Chapter 13
Nuclear Radiation Levels in the Forest at Minamisoma, Fukushima Prefecture

Iwao Uehara, Tomoko Seyama, Fumio Eguchi, Ryuichi Tachibana, Yukito Nakamura, and Hiroya Ohbayashi

Abstract The Great East Japan Earthquake occurred on March 11, 2011, and 4 days later, the Tokyo Electric Power Company (TEPCO) Fukushima No. 1 Nuclear Power Plant accident happened. The accident caused serious nuclear pollution damage for the Fukushima area, and it was reported that the forest area had received especially severe damage. However, its present situation has not been studied yet, nor has reforestation been planned. Therefore, we surveyed the amount of nuclear radiation at the forest of Minamisoma City where the amount of radiation has been reported as extremely high. We set several survey plots in the forest and surveyed the radiation amount of leaves, branches, wood (bark and stem), soil, litter interception, and irrigation water. The surveying results showed nuclear pollution was not spread equally in the Minamisoma forest, but in several "hot spots," that some litter interception indicated high radiation amounts, the extraction rates from bark to xylem were different between conifers and deciduous trees and between standing living trees and mushroom bed logs, and radioactive cesium was not detected in transpiration water.

Keywords Nuclear radiation • Minamisoma City • Fukushima • Forest

13.1 Introduction

The Great East Japan Earthquake occurred on March 11, 2011. It was followed during the next 4 days by the Tokyo Electric Power Company (TEPCO) Fukushima Daiichi Nuclear Power Station accident. The accident caused serious nuclear pollution damage in the Fukushima area, and it has been reported that forested areas sustained especially severe radiation damage (Uehara et al. 2014; Kaneko et al. 2013; Nonaka et al. 2012; Schreurs and Yoshida 2013; Takeuchi 2011). However, no

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definitive research has yet been undertaken into the consequences of the accident, and no plans exist for rehabilitating the forest. This study therefore surveyed the nuclear radiation levels in the forest at the city of Minamisoma, where radiation levels were reported to be extremely high (Ministry of Education, Culture, Sports, Science and Technology 2011).

13.2 Methods

We identified six survey areas in the Minamisoma forest (Fig. 13.1) and surveyed the radioactive cesium levels of leaves, branches, trunks (bark and xylem), soil, litter layer, and irrigation water. We also surveyed transpiration water from the leaves of trees. We used a radiation surveying system and survey meter from Hitachi Aloka Medical and a germanium detector system from CANBERRA Industries. The survey lasted from April 2012 to July 2013.

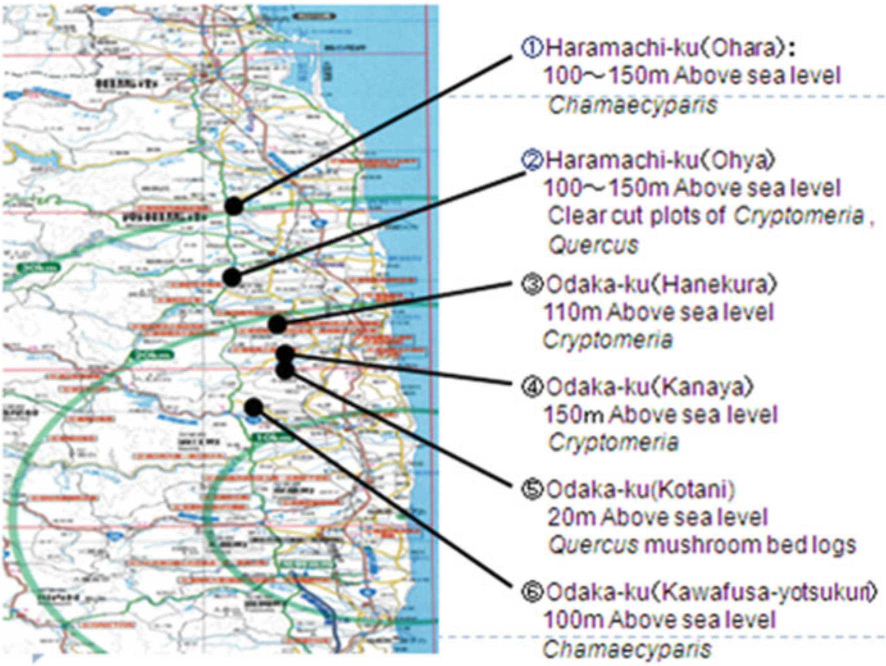

Fig. 13.1 Survey areas in Minamisoma

13.3 Results

13.3.1 Forest Soil

Radiation levels found in the soil around conifers (*Chamaecyparis* and *Cryptomeria*) were high, whereas levels around deciduous *Quercus* were lower. The radiation levels in clear-cut plots were lower than in the stands (Table 13.1).

13.3.2 Litter Layer

Some areas indicated extremely high levels of radiation. The data for Tetsuzan Dam in Haramachi and the *Chamaecyparis* stand were especially high (Table 13.2). In terms of geographic features, the former is in a valley and the latter is in a flat field without barrier materials (Figs. 13.2 and 13.3). It has already been reported that *Cryptomeria* and *Pinus* are sensitive to radiation, and the litter layer is where radioactive cesium is easily accumulated (Yoshida 2012). In addition, it was reported in the same work that evergreen trees absorb more radioactive cesium than deciduous trees. Our survey data corroborated these findings, indicating that radiation levels in evergreen conifer wood were higher than in deciduous wood.

Table 13.1 Radioactive cesium (Cs) detected at 5-cm depth in forest soil (Bq/kg)

Area	Altitude (m)	^{134}Cs	^{137}Cs	Total Cs
Haramachi-ku *Chamaecyparis* stand (25 years)	135	13,600	19,100	32,700
Haramachi-ku *Chamaecyparis* stand (25 years)	120	5,250	7,460	12,710
Haramachi-ku *Quercus acutissima stand*	20	3,220	5,550	8,770
Haramachi-ku Clear-cut plot of *Quercus serrata*	130	1,380	1,990	3,360
Haramachi-ku Clear-cut plot of *Cryptomeria*	120	78	177	255
Haramachi-ku Minamiebi seaside	0	68	143	211
Odaka-ku *Cryptomeria* stand (40 years)	20	14,700	22,300	37,000

Table 13.2 Radioactive cesium detected in litter layer (Bq/kg)

Area	Altitude (m)	^{134}Cs	^{137}Cs	Total Cs
Haramachi-ku Tetsusan Dam	280	78,300	143,000	221,300
Haramachi-ku *Cryptomeria* stand (40 years)	120	14,180	32,400	46,580
Haramachi-ku City museum: *Abies densiflora* stand	80	5,340	10,800	16,140
Haramachi-ku *Chamaecyparis* stand (20 years)	120	3,830	6,680	10,510
Odaka-ku *Chamaecyparis* stand (15 years)	50	113,000	177,000	290,000
Odaka-ku *Cryptomeria* stand (40 years)	120	53,200	93,600	146,800
Odaka-ku *Cryptomeria* stand (40 years)	100	11,300	19,200	30,500
Odaka-ku Meeting house	120	7,380	12,300	19,680
Odaka-ku Horse Park: *Prunus, Zelkoba*	110	697	1,100	1,797

Fig. 13.2 A 15-year *Chamaecyparis* stand in Odaka-ku

Fig. 13.3 Air radiation is 11–13 μSv at 15-year *Chamaecyparis* stand in Odaka-ku

13.3.3 Branches and Leaves

The levels of radioactive cesium varied considerably, but the levels in conifers and evergreen trees were higher than in deciduous trees (Table 13.3).

13.3.4 Bark and Wood of Standing Trees

The levels of radiation in conifers were higher than in deciduous trees (Table 13.4).

13.3.5 Quercus serrata *Mushroom Bed Logs Outdoors*

Fukushima Prefecture, and the city of Minamisoma in particular, are key locations for production of mushroom bed logs and are home to many mushroom farmers. After the nuclear accident, however, many bed logs were abandoned outdoors (Fig. 13.4). The levels of radiation found in these bed logs varied greatly, but the levels found in xylem were approximately around 60 % of the levels found in bark (Table 13.5).

Table 13.3 Radioactive cesium detected in branches and leaves (Bq/kg)

Area	Altitude (m)	^{134}Cs	^{137}Cs	Total Cs
Haramachi-ku *Cryptomeria* (40 years)	120	1,930	3,280	5,210
Haramachi-ku *Cephalotaxus harringtonia*	120	2,130	3,010	5,140
Haramachi-ku *Quercus myrsinifolia*	120	1,080	2,450	3,530
Haramachi-ku *Carpinus tschonoskii*	120	1,270	1,690	2,960
Haramachi-ku *Zanthoxylum piperitum*	120	1,030	1,560	2,590
Haramachi-ku *Orixa japonica*	120	337	814	1,151
Haramachi-ku *Padus grayana*	120	ND	171	171
Odaka-ku *Chamaecyparis* (15 years)	50	14,500	21,500	36,000
Odaka-ku *Cryptomeria* (40 years)	120	8,030	19,000	27,030
Odaka-ku *Callicarpa japonica*	50	4,180	6,030	10,210
Odaka-ku *Acer palmatum*	50	1,984	3,419	5,403

Table 13.4 Radioactive cesium detected in the bark and wood of standing trees (Bq/kg)

	Altitude (m)	Bark			Xylem			Xylem/bark
		^{134}Cs	^{137}Cs	Total Cs	^{134}Cs	^{137}Cs	Total Cs	
Haramachi-ku *Quercus serrata*	60	2,187	2,275	4,462	1,358	1,654	3,012	67.5 %
Odaka-ku *Quercus serrata* no. 1	20	233	249	482	144	150	294	61.0 %
Odaka-ku *Quercus serrata* no. 2	20	362	341	703	157	184	341	48.5 %
Odaka-ku *Quercus serrata* no. 3	20	719	1,213	1,932	4,258	762	5,020	63.1 %
Odaka-ku *Quercus serrata*	50	13,418	15,418	28,836	7,619	9,418	17,037	59.0 %

Fig. 13.4 Abandoned *Quercus serrata* mushroom bed logs in Odaka-ku

Table 13.5 Radioactive cesium detected in *Quercus serrata* mushroom bed logs outdoors (Bq/kg)

	Altitude (m)	Bark			Xylem			
		^{134}Cs	^{137}Cs	Total Cs	^{134}Cs	^{137}Cs	Total Cs	Xylem/bark
Haramachi-ku *Quercus serrata*	60	2,187	2,275	4,462	1,358	1,654	3,012	67.5 %
Odaka-ku *Quercus serrata* no. 1	20	233	249	482	144	150	294	61.0 %
Odaka-ku *Quercus serrata* no. 2	20	362	341	703	157	184	341	48.5 %
Odaka-ku *Quercus serrata* no. 3	20	719	1,213	1,932	4,258	762	5,020	63.1 %
Odaka-ku *Quercus serrata*	50	13,418	15,418	28,836	7,619	9,418	17,037	59.0 %

13.3.6 Herbaceous Vegetation and Sprouts in Clear-Cut Plots

We also studied herbaceous plants and sprouts that germinated in the spring of 2012. With the exception of *Lamiaceae*, these data show lower radiation levels than those for trees (Table 13.6).

Table 13.6 Radioactive cesium detected in herbaceous vegetation, flowers, and sprouts in clear-cut plots (Bq/kg)

	^{134}Cs	^{137}Cs	Total Cs
Follopia japonica	ND	ND	ND
Macleoya cordata	ND	ND	ND
Lamiaceae	3,320	4,720	8,040
Male flower of *Castanea crenata*	306	553	859
Sprout of *Quercus serrata* no. 1	663	1,000	1,663
Sprout of *Quercus serrata* no. 2	266	281	547
Sprout of *Quercus serrata* no. 3	257	295	552

Fig. 13.5 Trapping transpiration water from the leaves of young *Cryptomeria japonica* using plastic bags in June 2013

13.3.7 Transpiration Water and Irrigation Water

We also surveyed transpiration water from the leaves of trees (Fig. 13.5). The leaves of 8-year-old and 40-year-old *Cryptomeria* trees were wrapped in plastic bags (27 cm^2) for 24 h on June 13, 2013. Samples of 20 ml were analyzed, but radioactive cesium was not detected. This result suggests that the possibility of secondary radioactive contamination from living standing trees may be low.

We also surveyed irrigation water at some locations in the Haramachi and Odaka areas, but radioactive cesium was not detected.

13.4 Discussion

The foregoing results suggest these points.

1. Levels of nuclear radiation in Minamisoma were influenced mainly by the city's location to the northwest of the Fukushima Daiichi Nuclear Power Station and the prevailing wind direction on March 14, 2011.
2. High levels of radiation were distributed unevenly over valleys or fields without barriers.
3. In general, the nuclear pollution was not evenly distributed, but was in the form of "hot spots."
4. The litter layer in some areas showed extremely high levels of radiation.
5. Abandoned forests and multi-layered forests indicated high levels of radiation; levels were lower in clear-cut plots.
6. The extraction rates from bark to xylem were different between conifers and deciduous trees. They were also different between standing living trees and mushroom bed logs (*Quercus serrata*).
7. Levels of radiation found in mushroom bed logs abandoned in the outdoors varied greatly.
8. Radiation levels of herbaceous plants and *Quercus serrata* sprouts that germinated in the spring of 2012 were clearly lower than those of trees in stands.
9. No radioactive cesium was detected in transpiration water, suggesting that the probability of secondary radioactive contamination from living standing trees may be low.

Some attempts need to be made to decontaminate forest areas in Fukushima Prefecture, but the prefecture's forests are extensive and comprise geographically complex terrain, so it is not practically possible to decontaminate them all. However, we propose creating small clear-cut examination plots (Fig. 13.6) in locations where soil erosion cannot occur within the forests. Our survey data showed that the radiation levels of herbaceous vegetation and *Quercus serrata* sprouts germinated in the clear-cut plot in spring 2012 were clearly lower than those of trees in stands. One practical method, therefore, would be to promote growth of the newly germinated plants and sprouts in such plots while continuing to survey radioactive cesium levels.

13.5 Conclusion

The results of this study showed that there were still forests in which radioactive cesium levels were high. The half-life of cesium is more than 30 years, and forest regeneration also takes a long time. We should therefore continue to collect data on radioactive cesium and the dynamics of vegetative regeneration.

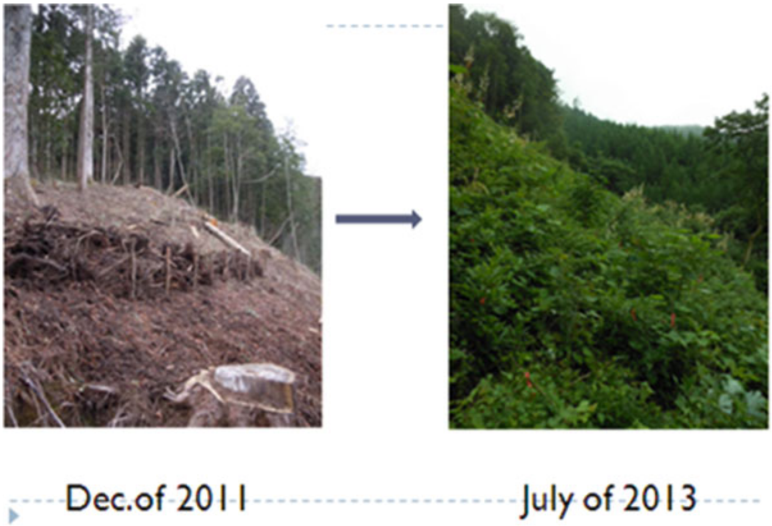

Fig. 13.6 Clear-cut plot within a *Cryptomeria japonica* stand in Haramachi, Minamisoma

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