Chapter 15
Radioactive Contamination in Some Arthropod Species in Fukushima

Tarô Adati and Sota Tanaka

Abstract To clarify the extent of radioactive contamination in a broad environment of Fukusima, in and around farming lands and residential areas, the amount of radionuclides in the Japanese grasshopper, *Oxya yezoensis*, the Emma field cricket, *Teleogryllus emma*, the wasp spider, *Argiope bruennichi*, and the Jorô spider, *Nephila clavata*, was investigated. Radioactive cesium was detected in all arthropods collected from survey sites in Fukushima. The highest radioactive cesium (^{134}Cs and ^{137}Cs) concentration of approximately 4.7×10^2 Bq/kg (wet weight) was detected from the grasshopper. The amount of radionuclides tended to rise in agreement with the space radiation dose rates in the survey sites. The spiders, which are classified at higher trophic levels on the food chain, therefore demonstrated correspondingly higher levels of cesium concentration, suggesting that bioaccumulation of radioactive cesium was occurring.

Keywords Insects • Spiders • Environmental indicator • Food chain • Bioaccumulation

15.1 Introduction

15.1.1 Radiation and the Ecosystem

Although 2 years have passed since the Fukushima Daiichi Nuclear Power Plant (FDNPP) accident, the recovery of agriculture in many areas of Fukushima Prefecture remains at a standstill. A major factor behind this hiatus is environmental

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contamination by radionuclides. Although decontamination is progressing, mainly in rice paddies and non-paddy arable fields, shipment restrictions on some crops in certain areas remain as of July 2013, including fruit varieties such as yuzu (citron), kiwifruit, and chestnuts, fungi such as shiitake mushrooms, and wild vegetables such as bamboo shoots and bracken shoots (Forestry Agency 2013; MAFF 2013). Despite decontamination of fields and areas near residences, moreover, in some cases the ambient radiation dose rate rises again as time passes, requiring re-decontamination.

Decontamination of cropland generally involves removing the top layer of soil, including plants contaminated with radioactive fallout from the FDNPP. When determining which areas to decontaminate, focus is placed on districts in which people are living, although land usage and administrative boundaries also are factors in decisions. However, in Fukushima, which has large areas of forest-covered mountains, inhabited districts cover a comparatively insignificant area, and even if local residential zones are decontaminated, subsequent rain or wind will bring radiation down from the mountains, re-contaminating them.

The landscape of Japan's farming villages resembles a mosaic, featuring not only rice paddies and non-paddy arable fields but also waterways, levees, and ponds, as well as houses and surrounding tree groves, backed by woodland that spreads into the mountains. This setting is home to a diverse range of life, including aquatic organisms (insects, crustaceans, shellfish, amphibians, fish, etc.), land organisms (insects, spiders, reptiles, mammals, etc.), birds, and plants (crops and weeds). This farming village ecosystem is not closed: each organism is linked through its activities to the outside world, in an open, dynamic environment.

Indeed, nature itself is inherently dynamic, and accordingly current decontamination methods, which target relatively stationary elements such as soil and plants, are unable to decontaminate the wide-ranging ecosystem in its entirety. To do this, the extent of radioactive contamination in this broad environment must first be ascertained. Effective environmental indicators for this purpose are organisms that are widespread throughout the area as components of the ecosystem. Organisms suggested as candidates for this indicator role are generally arthropods such as insects.

So what effect *do* radionuclides have on arthropods? Or more simply—how resilient are arthropods against radiation?

There is a pest control method that uses artificial radiation to eliminate insect pests that cause damage to crops and livestock. This process entails directing gamma rays or electron beams at insects to either kill them directly or render them infertile via sterilization before returning them to their environment. Detailed data have been gathered on the effects of radiation on the insects targeted by this process.

For example, the melon fly, *Bactrocera cucurbitae* (Coquillett) (Diptera: Tephritidae), once ravaged plants and fruit of the melon family on the Nansei Islands to the south of the Japanese archipelago before being eradicated via sterilization. It is known that the fly's reproductive cells are destroyed upon exposure to 70 Gy gamma radiation from ^{60}Co, rendering the organism infertile (Koyama 1994). In addition, it is known that the sweet potato weevil, *Cylas formicarius* (Fabricius)

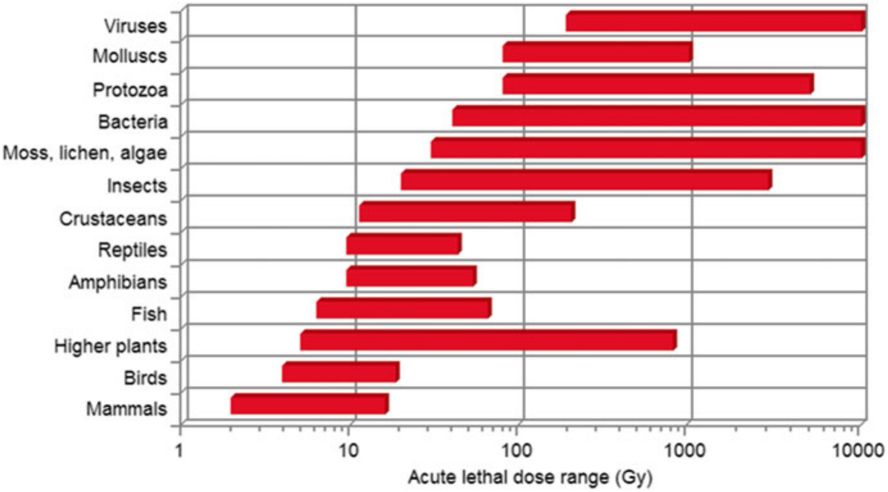

Fig. 15.1 Acute dose ranges that result in 100 % mortality in various taxonomic groups (Modified from IAEA 2006)

(Coleoptera: Brentidae) is also sterilized upon irradiation with gamma rays of 70 Gy or greater (Iwamoto et al. 1990), and an elimination program targeting the weevil is currently in progress on the Nansei Islands. In these instances, although the irradiation process sterilizes the organism, it has little to no effect on factors other than reproduction, such as survival rate or mating behavior. Gamma radiation of 70 Gy is equivalent to 70,000 mSv, a level that would instantly kill a human. As shown in Fig. 15.1, arthropods such as insects and crustaceans are relatively tolerant of radiation within the animal kingdom, whereas humans are among the most sensitive mammals and therefore among the most sensitive organisms (IAEA 2006).

However, in contrast to artificial radiation, at present little is known of the effect of environmental radionuclides on arthropods in the wild, even from the experience of the Chernobyl and FDNPP accidents. Despite the reported discovery of malformed insects in the irradiated zones after these two nuclear accidents (Hesse-Honegger and Wallimann 2008; Hiyama et al. 2012), it is not clear whether such malformations were in fact a result of radionuclides emitted by the accidents. No conclusion can be drawn because malformation in insects from unknown causes is often observed in nature.

Following the Fukushima accident, studies of the level of space radiation and the radionuclides in soil and crops have been conducted at various sites. However, reports related to arthropods are extremely limited (Fugo 2012; Hiyama et al. 2012). One area that is decidedly lacking data is internal irradiation from radionuclides. There is only one way to investigate this: by collecting arthropods from contaminated sites and measuring the amount of radionuclides accumulated inside their bodies.

15.1.2 Traveling to Fukushima

Tarô Adati, one of the authors of this chapter, was aware that the situation 1 year on from the nuclear accident was broadly as outlined in the previous section. However, he did not intend to visit Fukushima to study arthropods, because he believed this sort of study should be performed by well-organized teams of experts rather than a lone academic, who despite specializing in entomology was an amateur in the field of radiobiology. But as chance would have it, something unexpected occurred. Sota Tanaka was a fourth-year student whose graduation research project Adati happened to be in charge of supervising. Tanaka mentioned when selecting his research topic that he wanted to investigate something that would aid Tohoku's disaster zone. He asked to study the insects in Fukushima, and faced with his enthusiasm, Adati eventually came around to the idea. So that is how a young student's passion swayed a worn-out, middle-aged academic, leading to the creation of a very small research team composed of a duo with a generation gap.

We traveled from Tokyo to Fukushima on the bullet train and rented a car near the station. We were headed for the village of Iitate. The wind direction at the time of the accident meant that the area had sustained a large amount of radioactive fallout despite being located a relatively long distance from the nuclear plant. Most of the village had been declared a long-term evacuation zone, and part of its southern end had been designated a potentially permanent evacuation zone.

We visited a certain local resident who ran a farm in the village. He was a relative of a student in our department, and we had been in contact with him beforehand. Although the district in which his house and farm were located had recently been changed to a short-term evacuation zone in which the evacuation order would soon be lifted, he was not allowed to stay in his own house overnight. However, he was working part-time guarding the village administrative office, and after working night shifts he would rest at his home during the day. He told us that, despite the continuing restrictions, the space radiation dose in his area was relatively low, perhaps a result of the topography. Once the decontamination was complete, he planned to resume farming.

15.2 Surveys in Fukushima

15.2.1 Space Radiation Dose Rates in Survey Sites

The following is an overview of the study we conducted in Fukushima in 2012. We began by using a portable NaI (Tl) scintillation survey meter to measure the space radiation dose rate at two survey sites in Iitate and one survey site in the city of Soma. Comparison of the results with data measured in the city of Atsugi in Kanagawa Prefecture, about 270 km from the FDNPP, showed correspondence between ambient radiation levels and distance from the nuclear plant (Table 15.1).

Table 15.1 Space radiation dose rates and radioactive contamination in arthropods at survey sites (Sept.–Oct. 2012)

Survey site		Distance from FDNPP (km)	Median of space radiation dose rates (μSv/h)[a]	Median of radioactive cesium (^{134}Cs + ^{137}Cs) amounts in arthropod samples (Bq/kg fresh weight)[b]			
				Japanese grasshopper	Emma mole cricket	Wasp spider	Jorô spider
A	Iitate, Fukushima	40	3.74	469	156	114	310
B	Iitate, Fukushima	44	1.98	188	194	–	214
C	Sôma, Fukushima	46	1.14	3	76	6	–
D	Atsugi, Kanagawa	267	0.04	2	8	–	4

[a] Space radiation dose rates were measured 1 m above ground surface with 5 replications per site
[b] Radioactive contamination was detected in an arthropod sample containing 10–50 individuals with 4 replications. If the radioactive measurement of a sample was lower than the measurable limit, the limit value was considered as its amount.– No samples collected

Ambient radiation dose rates exceeded 1 μSv/h at each of the three sites in Fukushima Prefecture, clearly from the effect of radioactive fallout from the FDNPP accident. However, the variance recorded among the three survey sites is likely caused by a range of factors, such as topography and wind direction at the time of the accident, rather than distance from the nuclear plant alone. The highest dosage measured during the survey was at Survey Site A, a flat area of land in a long-term evacuation zone. Site B was a fallow field in a short-term evacuation zone within an area surrounded by woodland and rivers. Although Site C was a fallow field that had yet to be decontaminated, it had a relatively low dosage compared to the other survey sites, possibly because of the decontamination of nearby fields.

15.2.2 *Sampling of Arthropods and Detection of Radioactive Cesium*

Next, we collected arthropod samples at each survey site (Fig. 15.2) and used a Ge detector to investigate the levels of radioactive contamination. The arthropods sampled were the Japanese grasshopper, *Oxya yezoensis* Shiraki (Orthoptera: Catantopidae) (Fig. 15.3); the Emma field cricket, *Teleogryllus emma* (Ohmachi & Matsuura) (Orthoptera: Gryllidae) (Fig. 15.4); the wasp spider, *Argiope bruennichi* (Scopoli) (Araneae: Araneidae) (Fig. 15.5); and the Jorô spider, *Nephila clavata* L. Koch (Araneae: Nephilidae) (Fig. 15.6). The Japanese grasshopper is herbivorous, the Emma field cricket is omnivorous, and the wasp and Jorô spiders are predatory.

Fig. 15.2 Collecting arthropods at a survey site in Fukushima

Fig. 15.3 The Japanese grasshopper, *Oxya yezoensis*

Fig. 15.4 The Emma field cricket, *Teleogryllus emma*

Fig. 15.5 The wasp spider, *Argiope bruennichi*, feeding on a Japanese grasshopper

Fig. 15.6 The Jorô spider, *Nephila clavata*

As shown in Table 15.1, radioactive cesium was detected in all arthropods collected from survey sites A and B. At Survey Site C, radioactive cesium was detected in the Emma field cricket, but not at significant levels in the other arthropod types. The combined amount of ^{134}Cs and ^{137}Cs per kilogram (Bq/kg) of wet weight tended to increase in line with the space radiation dose rates in the survey sites.

At Site B, the predatory Jorô spider recorded the highest contamination of radioactive cesium at about $2.1 \times 10_2$ Bq/kg; levels in the herbivorous Japanese grasshopper and omnivorous Emma field cricket were lower. Arthropods at higher trophic levels on the food chain therefore demonstrated correspondingly higher levels of cesium concentration, suggesting that bioaccumulation of radioactive cesium was occurring. However, at Site A the Japanese grasshopper recorded a radioactive cesium concentration of about 470 Bq/kg, which was higher than the other arthropod types, including spiders.

15.3 Discussion

The presence of radioactive cesium in herbivores (primary consumers) such as the Japanese grasshopper can only be attributed to consumption of radioactive fallout from the the FDNPP that contaminated the grasses (producers) which serve as the species' main food source. Furthermore, if predatory spiders (secondary consumers) feed on several herbivorous or omnivorous organisms, radionuclides are likely to be concentrated in these predatory organisms, which are higher on the food chain. In fact, we observed a wasp spider feeding on a Japanese grasshopper at Survey Site A (Fig. 15.5). However, if the radioactive concentration in higher predator spiders is low, as at Site A, it is also possible that radioactive cesium does not accumulate readily in the primary consumers such as grasshoppers for some reason. During this study, for example, we immediately preserved the collected arthropods in ethanol. Thus, grasses consumed by the Japanese grasshoppers may have remained within the alimentary canal. As a result, it is possible that most of the radioactivity detected was attached to the undigested plant material and therefore concentrated in the digestive tract. Indeed, it has been reported that the concentration of radioactive cesium declines when grasshoppers are collected and left to excrete droppings for a period of time (Fugo 2012). The transfer of radionuclides from food to body tissue in arthropods therefore needs to be investigated further in future.

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