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The impact of the Fukushima nuclear accident on marine biota: Retrospective assessment of the first year and perspectives

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HIGHLIGHTS

- UNSCEAR assessment of the Fukushima accident impact on the marine environment.
- The study covers the period from March 2011 to August 2012.
- Doses to marine organisms are generally below levels for effects on populations.
- The only exception is ^{131}I in macroalgae near the plant early after the accident.
- Exposures to biota in the late phase are below the thresholds for population effects.
- Further away from the plant, potential effects on biota will be significantly lower.

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ABSTRACT

An international study under the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) was performed to assess radiological impact of the nuclear accident at the Fukushima-Daiichi Nuclear Power Station (FDNPS) on the marine environment. This work constitutes the first international assessment of this type, drawing upon methodologies that incorporate the most up-to-date radioecological models and knowledge.

To quantify the radiological impact on marine wildlife, a suite of state-of-the-art approaches to assess exposures to Fukushima derived radionuclides of marine biota, including predictive dynamic transfer modelling, was applied to a comprehensive dataset consisting of over 500 sediment, 6000 seawater and 5000 biota data points representative of the geographically relevant area during the first year after the accident. The dataset covers the period from May 2011 to August 2012. The method used to evaluate the ecological impact consists of comparing dose (rates) to which living species of interest are exposed during a defined period to critical effects values arising from the literature.

The assessed doses follow a highly variable pattern and generally do not seem to indicate the potential for effects. A possible exception of a transient nature is the relatively contaminated area in the vicinity of the discharge point, where effects on sensitive endpoints in individual plants and animals might have occurred in the weeks directly following the accident. However, impacts on population integrity would have been unlikely due to the short duration and the limited space area of the initially high exposures. Our understanding of the biological impact of radiation on chronically exposed plants and animals continues to evolve, and still needs to be improved through future studies in the FDNPS marine environment.

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1. Introduction

In the wake of the catastrophic earthquake and tsunami on 11 March 2011, reactor failures at the FDNPS resulted in a significant input of radionuclides to the marine environment. This input occurred both as direct releases into the sea and as deposition of atmospheric releases, given that the direction of the prevailing winds at the time of the accident was towards the sea. This situation presented the urgent need to investigate the radiological impact of accidental releases from Fukushima to marine biota, focussing not only on the first months of the accident when the situation was highly dynamic, but also on the intervening 1-year period, in order to follow-up the impact of radionuclides still persisting in that local environment. Additionally, a long-term prospective assessment would help to manage the situation.

A fuller description of the accident is given elsewhere (IAEA, 2011; IRSN, 2012; PMJHC, 2011; Povinec et al., 2013). The scope and magnitude of the marine radioactive releases were relatively well-known from shortly after the accident (Bailly du Bois et al., 2012; Buesseler et al., 2011; Garnier-Laplace et al., 2011; IRSN, 2011; Tsumune et al., 2012; Vives i Batlle, 2011). Several radionuclides such as ^{131,132}I, ^{134,136,137}Cs and ^{129,129m,132}Te were accidentally released into the marine environment, due to the combined effect of radioactive liquid effluent releases and the settling of the airborne radioactive particles. Some 10^{16} Bq of ^{137}Cs found their way into the Pacific Ocean, 80% of this input occurring between 11 March and 8 April 2011. Radionuclide levels in the coastal zone were seen to decrease with distance by a factor of roughly 10^3 over the first 30-km from the source, and with time by factors of about 30 (^{137}Cs) and 200 (^{131}I) over the few weeks post-accident (Buesseler et al., 2011; Garnier-Laplace et al., 2011). By the end of May 2011, the short-lived radioisotopes had largely disappeared and ^{134,137}Cs were the dominant radionuclides. Continued release of various effluents from land resulted in sustained contamination levels in the area during July 2011. A significant fraction of this contamination reached the seabed due to scavenging by suspended sediment or biogenic particles as well as sorption processes (Alekseev et al., 2006; Shiomoto et al., 1998; Vives i Batlle, 2011).

An initial screening study suggested that maximum dose rates for ^{131}I, ^{134}Cs, and ^{137}Cs to marine biota in the immediate aftermath of the accident could have ranged from 9 mGy h^{-1} for marine birds and 110 mGy h^{-1} for benthic biota to 190 mGy h^{-1} for macroalgae (Garnier-Laplace et al., 2011). This study assumed equilibrium of the biota with the highest seawater concentrations measured. Another early assessment carried out over a slightly longer period (March–May 2011) indicated that dose rates to fish and molluscs from the local coast did not exceed 420 μGy h^{-1} and were generally in the order of 80 μGy h^{-1} (Kryshev and Sazykina, 2011). Monitoring studies indicated that, due to their high concentration capacity (especially for iodine), macroalgae were the marine organisms with the highest activity concentrations, followed by molluscs and fish (Greenpeace, 2012).

The dose rates to marine biota calculated in the first screening study (Garnier-Laplace et al., 2011) are generally higher than the ERICA[1] screening value of 10 μGy h^{-1} below which 95% of the species of an ecosystem are exposed to doses less than the ones giving 10% effects on their survival, reproduction or growth (Beresford et al., 2007; Brown et al., 2008) and the UNSCEAR[2] level of 400 μGy h^{-1} which was defined as the "maximum dose rate to a small proportion of the individuals in aquatic populations of organisms that would not have any detrimental effect at the population level". Hence, this study alerted on potential effects of ionising radiation at various levels of intensity but the exposure dose rates were assessed for a limited space area and a limited time period. Discrepancies were highlighted: for Garnier-Laplace et al. since the dose rates reported only for the first 3-week period after the accident were based on equilibrium with maximum water concentrations for all radionuclides reported from water measurements and all irradiation pathways, they may have been overestimated (Buesseler et al., 2011; Vives i Batlle, 2011) — by at least one order of magnitude, according to other researchers (Kryshev and Sazykina, 2011; Kryshev et al., 2012). However, the latter studies, dealing with the first 2 months after the accident, did not take into account the external irradiation from sediment in the coastal zone.

The uncertainties associated with dose estimates to non-human species in the early studies, along with the need to establish the significance of these doses in terms of effects to the marine biota, prompted the UNSCEAR to approach this issue shortly after the accident (Weiss, 2012). There are very few reports of radiation effects in sensitive endpoints of marine biota for both acute high doses and chronic low dose rates. By necessity, one must rely on a combination of data for marine and freshwater species and the reasonable assumption that there will not be a significant difference in the radiosensitivity of freshwater versus marine species. Different endpoints need to be considered including mortality, morbidity and reproductive effects. The UNSCEAR had previously analysed extensively the relevant data in its scientific annexes of the 1996 (UNSCEAR, 1996) and 2008 (UNSCEAR, 2008) reports, concluding that maximum dose rates of less than 400 μGy h^{-1} to any individual in aquatic populations of organisms would be unlikely to have any detrimental effects at the population level (UNSCEAR, 2011). This is based on the knowledge that there is little consistent and significant evidence for any effects on reproductive capacity at dose rates <200 μGy h^{-1} (Copplestone et al., 2008; FREDERICA, 2006; Garnier-Laplace et al., 2008). Other benchmarks for contrasting purposes have been proposed. The ERICA and PROTECT[3] projects (Andersson et al., 2009; Beresford et al., 2007; Garnier-Laplace et al., 2008) suggested a generic dose rate of 10 μGy h^{-1} for use in screening out environmental exposure situations of negligible concern. The ICRP[4] also published derived consideration reference levels (DCRLs) that can be used to identify where there is likely to be some chance of deleterious effects of exposure to ionizing radiation on individual reference animals and plants (ICRP, 2008). The DCRLs published are broadly consistent with the benchmarks presented above, as UNSCEAR information shows (UNSCEAR, 2011).

The present study is the first comprehensive assessment for the marine environment, as part of an overall assessment for the terrestrial and aquatic ecosystems of Fukushima (Strand et al., 2014; UNSCEAR, 2014). It is based on a comprehensive set of monitoring data representative of the first year after the accident (500 sediment, 6000 seawater and 5000 biota data points) and compiled by the UNSCEAR along with other relevant reports and published scientific papers. It is complemented by additional predictive dynamic modelling of radionuclide transfer to biota for the earliest phase of the accident. As added value, the study demonstrates the advantages of using such dynamic transfer modelling in preference to equilibrium-based transfer models in accidental situations, in accordance with what had been observed earlier in the marine environment of Fukushima (Kryshev et al., 2012; Vives i Batlle, 2011; Vives i Batlle and Vandenhove, 2014) and other areas (Vives i Batlle et al., 2007b).

2. Materials and methods

To quantify the radiological impact on wildlife, a suite of recently developed approaches (Avila et al., 2004; Brown et al., 2008; ICRP, 2008; ICRP, 2009; Larsson, 2008; Sazykina, 2000; UNSCEAR, 2008; Vives i Batlle et al., 2008b) was applied to calculate exposure and thereafter effects were predicted through comparison with critical effects (or no-effect) values arising from compiled dose/response relationships.

[1] ERICA = "Environmental Risks from Ionising Contaminants: Assessment and management" an EC EURATOM Framework 6 funded project.
[2] UNSCEAR = "United Nations Scientific Committee on the Effects of Atomic Radiation."
[3] PROTECT = "Protection of the Environment from Ionising Radiation in a Regulatory Context" EC EURATOM Framework 6 funded project.
[4] ICRP = "International Commission on Radiological Protection."