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Short communication

Using an Ecosystem Approach to complement protection schemes based on organism-level endpoints

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ABSTRACT

Radiation protection goals for ecological resources are focussed on ecological structures and functions at population-, community-, and ecosystem-levels. The current approach to radiation safety for non-human biota relies on organism-level endpoints, and as such is not aligned with the stated overarching protection goals of international agencies. Exposure to stressors can trigger non-linear changes in ecosystem structure and function that cannot be predicted from effects on individual organisms. From the ecological sciences, we know that important interactive dynamics related to such emergent properties determine the flows of goods and services in ecological systems that human societies rely upon. A previous Task Group of the IUR (International Union of Radioecology) has presented the rationale for adding an Ecosystem Approach to the suite of tools available to manage radiation safety. In this paper, we summarize the arguments for an Ecosystem Approach and identify next steps and challenges ahead pertaining to developing and implementing a practical Ecosystem Approach to complement organism-level endpoints currently used in radiation safety.

1. Introduction

Ecosystem processes underpin a range of services that are vital to the sustainability of human societies such as flood control, pollination of crops, mineral recycling, maintenance of food web structure, and climate control (MEA, 2003). Under the pressure of environmental managers and policy makers, international legislation currently expresses management goals of protection in ecological terms featuring integrated objectives of protection such as maintaining ecosystem structure (biodiversity) and functions (life support, etc.). The Convention on Biological Diversity for example recommends adopting an "Ecosystem Approach" and has identified several principles to support it (CBD, 2000). Consistent with ecosystem-oriented policies, environmental scientists in fields such as fisheries and forestry are actively developing technical tools to support ecosystem management. Overall, this trend is now rooted in a broad consensus that environmental protection is best served by methods and concepts targeting populations and their interactions with other biota and abiotic components of ecological systems or other methods that holistically consider the ecosystem level.

The emerging focus on ecosystems is not yet reflected in the current approaches for protecting the environment (i.e. non-human biota, other biota or wildlife) against radiation advocated by the ICRP (ICRP, 2008) or other similar approaches (ERICA, 2007;

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US DOE, 2002). All such approaches take a limited set of reference organisms as in the "Reference Animals and Plants" of ICRP (abbreviated as RAPs) mimicking the concept of "reference person" used in human radiological protection (ICRP, 2007). The ICRP RAPs were chosen using various taxonomic and practical criteria to serve as points of comparison in ecological risk assessments. The radiosensitivity of each reference organism is documented (from a wide literature survey of radio-toxicological data) in terms of radiation-induced dose–response curves for four individual organism-level endpoints: early mortality, morbidity, reproductive success, and mutation frequency. Simple dosimetric models have been developed to map measured or derived activity concentrations of radionuclides in organisms and their habitat on to absorbed dose-rates. Dose rate bands for RAPs within which certain effects have been noted, or might be expected, are then used to construct a scale of risk (ICRP, 2008) to help decision makers. The components of the system provide the basis for relating exposure to dose, and dose to radiation effects, for different types of animals and plants in an internally consistent manner. One key aspect of this method, directly evolving from traditional toxicology, is to emphasise individual organisms rather than populations or ecosystems.

As a consequence, the existing approach to radiation protection, as best illustrated by recent ICRP developments (ICRP, 2008), is based on a conceptual method linked to individual reference organisms. This approach could be sufficient to protect ecosystems only if the suite of reference organisms included the most sensitive and most highly exposed species within the ecosystem. Since it will never be possible to test the radiosensitivity of all life stages of every species and since radiation exposures are likely to vary over even very small spatial scales, we can never guarantee that the reference organism approach will protect all components of an ecosystem. Moreover, exposure to stressors can trigger non-linear changes in ecosystem structure and function that cannot be predicted from effects on individual organisms. For these reasons, the reference organism approach and the resulting protection system is largely inconsistent with respect to current management goals (Fig. 1). Development of an Ecosystem Approach to radiation protection would eliminate this inconsistency.

2. Scientific limits of current approaches

In addition to being inconsistent with evolving environmental management goals, organism-level approaches to radiation protection only partially address potential environmental effects of ionising radiation, especially ecosystem-level effects. Ecologists have long known that perturbations induced by stressors such as harvesting (Fogarty and Murawski, 1998), species introductions (Mack et al., 2000), nutrient addition (Carpenter et al., 1998) or chemical discharges (Fleeger et al., 2003) cannot be entirely grasped from knowledge of the stressor's effects on individual organisms or single-species populations, even when addressed through statistical approaches such as species sensitivity distributions (Forbes and Calow, 2002; Garnier-Laplace et al., 2013; Posthuma et al., 2001). Such effects may act as triggers of perturbation, which propagate through higher levels of biological organisation within ecosystems, with ultimate system consequences that may differ radically from those expected based on effects observed at the organism-level. In extreme cases, irreversible changes in ecosystem structure and function, termed "regime shifts," can occur (Holling, 1973; Scheffer et al., 2001, and see Section 4). These phenomena are particularly relevant when considering the potential long-term ecological effects of chronic exposure to radiation, as such impacts may not be manifested as the result of direct radio-toxicological effects on individual organisms, but rather as the consequence of indirect effects resulting from differences in sensitivity of different species, potentially leading to changes in habitat structure or altered trophic relationships (Geras'kin et al., 2008; Woodwell, 1967). For example, in an area of pine-birch forest severely affected by releases of radionuclides following an accident in the Southern Urals, the amount of light energy reaching the earth's surface increased by up to a factor of 5 and the air temperature increased by 1–2 °C. Also, at Chernobyl, changes in the microclimate and structure of grassy communities within the area of dead pine stands and severely affected birch stands led to a 2–3 fold increase of grass-cover biomass (Alexakhin et al., 2004).

Such shortcomings in the protection frameworks have already been recognised and discussed in other fields of environmental protection (Tannenbaum, 2005), and have also been stressed in the area of radiological protection (Bréchignac, 2003; Bréchignac,

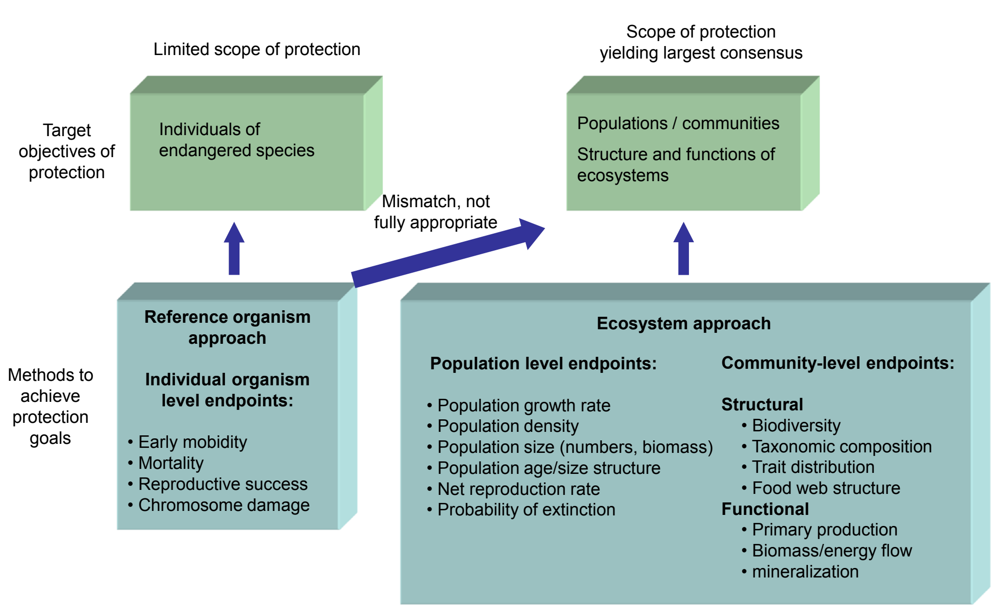

Fig. 1. Target objectives of environment protection versus methods to achieve them.