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On the divergences in assessment of environmental impacts from ionising radiation following the Fukushima accident

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ABSTRACT

The accident at the Fukushima-Daiichi Nuclear Power Station on March 11, 2011, led to significant contamination of the surrounding terrestrial and marine environments. Whilst impacts on human health remain the primary concern in the aftermath of such an accident, recent years have seen a significant body of work conducted on the assessment of the accident's impacts on both the terrestrial and marine environment. Such assessments have been undertaken at various levels of biological organisation, for different species, using different methodologies and coming, in many cases, to divergent conclusions as to the effects of the accident on the environment. This article provides an overview of the work conducted in relation to the environmental impacts of the Fukushima accident, critically comparing and contrasting methodologies and results with a view towards finding reasons for discrepancies, should they indeed exist. Based on the outcomes of studies conducted to date, it would appear that in order to avoid the fractured and disparate conclusions drawn in the aftermath of previous accidents, radioactive contaminants and their effects can no longer simply be viewed in isolation with respect to the ecosystems these effects may impact. A combination of laboratory based and field studies with a focus on ecosystem functioning and effects could offer the best opportunities for coherence in the interpretation of the results of studies into the environmental impacts of ionising radiation.

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1. Introduction

The accident of March 11, 2011 at the Fukushima-Daiichi Nuclear Power Station (FDNPS), resulted in atmospheric releases of significant amounts of radioactive substances leading to the contamination of the surrounding terrestrial (and freshwater) environment through deposition processes and interception by vegetation. Inputs of radioactivity to the marine environment also occurred through (i) atmospheric releases plus deposition to the sea surface and (ii) runoff of seawater used to cool the reactors during the accident plus leakage of wastewaters from damaged containment structures. The major releases primarily took place from 12 to 23 March 2011 i.e. in early spring. According to the International Atomic Energy Agency, IAEA (2015), atmospheric releases (excluding uncertain early estimates) of the key radionuclides ^{137}Cs and ^{131}I amounted to 7–20 PBq and 100–400 PBq respectively. Of these inventories, somewhere between 0.18 and 10 PBq ^{137}Cs and 60–100 PBq ^{131}I were estimated to have been deposited across the Pacific Ocean. Direct releases of contaminated water were estimated to have been 1–6 PBq ^{137}Cs (IAEA, 2015), bearing in mind that larger estimates have been published (e.g. Bailly du Bois et al., 2012). While a broad range of radioactive isotopes were released, the releases contained only very low levels of isotopes of strontium and actinides (owing to the nature of the accident), in contrast to the Chernobyl accident in 1986 (IAEA, 2015). Furthermore, the atmospheric releases were substantially smaller than those associated with the Chernobyl accident. In this regard, for the earlier accident, the releases were estimated to have been about 85 PBq ^{137}Cs and 1.76×10^3 PBq ^{131}I by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2000).

In the aftermath of the FDNPS accident, the protection of human health from radiation exposures was of foremost importance, a radius of 20 km from the site being evacuated on March 12, 2011 due to the risk of high radiation exposures. In contrast, the exposure to radiation of non-human organisms which inhabited the most affected areas, was inevitable. From the perspective of communicating the broader implications of the accident and informing decisions regarding management alternatives, an evaluation of the radiological consequences on the environment is important (see ICRP, 2014). In a general sense, the assessment of impacts on the environment from ionizing radiation is a subject that has received increased attention in recent years with initial focus on developing a system in relation to individual organisms but with less emphasis on establishing the consequences of exposures to radiation at an ecosystem level. The putative inertia against addressing ecosystem impacts is plausibly a reflection of the state of knowledge and the challenges associated with addressing a complex ecological situation.

Great progress has been made over the last two decades in expanding radiological assessment systems to encompass environmental perspectives. Of particular note were the activities of the International Union of Radioecology, which were key to providing momentum in moving the subject forward (IUR, 2000; IUR, 2002). Various internationally supported methods and norms have been developed (see ICRP, 2008, 2009, 2014) in this period, which allow environmental exposures to be quantified and contextualised. The impact on the environment may be manifested at all levels of organisation but the major societal concern is to protect ecosystems and natural populations with due consideration of those that have been provided legislative protection on the individual level, such as species considered as being endangered. However, as system relevance increases, from an ecological perspective, there is a concomitant increase in the system complexity and a resultant difficulty in assessing the response(s) to a stressor. Toxicological investigations, as a result of this, usually are oriented towards simpler systems, or towards tissue and individual effects but attempts must then be made to extrapolate this information to populations and higher levels of biological organisation (Garnier-Laplace et al., 2004). It seems logical to assume that the most pertinent biological endpoint in individuals after radiation exposure will be disturbances in reproduction, especially in view of known radiation sensitivities of the various concomitant stages (oocytes, spermatogonia, newborn etc.) and the importance of the endpoint for population sustainability. This point is recognized by the ICRP (ICRP, 2008). With this in mind, information regarding radiation induced effects in wild plants and animals has been collated under umbrella endpoints by the ICRP such as mortality, morbidity and reduced reproductive capacity. Through the work of the ICRP and others (see e.g. Strand et al., 2000; Strand and Larsson, 2001. Larsson, 2008; Vives i Batlle et al., 2007, Strand et al., 2014), various methods/methodologies are available to facilitate the process of assessing the impact of exposures in a robust manner. In recent years, the IUR has identified a need to move radiological impact assessments towards a more ecosystem based approach drawing on the advances made in other environmental science disciplines (IUR, 2012; IUR, 2015). An overview of the various effects commonly considered at different levels of biological organisation is given in Fig. 1.

Analyses of impacts on the environment following a nuclear accident are, of course, not without precedent. The temporal development of radiation impacts on plants and animals following nuclear accidents have been described in relation to the Chernobyl and Kyshtym accidents (e.g. Gerask'in et al., 2008; Alexakhin, 2009). After the Chernobyl accident, severe impacts were observed in areas near to the nuclear plant (Kryshev et al., 2005). The Chernobyl accident occurred in spring with accelerated growth in the natural

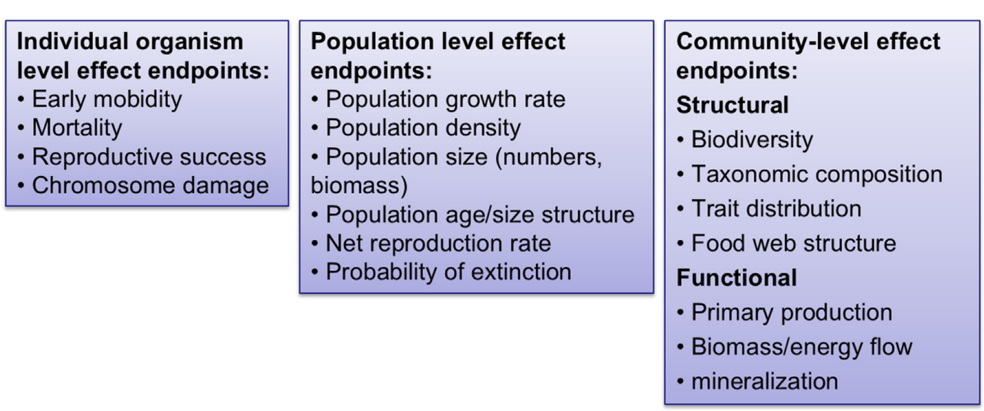

Fig. 1. Schematic of what is meant by "effects to individuals" versus "effects to populations" and "effects to ecosystems". Adapted from Bradshaw et al. (2014).