asymmetry was assessed in four meristic and one metrical trait. Significant differences in levels of pooled asymmetry were recorded between sample sites independent of sex and specific trait measured. However, there was no correlation of asymmetry with radiation doses, suggesting that differences in asymmetry were not attributed to radionuclide contamination and were driven by elevated asymmetry at a single site. No correlation between FA and measured environmental parameters suggested a biotic factor driving observed FA differences. This study appears to be the first to record no evident increase in developmental stability of biota from the Chernobyl region. These findings will aid in understanding the response of organisms to chronic pollutant exposure and the long term effects of large scale nuclear incidents such as Chernobyl and Fukushima.

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1. Introduction

The developmental stability of an organism is demonstrated by its capacity to produce an optimal phenotypic form under a specific set of environmental conditions (Palmer, 1994). Bilateral symmetry offers a method of determining levels of developmental stability founded on an a priori understanding of the ideal form; perfect bilateral symmetry. Fluctuating asymmetry (FA) refers to subtle, random deviations from the expected bilateral symmetry displaying a normal distribution with a mean of zero (Palmer and Strobeck, 1986). FA analyses have gained prominence as both an environmental monitoring tool and in evolutionary biology studies owing to the apparent ease with which such studies can be conducted and analysed compared with other phenotypic fitness indicators (Van Dongen, 2006). An increase in FA has been linked to a range of extrinsic and intrinsic stressors including organic pollutants (Jenssen et al., 2010), temperature (Vishalakshi and Singh, 2008a) and genetic stressors such as inbreeding (Özener, 2010). Studies have demonstrated relationships between levels of FA and traditional measures of fitness (Bakker et al., 2006; Silva et al., 2016), although the reliability of FA as a fitness indicator has been criticised (see Kruuk et al., 2003; Vishalakshi and Singh, 2008b).

The 1986 Chernobyl accident dispersed an estimated 5300 PBq of radioactivity into the environment (UNSCEAR, 2000) contaminating large areas of Europe. However, 30 years after the accident controversy still exists regarding the biological consequences of the incident and the dose levels at which these occur (Beresford and Copplestone, 2011; Beresford et al., 2016). For example, an order of magnitude decline in above ground invertebrates inhabiting Chernobyl (bumble bees, spiders, grasshoppers, butterflies and dragonflies) was recorded over a dose range of 0.1–10 μGy/h by Møller and Mousseau (2009) 20 years after the accident. Such dose rates fall within the range of exposure to terrestrial wildlife as a consequence of naturally occurring radionuclides (i.e. ^{40}K, ^{238}U and ^{232}Th) in the United Kingdom (Beresford et al., 2008). Conversely, no impact of radiation dose rates on the abundance and diversity of aquatic macroinvertebrates was found by Murphy et al. (2011) in Chernobyl contaminated lakes. The Tōhoku earthquake-tsunami at the Fukushima Dai-ichi nuclear power plant (NPP) in 2011 led to further contamination of the environment with radionuclides, with release estimates ranging from 7 to 50 and 1–5.5 PBq of ^{137}Cs for atmospheric and direct marine source term releases respectively (IAEA, 2015). At present, the radiological consequences of the Fukushima incident on non-human biota are unclear. These incidents underpin the necessity of robust evaluation of the impacts of radiation on wildlife.

Previous studies have demonstrated an increase in FA in populations of biota inhabiting areas impacted by elevated levels of radionuclides (Gileva and Nokhrin, 2001; Møller, 2002). For example, Oleksyk et al. (2004) demonstrated a 3.6 fold increase in mean skull FA in populations of the yellow necked mouse, *Apodemus flavicollis*, inhabiting areas closer to the failed Chernobyl reactor compared with reference populations over a range of dose rates from 0.107 to 4.146 μGy/h. Further, a high degree of FA was recorded in the freshwater mollusc, *Dreissena polymorpha* and floating pondweed *Potamogeton natans* from aquatic systems impacted by the Chernobyl incident (Yavnyuk et al., 2009). Williams et al. (2001) recorded an increase in morphological abnormalities in larval chironomids inhabiting Belarusian lakes impacted by the Chernobyl incident at ambient dose rates of 8–20 μSv/h, although FA was not directly quantified. FA therefore appears to be an appropriate indicator of radiation-induced developmental stress in organisms from the Chernobyl region.

This study aimed to assess the impacts of chronic radiation exposure along an established gradient of radionuclide contamination on the development of the water louse, *Asellus aquaticus* using FA as an indicator. FA has previously been induced in laboratory populations of *Asellus aquaticus* subjected to elevated temperatures (Savage and Hogarth, 1999) and is an effective indicator of developmental stability. *A. aquaticus* is a detritivorous isopod common in temperate freshwater ecosystems across Europe (Williams, 1962) that has gained prominence as an indicator species in ecotoxicity testing of sediment-borne contaminants (De Lange et al., 2005; McCahon and Pascoe, 1988).

2. Materials & methods

2.1. Sampling sites & collection of A. aquaticus

Six lakes were chosen ranging from 3 to 225 km in distance from the Chernobyl NPP. These sites exhibited varying degrees of contamination as a consequence of the Chernobyl incident (see Fig. 1). Where possible, localities with historic environmental data sets were selected. Samples were collected in littoral zones and amongst vegetation in June 2015 at three different sub sites of each lake by kick netting using a 1 mm mesh size net (EFE, UK). Following sieving, *A. aquaticus* were sorted and immediately preserved in 96% ethanol. Prior to analysis, samples were placed in randomly coded boxes to prevent measurement bias, a pervading problem in FA studies (Palmer, 1994).

2.2. Environmental parameters

Hydrochemical variable measurements, including conductivity oxygen saturation, pH and temperature were performed in situ using a multiparameter probe (HANNA Instruments 9828) at three stations of each lake. All lakes had similar fish communities comprised mainly of perch, roach and rudd (Smith et al., 2005; Murphy et al., 2011). Table 1 displays the measured environmental variables and available bathymetric data from Smith et al. (2005).

2.3. Estimation of external dose rates at sample sites

In the present study, external dose rates were calculated using deposition values of radiocaesium and strontium at sampling sites and dose conversion coefficients (DCC's) based on user inputted data for the geometry of *A. aquaticus* (Height = 2.2 mm, width = 1.7 mm, length = 4.7 mm and mass = 4.1 mg) using the ERICA tool (V1.2). DCC's for external dose rates were calculated to be 3.85×10^{-4} and 4.91×10^{-4} μGy/h per Bq/kg for ^{137}Cs and ^{90}Sr respectively.

Decay corrected activity concentrations of ^{137}Cs and ^{90}Sr in sediments were first calculated (Bq kg^{-1} fresh weight) as:

$$C_{sediment} = \frac{(D_{total}) \text{ x } (e^{-\lambda_r t})}{P_{sediment} \text{ x } d_{sediment}}$$

Where $C_{sediment}$ = Fresh weight activity concentration of sediment Bq kg D_{total} = Total deposition of radionuclide in Bq m^{-2}λ_r = Decay constant for radionuclide in d^{-1}t = time in days $P_{sedimentl}$ = wet sediment bulk density in kg m^{-3}$D_{sediment}$ = Depth of sediment in m within which the radionuclide has become mixed.

The dose estimates were based on a wet sediment bulk density of 1300 kg m^{-3} and assuming mixing to a depth of 0.15 m (Smith et al., 2005). The organism was assumed to occupy the sediment-water interface. Strontium – 90 (^{90}Sr) and radiocaesium (^{137}Cs) are the two major contributors to environmental radiation doses received by biota over chronic time scales (IAEA, 1995). Sr-90 is associated with fuel particles and shows a rapid decline with distance from Chernobyl relative to radiocaesium (Mück et al., 2002). Consequently, total doses from Strontium were only considered at Yanovsky Crawl and Glubokoye lake (3 and 10 km from the Chernobyl NPP respectively) as concentrations at other water bodies are known to be insignificant (Murphy et al., 2011) in comparison with radiocaesium. A generic value of 0.06 μGy/h was added to estimate cumulative external radiation doses in study lakes to account for natural background radiation (Murphy et al., 2011).