Chernobyl and Fukushima: Differences and Similarities, a Biological Perspective

Timothy A. Mousseau[1] and Anders P. Møller[2]

1: Department of Biological Sciences, University of South Carolina, Columbia, SC USA, 29208; email: Mousseau@sc.edu

2: Laboratoire d'Ecologie, Systématique et Evolution, CNRS UMR 8079, Université Paris-Sud, Bâtiment 362, F-91405, Orsay Cedex, France; email: anders.moller@u-psud.fr

INTRODUCTION

Until very recently, the environmental, and to a lesser extent, the health hazards related to nuclear accidents have been very difficult to assess. In fact, it has been suggested that the plant and animal life of the Chernobyl Exclusion Zone is thriving in the absence of human activity in the region and that much of the human morbidity linked to Chernobyl fallout was largely related to stress and other self-destructive behaviors (e.g. smoking and alcoholism)[1]. Unfortunately, these conclusions were based primarily on an absence of information related to these issues rather than any rigorous supporting data, and many recent reports have called into question the validity of these conclusions as well as the motives for their presentation[2].

In direct response to the optimistic forecasts of the Chernobyl Forum[1] concerning wildlife, a series of basic ecological, genetic, and evolutionary studies were initiated in 2005 by an international team of biologists (the Chernobyl Research Initiative, CRI, at the University of South Carolina)[3] to rigorously assess the impacts of the disaster on animal abundances and biodiversity within the Chernobyl Exclusion Zone. This initiative was expanded in 2011 to include the impacts of the Fukushima disaster on wildlife in contaminated areas of Japan.

Although the Fukushima accident is a terrible disaster, it has offered an opportunity for replication of studies conducted at Chernobyl. Because both Chernobyl and Fukushima are located in the same zoogeographic zone, numerous species co-occur in both regions implying that the effects of radiation on abundance, morphology, physiology and development can be investigated with the same techniques, and even by the same scientists. We have exploited this unique situation in an attempt to develop a rigorous understanding of the scope, scale, and time frame for biological responses to contamination by radionuclides. Of particular relevance is that these studies have been conducted under otherwise natural settings in a manner that permits assessing effects for wild, free living organisms. This is significant given that it is now widely appreciated that natural populations often respond very differently to stress than either laboratory or mesocosm study animals[4,5]. To date, the CRI research team has generated more than 40 peer-reviewed scientific publications related to this topic. Most of these papers can be viewed on the CRI website [3].

RESULTS

The overwhelming conclusion from this recent series of studies is that there is no evidence to suggest that animals are doing better inside the Chernobyl Exclusion zone. In fact, most of the organisms surveyed have shown large drops in abundance with a consequent drop in overall biodiversity in contaminated regions of the exclusion zone. It is not known if animal abundances in "clean" parts of the exclusion zone are higher than surrounding areas outside of the zone but this has little bearing on the primary question of interest which is whether or not there is any evidence for injury to any components of the ecosystem that are related in to exposure to radionuclides. The evidence from replicated and repeated independent observations is that abundances and biodiversity drop in relation to contamination levels. For example, the forest bird community showed a two-thirds drop in total abundance and a 50% drop in species richness in the more contaminated areas when compared to clean areas within the zone [6-8]. These patterns are consistent from year to year [8], although overall abundances show annual changes largely reflecting climatic effects in both Ukraine and in overwintering areas that could mask local patterns of variation if studies were not conducted with care over multiple years. Similar patterns of decline have also been seen for birds of prey, although there is a suggestion that numbers are rising for this group in the relatively "clean" areas outside the Exclusion Zone [9].

Bird communities were also surveyed in Fukushima prefecture in July, 2011, roughly four months following the disaster at the Fukushima Daiichi Nuclear Power Plant [10]. Significant declines in abundances were noted for many species with the magnitude of effect approximately double in Fukushima when compared to the same species inhabiting the Chernobyl region, pointing either to strong effects of acute exposure, some level of adaption to radionuclides in the Chernobyl populations, or differing effects of the different mixtures of radioactive chemicals that the animals were exposed to. For example, in Fukushima, birds were likely initially exposed to high levels of radioactive iodine (I-131)[11] and noble gases (e.g. Xenon-133) in addition to radioactive cesium isotopes (Cs-134 and Cs-137)[12]. The cesium isotopes will likely persist at high levels in the region for many years because of their longer half-lives (2 and 30 years, respectively). In contrast, radioactive iodine (I-131) and noble gasses have long since disappeared from the Chernobyl region, although strontium-90 and several isotopes of plutonium (e.g. Pu-238, Pu-239, Pu-240 and Pu-241) persist and americium-241 is increasing in the environment [13]. These differences in the present radioactive environments between Fukushima and Chernobyl reflect the different time periods since the disasters (1986 vs. 2011) and characteristics of the accidents.

The insect communities have also been intensely investigated with surveys of diversity and abundances conducted in 2006-2009 in Ukraine and Belarus and in 2011 in Japan. In the Chernobyl-contaminated regions of Ukraine and Belarus, where more than 20 generations of exposure had passed at the time of these surveys, almost all insect groups showed dramatic declines in areas of significant contamination. Bees, grasshoppers, dragonflies, moths and butterflies all showed reduced numbers in areas of high contamination [8,14] with consequent ecosystem-level effects on fruit trees [15]. Spiders also showed major declines proportional to the level of contamination in Chernobyl[14]. However, in Fukushima, as of July 2011, only butterflies, and to a lesser extent, cicadas, showed significant and obvious declines in areas of contamination, with no immediate effects detectable using simple survey methods for grasshoppers, bees, or dragonflies [16]. Curiously, spiders showed a significant rise in numbers, perhaps reflecting an absence of predators (e.g. birds) or an increased facility for capturing prey (e.g. moths and butterflies) that may have been incapacitated by exposure to radioactive contaminants [16]. These surveys of animal abundance and biodiversity were repeated during the summer of 2012 to assess repeatability of patterns among years for Fukushima populations.

Many of the likely causes of the observed declines in animals in Chernobyl have been documented and include reduced survival and longevity [17,18], high rates of developmental abnormalities (including tumors)[19], reduced fertility [20,21], reduced cognitive abilities (perhaps caused by smaller brains in Chernobyl birds)[22], among other likely mechanisms. Many of these effects can be attributed to the significantly elevated mutation rates that have been reported for many Chernobyl populations [23,24] It seems possible that many of the effects that have been observed in Chernobyl but not yet seen in Fukushima are the product of multiple generations of exposure and consequent mutation-accumulation rather than the effects of acute exposure [25] although a recent study of butterflies from Fukushima [26] has found conclusive evidence of genetically based mutations that have increased over time.

It has been sometimes suggested that the contamination levels currently observed in Chernobyl and Fukushima are generally quite low and lower than many of the naturally radioactive locations in the world (e.g. parts of Iran, India, Brazil and southern France). However, this is not accurate. Although maximum background radiation levels of almost 30 μSv/h have been reported for Ramsar, Iran, most other "hot" regions are considerably lower (e.g. 4.0 μSv/h in Kerala, India)[27,28]. Radiation levels inside the Chernobyl and Fukushima zones have vast areas greatly exceeding these levels [13,16,23]. In addition, a recent meta-analysis of studies of these naturally radioactive regions provides compelling evidence that these low levels are associated with deleterious effects for their plant and animal inhabitants [28]. Also, it has long been known that naturally occurring radon is the second leading cause of lung cancer in the US [29].

There have been many reports, mostly in the popular media, that the Chernobyl Zone is filled with animals as a consequence of reduced human population sizes, and this has by extension been used to suggest that humans have larger effects on biological conservation than do the effects of radiation even at the site of the world's largest nuclear catastrophe. This allegory, however, is not supported by any weight of evidence and its origin was largely anecdotal and can be traced back to a letter to an editor by two observers who were surprised to see physical evidence for more animals inside the zone than they had seen on the outside (the letter is available upon request from the authors). After all, almost everyone is surprised to see any signs of life at all in the highly contaminated regions of the Chernobyl Zone. Indeed, it is perhaps surprising that as many animals as are seen continue to be found in these areas. However, ***all*** of the rigorously conducted studies of abundance and biodiversity suggest that there are very significant dose-related negative impacts on all groups of animals studied to date (although there is significant heterogeneity among species in their responses), and that many species are likely only sustained via immigration from outside the zone. This is a matter of fact, not opinion.

To conclude, despite all that we have learned from these recent studies of animal populations living in Chernobyl and Fukushima [30], too little is known concerning the mechanisms underlying effects in the two regions and this very clearly underlines the urgent need for significant and sustained investments in research concerning the biological consequences of acute and chronic exposure to radioactive contaminants in the environment. Such research will not only be relevant for the wildlife inhabiting these regions but also for the large human populations living in contaminated areas of these countries.

Given unlimited funding, we would propose a sustained biological monitoring program of the ecology, genetics, physiology and evolution of the organisms living in Fukushima and Chernobyl. It is only through such research that policy makers and society as a whole can judge the financial, health and environmental risks and hazards of nuclear accidents. Clearly, recent developments in our broader understanding of the biological consequences of nuclear accidents point to many previously ignored or misunderstood costs that have not been a part of earlier discussions. Such shortcomings can easily be addressed through a sustained research effort.

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