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Terrestrial invertebrate population studies in the Chernobyl exclusion zone, Ukraine

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Abstract. The Chernobyl reactor accident in April 1986 released some 3-6.10^5 TBq ^{137}Cs and 2-4.10^5 TBq ^{90}Sr to atmosphere. About half of this was deposited within 20 km of the site, leading to extensive death of trees and other biota, and the establishment of a human exclusion zone. High levels of contamination remain in this zone. Nonetheless, birch (*Betula* spp.) and willow (*Salix* spp.) have recolonised the forest areas, while abandoned agricultural land has succeeded to tall grassland and scrub. This study summarises observations on invertebrate populations in sites with gamma dose rates varying from 0.1 to 140 µSv h^{-1}. Corresponding activity concentrations were 3.10^3 to 3.10^6 Bq kg^{-1} dw ^{137}Cs and 10^3 to 2.10^6 Bq kg^{-1} dw ^{90}Sr in the top 5 cm of soil. Sub-surface bait lamina penetration decreases with increasing concentrations of ^{137}Cs and ^{90}Sr in soil. At the highest levels of contamination there is also some loss of above-ground invertebrate diversity; although little change in total biomass. Trials on earthworms in soils from the region and matched soils spiked in the laboratory have proved variable. However, there is a non-significant indication of depressed growth rates in all contaminated regimes compared to control populations.

1. INTRODUCTION

There is currently much attention on the demonstration of protection of the environment from the potentially harmful effects of exposure to elevated levels radiation [e.g. 1, 2, 3, 4, 5 and 6]. In response to the European Habitats Directives, the UK Environment Agency and English Nature have issued guidance on the assessment of radiation doses to biota [7]. Similar methods have been advanced in America [8] and elsewhere [4 and 5]. UNSCEAR has a current Task Group considering the need to set environmental dose standards, and various programmes of work have been supported by the European Commission (e.g. EPIC, FASSET, ERICA). Much of the interest has focused on developing techniques for predicting doses to biota. This study presents preliminary findings from a field-based project investigating terrestrial invertebrate populations from the Chernobyl exclusion zone, in Ukraine, chronically exposed to high levels of ionising radiation.

The accident at Chernobyl nuclear power plant in April 1986 resulted in the destruction of Unit 4 reactor core. An intense graphite fire developed rapidly, with substantial release of radioactive materials to atmosphere over the next 10 days or so. Estimates of the total release vary. The USSR State Committee [9] presented information in August 1986 indicating a release of some 2.9x10^5 TBq ^{137}Cs and 2x10^5 TBq ^{90}Sr, with a total fission/activation product release of 1.7x10^6 TBq. Other commentators [e.g. 10, 11 and 12] suggest that up to double this amount may have been released.

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Both the rate of release of radioactivity and the proportion of contributing radionuclides varied over the release period in a fashion related to the core temperature. Initial releases were generally carried to the north of the reactor but releases during the latter period were carried in a more westerly direction. Releases of activity at a much reduced rate continued for a protracted time beyond the main release period, leading to general and widespread contamination, albeit often patchy in nature. Estimates of deposition vary, but it is probable that about half the released activity was deposited within 20 km of the release point. The United Nations Scientific Committee on the Effects of Atomic Radiation [13] estimated that in the first 10-20 days the radiation doses received by organisms within this exclusion zone reached up to 880 Gy, mainly attributable to beta radiation. The intense levels of radiation from both the contaminated plume and deposition to ground resulted in the death of pine trees over 400 ha, the abandonment of 100,000 to 150,000 ha of agricultural land and the establishment of an exclusion zone extending to 30 km from the site.

More than eighteen years after the accident, levels of radioactivity in the region remain high and general human utilisation of the region continues to be prohibited. As a consequence, the area is being colonised by biota without human intervention. Mixed deciduous woodlands, with a high proportion of birch (*Betula* spp.) and willow (*Salix* spp.), have become established in the forest areas previously subject to dieback. Agricultural land, no longer cultivated, has succeeded to tall grassland and scrub.

The purpose of this study was to determine species diversity, abundance and biomass at sites with varying degrees of radioactive contamination. Concurrent laboratory studies were conducted to investigate possible gross growth and reproductive effects.

2. FIELD SITES AND STUDY METHODS

During 2001 a number of sites were investigated to the west of the Chernobyl reactors to identify areas suitable to undertake a comparative study. On this basis, four sites were selected for further investigation during 2002 and 2003. The sites were chosen to provide distinct dose rate intervals within the same habitat type, referred to locally as ‘black forest’ – a mixed forest with pine domination, on acidic sandy soils (pH 4.5-5.5; bulk density 0.81-1.01 te m^{-3}; variable soil moisture content). Data reported in this preliminary analysis are for the 2002 sampling campaign only. The site at Pine Trees was considerably drier than the remaining three sites and was subsequently abandoned during the sampling campaign for 2003.

Sites were initially walked over with a gamma dose rate meter (Mini Instruments Series 900 monitor with 542A probe), taking one hundred measurements at each site. The physical characteristics of the sites are summarised in Table 1. Five replicate soil cores were taken from each site, using a metal percussion corer driven into the substrate at randomly selected locations. Depth intervals of 0-5, 5-10, 10-15 and 15-20 cm were used to section cores for analysis. Soil cannot be transported out of the exclusion zone. Consequently, all analyses were undertaken by staff from the International Chernobyl Centre, at the Chernobyl Division laboratory in Chernobyl City.

Table 1. Soil characteristics.

Sites	**Soil (0-5 cm surface layer)**					**Air kerma (uGy h^{-1})**
	pH	**Moisture content (%)**	**Bulk density (te m^{-3})**	**Activity Concentration (Bq kg^{-1} dw)**		
				^{137}Cs	**^{90}Sr**	
Paryshev	4.5	30.1	0.81	2.96E+03	1.21E+03	0.1-0.5
Pine Trees	4.5	5.0	0.99	7.18E+04	1.66E+04	3.1-5.9
Forestry	5.5	13.6	1.01	1.87E+05	8.69E+04	3.6-16.6
Red Forest	5.5	36.1	0.81	3.51E+06	2.49E+06	60.2-138

In general, canopy cover was sparser in the high contamination sites, which had been subject to extensive pine death following the accident. The high radiation stress after the accident has also limited regrowth. Consequently light penetration at these sites is higher and a more diverse and luxuriant understorey vegetation has developed. Ground vegetation and detritus was collected from five 10 cm sq. quadrats placed randomly within each sampling site (Table 2).

Table 2. Activity concentrations of ^{90}Sr and ^{137}Cs in vegetation and litter.

Sites	Litter layer			Vegetation		
	Biomass (kg fw m^{-2})	Activity Concentration (Bq kg^{-1} fw)		Biomass (kg fw m^{-2})	Activity Concentration (Bq kg^{-1} fw)	
		^{137}Cs	^{90}Sr		^{137}Cs	^{90}Sr
Paryshev	0.82	2.14E+03	2.24E+03	0.32	2.58E+03	1.65E+03
Pine Trees	0.64	1.15E+04	2.92E+04	0.31	1.57E+04	2.61E+04
Forestry	1.42	5.69E+04	8.82E+04	0.24	1.86E+04	2.32E+04
Red Forest	1.36	1.56E+06	1.37E+06	1.36	1.55E+06	3.49E+05

Bait lamina strips were used as an *in sit*u test for levels of movement of soil organisms. At each of the four sites three replicates of a 4 x 4 grid were set up, each grid covering 45 cm sq. Bait lamina sticks were removed and inspected after three weeks.

Population densities and biodiversity were determined using a number of approaches. Worm populations were determined by applying irritant 4 times at each site [14]. Sweep net sampling was conducted (again 4 times at each site) in a measured grid area, to determine populations of aerial and canopy dwelling invertebrates. Pitfall traps (12 to a site) were laid out to determine populations of surface dwelling invertebrates. All organisms caught were identified as far as possible to genus level.

Growth experiments on naïve earthworms (*Esiena fetida*) were undertaken in the laboratory, using soils from the region. All soils were sieved to remove any stones or other coarse material and 15 g manure was introduced to approximately 500 g of soil. Triplicate pots (2 l. in volume) were established and maintained for two months. Worms were removed at weekly intervals, weighed and replaced. Each pot initially contained 8 worms, with a collective biomass around 2 g.

All materials, other than the soil samples as noted above, were analysed using a pure geranium γ spectrometer, calibrated against internal standards of known activity (ITSC Odessa). Samples were dried and homogenised. Analysis of β particle activity was undertaken using Maestro Software, whilst γ emissions were analysed using Genie 2000 software. All determinations, other than the soils, were undertaken using the facilities of the Slavutych International Research Laboratory of International Chernobyl Centre, Slavutych, Ukraine. Limited comparisons were undertaken using facilities of the University of Liverpool, using sub-sampled material. No significant differences were identified (Figure 1).

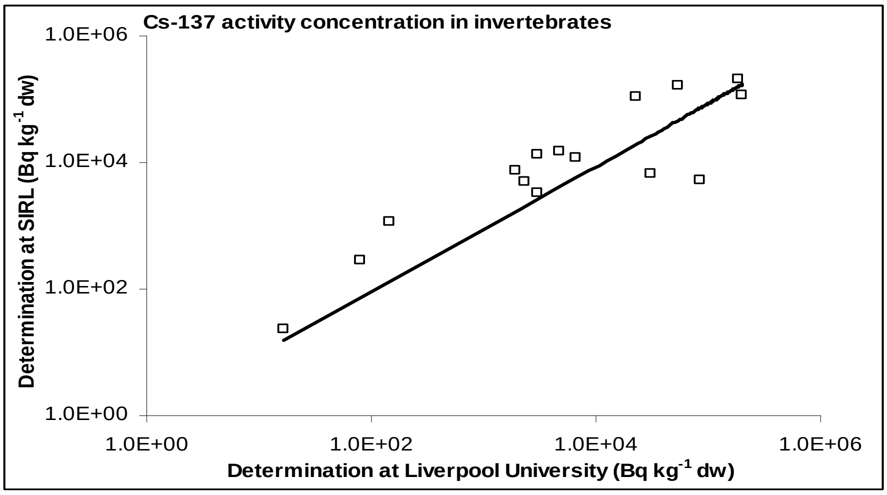

Figure 1. Comparison of activity concentration determinations in invertebrate samples.

3. RESULTS

Data obtained from the sub-surface deployment of bait lamina sticks indicates that that lower levels of activity by organisms are apparent at the more contaminated sites (Figure 2). Some uncertainty is always present with respect to damage to the lamina which may arise from physical abrasion as the sticks are inserted into and removed from the soil. Generally this occurs where the lamina show ‘nicks’ rather than clear penetration. Data in Figure 2 include uncertain results. These are relatively constant between sites and do not influence the general trend observed.

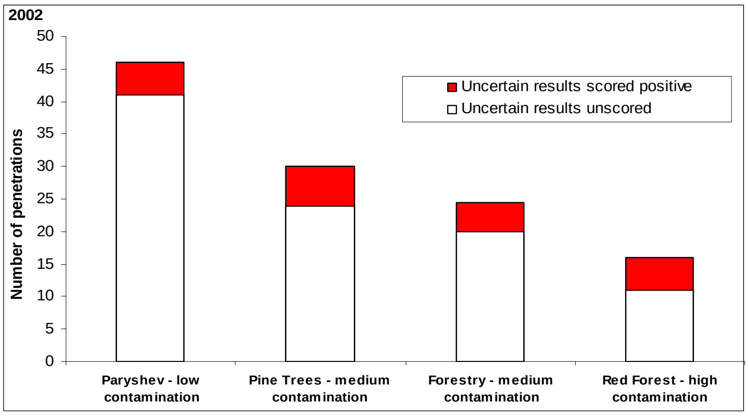

Figure 2. Bait lamina results.

Sampling for soil-surface and flying organism species indicated a general loss of diversity with increasing levels of soil activity concentrations (Table 3), but with no associated loss of total biomass. There is an inconsistent trend with respect to the number of individuals recovered, although more than twice the number of individuals were captured from the low contamination site (Paryshev) than from any other site during this campaign.

Table 3. Invertebrate population data, 2002.

Site ID	Grouping	Total biomass (g dw)	No. individuals	No. types	Activity concentration (Bq kg^{-1} dw)	
					^{137}Cs	^{90}Sr
Paryshev – low contamination	Spiders	0.289	60	10	9.56E+02	4.97E+03
	flying organisms	0.089	12	9	2.36E+03	9.43E+03
	ground dwellers	0.746	194	16	1.17E+03	4.69E+03
	beetles	1.684	19	6	2.85E+02	6.53E+02
	Total	*2.80*	*285*	*41*		
Pine Trees – medium contamination	spiders	0.523	12	5	7.27E+03	8.30E+03
	flying organisms	0.212	15	10	1.35E+04	2.45E+04
	ground dwellers	0.707	15	7	3.39E+03	2.12E+03
	beetles	25.43	38	14	5.34E+03	1.37E+03
	Total	*26.9*	*77*	*36*		
Forestry - medium contamination	spiders	0.13	12	7	4.92E+03	2.62E+04
	flying organisms	0.13	10	7	1.50E+04	2.92E+04
	ground dwellers	0.707	39	12	1.17E+04	1.30E+04
	beetles	32.68	63	5	6.53E+03	5.32E+02
	Total	*33.6*	*124*	*31*		
Red Forest - high contamination	spiders	0.195	16	6	1.17E+05	3.53E+05
	flying organisms	0.167	31	5	1.69E+05	3.35E+05
	ground dwellers	0.294	39	8	1.06E+05	4.57E+06
	beetles	3.253	31	7	2.05E+05	7.15E+04
	Total	*3.90*	*117*	*26*		

During the course of the field experiments to determine worm populations, only one individual was recovered from Paryshev (low contamination) and three from the Forestry (medium contamination) site. These were Lumbracids spp. No individuals were recovered from either Pine Trees or the Red Forest. The low pH of the soils means that this area is not an ideal habitat for worm populations.

Growth experiments on naïve earthworms maintained in soils from the study sites in laboratory conditions showed highly variable results, with no clear trends (Figure 3). In some pots the organisms gained biomass, whilst in others substantial weight loss was evident. This does not correlate with levels of soil contamination.

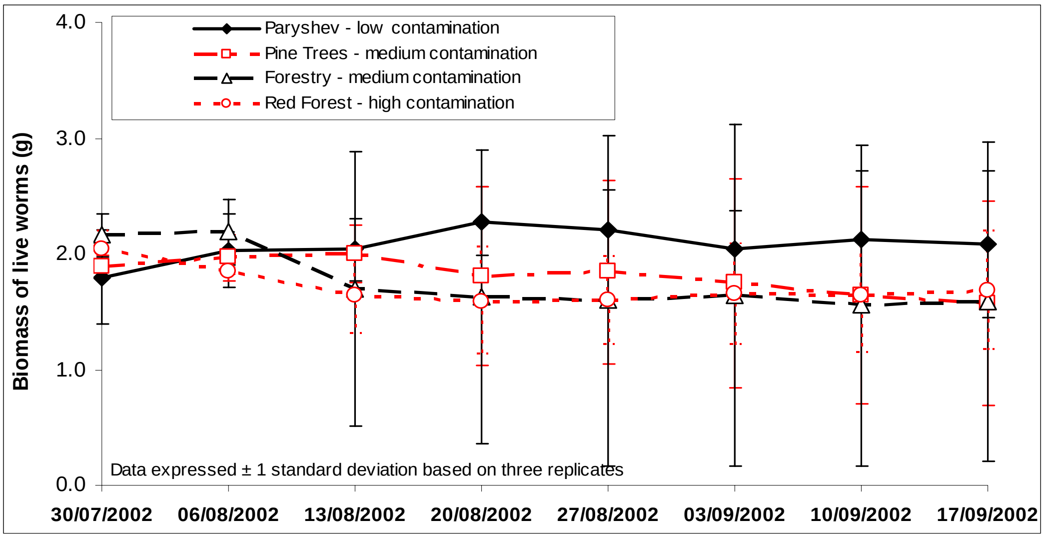

Figure 3. Worm breeding experiment observations.

At the end of the laboratory trial, a number of the worms had died. In total, two worms from the low contamination soil died, with 5 from the pots containing soil from Pine Trees, eight from the Forestry soils pots (all from one pot) and seven from the Red Forest soils pots.

4. DISCUSSION

Work is still ongoing, so all results presented are preliminary in nature. In any case, it would be inappropriate to draw firm conclusions from a single study conducted over one season, where many of the techniques used were of a scoping nature to guide further field campaigns. Nonetheless, a number of observations may be drawn from the results presented.

Bait lamina results are qualitative rather than quantitative, but are generally indicative here of lower levels of activity by sub-surface soil fauna. The paucity of worms at all sites may be a reflection on the method used (generally, the application of an irritant to the soil is more successful where worms construct vertical burrows and is less useful where worms construct horizontal or branching burrows) and may be due to the generally acidic nature of the soils in the region. The fact that the only individuals were recovered were from the lower contaminated sites may, therefore, be coincidental and the very few individuals available (4 in total) precludes any further meaningful analysis. However, it is notable that the overall number of types of organisms recovered from all trapping exercises declined with increasing levels of contamination. Within the broad groupings used to categorise types of organisms no consistent trends are evident (for instance, the low contamination site at Paryshev contained six identified genera of beetles whereas the high contamination site in the Red Forest region contained seven genera). Furthermore, although the highest number of individual organisms was recorded in the low contamination site (Paryshev) this coincided with the lowest overall biomass.

The flying organisms captured from each site are presumably the least affected by local radiation levels, due both to habitat and mobility. It is possibly significant, in this context, that the greatest number of these were recovered from the Red Forest site, although still with the lowest diversity.

The broad trend towards loss of diversity across all groups at higher contaminated sites indicates an apparent effect of high levels of chronic radiation on more sensitive species. Maksimova [15] identified a similar loss in soil invertebrate diversity during 1986-2001 in sites in Belarus affected by Chernobyl fallout. Interestingly, he noted also that during 1986-1987 all Lumbricidae (previously present at the sites) were absent. By 1993 some 3 species of Lumbricidae had recolonised the contaminated sites, but in comparable control sites 6 species were identified, indicating a continuing loss of diversity in worm populations at affected sites.

Data from growth experiments on earthworms in laboratory conditions proved highly variable. Nonetheless, they do not indicate any short term effect on growth rates.

The study programme has been continued through 2003/2004 and extended to include laboratory and field investigations in the UK. The data from those studies are not yet available for analysis but will be reported on subsequently.

At present, it seems reasonable to conclude that acute exposure to high levels of radiation may have denuded invertebrate populations immediately after the Chernobyl accident. Subsequently, recolonisation has been slower in regions subject to continuing high levels of soil contamination with ^{90}Sr and ^{137}Cs. In part, this may be linked to habitat changes (e.g. loss of tree canopy cover in areas of more extensive early die-back). Nonetheless, some niche expansion by remaining invertebrate populations appears to have occurred as there is little evidence for any overall loss of biomass when comparing high contaminated sites with relatively low contaminated sites.

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