1. Verification of the Impact of Litter Removal and Logging on Air Dose Rates

1.1. Grasp of the Impact of Clear-Cutting and Thinning on Air Dose Rates

(1) Purpose

Changes in the air dose rates have been measured before and after clear-cutting and thinning works, and the impact of such works on air dose rates has been verified.

(2) Summary of the Results

- The air dose rates exhibited different trends for 16 months after clear-cutting and thinning operations. The rate on the plot where clear-cutting was applied declined considerably more over the period compared to the rate on the plot where thinning was applied.
- The reduction in the air dose rates became smaller after 16 months. On the whole, the air dose rates declined more considerably than the reduction rate of radioactive decay, the former continuing declining gradually until 2018. The rate on the plot where clear-cutting was applied declined was greater than the rate on the plot where thinning was applied.
- Monitoring over a period of approximately seven years revealed a statistically significant difference in the post-work air dose rates between the clear-cut and thinned plots. The air dose rates after clear-cutting and thinning works declined by 22% and 13-18%, respectively, over the period. (The trees were collected and delivered out in February 2012.)

(3) Testing Site and Method

1) Summary of the Testing Site and Work

The survey was performed in a private forest in Hirono Town, Futaba-gun, Fukushima Prefecture (hereinafter referred to as the "Hirono Testing Site"). Table 1-1 outlines the work plots.

Thinning and line thinning works were conducted in the thinned plot from January to February 2012. Clear-cutting work was conducted in the clear-cut plot. Different site preparations (twig scattering, spot weeding, tanazumi work, and twig removal) were applied to different work plots from January to February 2012. The shrubs were then cleared and nursery stocks of konara oak were planted, in December of the same year.

Table 1-1 Outline of the Work plots

Work plot	Forest profile (Forest age)*1 (Population density)	Area	Ave. slope	Work descriptions	Air dose rate*2	Ave. deposition of radiocesium (Cs-137)*3
Thinned plot	Japanese cedar forest (49 years old) (870 trees/ha)	0.36ha (60m× 60m)	23°	Thinning (thinning rate of 25%, volume thinning rate of 15.4%) Trees were all collected and delivered out.	0.52 μSv/h	95 kBq/㎡
Line thinned plot	Japanese cedar forest (49 years old) (1460 trees/ha)	0.36ha (60m× 60m)	24°	Line thinning (thinning rate of 25% (1 in 3 trees are thinned), volume thinning rate of 21.7%) Trees were all collected and delivered out.	0.48 μSv/h	95 kBq/㎡
Clear-cut plot	Mixed forest of Japanese red pine and broad-leaved trees (46 to 63 years old)	0.50ha (25m× 50m × 4 plots)	20°	Clear-cutting and site preparations (twig scattering, spot weeding, tanazumi work, and twig removal) Stems (trees for the plot, where branches were removed) were all collected and delivered out.	0.65 μSv/h	110 kBq/㎡

*1 Data is as of January 2012, when the trees were cut.

*2 The air dose rates were measured at a height of 1 meter above the ground on January 25 and 26, 2012, before the thinning work.
Approximately 10cm of snow had accumulated when the rates were measured. Because the shielding effects of snow coverage might lower the air dose rates, corrected values were adopted (obtained based on the values measured at 10 points before and after snow accumulation), and a shielding rate of 23%.

*3 Published values from the 3rd aircraft monitoring (as of July 2, 2011)

2) Measurement of the Air Dose Rates

The air dose rates were measured every three months with NaI(T1) scintillation detectors. The measurements were taken when there was no rain or accumulated snow (factors that could affect the rates). Measuring points were placed in the form of a cross with the center of each work plot at the node. For the thinned plot, 21 measuring points were placed at intervals of six meters. For the clear-cut plot, 50 measuring points were placed at intervals of 6.25 meters. Seven points along paths scattered with wood chips and eight points at the edges of the forest (both ends of the longer line) were excluded from the analysis for the clear-cut plot.

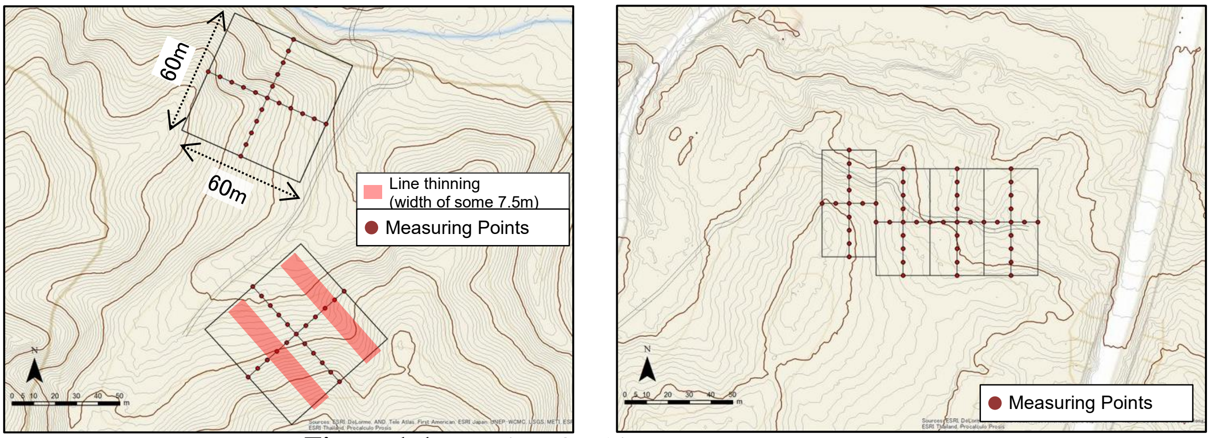


Figure 1-1 Points for Air Dose Rate Measurement

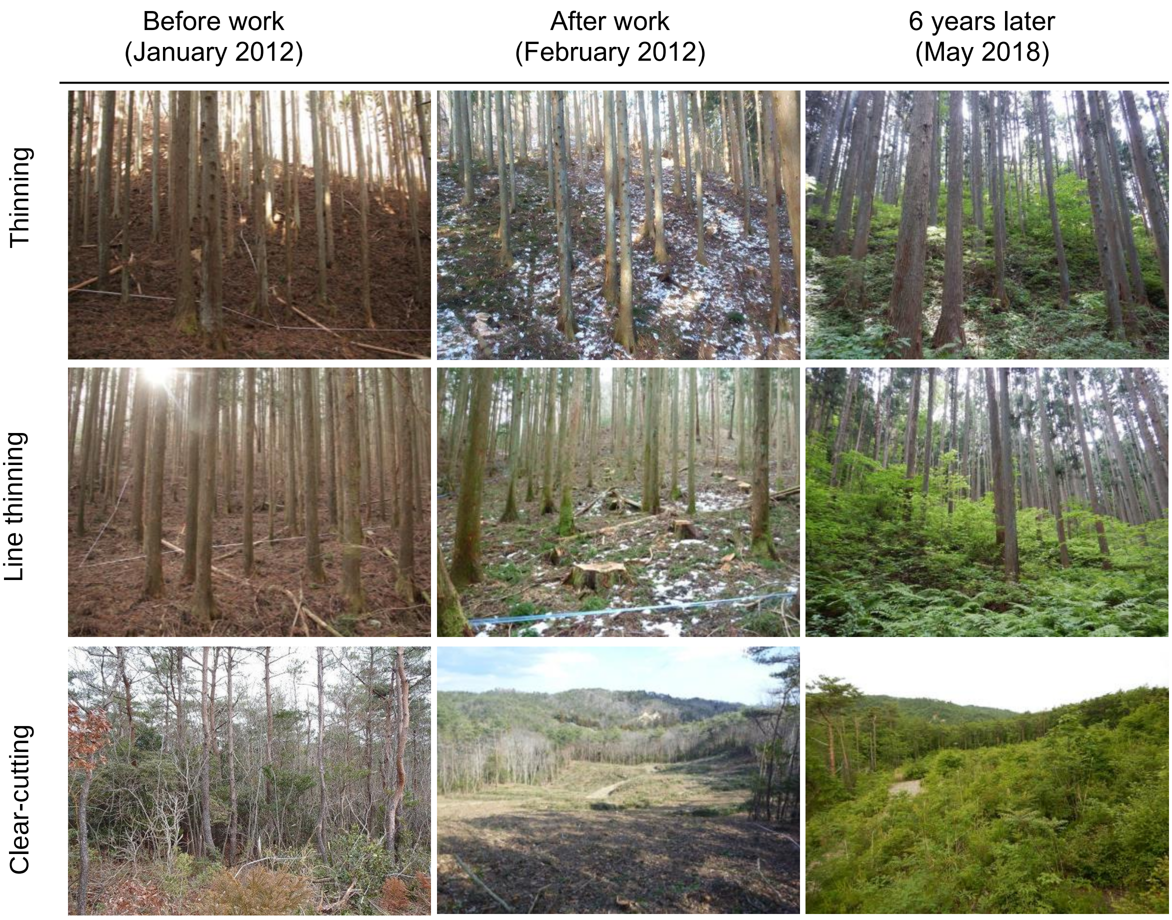


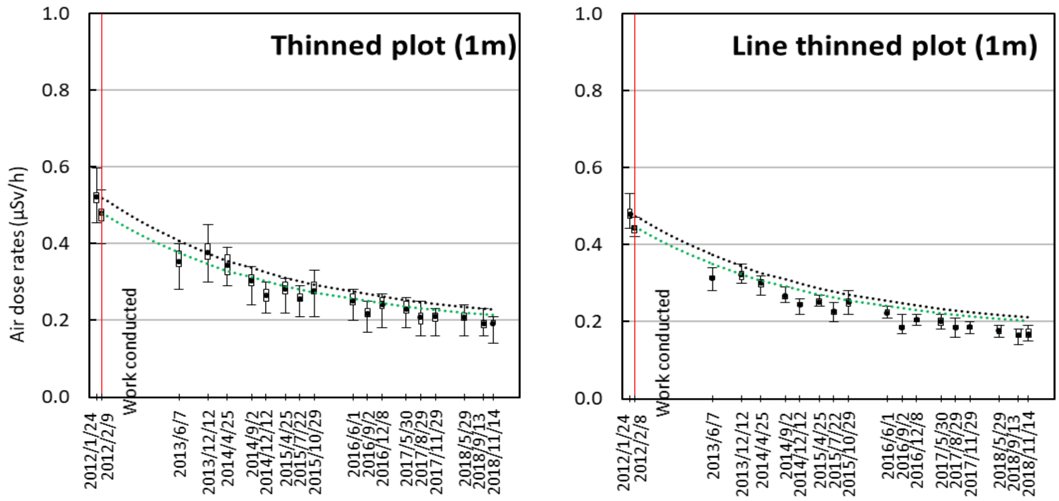
Photo 1-1 Views of the Work plots

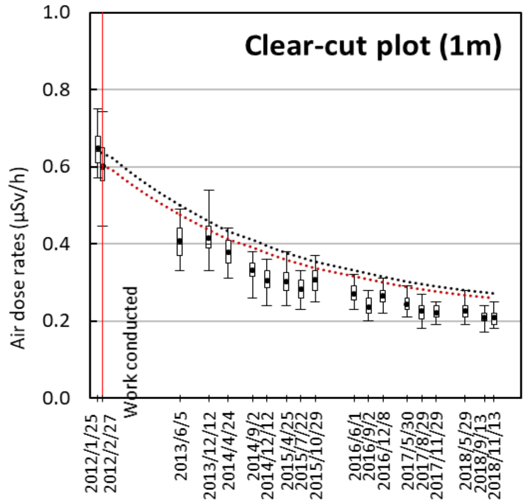
(4) Results

In approximately seven years after the works, the air dose rate in the clear-cut plot declined at a rate higher than the rate of radioactive decay ((Figure 1-2).

The trends of the air dose rates over this period were presented in terms of the ratio to the benchmark (100%) measured before the works were applied (Figure 1-3). There was no difference among different site arrangements in terms of the air dose rate immediately after the works (February 9, 2012, for the thinned plot and February 27, 2012 for the clear-cut plot). After the 16 months from the works (June 2013), the air dose rates continued declining, 19-27% down in the thinned plot and 28% down in the clear-cut plot compared to the rates before the works. After that period, no correlation was observed among the different site arrangements.

Monitoring activities carried out over a period of approximately seven years (February 2012 to November 2018) showed a stable trend of the air dose rates over a certain period (16 months) after the works. As for the mean value for the period starting from June 2013, when the trend was considered to be stable, the post-work air dose rates declined by 13-18% in the thinned plot and by 22% in the clear-cut plot. The reduction rate of clear-cutting was significantly (about 10%) lower than that of thinning.





The air dose rates are actual values (1m above the ground). In each box and whisker plot, the black dot indicates the mean value; the box shows the range from the first to third quartiles; and the whiskers span the first quartile, from the second quartile box down to the minimum, and the fourth quartile, from the third quartile box up to the maximum. n=21 for the thinned plot, and n=35 for the clear-cut plot. (For the latter, some observation points along the paths scattered with wood chips and elsewhere were excluded, out of a total of 50 points.)

The black broken line shows a reduction of the air dose rate due to radioactive decay, with the pre-work rate set as a benchmark. The green and red broken lines show reductions of the air dose rate due to radioactive decay, with the post-work rate being set as a benchmark.

In the thinned plot, approximately 10 cm of snow had accumulated when the air dose rates were measured. Because the shielding effects of snow coverage might lower the air dose rates, corrected values obtained based on values measured at 10 points before and after snow accumulation were adopted, and a shielding rate of 23%.

Radioactive decay correction was calculated in consideration of the difference between the initial abundance ratio and the half-lives of radiocesium Cs-134 and Cs-137.

Figure 1-2 Air Dose Rate Trends after Thinning (Japanese cedar forest) and Clear-Cutting (mixed forest of Japanese red pine and broad-leaved trees)

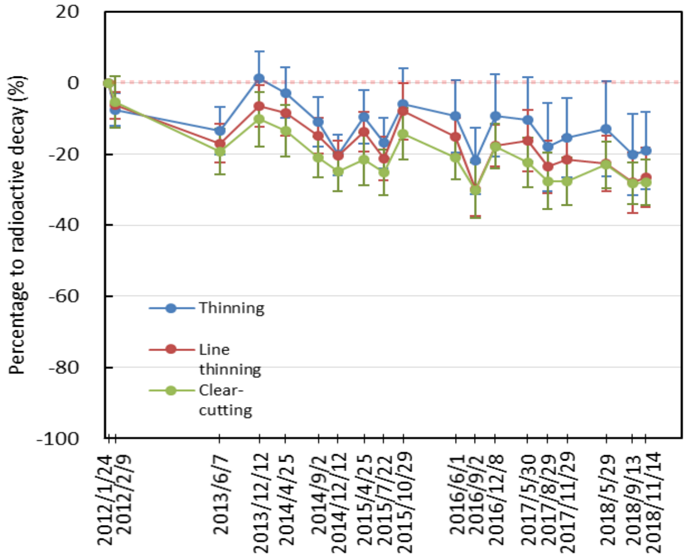


Figure 1-3 Trends in the Percentages of Air Dose Rates Relative to Radioactive Decay, and Comparisons among Plots Conditioned by Different Works

Error bars indicate standard deviations

1.2. Grasp of the Impact of Litter Removal and Logging on Air Dose Rates at a Forest Edge (Japanese Cedar Forest at the Kawauchi Testing Site (Zone A))

(1) Purpose

Litter removal and logging works have been conducted in a forest assumed to neighbor a residential area. Changes in the air dose rates have been measured before and after the works, and the impact of the works on the air dose rates has been verified.

(2) Summary of the Results

① The activities to make paths for the works, along with litter removal and logging activities themselves, caused the air dose rates at the forest edge and in the zones, to which different works were applied, to decline by about 20-30%, even after taking radioactive decay taken into account (Figure 1-5 and Figure 1-6).

② The test revealed no clear evidence that thinning and clear-cutting had an impact on the air dose rates when the works were completed (Figure 1-5 and Figure 1-6).

③ Even after the works were completed, the air dose rates at the forest edge and in all the work plots were declining at a rate higher than the rate of radioactive decay. The air dose rates exhibited considerable fluctuations while declining (Figure 1-7). This was possibly affected by changes in the distribution of radioactive materials on the forest floors.

(3) Testing Site and Method

1) Summary of Testing Site

The survey was performed in a Japanese cedar forest at the Kawauchi Testing Site (Zone A) created in 2012.

The test was conducted in a forest of 54-year-old Japanese cedar trees. The average deposition[1] of radiocesium was 1,110 kBq/m^2, and the air dose rates as of November 2012 ranged between 2.4 and 5.0 μSv/h. Five types of plots were created on this site: a litter-removed/clear-cut plot, a litter-removed/thinned plot, a litter-removed plot, a thinned plot, and an control plot (Table 1-2 and Figure 1-4). In the litter-removed/clear-cut plot, the litters were removed and the trees were then cut down. These trees were collected with a winch, turned into logs on the site, and delivered out. Then, nursery stocks of konara oak (1,000 stocks/ha) and Japanese cedar (3,000 stocks/ha) were planted in the cleared plot. In the litter-removed/thinned plot, litters were removed and two trees were cut down, leaving four trees standing in a straight line. The trees cut down were brought to the clear-cut plot with a swing yarder, turned into logs on the plot, and delivered out. In the thinned plot, no litters were removed and the trees were thinned in a straight line.

Table 1-2 Outline of the Work plots

Work plot	Work descriptions	Dates of work
Litter-removed/clear-cut plot	Creation of paths Litter removal Clear-cutting Planting of konara oak Planting of Japanese cedar	Dec 11-15, 2012 Dec 16, 2012 – Jan 10, 2013 Mar 9-13, 2013 Apr 6. 2013 Jul 9, 2013
Litter-removed/thinned plot	Litter removal Line thinning	Jan 31 – Feb 6, 2013 Jun 6-24, 2013
Litter-removed plot	Litter removal	Dec 16, 2012 – Jan 10, 2013
Thinned plot	Line thinning	Jun 6-24, 2013
Control plot	—	—

[1] Mean values based on the 3rd aircraft monitoring

2) **Measurement of the Air Dose Rates**

Constant air dose rate measurements were taken at measuring points arranged in a mesh-like pattern at 5m intervals using Nal(T1) scintillation detectors (Figure 1-4). Measurements were taken before and after path creation, litter removal, clear-cutting, and other works, and repeated every two to five months until November 2018. In consideration of any impact from outside the work plots, the survey targeted the air dose rates only at the measuring points shown in Figure 1-4.

(4) Test Results

1) Changes in the Air Dose Rates before and after the Works

Figure 1-5 shows the trends of the air dose rates before and after the works. The air dose rates conspicuously declined in the work plots where paths were created and litters were removed, and temporarily increased in the clear-cut plot. The rates declined in the plots where trees were thinned, but the rate similarly declined in the control plot. Thus, it remains uncertain if the reduction was caused by thinning.

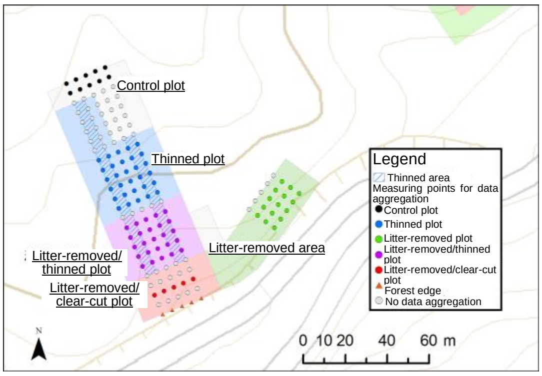


Figure 1-4 Arrangements of the Work plots in the Japanese Cedar Forest (Zone A) and Coverage of Air Dose Rate Measurements

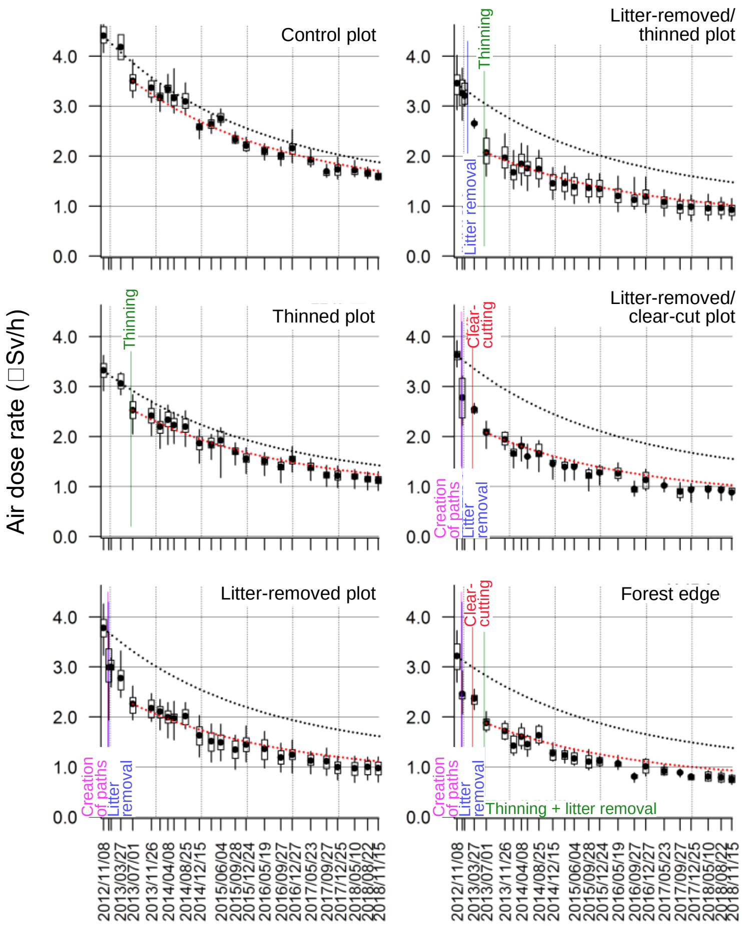


Figure 1-5 Trends of Air Dose Rates in the Work plots

Note: The black and red dotted lines indicate radioactive decay of the air dose rates before the works commenced (November 8, 2012) and after the works were completed (July 1, 2013), respectively.

Figure 1-6 shows the trends of the percentages of the air dose rates relative to radioactive decay before the works commenced (November 8, 2012)[2]. At the time all of the works, including the logging, were completed (July 1, 2013), the air dose rates at the forest edge and on all of the work plots declined at a rate higher than the rate of radioactive decay. Reductions in the post-work air dose rates were greater at the forest edge and work plots where litter removal was applied (the litter-removed plot, litter-removed/thinned plot, litter-removed/clear-cut plot) than in the control plot and in the thinned plot. The reduction rates stood at 32-34% for the former and 9-13% for the latter.

2) Trends of the Post-Work Air Dose Rates

To see differences in the trends of the air dose rates after different works were applied, Figure 1-7 shows the increase/decrease in the percentages of the air dose rates relative to radioactive decay

[2]The percentage of the post-work air dose rate to radioactive decay is definable as follows:
{(the air dose rate at a time/ as of the completion of the works (July 1, 2013) the post-work air dose rate decline attributable only to radioactive decay) – 1} x 100

after logging was completed (July 1, 2013). The percentages fluctuated considerably among the measurement periods, but the air dose rates continued declining from 2013 to 2018 at a rate higher than the rate of radioactive decay. The reduction rates were conspicuously greater in the litter-removed/clear-cut plot and at the forest edge than elsewhere.

Table 1-3 shows the trends of year-on-year percentage differences in the annual mean of the air dose rates[3]. The annual average fluctuations of the air dose rates were considerable, but the reduction rate may have gradually slowed down over the period.

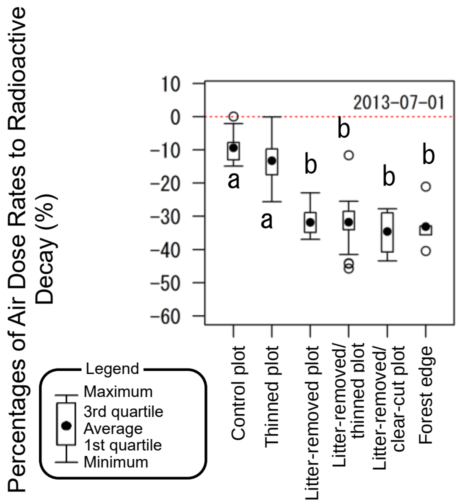


Figure 1-6 Comparisons of Percentages of Post-Work Air Dose Rates to Pre-Work Radioactive Decay

Note: In each box and whisker plot, the black dot indicates the mean value, the white dots indicate outliers, the whiskers indicate the maximum and minimum except outliers, and the box shows the range from first to third quartiles. The work plots with the same sign have no statistically significant difference (Steel-Dwass multiple comparison test: a 5% standard level).

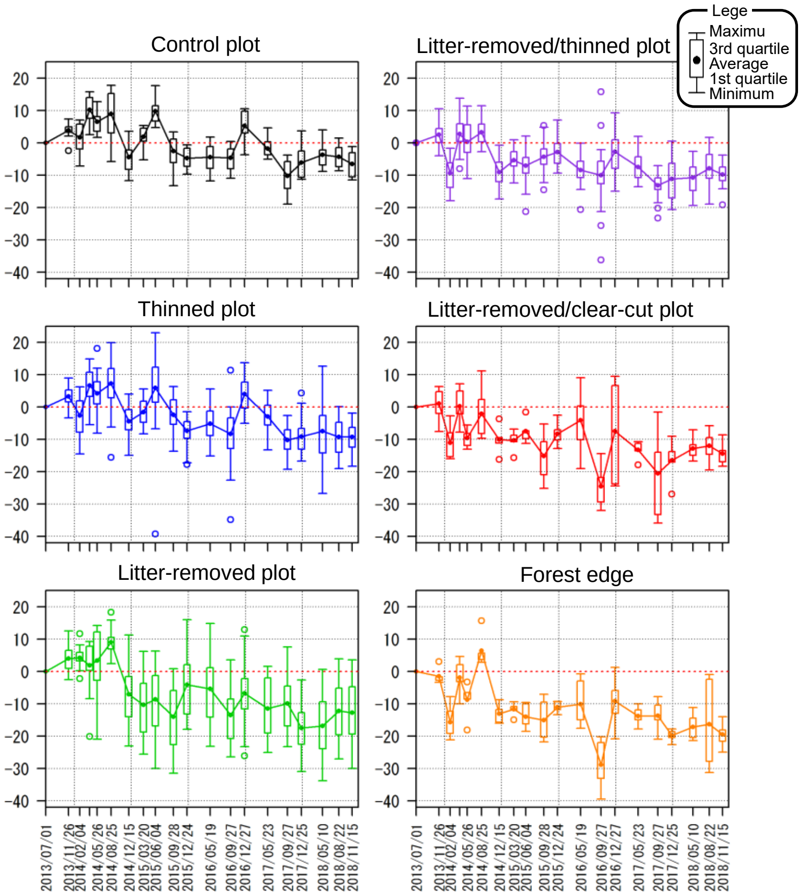


Figure 1-7 Trends in the Percentages of Air Dose Rates to Post-Work Radioactive Decay

Note: The percentage of the actual air dose rate to the air dose rate decline attributable only to radioactive decay at each measuring point as of the completion of the works (July 1, 2013) was calculated. The figure shows the trend of the mean percentage value for each work plot.

Table 1-3 Percent Changes in the Annual Mean Air Dose Rates in the Japanese Cedar Forest (Zone A)

	Control plot	Thinned plot	Litter-removed plot	Litter-removed / thinned plot	Litter-removed / clear-cut plot	Forest edge
2014	4.8	1.9	4.1	-3.4	-6.4	-7.1
2015	-3.4	-3.2	-12.9	-1.6	-4.3	-6.4
2016	-2.3	-1.8	0.9	-2.3	-1.6	-3.7
2017	-4.9	-4.4	-4.7	-3.9	-5.1	0.4
2018	1.4	-1.4	-1.4	1.3	4.9	-2.4

Note: The calculation uses corrected air dose rates that take into account radioactive decay with the value on July 1, 2013 set as the benchmark. The values for 2014 are as of July 2013, and those for other years show the percentages relative to the annual means in the previous year.

[3] (The mean value of the air dose rates in the year) / (the mean value in the previous year) – 1 x 100 (%)

1.3. Grasp of the Impact of Work Area Expansion on Air Dose Rates (Japanese Cedar Forest at the Kawauchi Testing Site (Zone B))

(1) Purpose

Litter removal and clear-cutting have been conducted in a wider area, changes in the aid dose rates have been measured as the works have progressed, and correlations between the work area and air dose rates have been verified.

(2) Summary of the Results

① On a 40m x 40m plot from which litters were removed in a 20m x 20m area in the center, the air dose rates declined as the area where the work was applied expanded. The air dose rate at the center of the plot declined by some 20% even after taking radioactive decay into account. The test revealed no clear evidence that clear-cutting had an impact on the air dose rates (Figure 1 9).

② The air dose rates continued declining even after the work was completed. The rate at the center had declined by 48% by December 2017, even after taking radioactive decay into account. (The rate also declined by 20% in the control plot, Figure 1 9).
Changes in the air dose rates around the work plot were moderate compared to those at the center.

(3) Testing Site and Method

1) Summary of the Testing Site

The survey was performed in a Japanese cedar forest at the Kawauchi Testing Site (Zone B) created in 2012. The testing site was a 60m x 60m area with 43-year-old Japanese cedar trees. The average gradient was 34 degrees, the mean deposition of radiocesium was 1,120 kBq/m^2, and the air dose rates as of November 2012 ranged between 2.2 and 4.5 μSv/h. Litter was removed gradually from this site, initially from a 2.5m x 2.5m area in the center and ultimately from the entire 60m x 60m area. Next, gradual clear-cutting was conducted, starting from a 2.5m x 2.5m area in the center and culminating in a 40m x 40m area. The trees cut down were collected with a winch, brought outside the work plot, turned into logs, and delivered out. Then Japanese cedar trees (3,000 trees/ha) were planted in the cleared area. For comparison, two control plots were created outside this testing site (Table 1-4 and Figure 1-8).

2) Measurement of the Air Dose Rates

Constant air dose rate measurement started at measuring points arranged in a mesh-like pattern at 5m intervals (Figure 1-8) before the works commenced. In this survey, the air dose rates were measured with Nal(T1) scintillation detectors before and after the works until the works were fully completed in January 2013, as shown in Table 1-5, and at intervals of two to five months thereafter.

The values measured at the center of the work plot and the mean values of the measuring points in the zones where the works were applied at each stage were assessed as test results. For the analysis, the measurements were divided into a group of measuring points within 10m from the center (the central part within the red dotted line) and another group of measuring points 15-20m away from the center (the forest edge) (Figure 1-8). The mean values were obtained from different numbers of measuring points, depending on the type of work (1 point for the minimum 2.5m x 2.5m area to 169 points for the maximum 60m x 60m area).

(4) Test Results

1) Changes in the Air Dose Rates before and after the Works

Figure 1-9 shows the trends of the air dose rates before and after the works. As the work area expanded, the air dose rates at the center and within the work plot gradually declined. The air dose rate at the center of the work plot moved at a lower level than the mean values of the measuring points in the work plot. As for litter removal, the air dose rate at the center gradually declined as the works were applied up to a 40m x 40m area, but the declines stopped as the work area was expanded further. When litter removal was applied to the 40x40m area, the air dose rate declined by 21% compared to the pre-work air dose rate (November 2012), even after taking radioactive decay into account.

Table 1-4 Outline of the Work Plot in the Japanese Cedar Forest (Zone B), and Abbreviation of the Testing Slope Frames

Work plot	Work descriptions	Dates of work
Litter-removed/ clear-cut plot	Litter removal Clear-cutting (Trees cut down were collected with a winch.)	Nov. 26 – Dec. 2, 2012 Dec 13, 2012 – Jan. 11, 2013 Oct. 29, 2013
Control plot	—	—

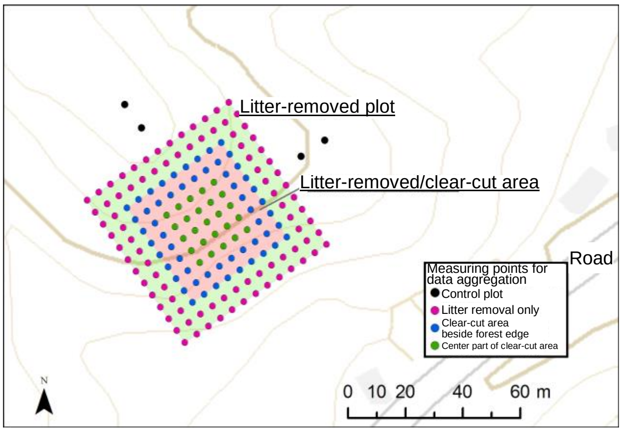


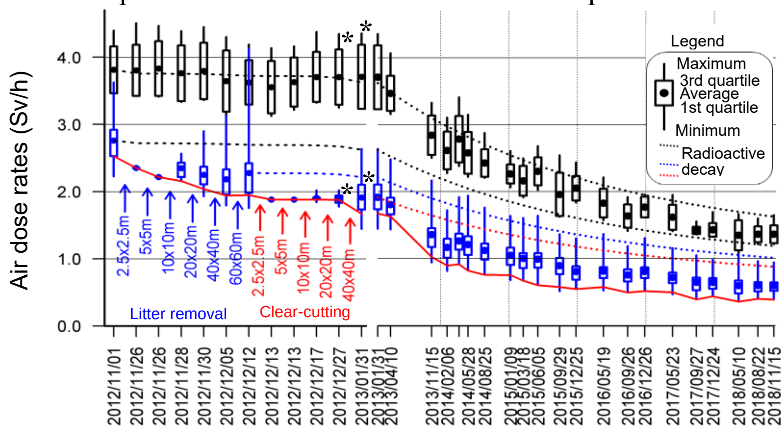
Figure 1-8 Arrangements of the Work Plot and Coverage of Air Dose Rate Measurements

The air dose rates did not decline when clear-cutting was applied to a 20m x 20m area. When the area was expanded to 40m x 40m, however, the rate at the center declined by 31% versus the pre-work rate and by 12% compared to the rate before clear-cutting was conducted. This result, however, might have stemmed from insufficient correction for the shielding effects of snow coverage[4].

2) Changes in the Post-Work Air Dose Rates

Figure 1-10 shows the trends in the percentages of the post-work air dose rates relative to radioactive decay (January 31, 2013). The percentages generally exhibited downward trends in all areas after the works were completed, though there were some temporary fluctuations. This trend was particularly strong in areas closer to the center of the work plot.

Table 1-5 shows the trends in the percentage air dose rate differences between the annual means and those in the previous year. The air dose rates in the work plots, including the control plot, considerably declined from the time the works were completed to 2014, even after taking radioactive decay into account. The reduction rate was greater at places closer to the center of the work plot. The reduction rate of the air dose rates in the peripheral part was somewhat gentle compared to the other areas and moved in a pattern similar to that in the control plot.



Note: the values in black indicate the average values of the measuring points in the zones where the works were applied at each stage. The black, blue, and red dotted lines indicate radioactive decay of the air dose rates before the works, after litter removal was completed, and when the works were completed, respectively. The air dose rates when snow was accumulated (with asterisk) were corrected values.

Figure 1-9 Trends of Air Dose Rates in the control plot (Black), the Plot Where Works Were Applied (Blue), and at the Center (Red)

4 The collection value for snow accumulation was set as a percentage determined by the air dose rate measurements in the control plot when snow was accumulated, which were lower than the measurements recorded when no snow was accumulated. The air dose rate on the work plot was divided by this collection value to remove the effects of snow accumulation.

Table 1-5 Year-on-year Percentage Changes in the Annual Mean Air Dose Rates in the Japanese Cedar Forest (Zone B), (%)

	Control plot	Works applied to forest edge	Works applied to central part	Center of the plot
2014	-10.7	-17.1	-28.9	-36.5
2015	-1.3	-4.6	-6.3	-12.3
2016	-4.2	-3.1	-3.4	-3.4
2017	-4.8	-6.1	-7.6	-8.5
2018	-1.0	-3.2	-5.5	-7.4

Note: The air dose rates are corrected to reflect the radioactive decay, setting January 31, 2013 as the benchmark date. The figures for 2014 were measured in January 2013. Those for other years are year-on-year percentage changes in the annual means.

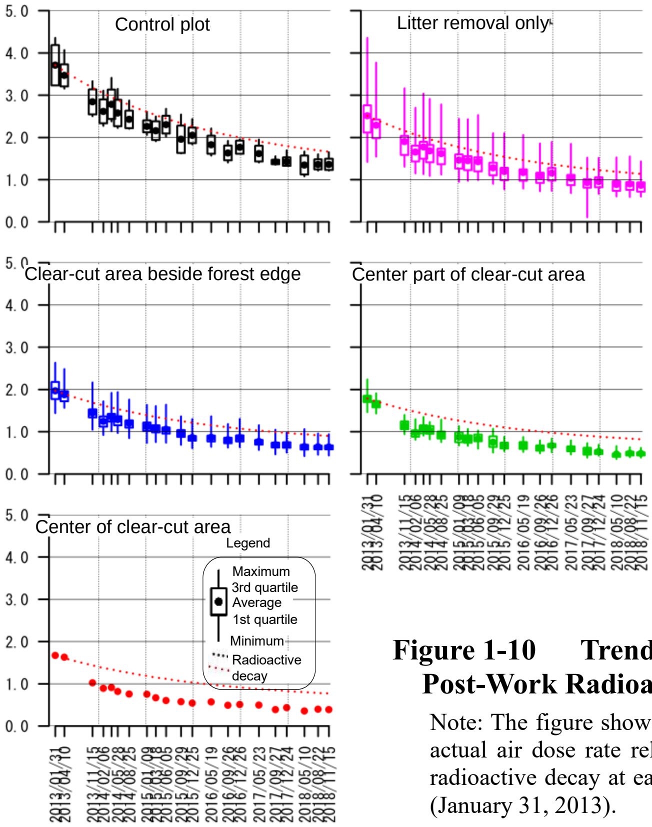


Figure 1-10 Trends in the Percentages of Air Dose Rates to Post-Work Radioactive Decay by Location

Note: The figure shows the trend of the mean value of the percentage of the actual air dose rate relative to the air dose rate decline attributable only to radioactive decay at each measuring point as of the completion of the works (January 31, 2013).

1.4. Grasp of the Impact of Litter Removal and Clear-Cutting on Air Dose Rates (Model Zone for Mushroom Bed Log Collection)

(1) Purpose

Litter removal and clear-cutting have been conducted in a deciduous broad-leaved forest. Changes in air dose rates have been measured before and after the works, and the impact of the works on air dose rates has been verified.

(2) Summary of the Results

① The air dose rates before and after the works in the clear-cut plot and the litter-removed/clear-cut plot were compared. No difference was found after litters were removed from the latter, and the reduction rate on the latter was greater than that on the former by 10% after clear-cutting was conducted on the two plots (Figure 1-12 and Figure 1-13).

② The post-work air dose rates declined by about 20% compared to radioactive decay at about one year after the completion of the clear-cutting. However, there was no clear difference between the two work plots (Figure 1-14).

(3) Testing Site and Method

1) Summary of Testing Site

The survey was performed in a model zone for mushroom bed log collection created in FY2012.

The model zone is a deciduous broad-leaved forest (0.18 ha) in which 57-year-old konara oak trees were planted as the dominant species. The average gradient was 39 degrees, the mean deposition of radiocesium was 1,160 kBq/m^2, and the air dose rates as of November 2012 ranged between 1.7 and 2.4 μSv/h. Two work plots were created on this site. One was a clear-cut plot, where trees were cut down but no litters were removed. The other was a litter-removed/clear-cut plot, where litters were removed and trees were subsequently cut down (Table 1-6 and Figure 1-11). The trees cut down were collected with a winch, brought outside the work plots, and turned into logs.

2) **Measurement of the Air Dose Rates**

Before and after the works, constant air dose rate measurements were performed using NaI(Tl) scintillation detectors at measuring points arranged in a mesh-like pattern at 5m intervals (Figure 1-11), at intervals of two to five months. To exclude any impact from outside the plot, the survey used only the air dose rates at measuring points (within the red dotted line in Figure 1-11) more than 10m away from the work area.

Table 1-6 Outline of the Work Plots in the Model Zone, and Abbreviation of the Testing Slope Frames

Work plot	Work descriptions	Dates of work
Clear-cut plot	Clear-cutting (Trees cut down were collected with a winch.)	Mar. 16-18, 2013
Litter-removed/ clear-cut plot	Litter removal Clear-cutting (trees cut down were collected with a winch.)	Jan. 8-9, Mar. 11-15, 2013
Control plot	—	—

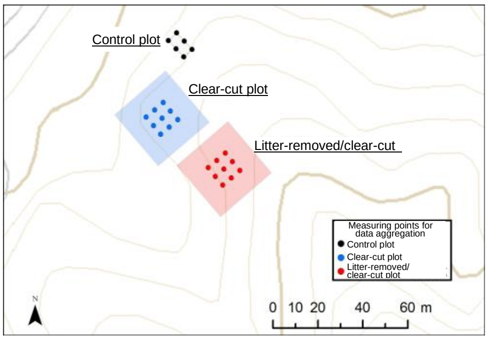


Figure 1-11 Arrangements of the Work Plots and Coverage of Air Dose Rate Measurements

Note: The blue area is where trees were logged; the red area is where the air dose rates were measured.

(4) **Test Results**

1) **Changes in the Air Dose Rates before and after the Works**

Figure 1-12 shows the trends of the air dose rates before and after the works. Figure 1-13 shows the percentages of the air dose rates after clear-cutting (March 2013) relative to the radioactive decay that had continued before the works (November 2012). After litter was removed, the air dose rates declined by some 5% both in the clear-cut plot and the litter-removed/clear-cut plot. After clear-cutting, on the other hand, the reduction rates of the air dose rates were significantly greater in the litter-removed/clear-cut plot (-22%) than in the clear-cut plot (-13%) (significant according to the Kruskal-Wallis test).

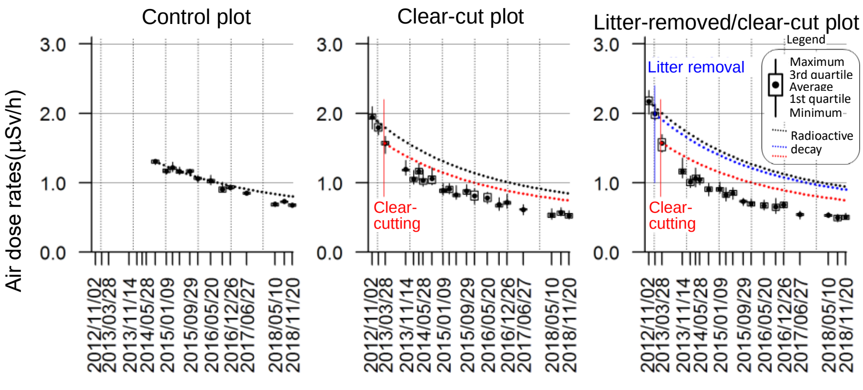


Figure 1-12 Trends of Air Dose Rates in the Work Plots in Model Zone for Mushroom Bed Log Collection

Note: In each box and whisker plot, the black dot indicates the mean value, white dots indicate outliers, the whiskers indicate the maximum and minimum, and the box shows the range from first to third quartiles. The black, blue, and red dotted lines indicate radioactive decay of the air dose rates before the works, after litter removal was completed, and after the works were completed, respectively.

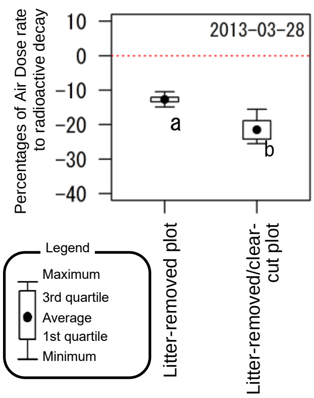


Figure 1-13 Comparisons of Percentages of Post-Work Air Dose Rates to Pre-Work Radioactive Decay

Note: Different letters (a, b) indicate significant difference among decay classes (significance level of 0.05 according to the Kruskal-Wallis test).

2） Trends of the Post-Work Air Dose Rates

Figure 1-14 shows the trends of the percentage increase/decrease of the air dose rates relative to the radioactive decay after the litter removal and clear-cutting were completed (March 2013). In both plots, the percentages declined by about 20% over the approximately one year after the completion of the works, considerably fluctuated afterwards, and continued declining gently in the longer term.

Table 1-7 shows the trends in the year-on-year percentage changes in the annual means of the air dose rates in the work plots. The air dose rates considerably declined after the works up to 2014, but the rates of reduction may be declining gradually year by year.

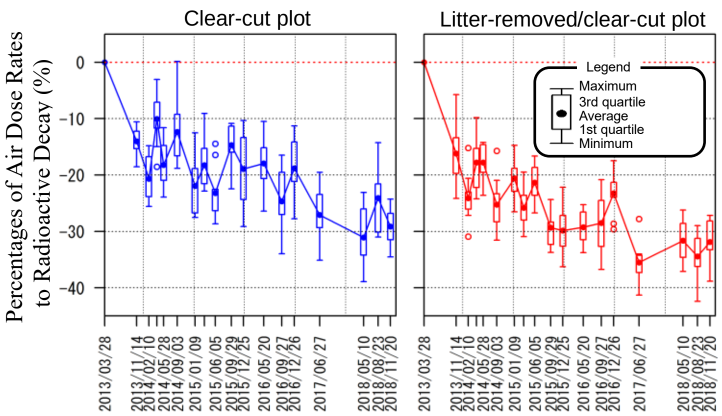


Figure 1-14 Trends in the Percentages of Air Dose Rates to Post-Work Radioactive Decay on the Work Plots in the Model Zone for Mushroom Bed Log Collection

Note: The figure shows the trend of the mean value of the percentage of the actual air dose rate relative to the air dose rate decline attributable only to radioactive decay at each measuring point as of the completion of the works (March 28, 2013).

Table 1-7 Year-on-Year Percentage Changes of the Annual Mean Air Dose Rates in the Model Zone for Mushroom Bed Log Collection (%)

	Clear-cut plot	Litter-removed / clear-cut plot	Control plot
2014	-15.5	-21.5	-
2015	-5.1	-5.6	-0.3
2016	-1.6	-2.6	-3.0
2017	-8.9	-12.5	-3.2
2018	-1.7	4.5	-9.6

Note 1: The air dose rates were corrected values reflecting the radioactive decay as of the benchmark date of March 28, 2013. The figures for 2014 were measured in March 2013, and those in other years were percentages relative to the annual means of the previous year.

Note 2: The air dose rate measurements in the control plot started in September 2014.

1.5. Grasp of the Impact of Litter Removal and Logging on the Amount of Eroded Radioactive Materials (Testing Slope Frames at the Hirono and Kawauchi Testing Sites)

(1) Purpose

The amounts of sediment movement, surface runoff, and radioactive materials contained in the sediment have been measured at places where litter removal and logging were conducted, and the impact of such works on the movement of radioactive materials has been grasped.

(2) Summary of the Results

① The amount of radiocesium in surface runoff was limited.

② In the first year after the works were completed, the amounts of soil and radiocesium erosion increased, particularly at places where litter was removed.

③ In the second and subsequent years after the works were completed, the understory vegetation recovered and the amounts of the soil and radiocesium erosion decreased. The amount of erosion hardly increased even after heavy rains.

(3) Testing Site and Method

1) Summary of the Testing Site

This survey was performed in the Hirono Testing Site created in 2011 and the Kawauchi Testing Site created in 2012. (cf. Section 1.1).

2) Testing Method

① Measurement of rainfall and the radiocesium concentration in rainwater

Rain gauges were installed at the work plots to measure the amount of rainfall and the concentration of radiocesium in rainwater. Test samples of rainwater were collected basically every three weeks to measure the concentration of radiocesium after the rainwater was filtrated and converted into gel. The measurements were performed by a spectrometry method.

② Measurement of the radiocesium concentration in sediment movement and surface runoff

Sediment movement and surface runoff captured at testing slope frames in the work plots (Figure 1-15 and Figure 1-16) were collected basically every three weeks. The amount of radiocesium captured and its concentration were measured. To measure the concentration in the soil, etc., a Gamma Spectrometry method was applied to sediment dried at a temperature of 105℃. During the period of sparse rainfall after 2015, the survey used mixed samples from multiple rainfalls (for about two months).

The amount of sediment erosion was corrected according to the RUSTLE formula to adjust the testing slopes to an inclination of 30 degrees, the average gradient of Japan's forests (the case where the impact of rill and runoff is minimum), and converted into the amount per unit area. The converted amount was multiplied by the radiocesium concentration to obtain the amount of radiocesium erosion per unit area.

In the litter-removed/thinned plot and the thinned plot in the Japanese cedar forest (Zone A), testing slope frames were installed both in the cleared area and in the area where trees remained standing in order to gain a weighted average to adjust the ratio between the two areas to 1:3.

③ Measurement of the rates of coverage of the forest floor

To verify the impact of vegetation recovery on sediment erosion, the rates of coverage of the forest floor[5] and vegetation coverage[6] were visually observed and judged in units of 10%.

[5] To follow the definition used in the project in FY2012, the rate of forest floor coverage was defined as the ratio physically covered by vegetation, including herbaceous plants, roots, moss, plant residues of deciduous leaves, boulders, and rocks within each testing slope frame.

[6] The rate of vegetation coverage was defined as the ratio of an area covered by living vegetation, including herbaceous plants and moss, at a height of 80cm or less within each testing slope frame.

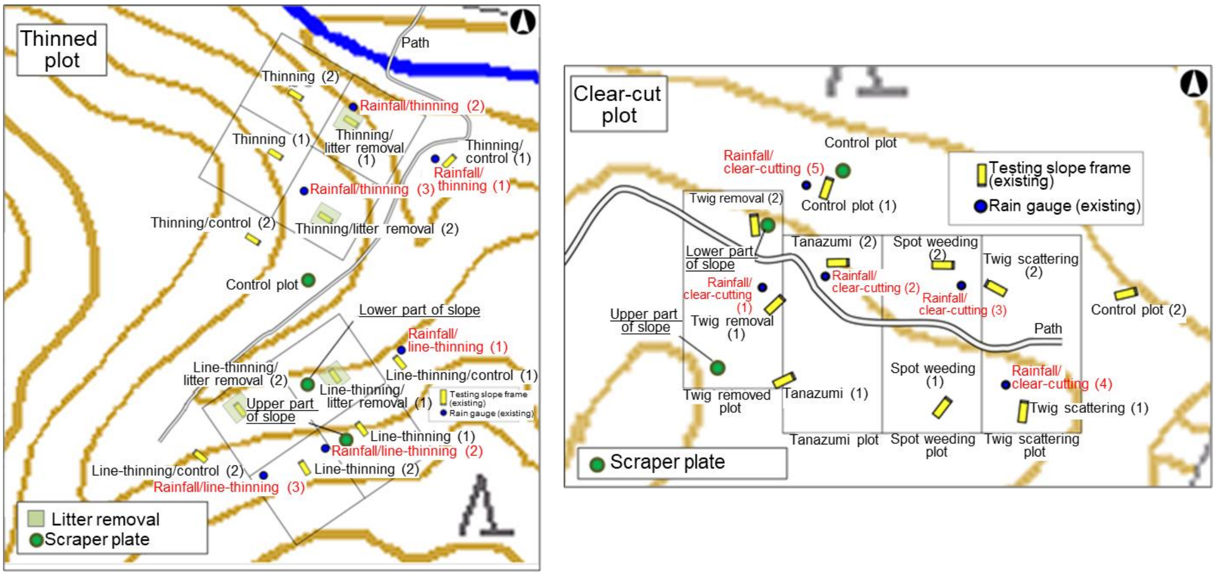


Figure 1-15 Locations of the Testing Slope Frames at the Hirono Testing Site

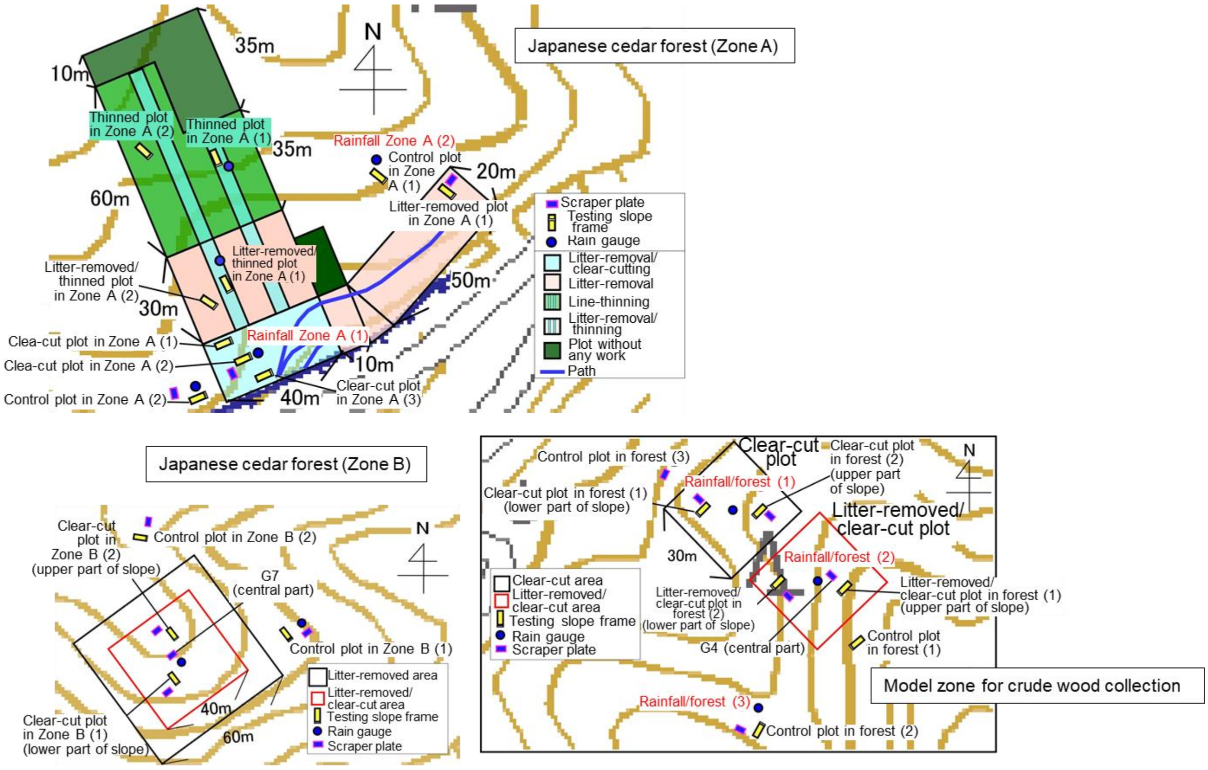


Figure 1-16 Locations of the Testing Slope Frames in the Kawauchi Testing Site

(4) Test Results and Considerations

1) Hirono Testing Site

Little radiocesium (Cs-137) has been detected in the surface runoff in the Hirono Testing Site since 2012, when the measurements started.

Figure 1-17 shows the trends in the rainfall, rate of forest floor coverage, rate of vegetation coverage, amount of sediment erosion, and amount of radiocesium (Cs-137) erosion in the thinned plots.

The amounts of sediment and radiocesium erosion (Cs-137) were conspicuously large in the thinned and line-thinned plots from which litters were removed in the first year after the works (2012). The amounts in the work plots from which no litters were removed were more or less the same as those in the control plot, and there was no difference even if the litters were removed in the second year or afterwards. The third and fourth years saw slight changes in the amounts of sediment erosion, but no such changes were observed in the fifth year. The concentration of radiocesium in sediments was higher in the thinned plot from 2012 to 2013, and generally higher than that in the control plot, which had an impact on the radiocesium erosion.

In the clear-cut plot, on the other hand, the amount of sediment and the radiocesium concentration were not different than those in the control plot.

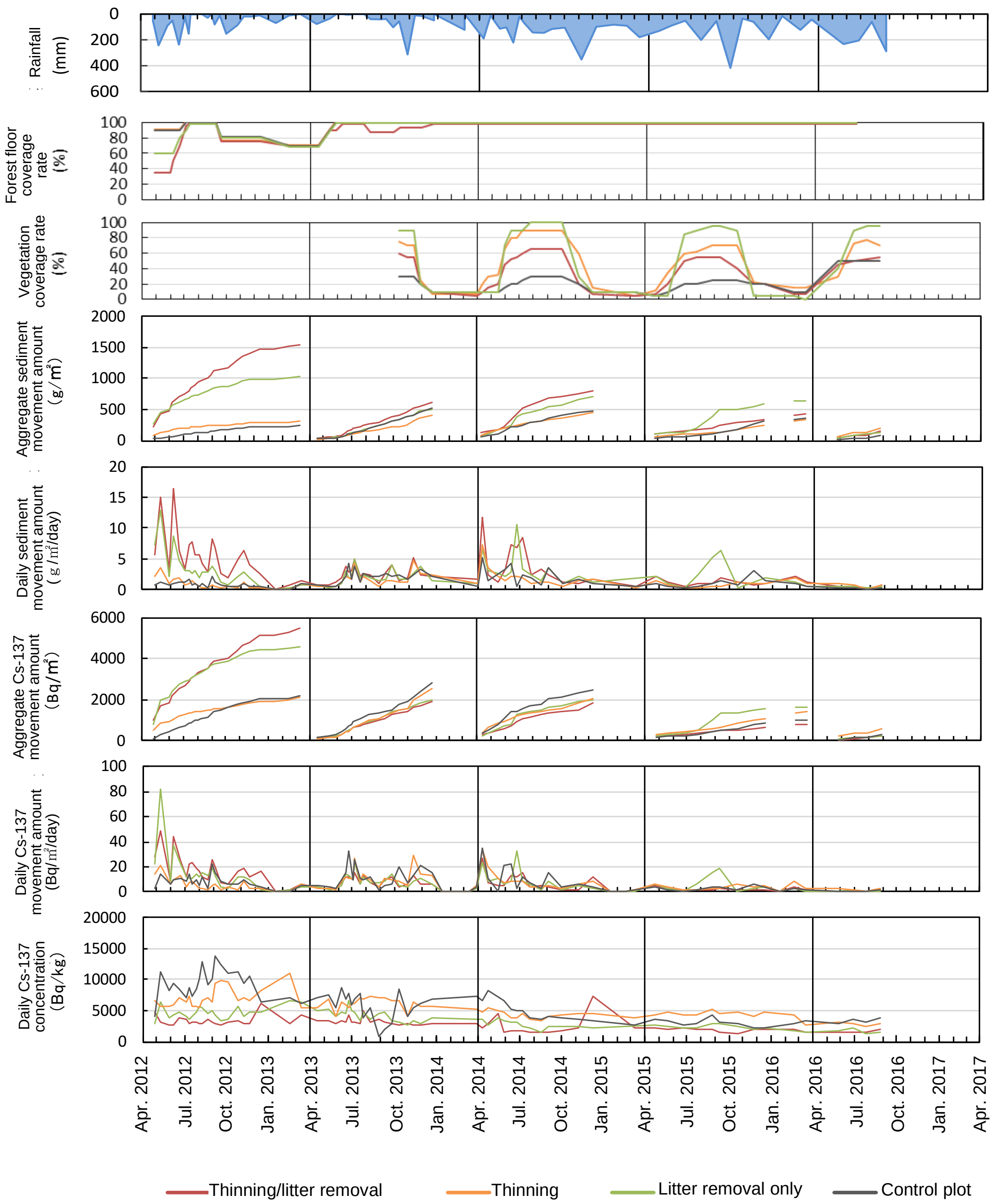


Figure 1-17 Amount of Sediment Erosion, Amount of Radiocesium (Cs-137) Erosion, and Radiocesium Concentration in the thinned Plot

Note: Sediment includes sand and litter. The figures for radiocesium (Cs-137) are the sums of the values measured in sediment and in sand and gravel.

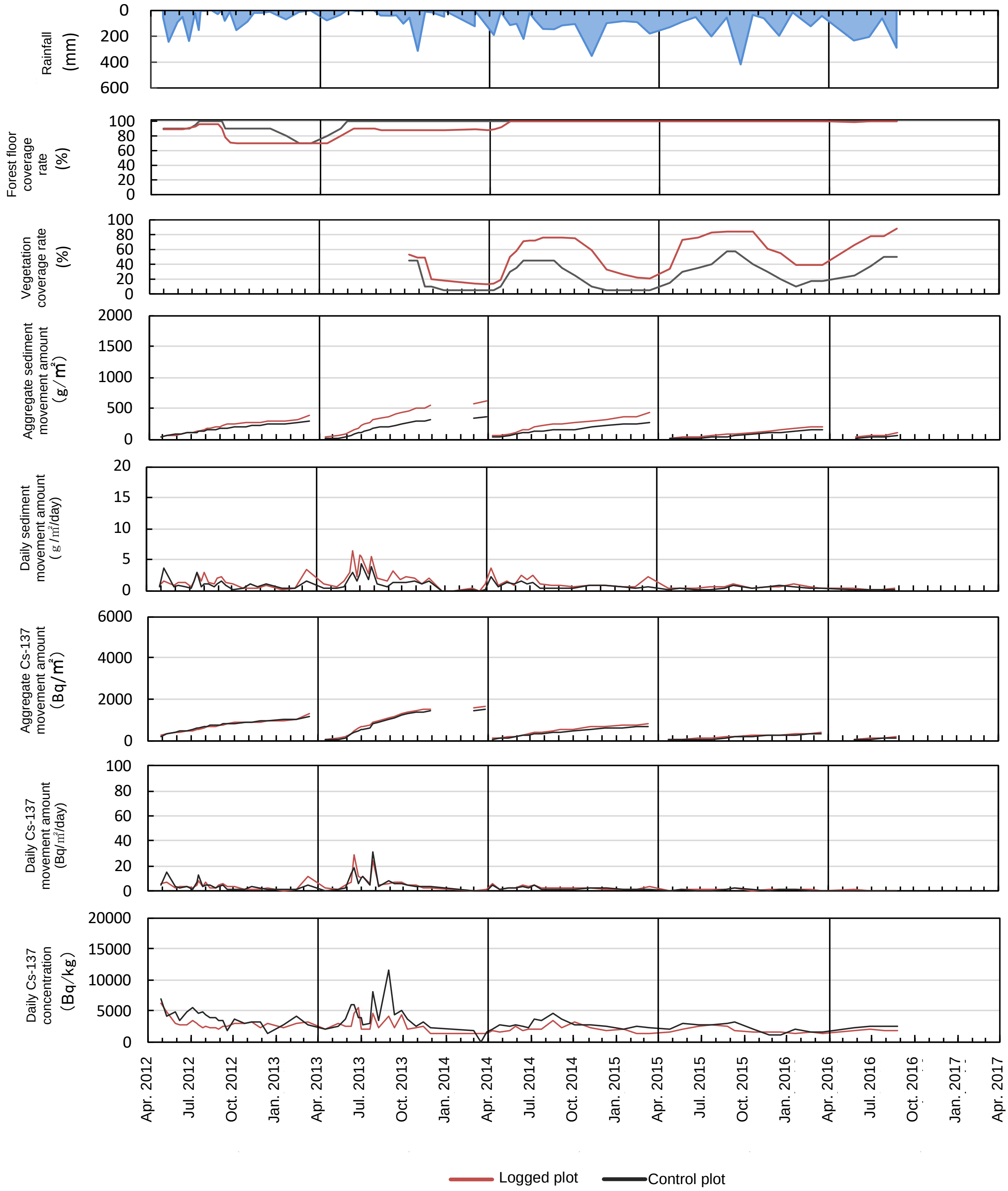


Figure 1-18 Amount of Sediment Erosion, Amount of Radiocesium (Cs-137) Erosion, and Radiocesium Concentration in the Clear-cut Plot

Note: Sediment includes sand and litter. The figures for radiocesium (Cs-137) are the sums of the values measured in sediment and in sand and gravel.

2) Kawauchi Testing Site

The amount of radiocesium erosion (Cs-137) resulting from surface runoff and sediment movement in each testing slope frame was limited compared to the radiocesium movement resulting from the sediment movement alone.

Figure 1-19 shows the trends of rainfall, rate of forest floor coverage, rate of vegetation coverage, amount of sediment erosion, amount of radiocesium (Cs-137) in sediment movement, and concentration of radiocesium. In the work plots where litters were removed and all of the trees were cut down or thinned, the rates of forest floor coverage temporarily declined as a result of these works. Subsequently, in the following year (2014), the rates returned to nearly the initial levels in all but some areas. The vegetation coverage rates also steadily recovered after the works (to 50%, in general, after 2014), but no conspicuous change was observed in the control plot.

The amounts of sediment and radiocesium erosion resulting from sediment movement increased in the work plots where litters were removed and trees were cut down, in the first year after these works (2013). In the second year and afterwards, the amounts were more or less the same as or smaller than those in the control plot. The growth of understory vegetation seemed to help recover the rates of forest floor coverage and vegetation coverage and to control the sediment movement. The concentrations of radiocesium (Cs-137) in the sediment movement in the work plots and control plot gradually declined in the long run.

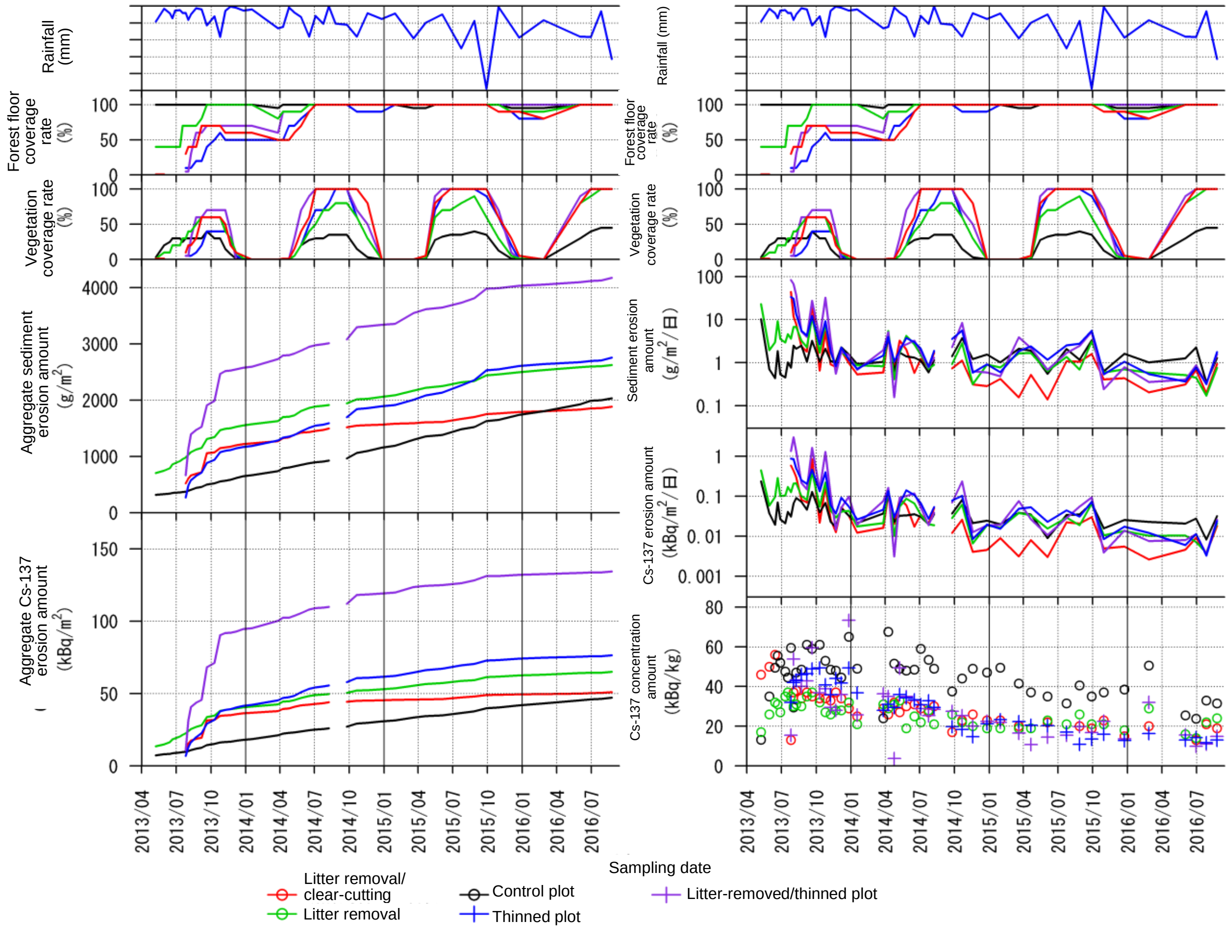


Figure 1-19 Trends in Rainfall, Rate of Forest Floor Coverage, Rate of Vegetation Coverage, Amount of Sediment Erosion, and Amount of Radiocesium (Cs-137) Erosion in the Testing Slope Frames in the Japanese Cedar Forest (Zone A)

Note: Measurement in the clear-cut plot (1), thinned plots (1) and (2), and litter-removed/thinned plot (1) and (2) in Zone A started in July 2013.

Figure 1-20 shows the correlations between the rainfall factor (R-factor) [7] and the amount of radiocesium (Cs-137) erosion for each measurement period in the Kawauchi Testing Site (Japanese cedar forest (Zone A)). In the work plots, where trees were all cut down or litters were removed, the amount of radiocesium erosion increased when the R-factor was high immediately after the works (2013) but did not increase considerably in the second year (2014) and afterwards.

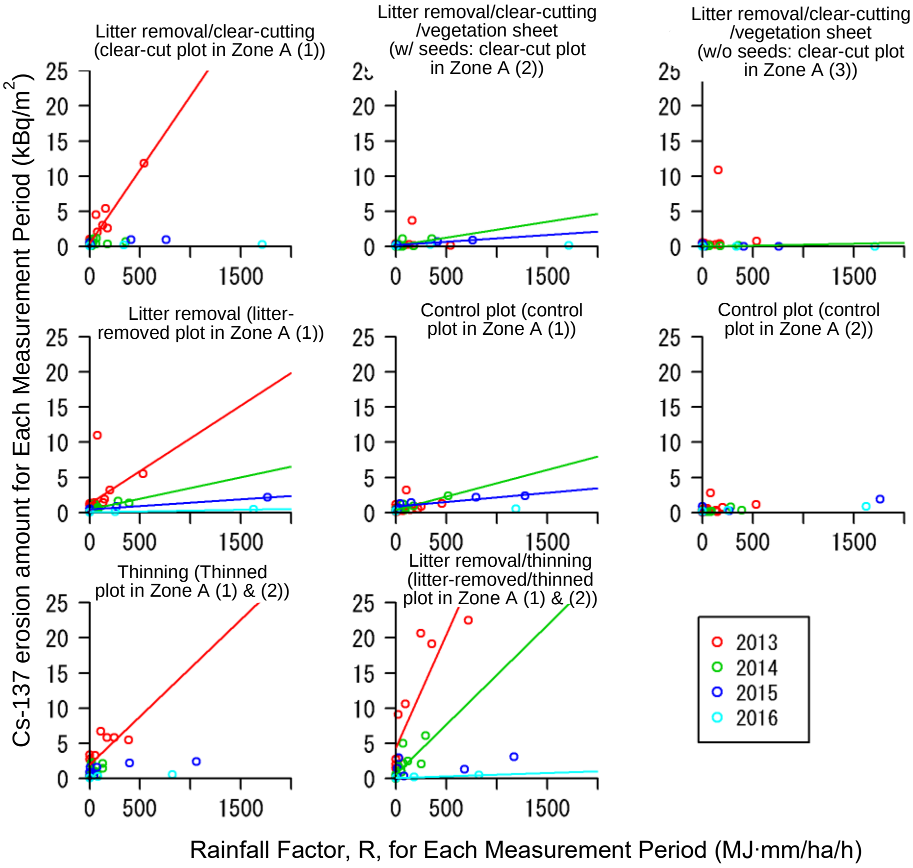


Figure 1-20 Correlations between the Rainfall Factor, R-factor, and Amount of Radiocesium (Cs-137) Erosion for Each Measurement Period in the Testing Slope Frames in the Japanese Cedar Forest (Zone A) at the Kawauchi Testing Site

Note: The amount of radiocesium (Cs-137) erosion was corrected to the amount as of May 8, 2013 to adjust for the radioactive decay. The figure only shows regression lines that are statistically significant ($p < 0.05$).

[7] The rainfall factor (R-factor: MJ mm/ha/hour) in the RUSLE formula was calculated for each measurement period as an indicator of rainfall strength. Data on rainfall recorded every 10 minutes with rainfall gauges were used to calculate values according to the following formula for each continuous rainfall event (the time duration without rainfall was six hours or less) for each measurement period. $R = E \times I_{30}$, where I_{30} denotes the maximum rainfall strength for 30 minutes (mm/hour) and E denotes the kinetic energy of each rainfall event (MJ mm/ha). E was obtained using the formula of Brown & Foster (1987) ($E = 0.29\ [1 - 0.72\ \exp(-\ 0.05i\ )]$, where i denotes the rainfall strength of each rainfall event (mm/hour)). The calculation used data on continuous rainfall of 12.7mm or more, or erosive rainfall in every 15 minutes whose strength was 6.4mm or greater.

1.6. Verification of the Impact of Litter Removal and Logging on Air Dose Rates

(1) Purpose

The results of surveys on changes in the concentration of radioactive materials in litter layers and sediment and the amount of litter fall in places where litter removal and logging were conducted have been examined to verify factors that influence the increases/decreases of the air dose rates.

(2) Summary of the Results

① The reduction rates of the air dose rates before and after the works were large in the plots in the Japanese cedar forest where litters were removed. At the time the works commenced, about 30% of radiocesium (Cs-134 and Cs-137) deposited in the forest existed in litter layers, where the concentration was found to be high (Figure 1-25). The large reduction rates of the air dose rates might be attributable to the litter removal work.

② The survey indicates that the radiocesium in the litter layers was gradually moving into the soil (Figure 1-27 to Figure 1-30), particularly into the deeper layers (Figure 1-31).

③ The concentration of radiocesium in litter fall and the amount deposited exhibited considerable seasonal fluctuations, but both were in general on declining trends (Figure 1-33 and Figure 1-34).

④ Both in the Japanese cedar and deciduous broad-leaved forests, the reduction rates of the post-work air dose rates were greater in the plots where more radioactive materials were removed as a result of the works (Figure 1-36).

(3) Testing Sites and Method

1) Summary of the Testing Sites

This survey was conducted at the Hirono and Kawauchi Testing Sites (Table 1-8). The results from the Kawauchi Testing Sites are presented in this chapter.

Table 1-8 Outline of the Work plots at Kawauchi Testing Sites

Work plot	Forest profile	Forest age	Ave. diameter at breast height	Ave. height	Population density
A plot	Japanese cedar forest	54 years old	33.2cm	23.1m	820 trees/ha
B plot	Japanese cedar forest	43 years old	22.8cm	16.8m	1,802 trees /ha
Model zone for mushroom bed log collection	broad-leaved tree forest	53 years old	9.2cm	6.9m	3,822 trees /ha

2) Distribution of Radioactive Materials by Part of Tree

Measurements were conducted by the following procedure in FY2012 and FY2013 to grasp the distribution of radioactive materials in the various parts of the trees in the testing zones at the Kawauchi Testing Site.

① Selection of sample trees

One relatively thick tree, one standard-sized tree, and one relatively thin tree were selected on each testing zone as sample trees.

② Logging, measurement, and sample collection

Sample parts of these trees were wrapped with blue sheets before logging so that their trunks would not directly contact the earth. After logging, the trees were cut down at a height of 2.5m from the bottom end to collect sample parts. About 500g of bark was stripped off from the upper part of each logs (about 2-2.5m from the bottom end). Sapwood was taken from the part from which bark was stripped, and 5-10cm wood disks were collected as heartwood samples. The top, central, and bottom parts of the stems not in contact with the earth after the tree was cut down were collected and divided into branches and leaves on the blue sheets. A total of about 300g each of branches and leaves were collected, and the branches were then separated by their thicknesses.

③ **Measurement of the concentrations of the radioactive materials**

After the collected samples were dried at a temperature of 105℃, the concentration of radiocesium was measured using a Gamma Spectrometry method.

④ **Calculation of radioactive materials deposited**

The height of each tree and the diameter at breast height were measured on each testing zone, and trees with breast-height diameters of more than 4cm were selected. Based on this so-called complete enumeration survey, the stem volume was calculated according to the volume equation for Fukushima Prefecture (Naka-dori and Hama-dori) in the "Standing Tree Trunk Volume Table – East Japan Edition" (edited by the Planning Division of the Forest Agency, 1970). The weights per unit area of branches and leaves were calculated according to the allometry equation provided by the Forestry and Forest Products Research Institute. The weights per unit area of the trees were calculated based on the volume ratio and density of the stem volume to the bark, heartwood, and sapwood. The weight per unit area of these parts was multiplied by the corresponding radiocesium concentration to obtain the radiocesium deposited per unit area. Incidentally, small-diameter trees were not collected as samples, and trees with breast-height diameters of 10cm or less were excluded from the calculation of radiocesium deposited in the model zone for mushroom bed log collection.

3） Measurement of Radiocesium in the Soil and Litter Layer

① **Surveys with a cylinder soil sampler**

To measure the radiocesium concentration and radiocesium deposited, samples of soil and litter layers were collected from the work plots in the Kawauchi Testing Site (Figure 1-22 to Figure 1-24) before and after the works, and once a year thereafter. To collect samples of litter layers, all the soil was dug down to the mineral soil layer in a 20cm x 20cm area at 3-5 locations on each survey point (Figure 1-21). After samples of the litter layers were collected, 5cm-deep samples of mineral soil were collected with a 100mL cylinder soil sampler at the same locations. Samples collected in the survey points were mixed to create a single sample of litter layers and soil for each survey point (Table 1-9). The samples were collected from locations where no samples had been collected previously. In addition, gradient correction was conducted to obtain the horizontal sampling areas for litter layer collection sites, as the sampling was conducted in areas ($0.04m^2$) on sloping ground.

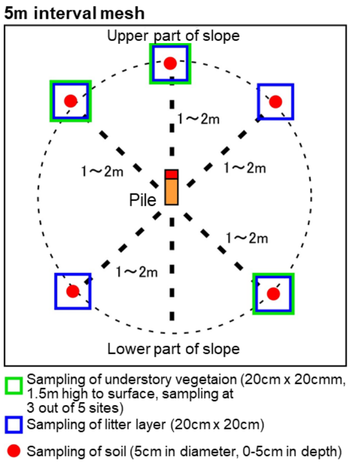


Figure 1-21 Litter Layers and Soil Sample Collection Sites and Understory Vegetation at Each Survey Point

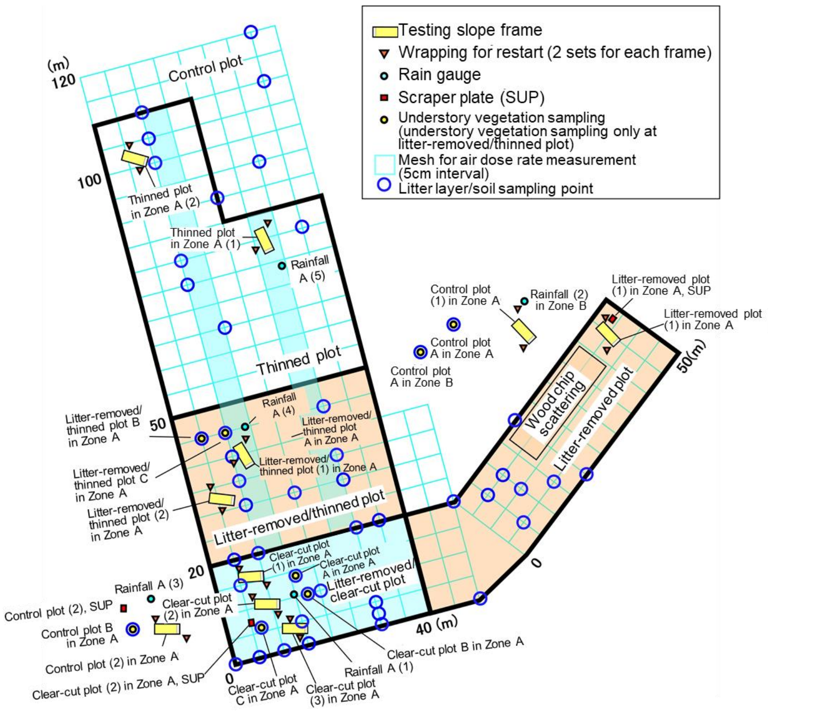


Figure 1-22 Locations of Survey Points in the Japanese Cedar Forest (Zone A)

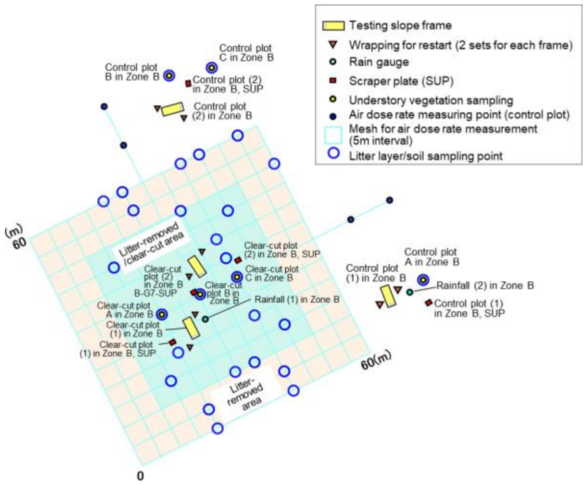


Figure 1-23 Locations of the Survey Points in the Japanese Cedar Forest (Zone B)

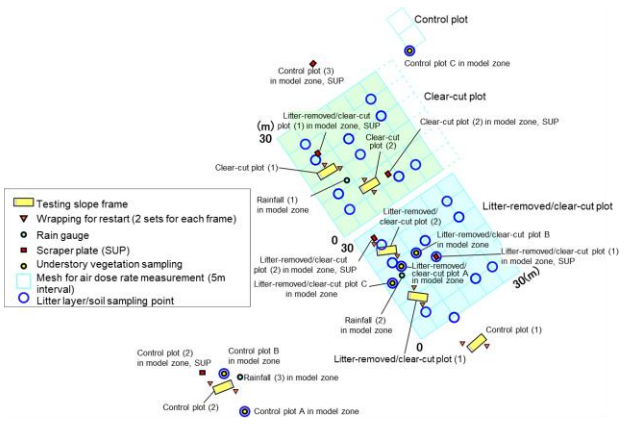


Figure 1-24 Locations of the Survey Points in the Model Zone for Mushroom Bed Log Collection

Table 1-9 Sampling Dates and Numbers of Sampling Points for Radiocesium Measurement in Soil and Litter Layers

Testing Zone	Japanese cedar forest (Zone A)					Japanese cedar forest (Zone B)			Model zone for mushroom bed log collection		
Work plot	Litter-removed/clear-cut plot	Litter-removed plot	Litter-removed/thinned plot	Thinned plot	Control plot	Litter-removed/clear-cut plot	Litter-removed plot	Control plot	Litter-removed/clear-cut plot	Clear-cut plot	Control plot
Pre-work	2012/12/14 (6)	2012/12/14 (5)	2012/12/14 (5)	2012/12/14 (6)	2012/12/14 (5)	2012/12/11 (4)	2012/12/11 (7)	-	2012/12/11 (5)	2012/12/11 (5)	-
After litter removal	2013/2/15 (6)	-	2013/4/4 (5)	-	-	-	-	-	2013/2/15 (5)	-	-
After clear-cutting	2013/4/4 (6)	-	-	-	-	2013/2/15 (4)	2013/2/15 (2)	-	2013/4/5 (5)	2013/4/5 (5)	-
Post-work	2013/10/13, 14 (6)	2013/7/9, 8/20, 10/14 (5)	2013/10/12, 13 (5)	2013/10/12, 13 (6)	2013/10/12, 13 (5)	2013/8/21, 9/13, 21 (4)	2013/8/21, 9/13, 21 (7)	-	2013/7/11, 12 (5)	2013/8/20 (5)	-
FY2014	2015/1/21 (6)	2015/1/29, 30 (3)	2015/1/22 (5)	2015/1/22 (6)	2015/1/22 (3)	2015/1/21 (4)	2015/1/21 (7)	-	2015/1/29 (5)	2015/1/29 (5)	-
FY2015	2015/11/27～30 (6)	2015/11/19 (3)	2015/11/26～12/3 (5)	2015/11/26～12/2 (6)	2015/11/30～12/3 (6)	2015/12/2 (7)	2015/12/2 (4)	2015/12/2 (3)	2015/12/1 (5)	2015/12/1 (5)	2015/12/1～3 (5)
FY2016	2016/11/15 (6)	2016/11/15 (3)	2016/11/15, 16 (5)	2016/11/16 (6)	2016/11/15 (6)	2016/11/16, 17 (7)	2016/11/16, 17 (4)	2016/11/16, 17 (3)	2016/11/14, 15 (5)	2016/11/14, 15 (5)	2016/11/14 (3)
FY2017	2017/11/27, 28 (6)	2017/11/29 (3)	2017/11/28 (5)	2017/11/28, 29 (6)	2017/11/27, 29 (6)	2017/11/30, 12/1 (7)	2017/11/30, 12/1 (4)	2017/11/30, 12/1 (3)	2017/11/30, 12/1 (7)	2017/11/30, 12/1 (4)	2017/11/30, 12/1 (3)
FY2018	2018/11/12～14 (6)	2018/11/12, 13 (3)	2018/11/13, 14 (5)	2018/11/14, 15 (6)	2018/11/13, 15 (6)	2018/11/10, 16 (7)	2018/11/16 (4)	2018/11/16 (3)	2018/11/10, 16 (7)	2018/11/16 (4)	2018/11/16 (3)

The figures in parentheses indicate the numbers of survey points.

② Scraper plate surveys

Scraper plate surveys have been conducted to determine the vertical distributions of the radiocesium concentration in the litter layers and soil at the Hirono Testing Site since 2013, in the Japanese cedar forest at the Kawauchi Testing Site (Zone A) since 2014, and in the Japanese cedar forest (Zone B) and model zone for mushroom bed log collection since 2012, before the works were applied. In each fiscal year, the samples were collected at locations as close as possible to the places where the samples had been collected in the previous years. Table 1-11 shows the sampling dates and numbers, and Figure 1-22 to Figure 1-24 show sampling points. Each sampling area was 15cm x 30cm in size, the same size as the scraper plate frame. All of the soil within the frame down to the mineral soil layer was collected with the scraper plate at incremental depths of 0-0.5cm, 0.5-1.0cm, 1.0-1.5cm, 1.5-2.0cm, 2.0-3.0cm, 3.0-5.0cm, 5.0-7.0cm, and 7.0-10.0cm (8 depths in total). The collected samples were used to measure the radiocesium concentration by the method described above. The radiocesium (Cs-137) concentration at each depth was regressed using an exponential function[8].

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[8] The radiocesium concentration, C (x) (Bq/kg), at the soil depth x (cm) was regressed using the following formula:

Table 1-10 Sampling Date and Numbers of Litter Layer and Soil Sampling Points for Radiocesium Measurement, by Soil Depth

Testing Zone	Japanese cedar forest (Zone A)			Japanese cedar forest (Zone B)		Model zone for mushroom bed log collection		
Work plot	Litter-removed/clear-cut plot	Litter-removed plot	Control plot	Litter-removed/clear-cut plot	Control plot	Litter-removed/clear-cut plot	Clear-cut plot	Control plot
Pre-work	-	-	-	2012/10/31 (1)	-	2012/10/31 (1)	-	-
Post-work	-	-	-	2013/2/8 (1)	-	2013/2/8 (1)	-	-
FY2013	-	-	-	2013/11/12 ～14 (3)	2013/11/12 ～14 (2)	2013/11/14 (2)	2013/11/13 (2)	2013/11/13 ～15 (2)
FY2014	2014/12/2 (1)	2014/11/26 (1)	2014/11/26 (1)	2014/11/27～28 (3)	2014/11/25 ～11/27 (2)	2014/11/27 , 28 (2)	2014/11/28 ～12/3 (2)	2014/11/27 ～12/3 (2)
FY2015	2015/11/27 (1)	2015/11/27 (1)	2015/11/26 (1)	2015/11/24, 25 (3)	2015/11/24, 25 (2)	2015/11/27 ～12/1 (2)	2015/11/27 ～12/1 (2)	2015/11/26 ～12/1 (2)
FY2016	2016/11/30 (1)	2016/11/30 (1)	2016/12/1 (1)	2016/11/29 (3)	2017/11/29 (2)	2016/11/30 (2)	2016/11/28 ～30 (2)	2016/11/28 ～30 (2)
FY2017	2017/12/13 (1)	2017/12/12 (1)	2017/12/12 (1)	2017/12/12, 13 (3)	2017/12/11 (2)	-	-	-
FY2018	2018/11/15 (1)	2018/11/15 (1)	2018/11/14 (1)	2018/11/12～14 (3)	2018/11/12, 13 (2)	-	-	-

Note: The figures in parentheses indicate the numbers of sampling locations.

4) Survey on Radiocesium in Understory Vegetation

Samples of understory vegetation were collected in the testing zones at the Kawauchi Testing Site to measure the radiocesium concentration (Table 1-12). Samples were collected from three of the sampling locations used in Section 3)①, where understory vegetation up to 1.5m high was collected within the same 20cm x 20cm area as the areas to collect sample litter layers. Samples collected at each survey point were mixed to create a single sample for measurement of the radiocesium concentration.

Table 1-11 Sampling Date and Numbers of Sampling Points for Radiocesium Measurement in Understory Vegetation

Testing Zone	Japanese cedar forest (Zone A)					Japanese cedar forest (Zone B)		Model zone for mushroom bed log collection		
Work plot	Litter-removed/clear-cut plot	Litter-removed plot	Litter-removed/thinned plot	Thinned plot	Control plot	Litter-removed/clear-cut plot	Control plot	Litter-removed/clear-cut plot	Clear-cut plot	Control plot
FY 2015	2015/10/14 (3)	-	2015/10/14 (3)	-	2015/10/14 (3)	2015/10/13 (3)	2015/10/13 (3)	2015/10/14 (3)	-	2015/10/14 (3)
FY 2016	2016/10/20 (3)	-	2016/10/20 (3)	-	2016/10/20 (3)	2016/10/20 (3)	2016/10/20 (3)	2016/10/20 (3)	-	2016/10/20 (3)
FY 2017	2017/9/25 (3)	-	2017/9/25 (3)	-	2017/9/25 (3)	2017/9/26 (3)	2017/9/26 (3)	-	-	-
FY 2018	2018/10/25 (3)	-	2018/10/25 (3)	-	2018/10/25 (3)	2018/10/25 (3)	2018/10/25 (3)			

Note: The figures in parentheses indicate the numbers of sampling locations.

$$C(x) = C(0) \cdot \exp(-x/\beta) \quad \text{(1), where}$$

C (0) denotes the radiocesium concentration on the ground surface and coefficient β denotes a buffer depth, where the radiocesium concentration equals 1/e (approx. 36.8%, where e denotes the base of the natural logarithm). This indicates that, with no soil disturbance, a greater buffer depth results in a deeper penetration of radiocesium into soil. For regression of equation (1), we took the logarithm on both sides, converted it into equation (2), and obtained the coefficient by the least squares method.

$$\ln(C(x)) = ax + b \quad \text{(2), where } \beta = -1/a \text{ and } C(0) = e^{b}.$$

5) **Measurement of Radiocesium Concentration in Litter Fall**

Two litter traps (trapping area of 0.5m^2/piece) were placed near each testing slope frame at the Kawauchi Testing Site (total of 40 traps; Figure 1-22 to Figure 1-24), and litter fall was collected about once a month after April 2014. The sample litter collected in each frame was weighed, the samples collected from each work plot over a period of three months were mixed, and the radiocesium concentration was measured according to the method described in the previous section.

(4) Test Results

1) Concentration and Deposit of Radioactive Materials by Tree Part

Figure 1-25 shows the concentration of radiocesium (Cs-134 and Cs-137) by tree part in the testing zone forests at the Kawauchi Testing Site. As of December 2012 and February 2013, the radiocesium concentration was the highest in the litter layers. In a tree, the concentration was high in leaves and branches, and considerably lower in the sapwood and heartwood than in the other parts. As of November 2013, the concentration was increasing in soil, was unchanged in the sapwood and heartwood, and was decreasing in the other parts.

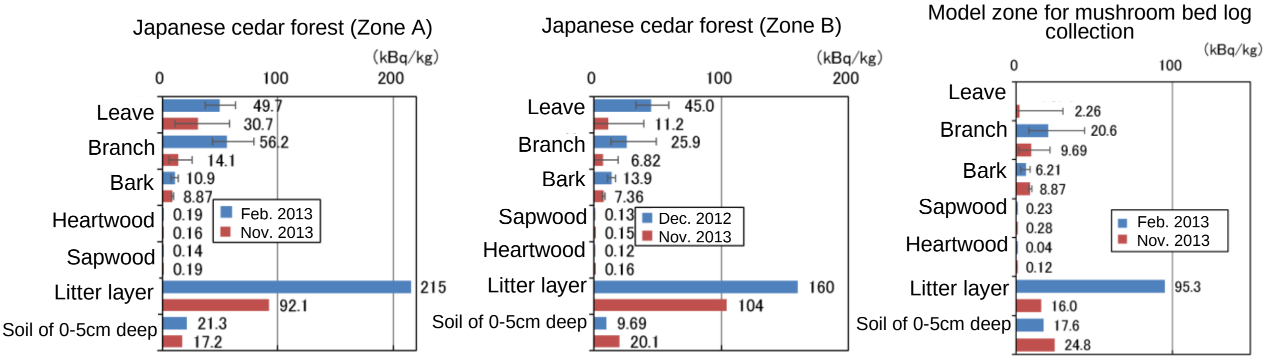

Figure 1-25 Radiocesium (Cs-134 and Cs-137) Concentration by Tree Part

Note: The horizontal bar indicates the average value. The right and left ends of the whisker indicate the maximum and minimum values, respectively.

Figure 1-26 shows the current deposits of radiocesium (Cs-134 and Cs-137) on tree parts. According to data collected in December 2012 and February and November 2013, the deposited radiocesium was declining in leaves and branches, increasing in soil, and not considerably changed in trunks (barks, sapwood, and heartwood). In the model zone for mushroom bed log collection, the deposited radiocesium had declined in trees, considerably declined in litter layers, and increased in soil.

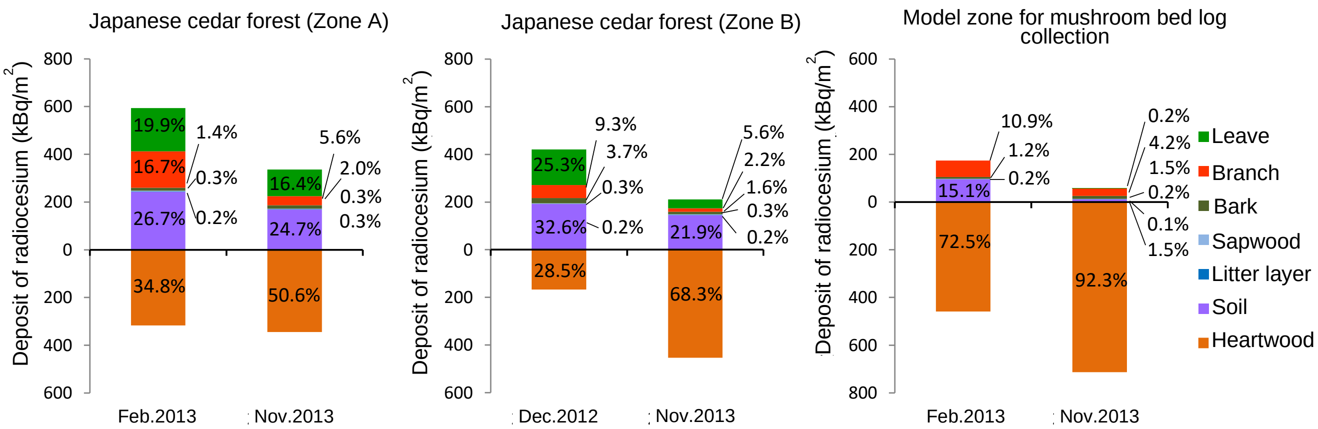

Figure 1-26 Distributions of Radiocesium (Cs-134 and Cs-137) by Tree Part (%)

Note: The levels of radiocesium deposited in litter layers and soil in the Japanese cedar forest (Zone A) and model zone for mushroom bed log collection as of December 2013 were corrected to values as of February 2013, to adjust for radioactive decay in the comparison with the other values measured in other parts.

2） Trends of the Radioactive Materials Deposited in Litter Layers and Soil, and the Radioactive Concentration (Kawauchi Testing Site)

Figure 1-27 to Figure 1-30 show the trends of the radiocesium (Cs-137) deposited in the litter layers and soil, and of the radiocesium concentration, in the work plots of the Japanese cedar forest (Zone A) at the Kawauchi Testing Site.

The radiocesium deposited in the litter layers was almost completely removed from the work plots where litters were removed, but they had increased continuously up to January 2015 before declining in all the plots, except in the litter-removed/clear-cut plot, where the radiocesium deposited little increased.

The radiocesium (Cs-137) concentration in the litter layers was considerably declined in the plots from which litters were removed and remained lower than that in the other work plots. The concentration was found to be on a moderately downward trend in the long run in all of the work plots and in the control plot, though some temporary fluctuations were observed in some plots.

The amount of radiocesium (Cs-137) deposited in soil (0-5cm in depth) fluctuated in the short run but might continue increasing in the long run.

The radiocesium concentration in soil had been low in the plots from which litters were removed until 2015, though it temporarily increased in the clear-cut plot.. The concentration was found to be on a moderately downward trend afterwards.

Similar trends were observed in the Japanese cedar forest (Zone B) at the Kawauchi Testing Site and the model zone for mushroom bed log collection.

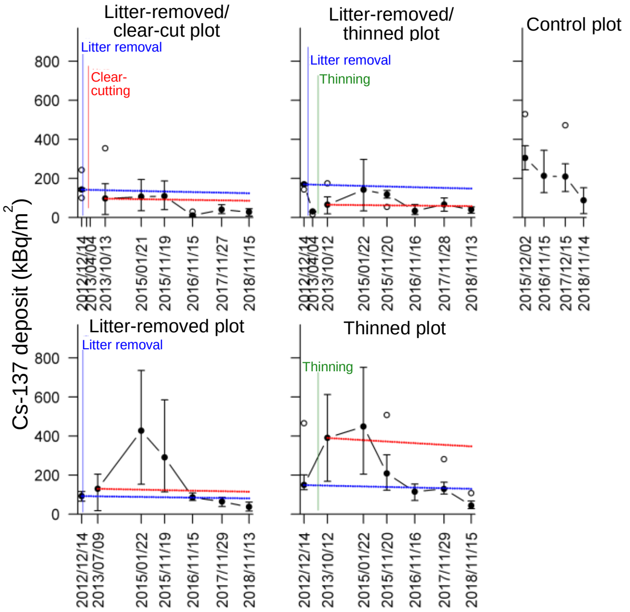

Figure 1-27 Trends of Cs-137 (kBq/m^2) Deposited in Litter Layers in the Japanese Cedar Forest (Zone A)

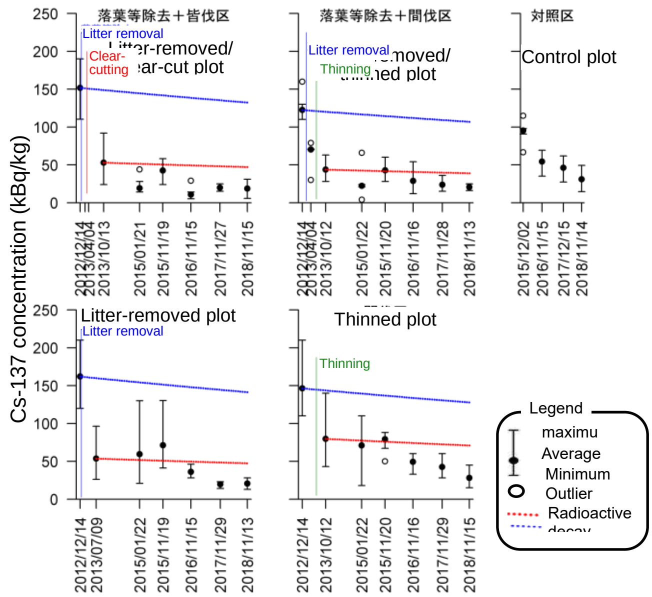

Figure 1-28 Trends of the Cs-137 Concentration (kBq/ kg) in Litter Layers in the Japanese Cedar Forest (Zone A)

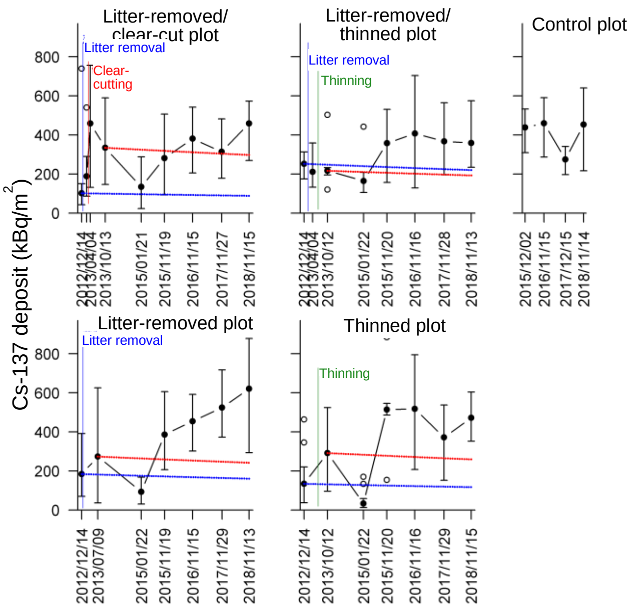

Figure 1-29 Trends of Cs-137 (kBq/m^2) Deposited in Soil in the Japanese Cedar Forest (Zone A)

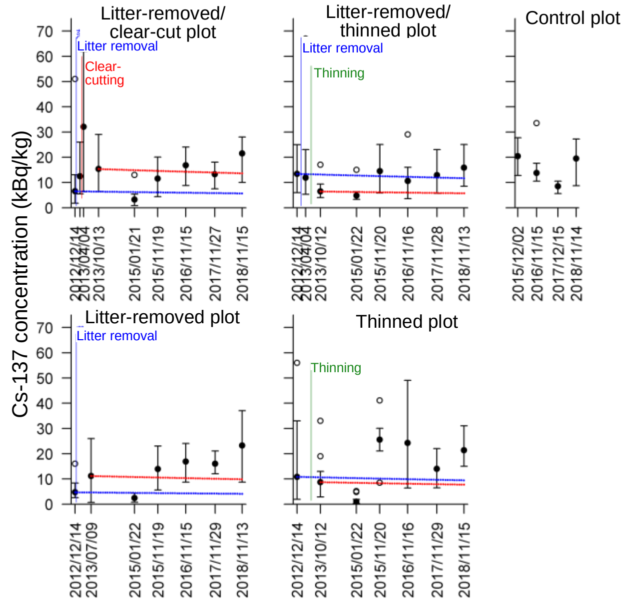

Figure 1-30 Trends of the Cs-137 Concentration (kBq/ kg) in Soil in the Japanese Cedar Forest (Zone A)

Note: In each box and whisker plot, the black dot indicates the mean value, white dots indicate outliers, and the whiskers indicate the maximum and minimum values other than outliers.

3） Distribution of Radioactive Materials in Litter Layers and Different Soil Depths (Scraper Survey)

Figure 1-31 shows the results of measurements of the distribution of radiocesium (Cs-137) in the litter layers and soil at different depths in the Japanese cedar forest (Zone B) at the Kawauchi Testing Site.

In the control plot, the litter layers had the concentration of radiocesium approximately five to seven times higher than that in the soil layer of 0-0.5cm depth in 2013. But radiocesium gradually moved into the soil afterwards, so the concentration became higher in the soil layer of 0-0.5cm depth than in the litter layers by 2016. The survey also found that the concentration of radiocesium became higher in deeper layers than the surface soil in the litter-removed/clear-cut plot and other plots with works over the period from 2013 to 2017, that the buffer depth tended to gradually increase, and thus that radioactive cesium was gradually moving from the topsoil to the deeper layers. This tendency was not clearly exhibited in the control plot.

A similar trend was observed in the results of the survey conducted in other testing zones (the Japanese cedar forest (Zone A) and the model zone for mushroom bed log collection) at the Kawauchi Testing Site, and in the thinned plot (Japanese cedar forest) and clear-cut plot (mixed forest of Japanese red pine and broad-leaved trees) at the Hirono Testing Site.

Incidentally, strong winds often blew in autumn in 2017, so the amount of litter fall was greater in December 2017, when the survey was conducted in the Japanese cedar forest (Zone B) at the Kawauchi Testing Site. The litter layers in the testing zones were thicker than in other years as a consequence, except in the central part of the litter-removed/clear-cut plot. This also increased the amount of radiocesium (Cs-137) deposited in the litter layers in many locations, compared to the previous year.

4） Concentration and Deposit of Radiocesium in Understory Vegetation

Figure 1-32 shows the radiocesium (Cs-137) concentration and deposits in understory vegetation in the Japanese cedar forests (Zones A and B) and in the model zone for mushroom bed log collection at the Kawauchi Testing Site.

The concentration of radiocesium in understory vegetation was higher on the control plot than in the work plots in both the Japanese cedar forests and model zone for mushroom bed log collection (broad-leaved tree forest). In all locations investigated except the Japanese cedar forest (Zone B), the amount of radiocesium deposited was greater in the clear-cut plot and thinned plot, where understory vegetation grew more thickly after logging than in the control plot, where the forest floor was dark and understory vegetation poorly grew. The concentration and deposit of radiocesium (Cs-137) in understory vegetation declines on most of all the work plots from 2015 to 2018.

5） Movements of Radioactive Materials due to Litter Fall

Figure 1-33 and Figure 1-34 show the concentration and deposit of radioactive materials as a result of litter fall in the Japanese cedar forest (Zone A) and the model zone for mushroom bed log collection in the Kawauchi Testing Site, respectively.

The amount of litter fall increased from autumn to winter (October to January) and early spring (February to April) every year in all the testing zones. The amount was large in the control plot and the thinned plots, and small in the clear-cut plots and elsewhere, where trees were cut down. The litter captured with litter traps in the clear-cut plot in the Japanese cedar forest (Zone A) chiefly consisted of understory vegetation.

The radiocesium (Cs-137) concentration of litter fall increased in all the testing zones in summer (around July) every year, and declined from autumn to winter (October to January). The concentration was on a downward trend in all the testing zones.

The amount of radiocesium, which moved together with movements of litter fall, was smaller in the plots where clear-cutting was conducted than in the control plot. This tendency was particularly conspicuous in the model zone for mushroom bed log collection.

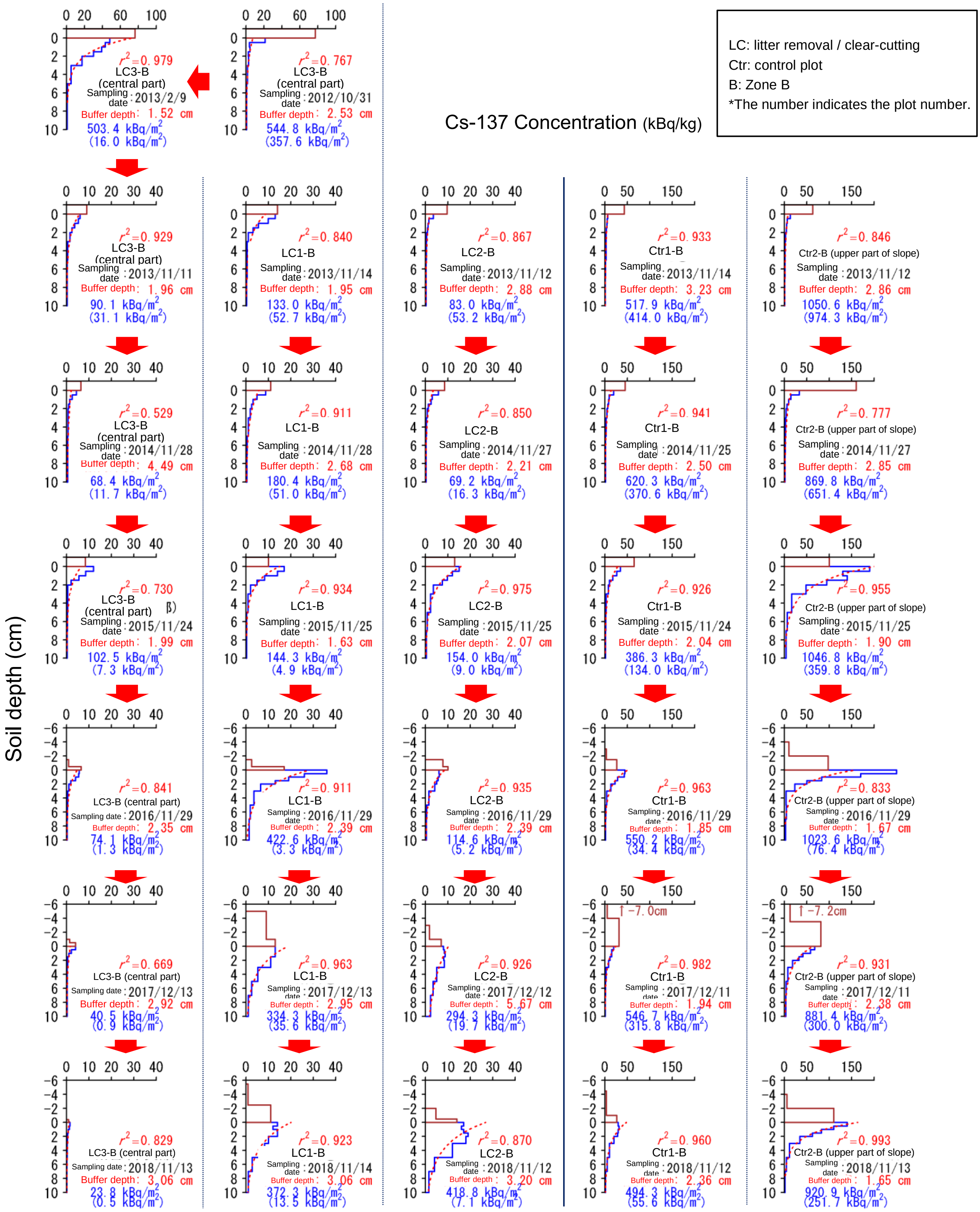

Figure 1-31 Trends of the Radiocesium (Cs-137) Concentration in Littler Layers and Different Soil Depths in the Japanese Cedar Forest (Zone B)

In each graph, the red dotted line indicates the exponential[8] regression curve of the radiocesium (Cs-137) concentration in soil and r^2 denotes the coefficient of determination on the adjusted degree of freedom. The values in red are the buffer depths (cm, see p.26), the values in blue are the sums of radiocesium (Cs-137) deposited in litter layers and soil at the measuring points, and the values in parentheses are radiocesium deposited solely in litter layers. The thickness of the litter layers (reddish brown line) for 2014 and 2015 is fixed at 1cm for comparison, and is not the actual thickness.

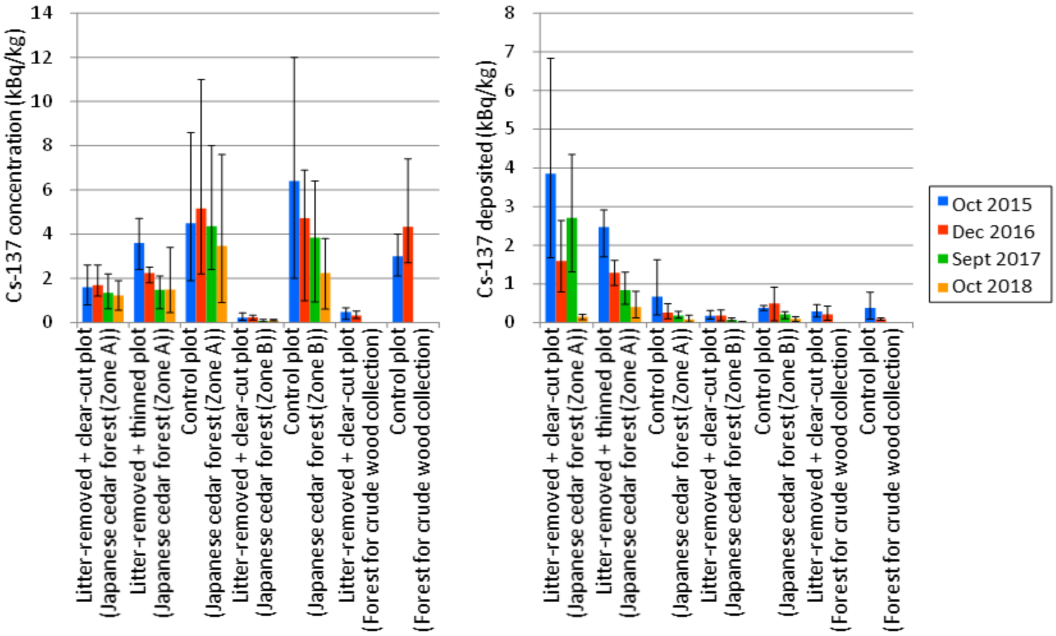

Figure 1-32 Concentration (left) and Deposit (right) of Radiocesium (Cs-137) in Understory Vegetation at the Kawauchi Testing Site

The litter-removed/thinned plots in the Japanese cedar forests (Zones A and B) were weeded in August 2018.
* No survey has been conducted on understory vegetation in the model zone for mushroom bed log collection since 2017.

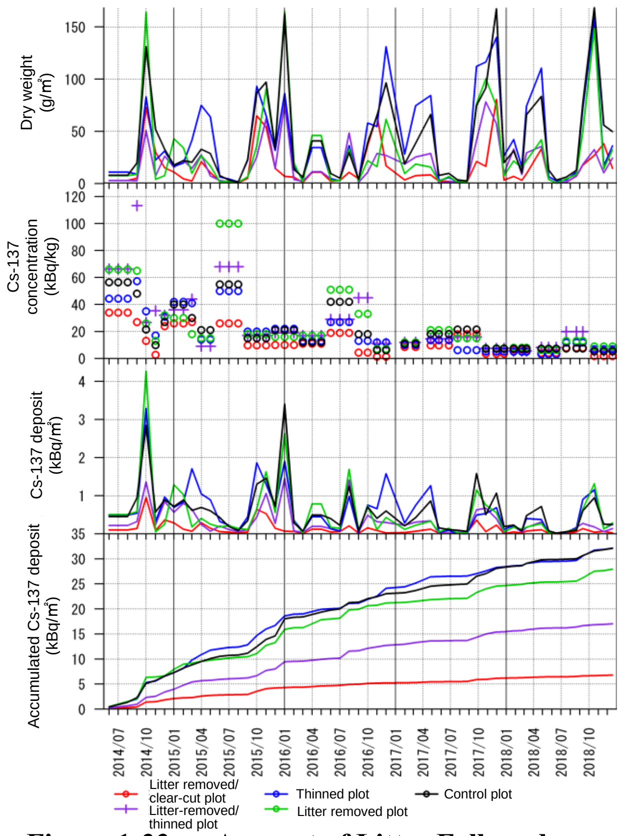

Figure 1-33 Amount of Litter Fall, and Concentration, Deposit, and Accumulated Value of Radiocesium (Cs-137) in Litter Fall in the Japanese Cedar Forest (Zone A) (after June 2014)

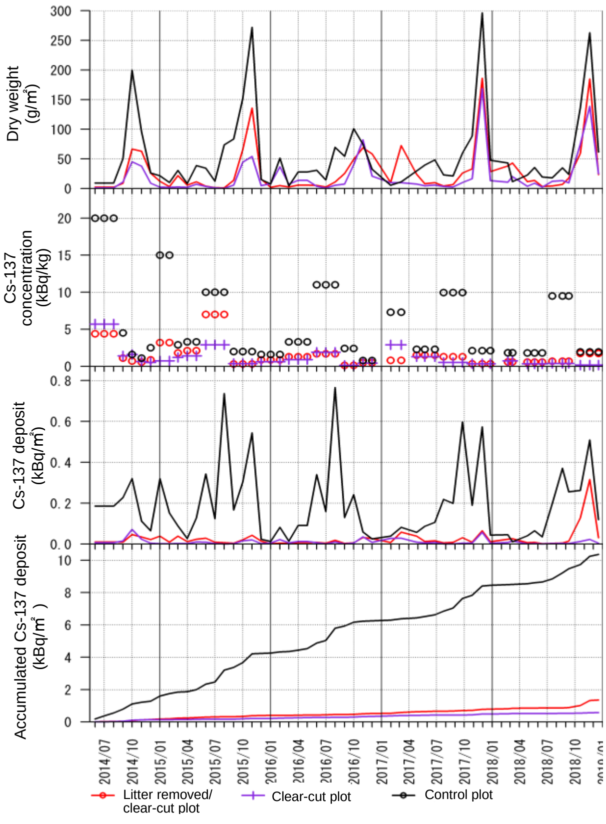

Figure 1-34 Amount of Litter Fall, and Concentration, Deposit, and Accumulated Value of Radiocesium (Cs-137) in Litter Fall in the Model Zone for Mushroom Bed Log Collection (after June 2014)

Note: Litter traps were installed both under tree crowns and in the cleared areas. Thus, the weighted averages, with the ratio of the two areas set at 2:1, are used for the thinned plot and the litter-removed/thinned plot in the Japanese cedar forest (Zone A).

(5) Conclusions

1) The Impact of Works on Air Dose Rates

Table 1-11 shows the volumes and percentages of radioactive materials[9] in the work plots of the Kawauchi Testing Site when it was assumed that the litter removal, thinning, clear-cutting works removed all radiocesium (Cs-137) from the target parts (litter layers by litter removal; leaves, branches, barks, sapwood, and heartwood by logging). Figure 1-35 and Figure 1-36 show the correlation between the volumes of radiocesium removed due to the works and the percentage of the increases or decreases of the air dose rates relative to radioactive decay for two respective periods, that is, the period before and after the works, and the period after the period up to September 2017.

Table 1-12 The Volumes and Percentages of Radiocesium (Cs-137) Removed from the Work Plots due to the Various Types of Works

Japanese cedar forest (Zone A)

Work plot	Volume of Cs-137 removed (kBq/m²)	Percentage of Cs-137 removed	Remarks
Control plot	0.0	0.0%	
Thinned plot	76.0	13.0%	2 in 4 trees are thinned
Litter-removed plot	154.8	26.5%	
Litter-removed/thinned plot	230.7	39.5%	
Litter-removed/clear-cut plot	382.7	65.5%	
Forest edge	382.7	65.5%	Peripheral part of the litter-removed/clear-cut plot

Japanese cedar forest (Zone B)

Work plot	Volume of Cs-137 removed (kBq/m²)	Percentage of Cs-137 removed
Control plot	0.0	0.0%
Litter-removed/clear-cut area	267.1	71.5%

Model zone for mushroom bed log collection

Work plot	Volume of Cs-137 removed	Percentage of Cs-137 removed
Control plot	0.0	0.0%
Clear-cut plot	51.1	17.2%
Litter-removed/clear-cut plot	113.0	27.6%

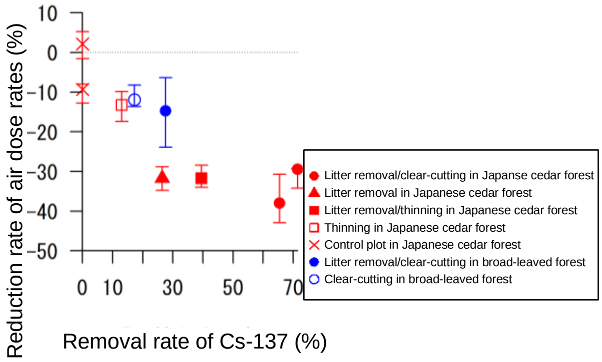

Figure 1-35 Correlation between the Percentage of Radiocesium (Cs-137) Removed by the Different Types of Work and the Reduction Rate of the Air Dose Rates at the Kawauchi Testing Site (before and after the works)

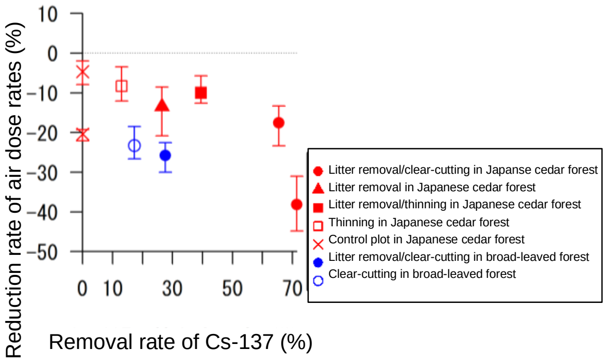

Figure 1-36 Correlation between the Percentage of Radiocesium (Cs-137) Removed by the Different Types Works and the Reduction Rate of the Air Dose Rates at Kawauchi Testing Site (after the works, up September 2017)

Note: In each plot, the symbol indicates the mean value and the whiskers indicate the range from the first to third quartiles.

During the period up to the end of the works, the percentage of radiocesium (Cs-137) removed was high and the air dose rates considerably declined in the plots of Japanese cedar forest where litters were removed. The percentage of radiocesium removed increased in the plots where clear-

[9] The percentages of radioactive materials removed were computed with the total amount of radiocesium in the parts of standing trees above the ground (leaves, branches, barks, sapwood, and heartwood), litter layers, and soil as the denominator.

cutting or thinning was applied, but the increased volume was smaller, a half or one third of the volume observed in the plots where litters were removed. During the period after the works ended, up to September 2017, the air dose rate declined more in the plot where the volume of radiocesium (Cs-137) removed was greater, though the reduction rates varied among the testing zones. (Cs-137) removed.

2） Changes in the Distribution and Impact of Radioactive Materials in Forest

Figure 1-37 shows the trends of the radioactive materials deposited near forest floors in the work plots of the Kawauchi Testing Site.

① Post-works (2012-14)

Most radioactive materials were removed from litter layers in the plots where litter was removed. The air dose rates also declined in these spots. However, the volume of radioactive materials in the litter layers of the broad-leaved forest was smaller (Figure 1-26), and the reduction rates of the air dose rates were also small (Figure 1-35). On the other hand, the impact of logging on the air dose rates was relatively small, and the radiocesium deposited in the litter layers subsequently increased in the work plots, in around 2014.

② Around 2015 and afterwards

In 2015 and afterwards, the radiocesium deposited in the litter layers was declining while that in the soil was generally increasing. The results of the scraper plate survey also found that the radiocesium in the soil was gradually moving from the surface into the deeper layers (Figure 1-31). The volume of radiocesium deposited in the litter fall surveyed after 2014 was fairly limited, compared to the volume found in the soil or litter layers (Figure 1-37). The radiocesium (Cs-137) concentration in the litter fall was also declining (Figure 1-33 and Figure 1-34).

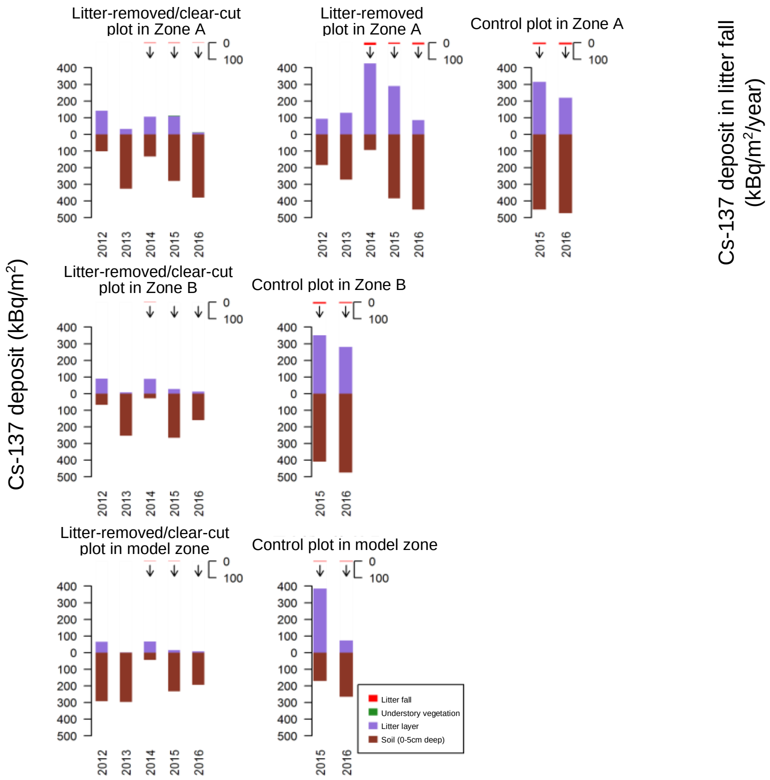

Figure 1-37 Yearly Changes in the Distribution of Radiocesium (Cs-137) in the Testing Zones at the Kawauchi Testing Site

Note: The values for soil are the mean values of samples collected from soil at a 0-5cm depth with a cylinder soil sampler. Measurements for litter fall commenced in 2014, and those for understory vegetation commenced in 2015. No survey was conducted on understory vegetation in the litter-removed plot or the thinned plot.