THESIS

INVENTORY DYNAMICS AND SOIL FACTORS AFFECTING SOIL-TO-PLANT ^{137}Cs TRANSFERS IN FUKUSHIMA FOREST ECOSYSTEMS

Submitted by

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ABSTRACT

INVENTORY DYNAMICS AND SOIL FACTORS AFFECTING SOIL-TO-PLANT ^{137}Cs TRANSFERS IN FUKUSHIMA FOREST ECOSYSTEMS

The objective of this study was to understand the soil factors affecting soil-to-plant transfer factors in understory plant species as well as their contribution to the total ^{137}Cs inventory in aboveground biomass within the Fukushima forest ecosystem.

Radiocesium contamination from the March 2011 accident at the Fukushima Da-ichi Nuclear Power Station (FDNPS) was initially deposited on the forest canopies with deposition into the soil occurring over the next few years through litterfall and precipitation. Measurements taken from the Yamakiya site in 2014 show that the contribution of understory plants to the total inventory of radiocesium in aboveground biomass was very low compared to the dominant Japanese cedar trees. However, measurements were not taken in other affected sites within Fukushima prefecture as well as potential change in concentrations of radiocesium in understory biomass since 2014.

Data for evaluating the transfer factors was obtained through sampling of soil and understory plants at the Yamakiya, Tsushima, Tomioka, Okuma, and Yokomuki sites inside Fukushima Prefecture. Both ^{134}Cs and ^{137}Cs measurements were collected, however ^{134}Cs concentrations were negligible compared to ^{137}Cs so only ^{137}Cs data was considered. ^{137}Cs content was determined using gamma spectroscopy of the soil and plant samples and to find the concentration of bioavailable ^{137}Cs within the root profile of the understory plants as well as

^{137}Cs concentration within the understory plant itself. The soil and plant ^{137}Cs concentration was used to determine the soil-to-plant uptake factors for the sampled understory species as well as the contribution of the understory plants to the total ^{137}Cs inventory in aboveground biomass. The effect of soil exchangeable [K^+], exchangeable [Cs^+], exchangeable ^{137}Cs activity concentration, total ^{137}Cs activity concentration, and pH on ^{137}Cs uptake by understory plants was determined through the soil-to-plant uptake factors at the various sample sites. The same data was used to find the ^{137}Cs deposition in the soil, ^{137}Cs inventory in Yamakiya, and patterns between plant activity concentration between plant species.

Soil measurements showed a logarithmic decrease in ^{137}Cs activity concentration with decreasing soil depth. Measurements also supported a 4.39 year effective half-life using GIS and Nuclear Regulatory Authority data, however using IER data a radiological half-life of 30.17 years was supported instead. The majority of ^{137}Cs inventory in Yamakiya was found to be in soil (80.54%) and trees (18.52%) with understory plants making up a negligible contribution. This contribution by trees was much higher than the one found in previous years. For understory plants, it was found that there are higher 137Cs activity concentrations in the more metabolically active portions of the plants. ^{137}Cs was a significant contributing factor across all understory plant species in predicting the soil to plant transfer factors. The ability to properly estimate the activity concentration of understory plants using only the one soil factor can contribute to faster estimation of potential ^{137}Cs concentrations in plants or uptakes by herbivores in areas contaminated by ^{137}Cs. The further understanding of ^{137}Cs dynamics in forest ecosystems will assist in creation of a long-term forest radiation contamination management strategy.

ACKNOWLEDGEMENTS

Thanks to all the faculty at both the Health Physics program at Colorado State University (CSU) and at the Institute of Environmental Radioactivity (IER) at Fukushima University (FU). Dr. Thomas Johnson, Dr. Alexander Brandl, and Dr. Ralf Sudowe have been excellent instructors who strove far beyond what they are expected in educating all the students under them, assisting them in their research, and helping in their careers after graduation. It was a pleasure to work with Dr. Vasyl Yoschenko who helped organize and conduct this research in Fukushima Prefecture as well as providing needed mentorship and guidance during my time in Japan. Thank you, Dr. Kenji Nanba without whose organization of the CSU-FU student program, none of this would have even been possible. Thank you, Dr. Tsugiko Takase and Azusa Goto, for providing their much-needed support and skills in conducting sample preparation and analysis. Thank you, Kenji Watanabe and Hiroko Nagata, for going out to the field and assist in collecting the soil and plant samples for this research project. Thank you, Matt Meengs for all your help with how to use R to analyze my data. Thank you, to the Radioactivity Research Network Center and the United States Air Force, for funding the research trip to Fukushima, Japan. I hope to be able to work with everyone again in the future.

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INTRODUCTION

1.1 Background

On 11 Mar 2011 an earthquake struck 70 km east of Oshika Peninsula off the coast of Miyagi Prefecture, Japan (USGS, 2016). The earthquake caused a catastrophic tsunami which hit the east coast of Japan causing 18,483 fatalities and damage to the Fukushima Dai-ichi Nuclear Power Plant (FDNPP) consisting of 6 boiling water reactors (BWR) (Sato, 2015). This damage eventually resulted in the release of large quantities of radiocesium along with other isotopes into the environment. Sixty six percent the heavily contaminated areas ($^{134,137}Cs \geq 1000$ kBq m^{-2}) were forest ecosystems (Hashimoto et al, 2012). Due to this, a great amount of research has been conducted on forest ecosystems and more specifically the trees that make up the vast majority of the forest biomass (Yoschenko et al, 2017). The dynamics of understory plants in Fukushima forest ecosystems is less studied and continued research to find a more complete picture of ^{137}Cs dynamics in forest ecosystems contributes to the creation of a complete long-term forest contamination management strategy and also to future studies involving herbivore radiocesium uptakes from understory plants.

1.2 FDNPP Accident

The tsunami that struck FDNPP was of a height of more than13 m and the protective seawall was only 10 m tall (Matthews et al, 2017). The seawater from the tsunami flooded the FDNPP complex causing a power outage and disabling 12 of the 13 emergency diesel generators with only one generator at unit 6 surviving, as it was 13 m above sea level (Springer, 2014). Due to the loss of site power and key systems due to the tsunami, shutdown cooling systems were no longer operational. Loss of cooling led to a heat buildup in the recently shutdown reactors and an eventual meltdown. The reaction of water and zirconium in the fuel rod cladding created large amounts of hydrogen gas resulting in a hydrogen explosion and subsequent release of the volatile fission products and radiocesium present in the reactor (Springer, 2014).

1.3 FDNPP Release and Isotopes of Concern

An estimated total source term of 340-800 PBq was released into the atmosphere from the FDNPP (Steinhauser et al, 2014). Radioactive noble gases such as ^{85}Kr and ^{133}Xe were not included in the release estimate, as they have much less impact onto the terrestrial environment. Volatile fission products such as ^{131}I and ^{132}Te were also released in large amounts (Table 1) but due to their short half-lives (8 and 3 days, respectively) are not a long term concern for forest contamination. As 8 years have passed since the release, even ^{134}Cs has become a negligible source of soil contamination, especially considering that the effective half-life of ^{134}Cs would be even shorter taking into account the environmental half-life of Cs in the Fukushima soils (Hayes et al, 2019). The vast majority of the radioactivity currently present in the forests surrounding FDNPP is from ^{137}Cs (30.17 year half-life). While Chaisan et al, 2013 had a corrected ^{134}Cs/^{137}Cs ratio in soil of 0.90 ± 0.01, more recent studies had observed activity ratios closer to 1 (Aoyama et al, 2015; Steinhauser et al, 2014).

Table 1: **Isotopes of concern released at Fukushima**

Average corrected ratio from soil samples within 80 km of the FDNPP and taken within 30 days following the accident.

Radionuclide	Half-life	Activity Release (PBq) *(IAEA, 2016)*	Corrected Ratio to ^{137}Cs in Soil *(Chaisan et al, 2013)*
^{131}I	8.020 days	100-400	22.5 ± 3.70
^{132}Te	3.204 days	0.76-162	18.3 ± 1.70
^{134}Cs	2.065 years	8.3-50	0.90 ± 0.01
^{137}Cs	30.17 years	7-20	1.00 ± 0.00

1.4 Fukushima Forest ^{137}Cs Dynamics

During the early period after the FDNPP accident, the majority of radiocesium was intercepted by tree canopies and eventually transported to the surface through litterfall, throughfall, and stemflow (Yoschenko et al, 2017). Radiocesium falling on the soil and the decomposition of organic matter into the soil eventually results in a decrease in radiocesium in litter and increase in radiocesium in soil with respect to the total radiocesium percentage of the soil profile. The total radiocesium inventory of soil is expected to increase over time while radiocesium content of litter decreases over time as shown in Figure 1. Figure 2 shows increasing ^{137}Cs concentration in soil and decrease in ^{137}Cs concentration in litter.

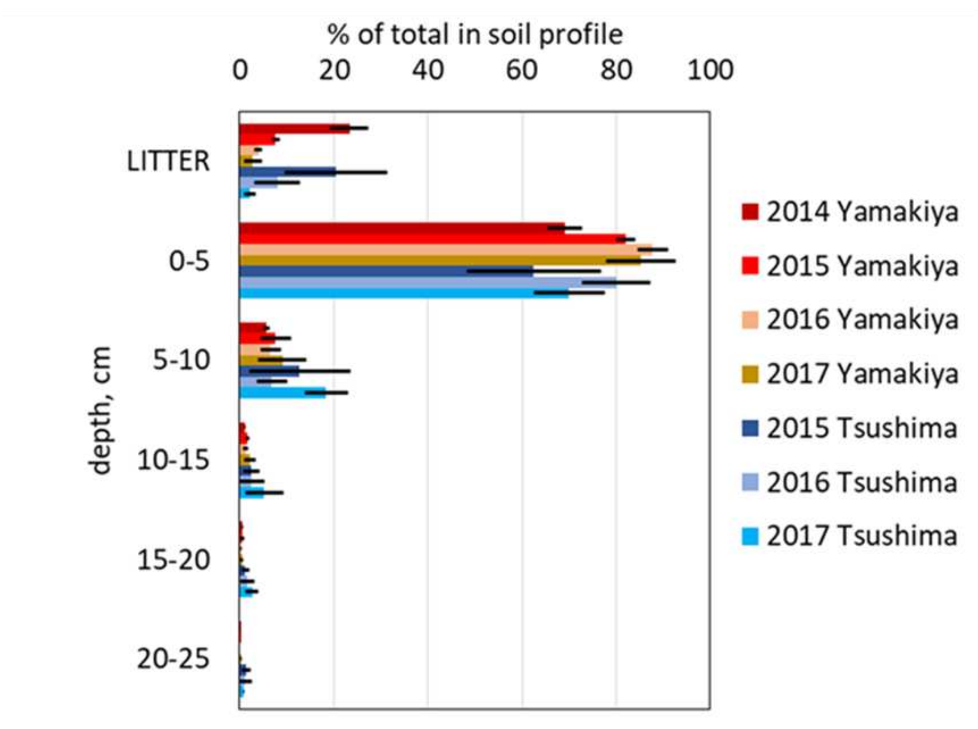


Figure 1: Soil radiocesium vertical distribution over time

Decreasing litter radiocesium contribution to soil profile over time (Yoschenko et al, 2018)

Figure 2 does not show how understory plants contribute to or remove ^{137}Cs from soil. Understory plants comprise a very small percentage of the aboveground ^{137}Cs inventory as seen in figure 3. Trees comprise over 98% of aboveground ^{137}Cs inventory (Yoschenko et al, 2017). Trees encompass the vast majority of the aboveground biomass in forests. The topmost layers of soil contain the majority of the contaminant deposition, and much of the remediation work since the accident has been the removal of the top layer of soil. Remediation efforts of Japanese cedar forests near Iawaki, Japan in 2013 have led to a ^{137}Cs reduction of 31±3% compared to the control area of 17.5±1.3% in 2014 (Sanderson et al, 2016).

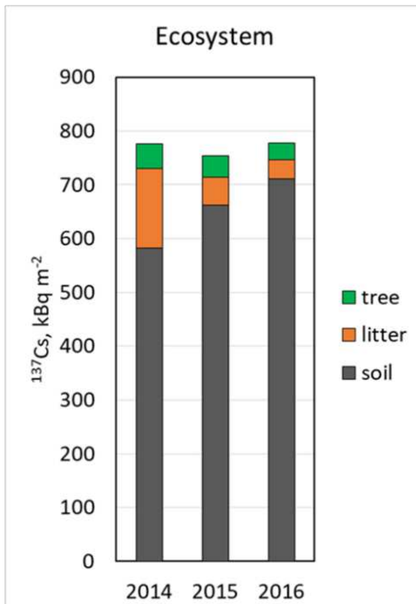
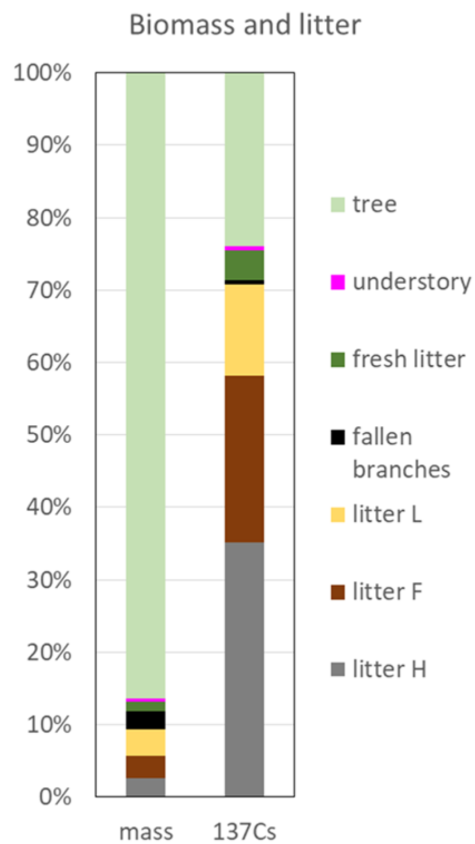


Figure 2: Yamakiya ^{137}Cs inventory contributions in Yamakiya forest

Decreasing litter and increasing soil ^{137}Cs contribution to Yamakiya forest ecosystem over time (Yoschenko et al, 2018)



Litter L	Minimally decomposed litter
Litter F	Partially decomposed litter
Litter H	Mostly decomposed litter

Figure 3: Distributions of biomass and ^{137}Cs inventories in the aboveground forest compartments of Yamakiya

Understory plants contribute little to total ^{137}Cs inventory due to low mass contribution in Yamakiya forest ecosystem *(Yoschenko et al, 2017)*

1.5 Factors Affecting ^{137}Cs Uptake by Understory Plants

Radioactive elements are chemically indistinguishable from their stable counterparts (such as ^{133}Cs and ^{137}Cs) and are expected to behave in the same way in soil and how they are taken up by plants. Soil chemistry can, however, affect how much cesium can be taken up by plants through the fixation of Cs^+ in the soil as well as competition from group I alkali metal analogues such as K^+ (Wakeel, 2013). Due to Cs^+ being an analogue of K^+, Cs^+ is able to use plant K^+ transporters to be taken up by plants (Nobori et al, 2014). K^+ in the soil will compete with Cs^+

in being taken up by plants, with higher concentrations of K^+ causing a decreased uptake of ^{137}Cs by plants (Burger and Lichtscheidl, 2018). Figure 4 shows that the addition of K^+ fertilizer has been shown to reduce the total uptake of ^{137}Cs in brown rice grown in paddy fields (Nobori et al, 2014).

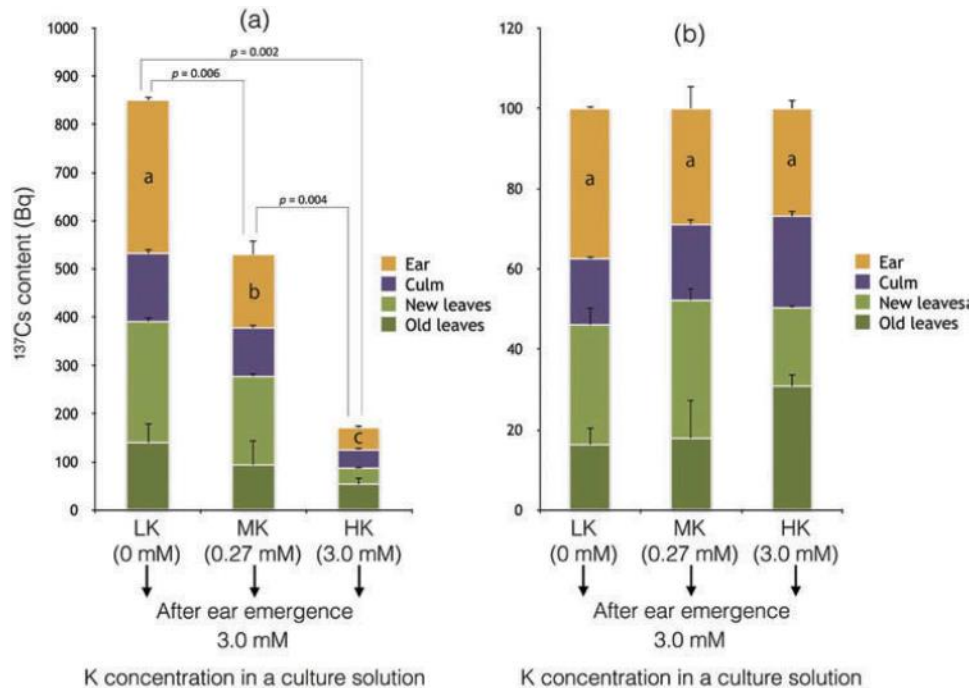


Figure 4: ^{137}Cs content in Oryza sativa L. rice plant (left) and percent contribution in various rice plant parts (right) with increasing K^+ added
Increasing concentrations of K^+ in the soil decreases the amount of ^{137}Cs taken up by the rice *(Nobori et al, 2014)*

It has been well established that Cs^+ adsorbs very well on clay minerals and the fixation of ^{137}Cs in soil will depend heavily on the percent clay composition of soil (Cornell, 1993). Negligible amounts of clay are found in the soils of Yamakiya, Tomioka, and Tsushima sampling sites, as shown in previous studies (Personal communication, 29 Jul 2019, Vasyl Yoschenko). Clay content at the Okuma site was 15-23%, typical of gray lowland soil at 0-12 cm depth (USDA, 1999).

Highly organic soils have high amounts of bioavailable Cs^+ (Dumat and Staunton, 1999). Highly organic soils also have higher radiocesium concentration and mobility, which in turn is related to low clay content, high NH_4^+ concentration of the soil, and low K^+ availability (Sanchez et al, 1999 & Rigol et al, 2002).

The objective of this study was to examine how exchangeable [K^+], [Cs^+], exchangeable ^{137}Cs activity concentration, total ^{137}Cs activity concentration, and pH in soil would affect ^{137}Cs uptake on understory plants. A correlation between total ^{137}Cs activity concentration in the soil and soil to plant transfer factors was found for all understory plant species. Soil to plant transfer factors varied between plant species with [K^+], [Cs^+], exchangeable ^{137}Cs activity concentration, and pH. Soil exchangeable ^{137}Cs was hypothesized to correlate with plant uptake, as plants are expected to uptake more ^{137}Cs if more is present in the soil. Unexpectedly, the hypothesis was not proven. The total soil ^{137}Cs activity concentration had more influence on ^{137}Cs uptake by plants then the soil exchangeable ^{137}Cs activity concentration. Only exchangeable ^{137}Cs was expected to be available for plant uptake.

METHODS

2.1 Sampling Locations

Plant, litter, and soil samples were taken from six different areas within five sites in or near the Difficult to Return Zone (exclusion zone) and one control area expected to have low radiocesium contamination. Both ^{134}Cs and ^{137}Cs measurements were conducted, however ^{134}Cs concentrations were negligible compared to ^{137}Cs, so only ^{137}Cs data were considered. Sample locations were chosen for their expected varying ^{137}Cs concentrations along with previous data locations for comparison. Table 2 lists the location name, initial ^{137}Cs deposition data (Kato, H and Onda, Y, 2019), dominant tree type, and soil type (NARO 2019). Figure 5 and 6 show the sample sites and the sample location overlaid on a dose rate and ^{137}Cs soil concentration map from the Japan Map Center respectively (GSI, 2019).

Table 2: Sampling Location Information

^{137}Cs soil concentration range data chosen from nearest from the nearest soil sampling location shown in figure 2. Soil Type from the National Agriculture and Food Research Organization.
1. Sugi is Japanese cedar (Cryptomeria japonica)
2. Pine is Japanese red pine (Pinus densiflora)

Location Name	Coordinates of location	Dominant Tree Species	Soil Type
Yamakiya	37.5884, 140.7108	Sugi	Allophanic Black Soil
Tomioka	37.36942, 140.9461	Sugi	Brown Forest Soil
Tsushima Sugi[1]	37.5528, 140.789	Sugi	Allophanic Black Soil
Tsushima Pine[2]	37.5528, 140.789	Pine	Allophanic Black Soil
Okuma	37.40637, 141.03242	N/A	Gravel Ordinary Gray Lowland Soil
Yokomuki	37.65557, 140.25255	Multiple	Multiple Soil Types

Figure 5a: Yamakiya sugi forest (37.5884, 140.7108)

Figure 5b: Tsushima sugi forest (37.5528, 140.789)

Figure 5c: Tsushima pine forest (37.5528, 140.789)

Figure 5d: Tomioka sugi forest (37.36942, 140.9461)

Figure 5e: Okuma site (37.40637, 141.03242)

Figure 5f: Yokomuki control site (37.65557, 140.25255)

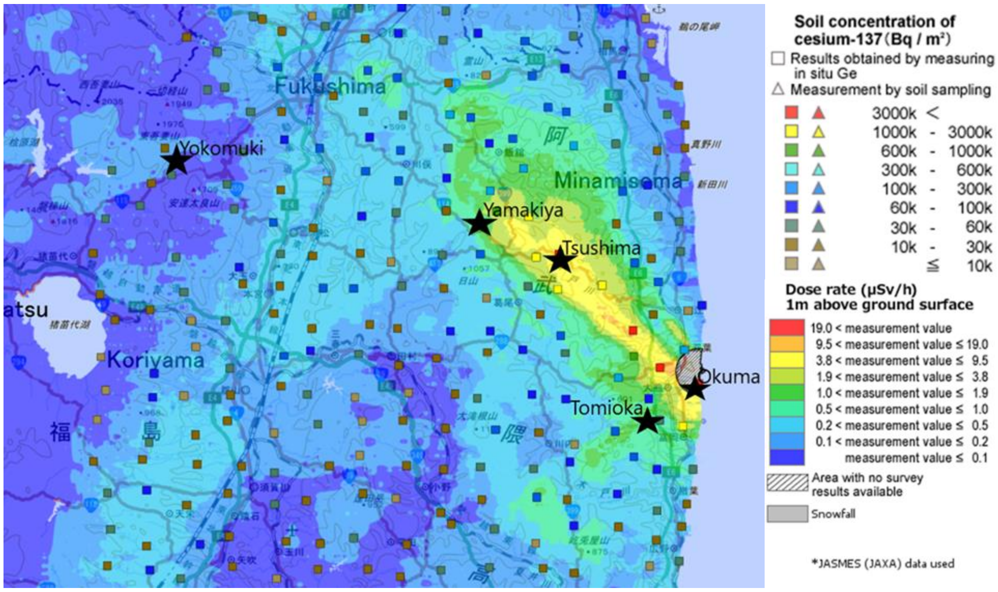


Figure 6: Sampling locations

1 Oct 2018 ^{137}Cs soil concentration data and 15 Nov 2018 dose rate data.
Map overlay and data from the Japan Map Center (GSI, 2019)

2.2 Sample Collection

Three types of samples were collected at each site; plant, litter, and soil. Only understory plants with a noticeable contribution to the biomass in the sampling area were collected. A noticeable contribution was ascertained visually. A noticeable contribution was assumed if >1% of the total biomass were understory plants in the designated sampling perimeter. At the Yamakiya, Tsushima Sugi, and Tomioka sites, a perimeter was established with all understory plants collected and measured for mass to find the total aboveground biomass contribution to ^{137}Cs inventory (Figure 7). Sites were selected based on previous samples at these locations. The sampling perimeter was established using a string with both the length of the perimeter and diagonal of the site being measured to calculate the area. The perimeter and diagonal distances of the site were found using a Leica Disto D510 E7500i laser measuring device (Figure 8). The perimeter and area for the Yamakiya, Tsushima Sugi, and

Tomioka sites (Table 3) were not all used to find the total biomass inventory, but data were collected for future research at these sites.

Table 3: Sampling site perimeter and area

Sampling Site	Perimeter (m)	Area(m^2)
Yamakiya	41.04	101.66
Tsushima Sugi	20.53	24.48
Tomioka	27.27	45.70

Figure 7: Tomioka sampling site

The left and right picture shows the before and after the collection of all major aboveground understory plants at the same location but taken at a different angle and time on same day at the Tomioka site

Soil sampling locations were determined by proximity to certain different understory plant species. A soil core sampler was used to collect a 30 cm soil core in a plastic liner inside the sampler apparatus (Figure 8). The core sampler was first pushed into the soil by hand until standing stably on its own. A hammer was then used to drive the full length of the core sampler tube into the soil. The core sampler was then extracted using the handle on the core sampler. The 30 cm plastic liner containing the sample was removed from the core sampler and placed into a sample bag for future sample preparation.

Figure 8: Soil core sampler (top), field weight balance (bottom left) and laser distance measuring device (bottom right)

The aboveground portion of the understory plants within 0.5 m of the soil sample locations were cut using plant shears and separated into different sample bags by plant species. The field weight (f.w.) of the samples was then taken using a 400-TST005 digital scale (Figure 8). A tray with a known area was used to identify and collect litter samples (Figure 9). A plant shear was used to cut all litter around the tray and only litter within the tray area was collected.

Figure 9: Tray used for litter collection area

2.3 Soil and Plant ^{137}Cs Concentration Measurements

The 30 cm soil core was cut up into three 5 cm thick and one 15 cm thick section and placed into a metal bin located in the plant preparation lab (Figure 10). The metal bins containing the soil sections were placed in a Panasonic MOV-212-PJ natural convection oven to dry at 105°C until at constant dry weight (d.w.). Soil samples were dried for 24 hours, a time found to be sufficient to achieve to a constant d.w. which was recorded upon completion. Some litter samples required 48-hours to achieve a constant d.w. Both litter and plant samples were further shredded using a plant shear and placed into a metal bin before being dried in the oven. All equipment used in all procedures was cleaned between each sample to prevent cross-contamination.

Figure 10: Soil core sections

Both the dry soil sections and plant samples were homogenized using an Absolute3 Vita-Mix or Pure Natura blender (Figure 11) before being placed into 100 mL U-8 containers (Figure 12). As some homogenized soil and litter samples were too large to fit in the U-8 containers, the mass of the soil in the sample was measured and recorded. The ^{137}Cs content for the soil, plant, and litter samples were found through gamma spectroscopy using a Canberra High Purity Germanium (HPGe) auto-sampler detector.

Figure 11: Absolute3 Vita-Mix blender

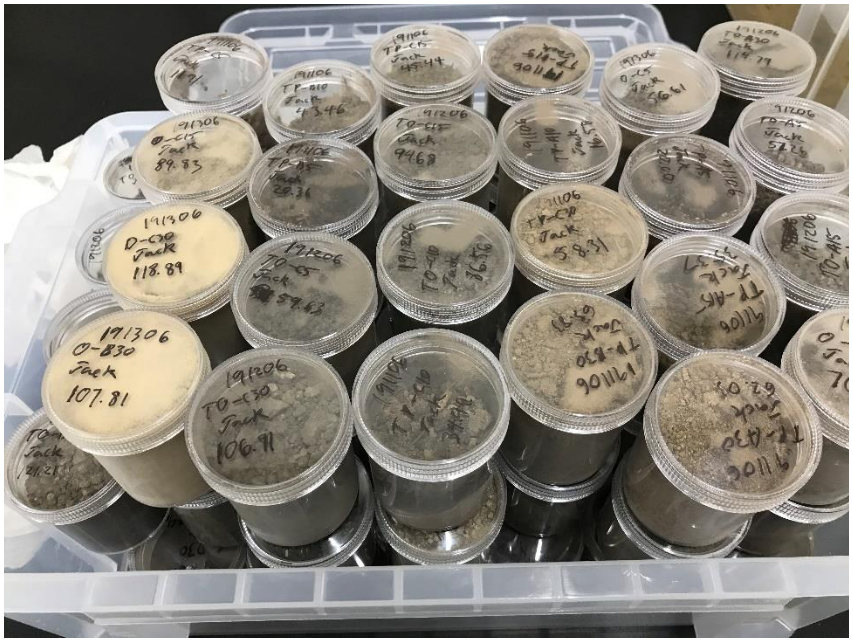


Figure 12: Homogenized soil samples in U-8 containers

Figure 13: Canberra HPGe auto-sampler detector

2.4 Exchangeable Soil [K^+] and [Cs^+] Measurements

One molar ammonium acetate (NH_4Ac) was used to extract the exchangeable cations bound in the soil aliquots. Three grams of each soil aliquot were placed into 15 mL tubes and mixed with one molar NH_4Ac until all interspatial space in the soil was filled. Some soil aliquots could not be placed into 15 mL tubes and were put into 50 mL tubes instead. An orbital shaker was used to mix the samples for 20 hours.

Figure 14: Soil aliquots on orbital shaker

A filtration system using a Nalgene vacuum flask with a 0.45 µm PES filter along with an additional 0.45 µm filter placed on top along with a portable pump was used to filter samples (Figure 15). The soil aliquot was filtered and then transferred to a U-8 container where the filtrates mass was measured and recorded. The top filter was removed, and the flask and built-in filter rinsed with tap water after each use. A new Millipore filter was placed on top of the built-in filter. The Nalgene vacuum flask was reused for 8 samples before being discarded and replaced. The soil aliquots were then analyzed for ^{137}Cs activity via gamma spectroscopy using a Canberra HPGe auto-sampler detector before being analyzed for $[K^+]$ and $[Cs^+]$ using an Agilent 4100 Microwave Plasma – Atomic Emission Spectrometer (MP-AES).

Figure 15: Thermo Scientific^{TM} Nalgene^{TM} Sterile Disposable Filter Unit with 0.45µm PES filter and additional Millipore^{TM} Membrane Filter (90 mm, 0.45 µm) and pump

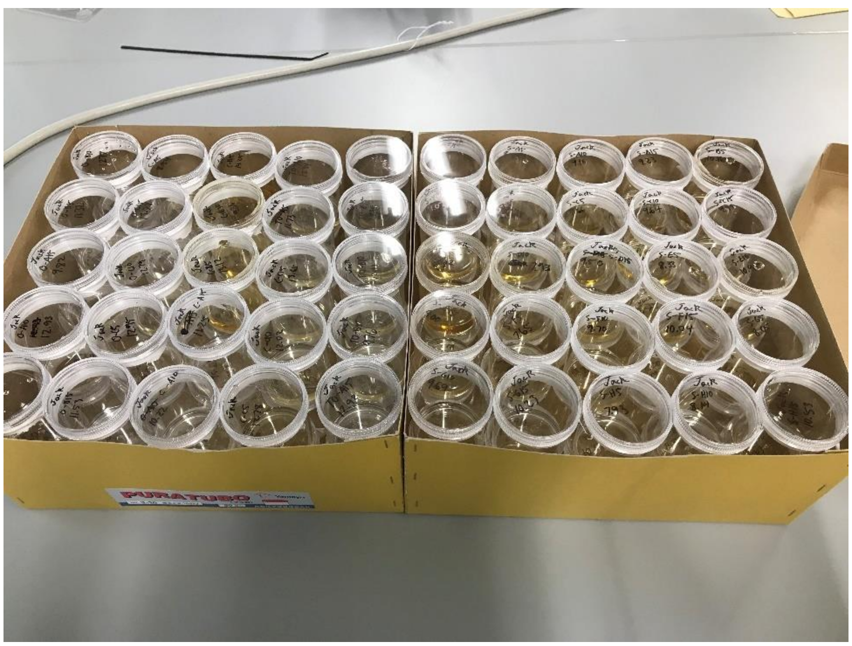


Figure 16: After filtration soil aliquots in U-8 containers

2.5 Understory Plant [K^+] and [Cs^+] Measurements

The plant aliquots were homogenized using a blender (Figure 11) and passed through a 1 mm sieve to sort out any plant particles >1 mm in diameter. One gram of the sorted plant aliquot was placed into a ceramic crucible where the mass of the crucible and the plant aliquot together was determined. The crucible then was placed into a furnace for 12 hours at 450°C to ash the plant aliquot (Figure 17). The crucible was weighed again to find the ash weight (a.w.) of the plant aliquot.

Figure 17: Furnace and plant aliquot after

50 mL tubes were filled with 45 mL of 18.2MΩ ultra-pure water (UPW) before the acid digestion of the plant ash. 2.5 mL of 13M nitric acid (HNO_3) were mixed with the plant ash in the crucible to digest the plant ash. If the plant ash was not dissolved, then another 2.5 mL of HNO_3 were added before being transferred to a 50 mL tube. Some of the plant species could not be properly dissolved in the HNO_3. Due to the insufficient dissolution of certain plants, particulates too large to be analyzed by MP-AES remained in the aliquot. To solve this issue, new plant aliquots were filtered using the same 0.45 µm filter apparatus as the soil aliquots before MP-AES. Acknowledging that there will be loss, the filtrate was also transferred into U-8 containers and counted for ^{137}Cs activity. Since the total ^{137}Cs activity for each plant sample was known, the difference between the filtrate ^{137}Cs activity and the total ^{137}Cs activity was used to correlate the loss of K^+ and Cs^+ due to the incomplete acid digestion and filtration.

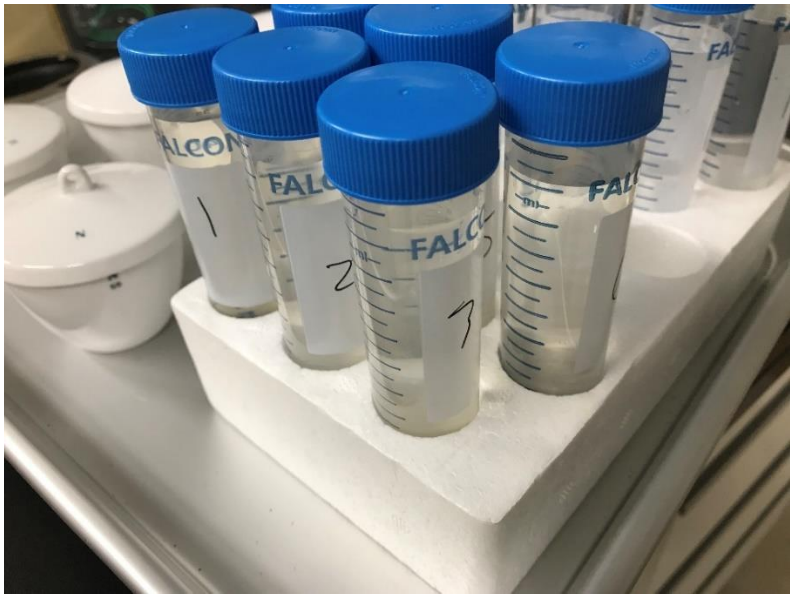


Figure 18: Plant aliquot after acid treatment in 50 mL U-8 containers

2.6 Soil pH Measurements

Soil samples were prepared for pH measurement by mixing 1:10 soil to UPW liquid mixture. This ratio was used due to the high organic matter content of the soil samples. 2 g of soil were mixed with 18 mL of UPW in a 50 mL tube. A digital pH meter with a 9615S-10D ToupH electrode was used to measure the pH of the soil. The pH meter was calibrated using pH 4, 7, and 12 standards at the beginning of each new day or every 25 samples., and Soil pH was determined after the electrode was placed into the liquid mixture and after pH readings had stabilized.

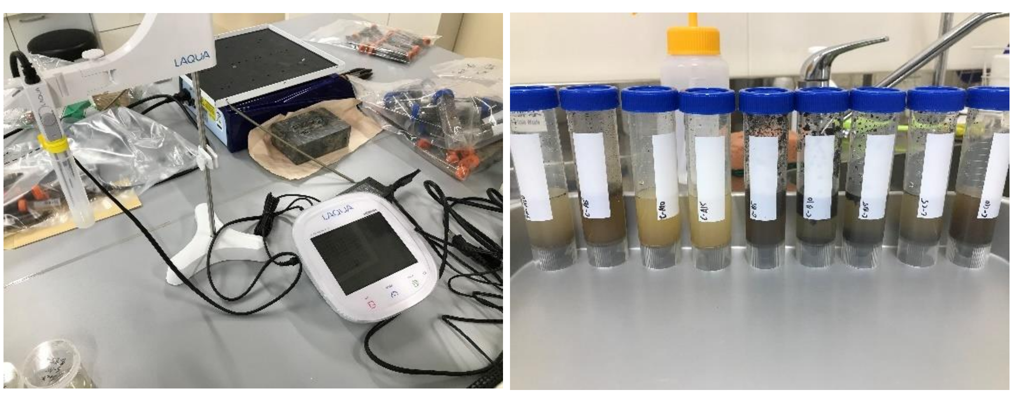


Figure 19: Laqua pH meter and soil samples

RESULTS

3.1 ^{137}Cs Deposition in Soil

The ^{137}Cs soil deposition was found through averaging the total ^{137}Cs activity across the 30 cm depth of soil and dividing it by the area of the soil core sampler. Table 4 shows the deposition density of the soil samples collected compared to the initial deposition study conducted by an airborne survey 2 Jul 2011 (Kato, H and Onda Y., 2019).

Table 4: Soil ^{137}Cs Deposition Density Results and Comparison

1. Initial deposition density for ^{137}Cs only (Kato, H and Onda Y., 2019)
2. 30.17 year radiological half-life for ^{137}Cs
3. 4.39 year effective half-life for disturbed areas post disturbance (Hayes et al, 2010)

Location	2 Jul 2011 Deposition Density[1] (kBq/m^2)	Sample Deposition Density (kBq/m^2)	2 Jul 2011 Radiological Decay Corrected[2] Deposition Density (kBq/m^2)	2 Jul 2011 Effective Decay Corrected[3] Deposition Density (kBq/m^2)
Okuma	4001	6000±1611	21007±9773	7200±3350
Tomioka	740	551±127	1928±768	661±263
Tsushima Pine	2370	1221±90	4274±545	1465±187
Tsushima Sugi	2370	1196±39	4188±203	1435±70
Yamakiya	752	684±119	2394±1168	821±400
Yokomuki	44	25±8	87±49	30±17

Figure 20a provides a comparison of ^{137}Cs concentration in terms of soil depth and sample location while Figure 20b provides a linear regression comparison of the ^{137}Cs concentration (Bq/m^2) at the different sampling locations as a factor of soil depth. Figures 21a and 21b provide the same information, respectively, in terms of ^{137}Cs activity deposition (Bq/m^2). Figure 22 provides a comparison of the contributions to the total ^{137}Cs inventory for each sampling location in terms of litter and soil depth.

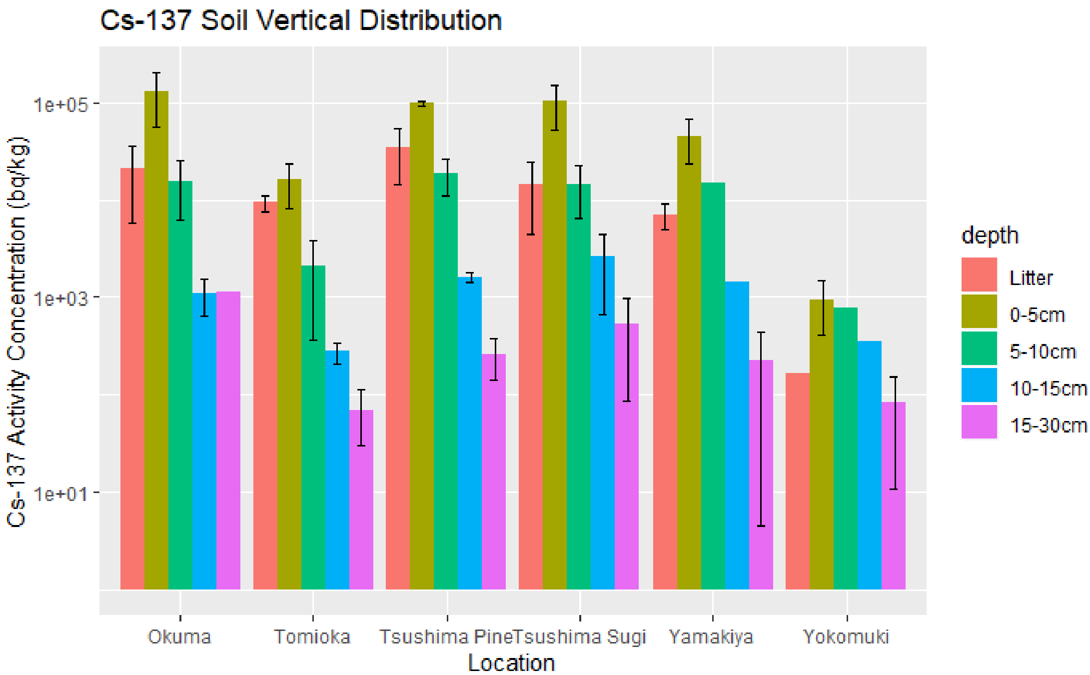


Figure 20a: Mean ^{137}Cs Soil Vertical Concentration Distribution

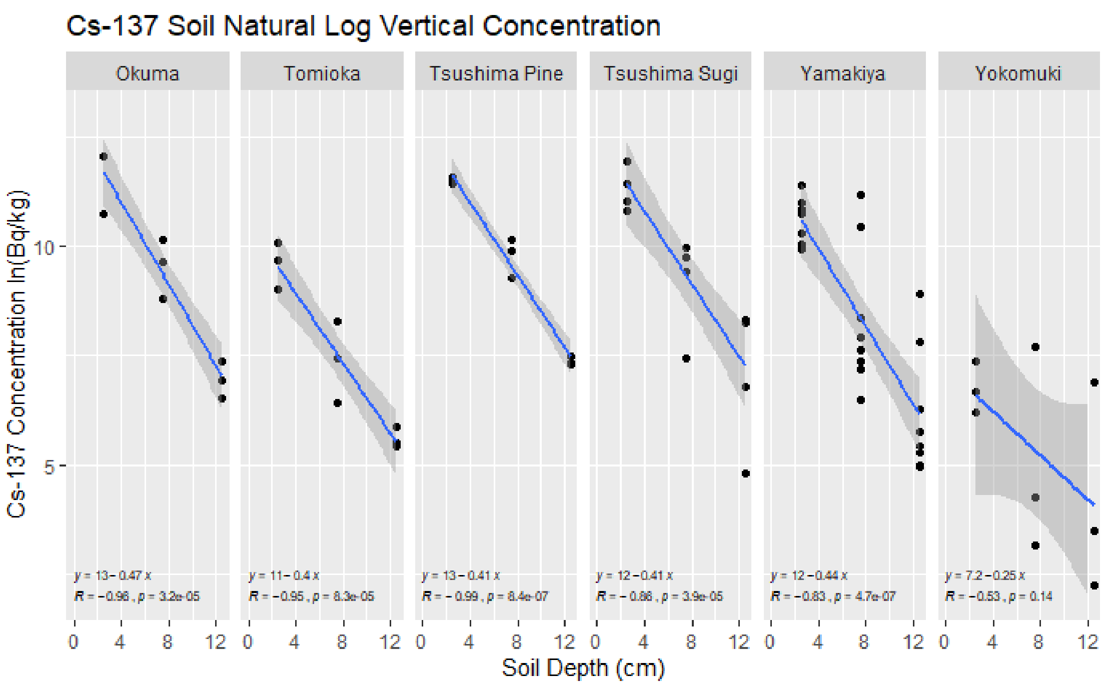


Figure 20b: ^{137}Cs Soil Vertical Concentration Linear Regression

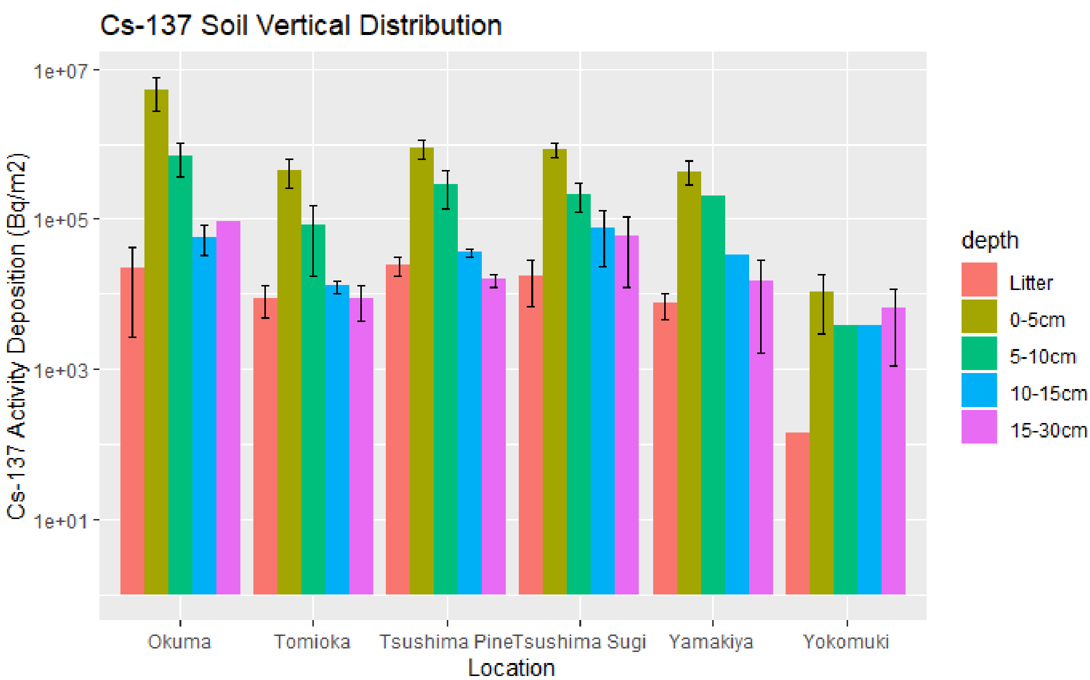


Figure 21a: Mean ^{137}Cs Soil Vertical Deposition Distribution

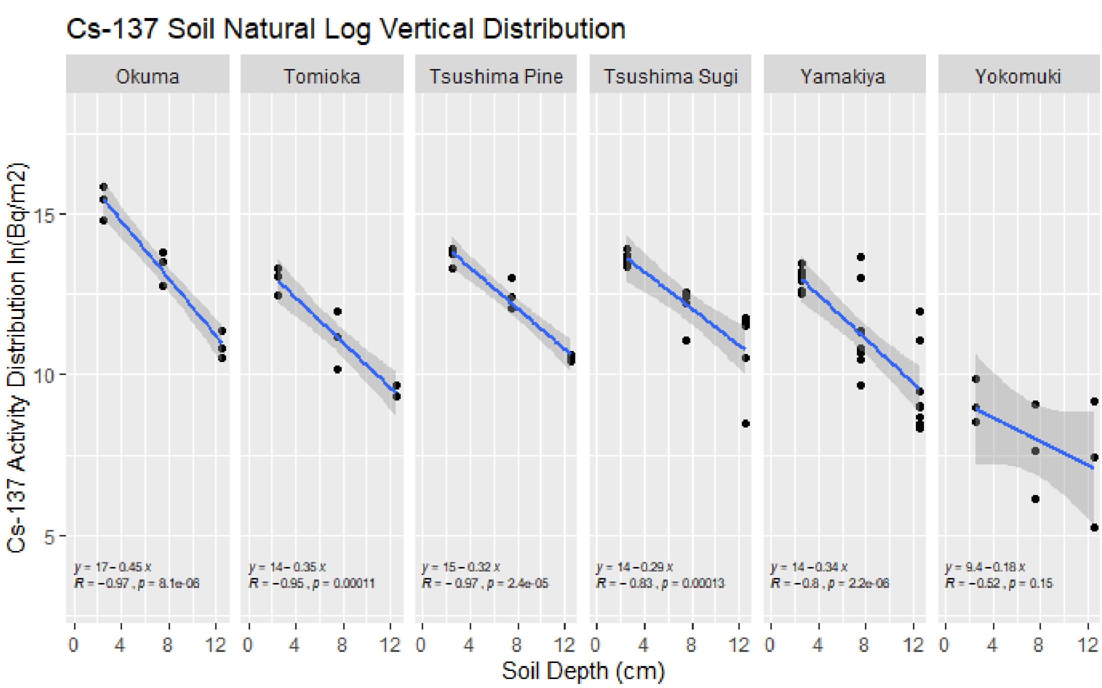


Figure 21b: ^{137}Cs Soil Vertical Deposition Distribution Linear Regression

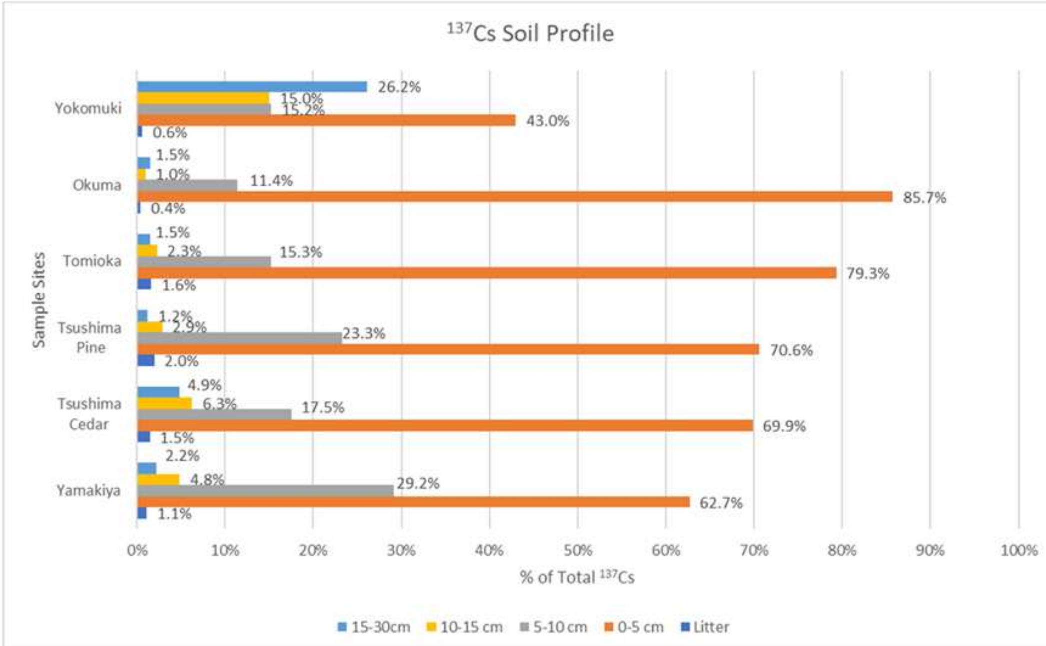


Figure 22: ^{137}Cs percent contribution to soil profile

3.2 ^{137}Cs, Cs^+, and K^+ Concentrations and Concentration Ratios in Understory Plants

Figures 23 to 26 shows the mean plant ^{137}Cs concentration for each sampling location with reported activity concentration in Bq per dry weight kg of the plant. All plant radiocesium concentrations, total dry weight, and dry weight in U-8 container are provided in Appendix A. The common and scientific names for the sampled plants are listed in Table 5 with the common name being used for all other graphs and tables.

Table 5: Plant Sample Common and Scientific Names

Common Name	Sample Classification	Scientific Name
Bamboo Grass	Species	*Microstegium vimineum*
Dogwood	Genus	*Cornus*
Fern	Genus	*Athyrium*
Glory-Bower	Species	*Clerodendrum trichotomum*
Hazelnut	Species	*Corylus heterophylla*
Hydrangea	Genus	*Hydrangea*
Myoga	Species	*Zingiber mioga*
Wisteria	Genus	*Wisteria*
Japanese Knotweed	Species	*Reynoutria japonica*
Japanese Lacquer	Species	*Toxicodendron vernicifluum*
Japanese Maple	Species	*Acer palmatum*

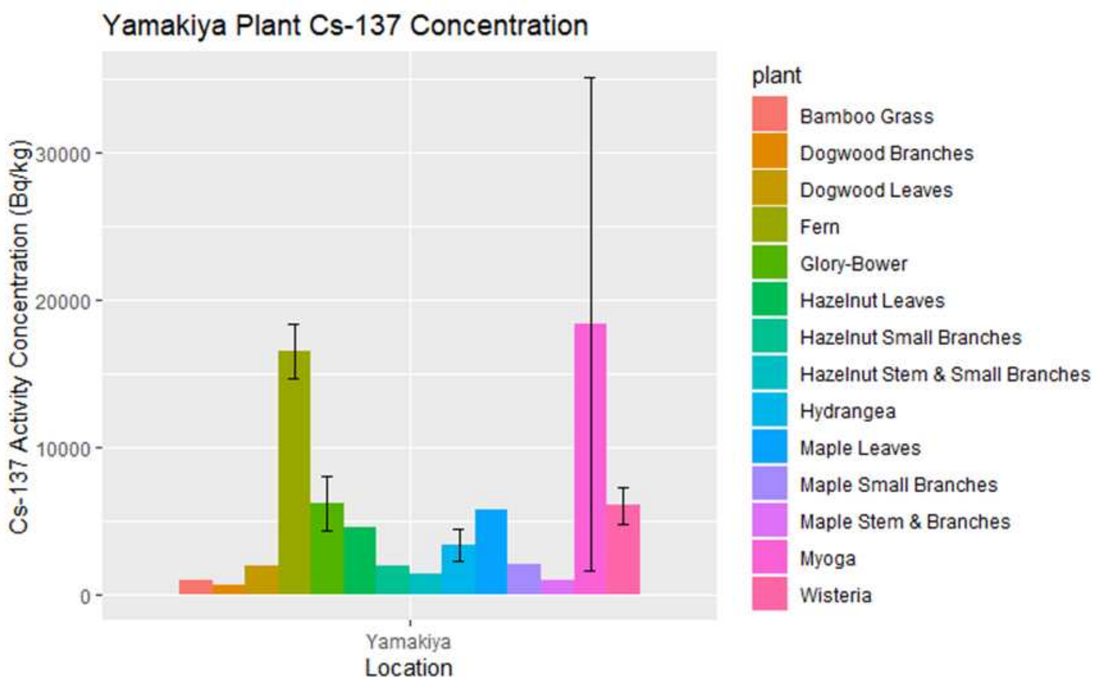


Figure 23: Yamakiya plant ^{137}Cs dry weight concentration

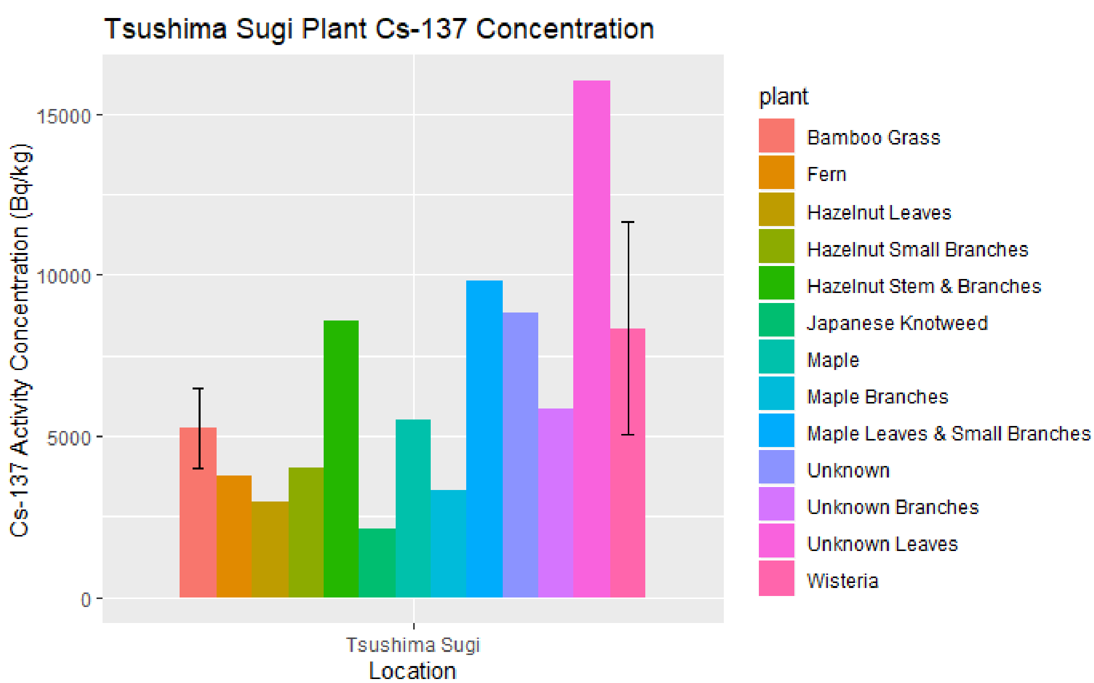


Figure 24: Tsushima Sugi plant ^{137}Cs dry weight concentration

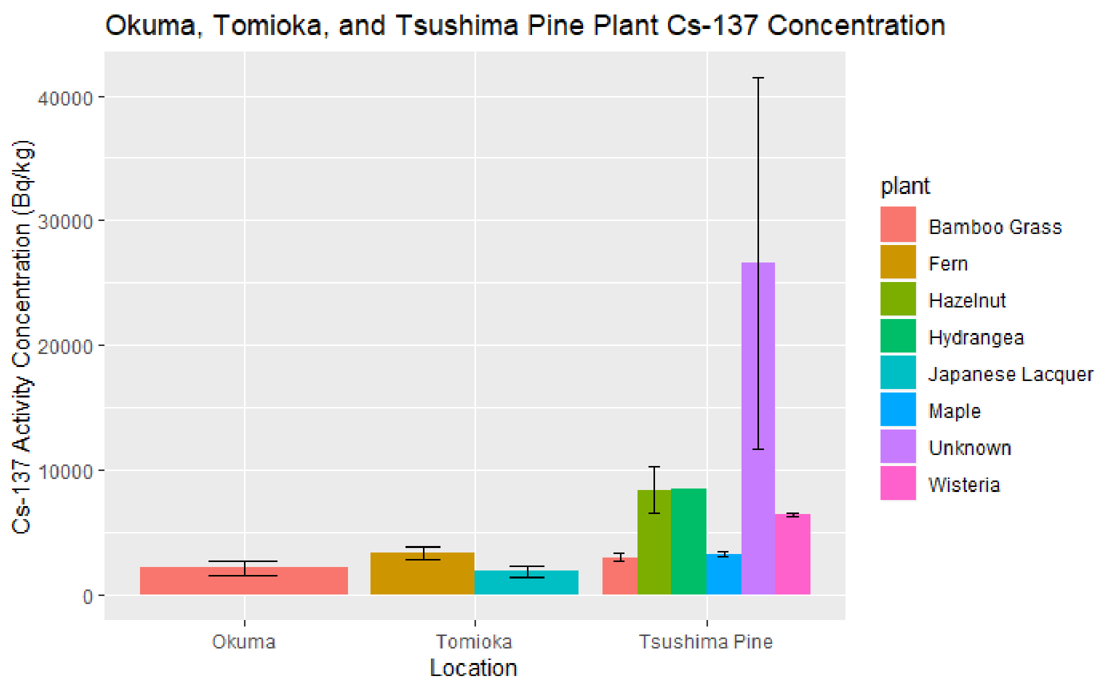


Figure 25: Okuma, Tomioka, and Tsushima Pine plant ^{137}Cs dry weight concentration

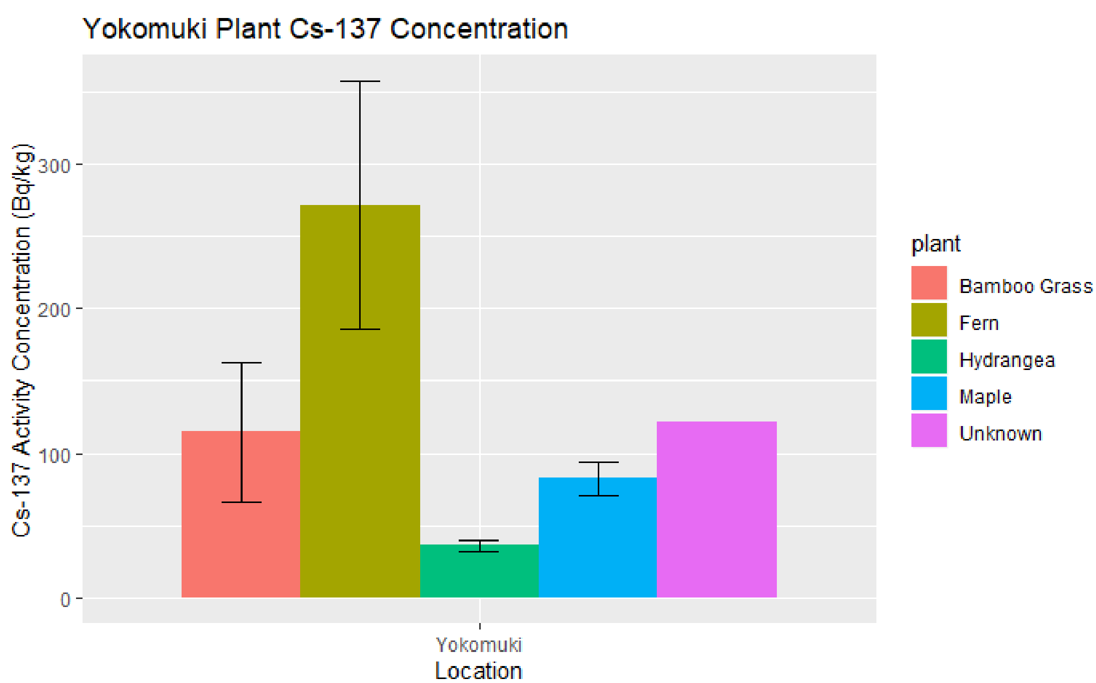


Figure 26: Yokomuki plant ^{137}Cs dry weight concentration

Figure 27 shows the mean ^{137}Cs concentration ratios for the most sampled understory plant species located at more than one of the sampling sites. Figures 28 to 32 show the natural log of the soil to plant concentration ratio at each measured soil depth. The soil to plant concentration ratio was calculated by dividing the plant ^{137}Cs concentration by the soil ^{137}Cs concentration at each soil depth. Figures 33 to 36 show the same information only with comparisons of different understory plant species within each sampling site. While ^{137}Cs activity was measured for the 15-30 cm soil depth, it was omitted due to the low contribution to the total ^{137}Cs inventory in the soil (Figure 22).

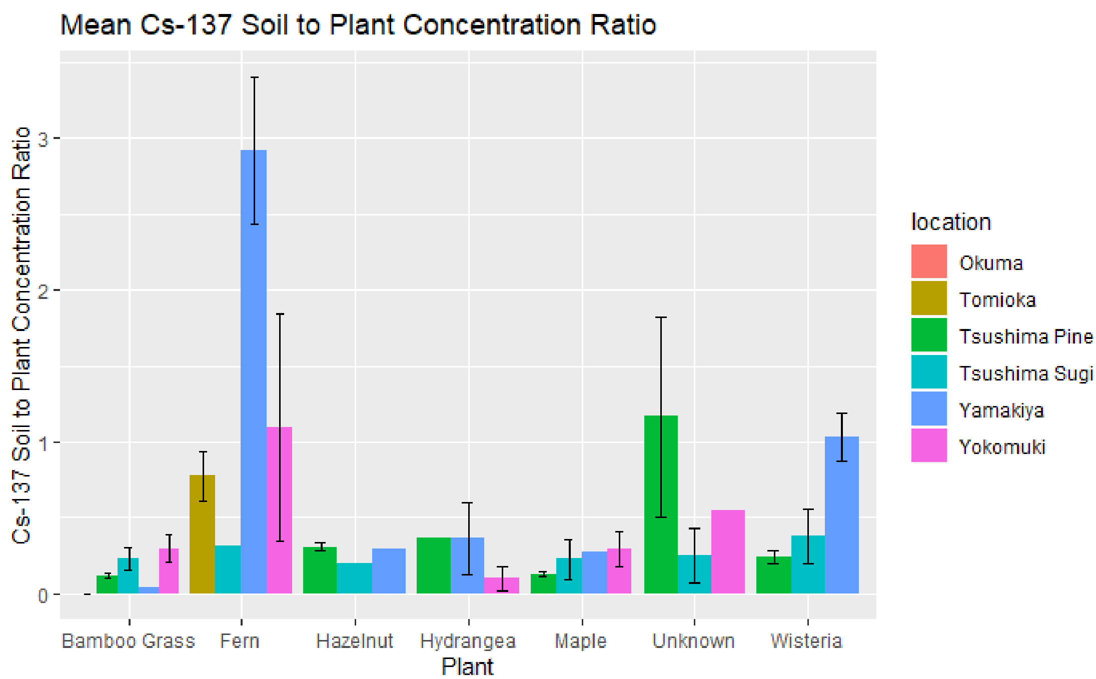


Figure 27: Soil to plant mean ^{137}Cs concentration ratio at 0-15 cm soil depth

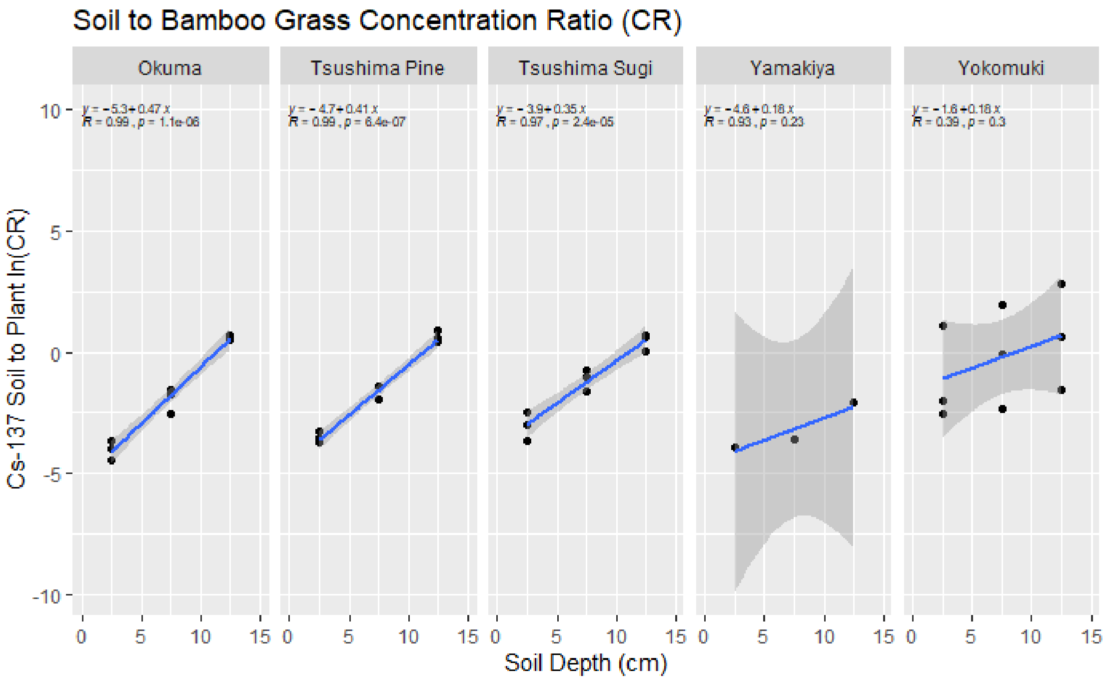


Figure 28: Soil to bamboo grass ^{137}Cs concentration ratio ln[soil (Bq/kg)/plant (Bq/kg)]

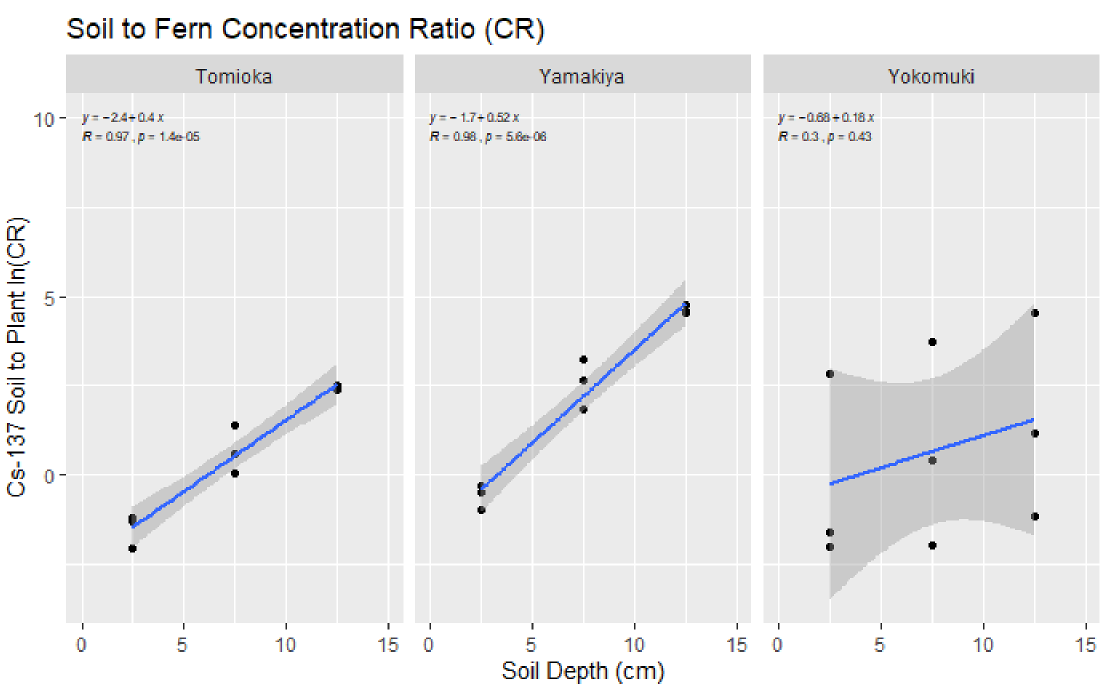


Figure 29: Soil to fern ^{137}Cs concentration ratio soil ln[(Bq/kg)/plant (Bq/kg)]

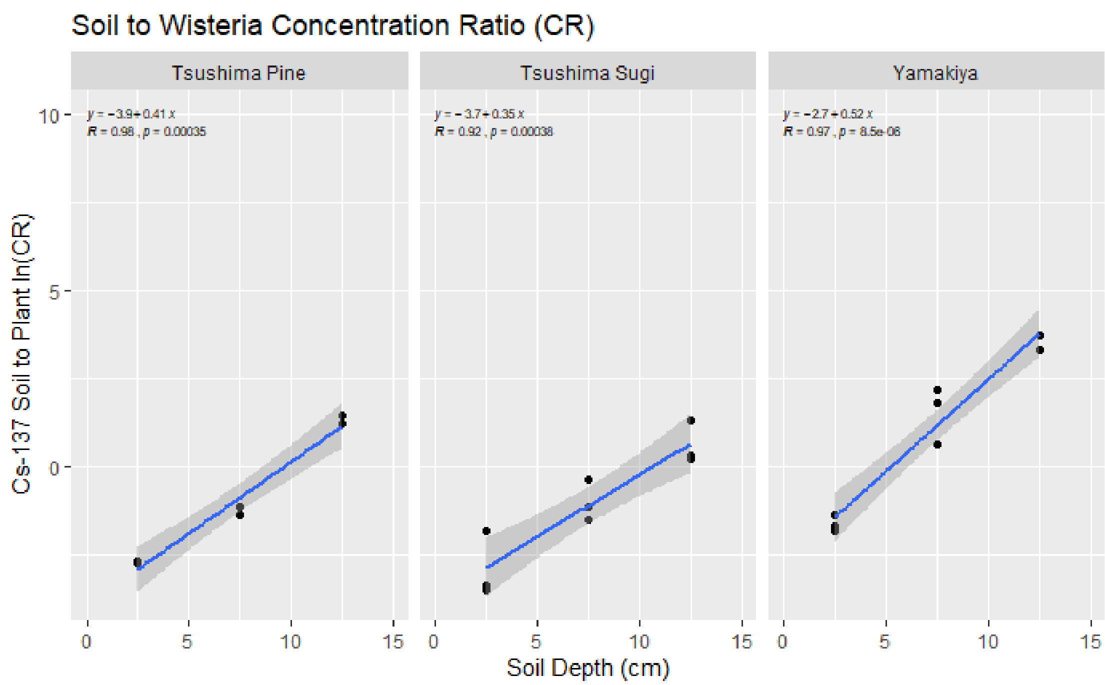


Figure 30: Soil to wisteria ^{137}Cs concentration ratio soil ln[(Bq/kg)/plant (Bq/kg)]

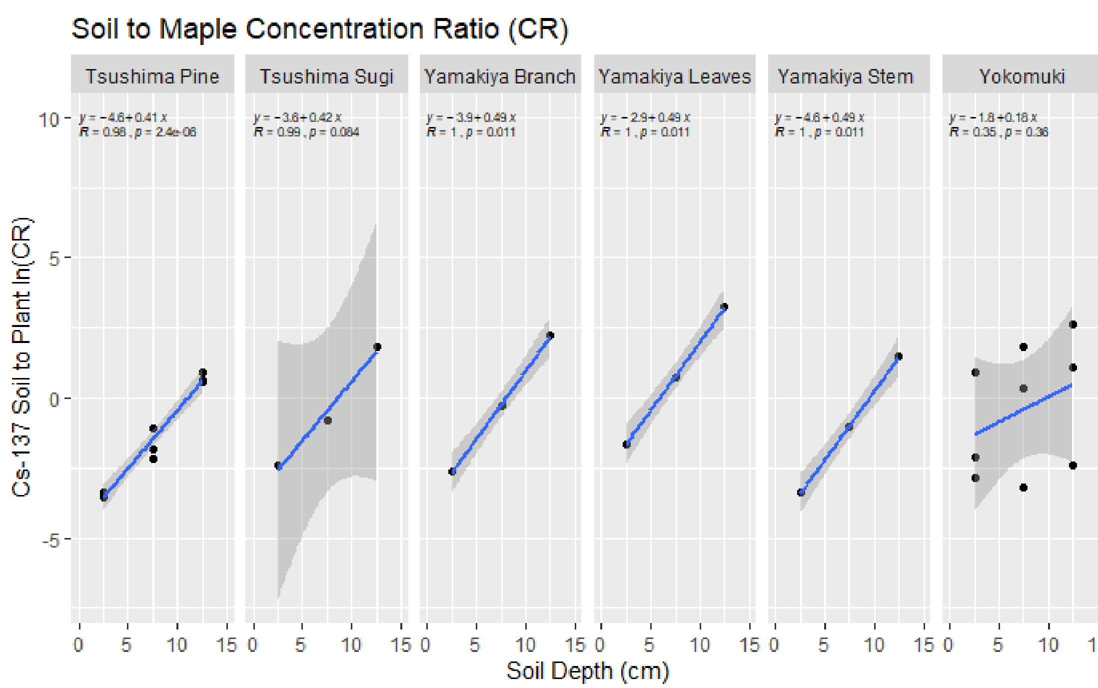


Figure 31: Soil to maple concentration ratio soil ln[(Bq/kg)/plant (Bq/kg)]

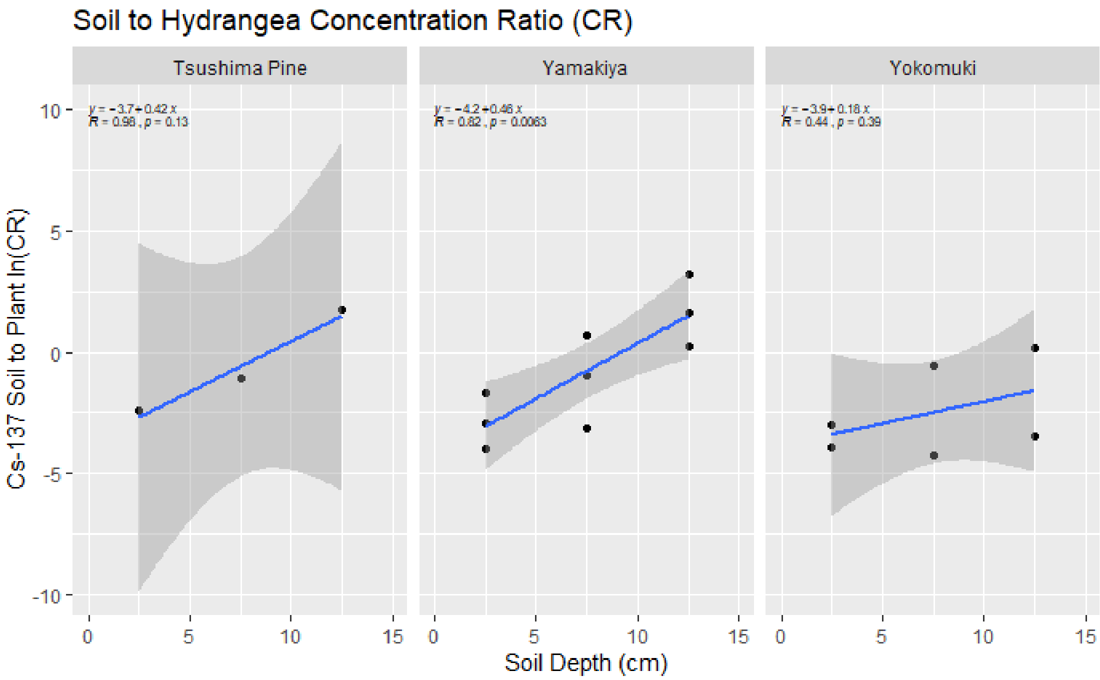


Figure 32: Soil to hydrangea concentration ratio soil ln[(Bq/kg)/plant (Bq/kg)]

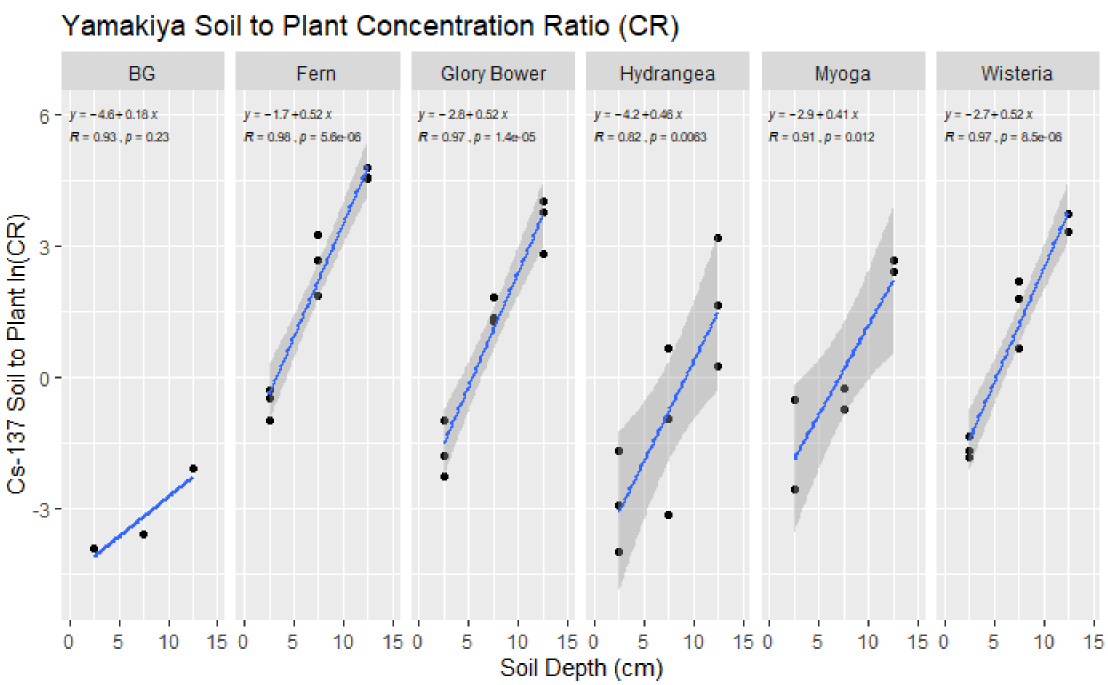


Figure 33: Yamakiya soil to plant concentration ratio soil ln[(Bq/kg)/plant (Bq/kg)]

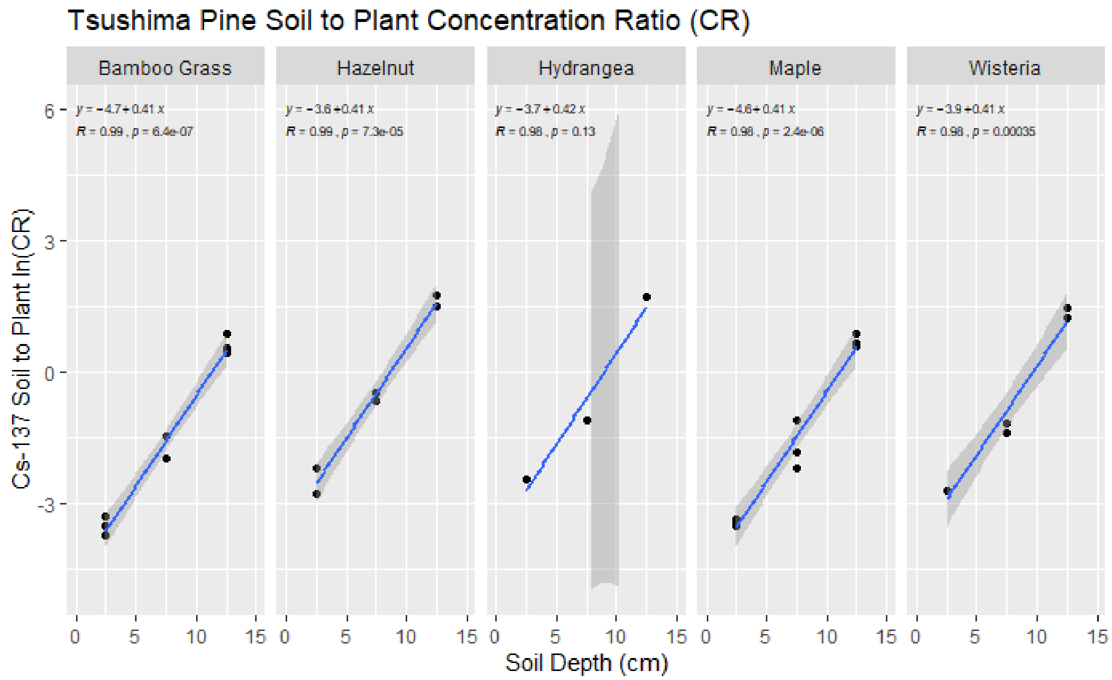


Figure 34: Tsushima Pine soil to plant concentration ratio soil ln[(Bq/kg)/plant (Bq/kg)]

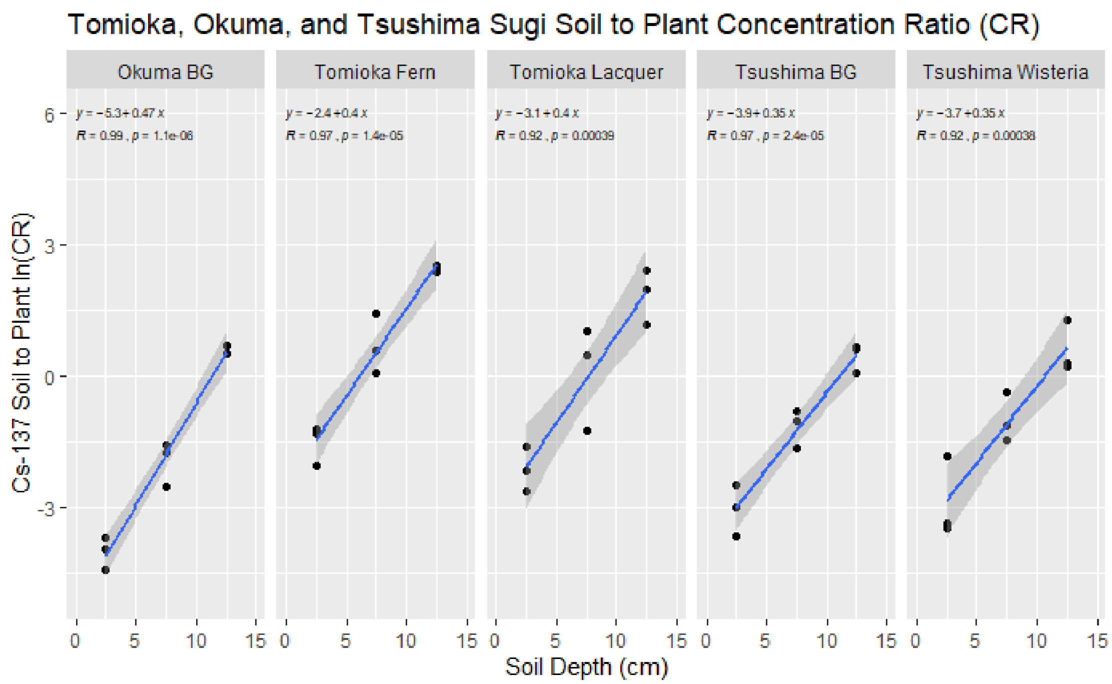


Figure 35: Tomioka, Okuma, and Tsushima Sugi soil to plant concentration ratio ln[soil (Bq/kg)/plant (Bq/kg)]

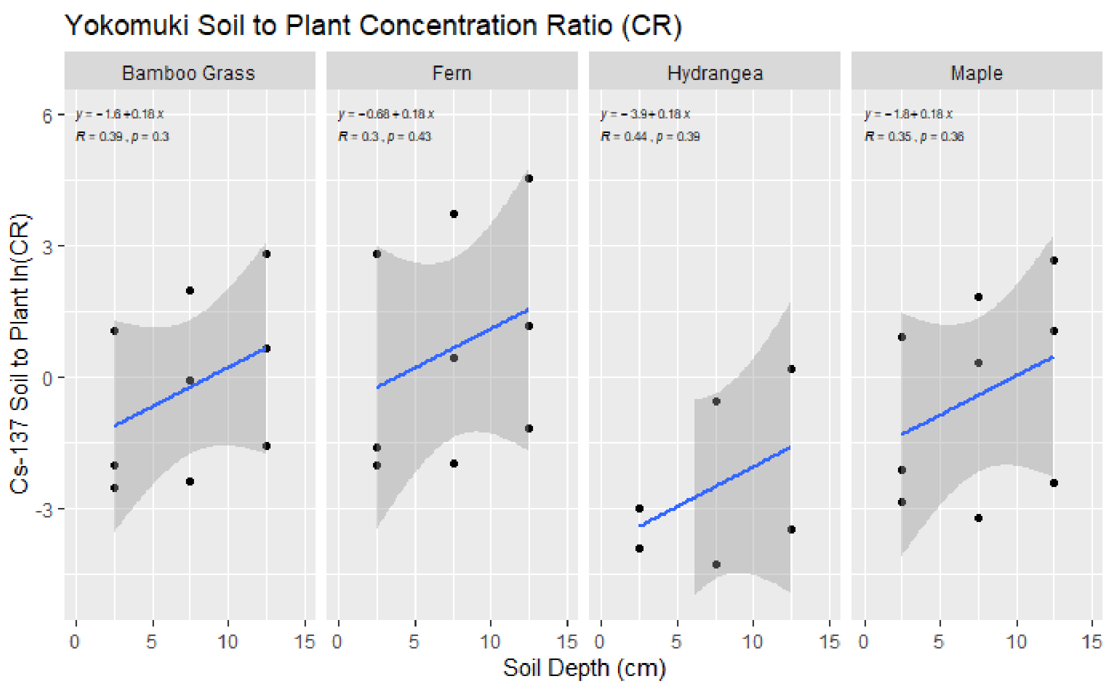


Figure 36: Yokomuki soil to plant concentration ratio ln[soil (Bq/kg)/plant (Bq/kg)]

3.3 Understory Plant Contribution to Forest Aboveground Biomass ^{137}Cs Inventory

Total dry biomass contributed by each compartment of the Japanese Sugi tree dominant forest at Yamakiya were determined using model tree #84 (Yoschenko et al., 2018). The activity concentration data was determined using tree #B1, #B3, and #B10 samples collected 6 Jun 2019 at the Yamakiya site for new leaves, old leaves, small branches, and big branch compartments of the Japanese Sugi tree (Appendix G). The inner bark, outer bark, sapwood 1-3, sapwood, and heartwood compartment activity concentrations were determined using tree #B99 samples also collected on 6 Jun 2019. Total ^{137}Cs was calculated through multiplying the model tree #84 biomass with the average activity concentration of tree #B1, #B3, #B10 for their compartments and tree #B99 for its compartments.

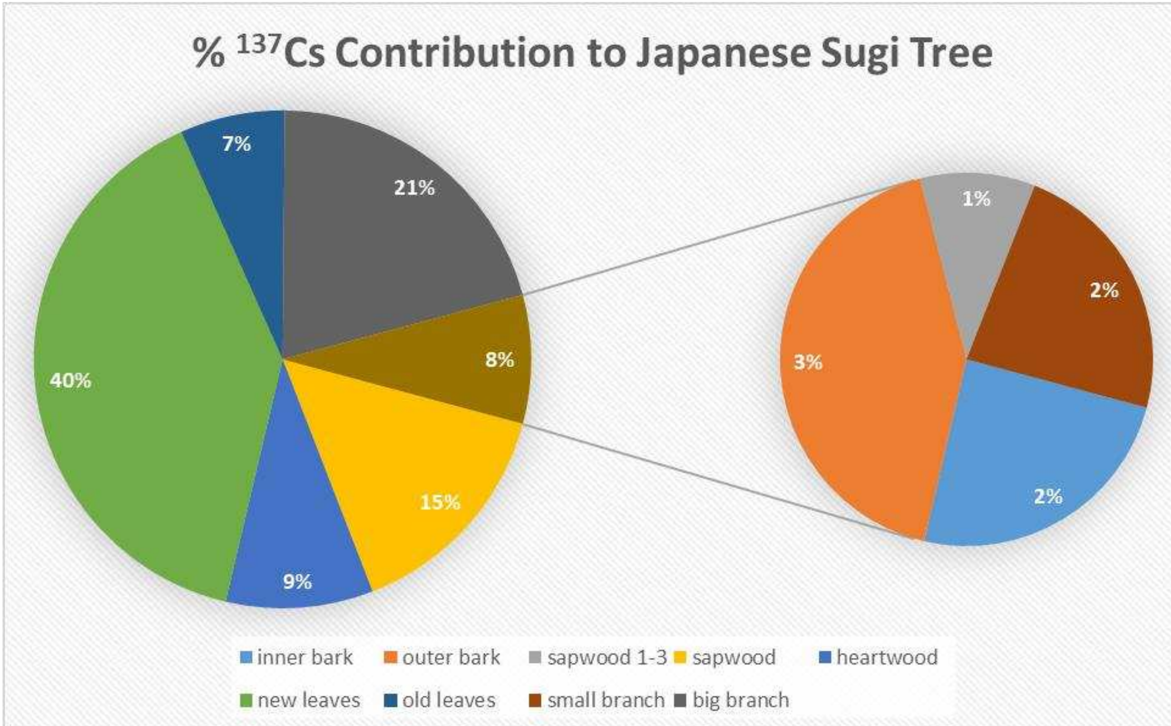


Figure 37: % ^{137}Cs contribution to Japanese Sugi tree in Yamakiya

A dogwood in Yamakiya and a maple tree at Tsushima Sugi were not included in the study as they grew sizably and could not readily be cut down. Bamboo grass at Yamakiya and fern at Tsushima Sugi were not included as they were collected outside the sampling perimeter set up at each respective site. The activity concentration and dry weight to fresh weight ratio for Yamakiya whole maple were determined by using maple leaves, as no whole maple was counted for ^{137}Cs. Maple leaves were sampled as they were assumed to best represent radiocesium uptake in early life maple trees when they are still very small plants. Figure 39 shows a comparison between the percent contribution of aboveground biomass and ^{137}Cs activity in Yamakiya.

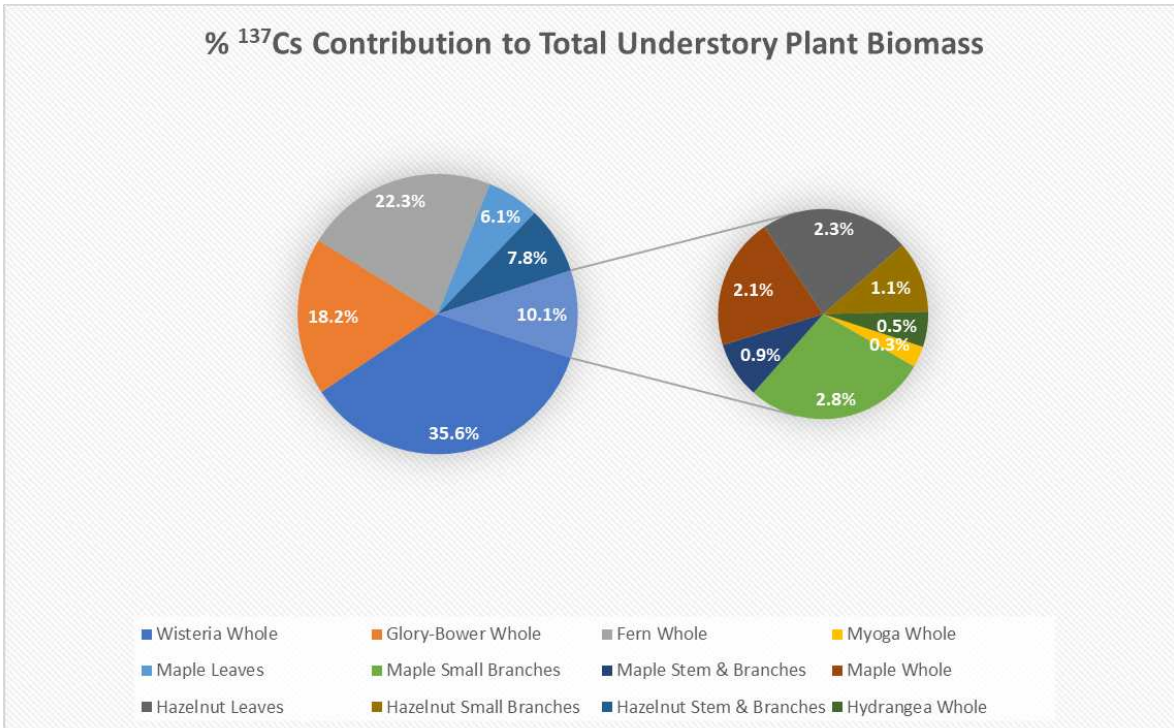


Figure 38: % ^{137}Cs contribution to total understory plant biomass in Yamakiya

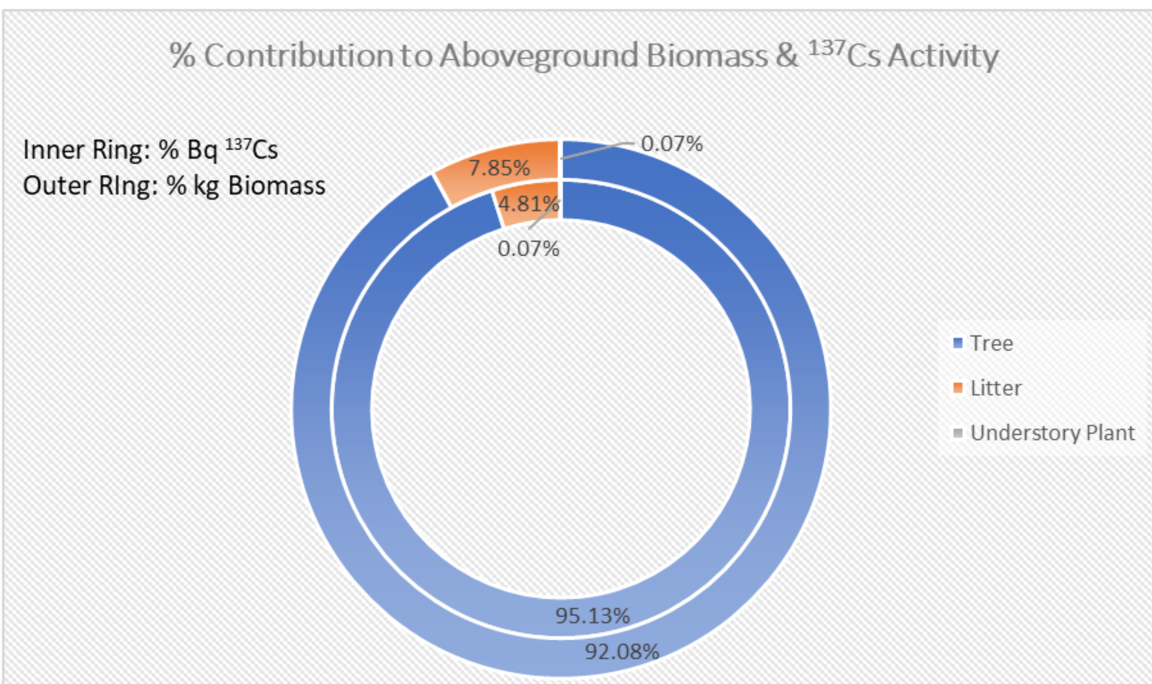


Figure 39a: % Contribution to aboveground biomass and ^{137}Cs activity in Yamakiya

Inner ring (% Bq ^{137}Cs), Outer ring (% biomass kg)

3.4 Exchangeable [K^+], Exchangeable [Cs^+], and pH in Soil

Figure 40a provides a comparison of exchangeable ^{137}Cs concentration in terms of soil depth and sample location while Figure 40b provides a linear regression comparison of the exchangeable ^{137}Cs concentration (Bq/kg) at the different sampling locations as a factor of soil depth. Figures 41 to 46 show the linear regression comparison of ^{137}Cs total soil to exchangeable ratio, exchangeable soil [K^+], exchangeable soil [Cs^+], and exchangeable soil [Cs^+]/[K^+], exchangeable [^{137}Cs] to total [Cs^+] ratio, and total ^{137}Cs to total [Cs^+] ratio as a function of soil depth. The exchangeable [^{137}Cs] to total [Cs^+] ratio and total ^{137}Cs to total [Cs^+] ratio graphs have been natural log transformed as well as removing Yokomuki data to fit the facet-graph so a proper comparison can be performed between each sampling site. Figure 47 provides the soil pH vertical distribution comparison between soil depths and sampling locations.

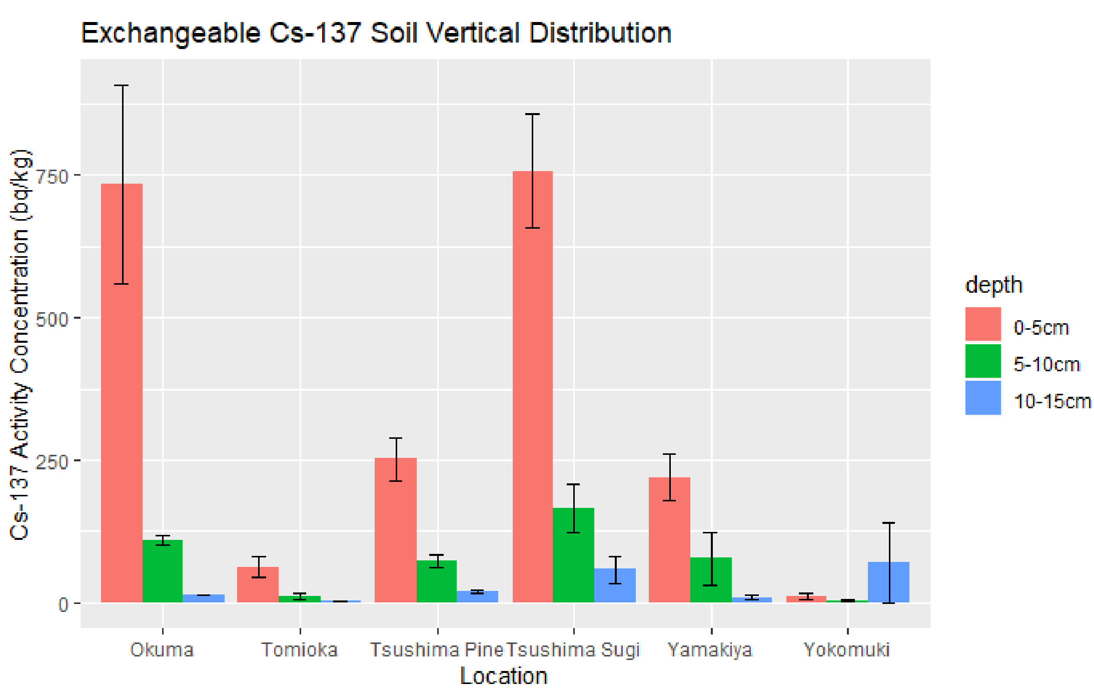


Figure 40a: Mean Exchangeable ^{137}Cs soil vertical concentration distribution

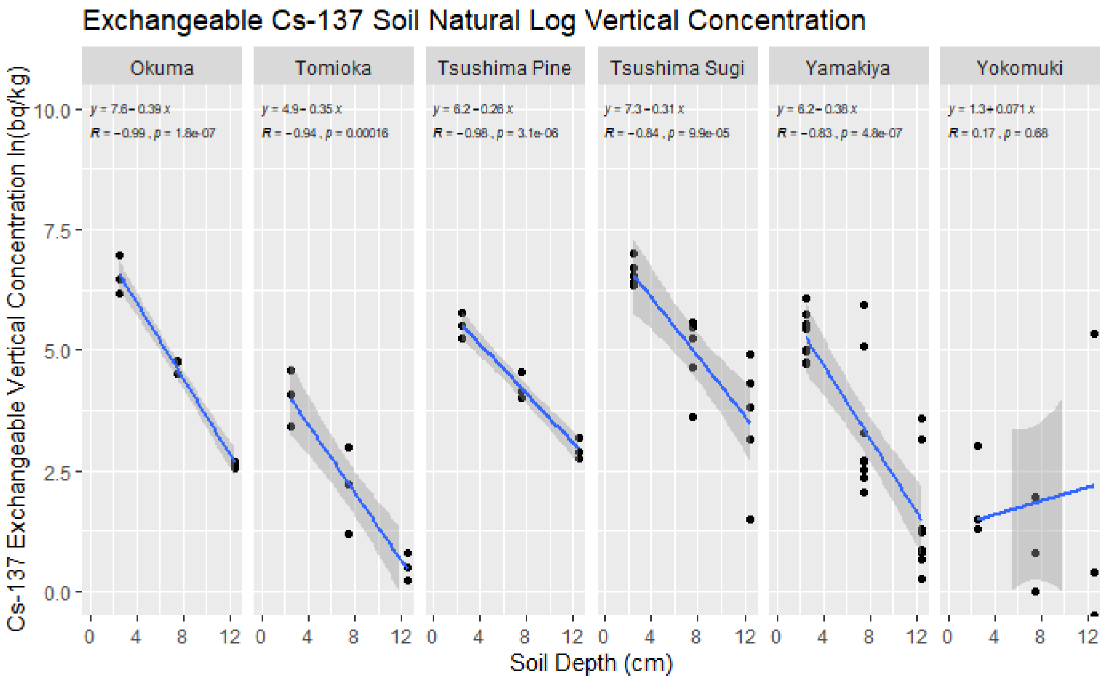


Figure 40b: Exchangeable ^{137}Cs soil vertical concentration distribution

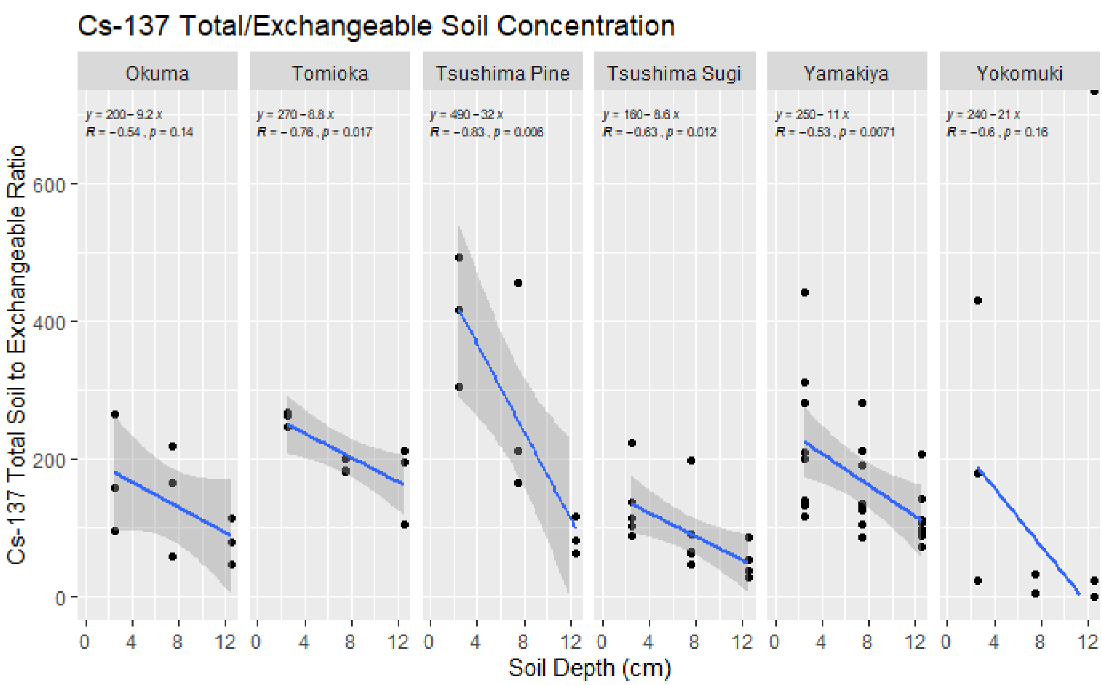


Figure 41: Total to Exchangeable ^{137}Cs in soil

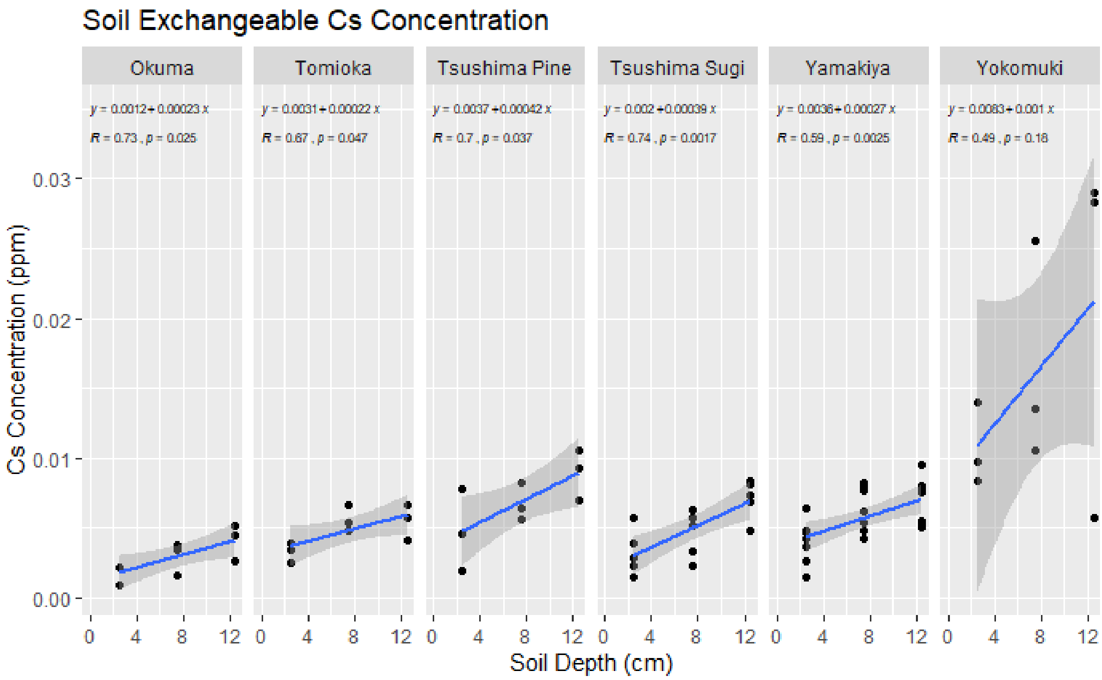


Figure 42: Exchangeable [Cs] in soil

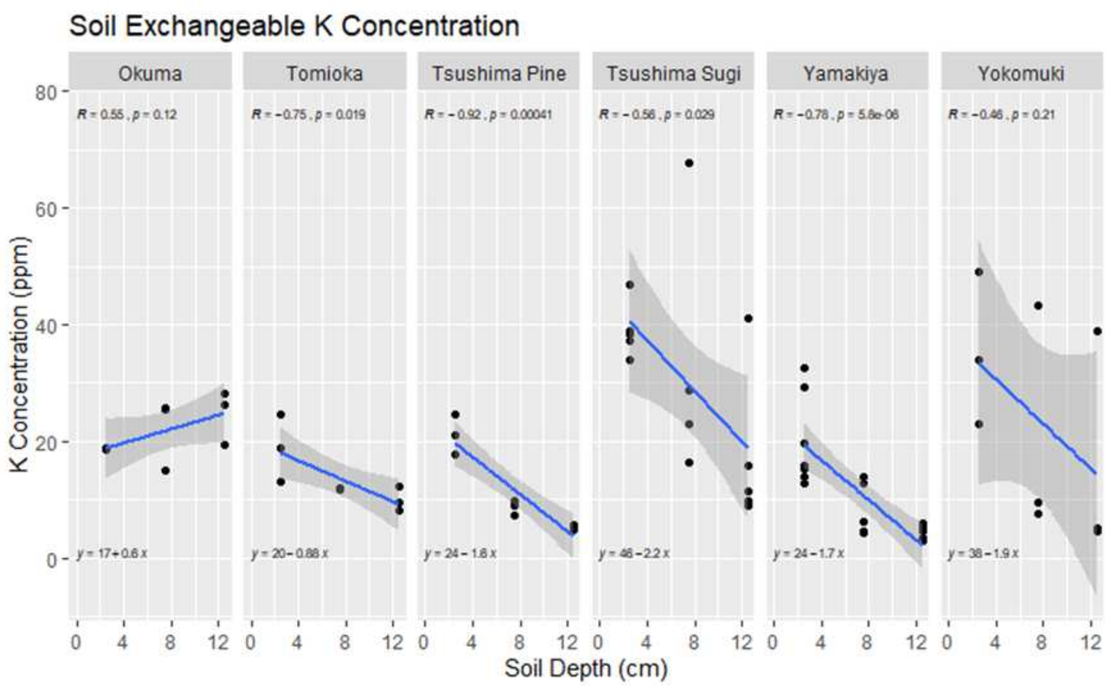


Figure 43: Exchangeable [K] in soil

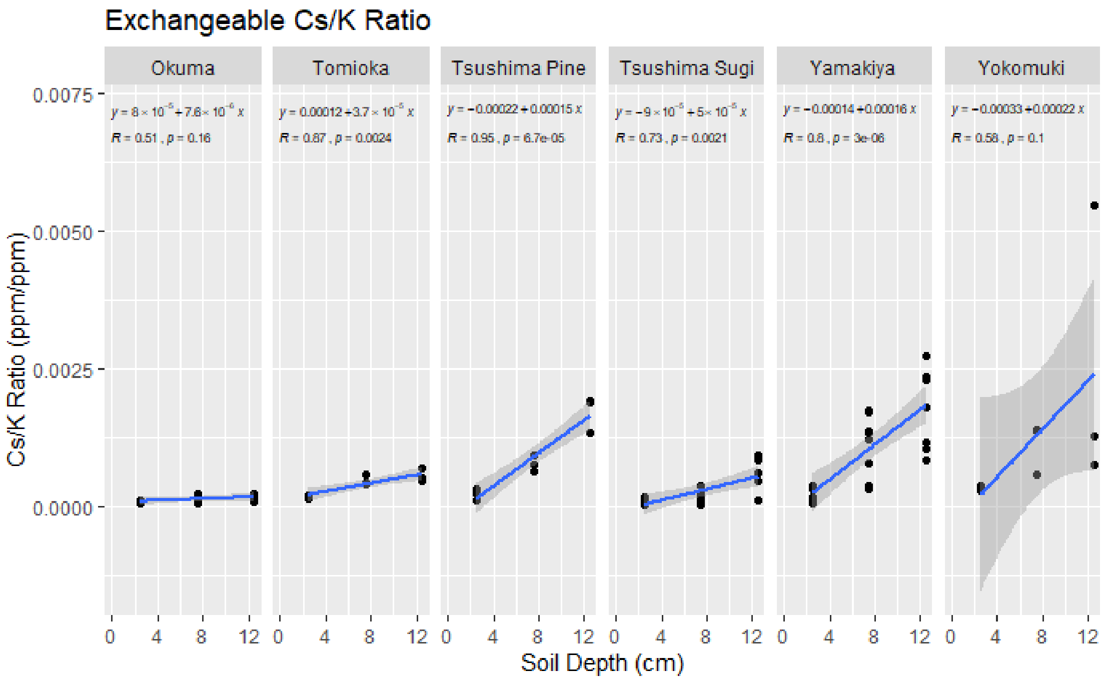


Figure 44: Exchangeable [Cs]/[K] ratio in soil (ppm/ppm)

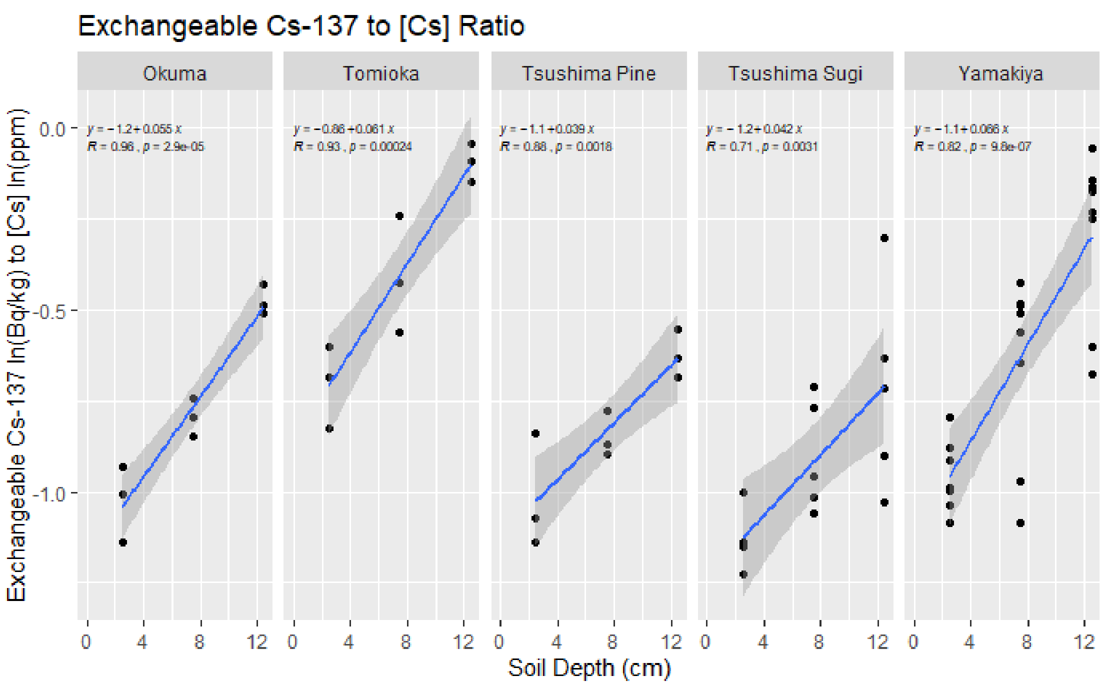


Figure 45: Exchangeable ^{137}Cs to exchangeable [Cs] ratio

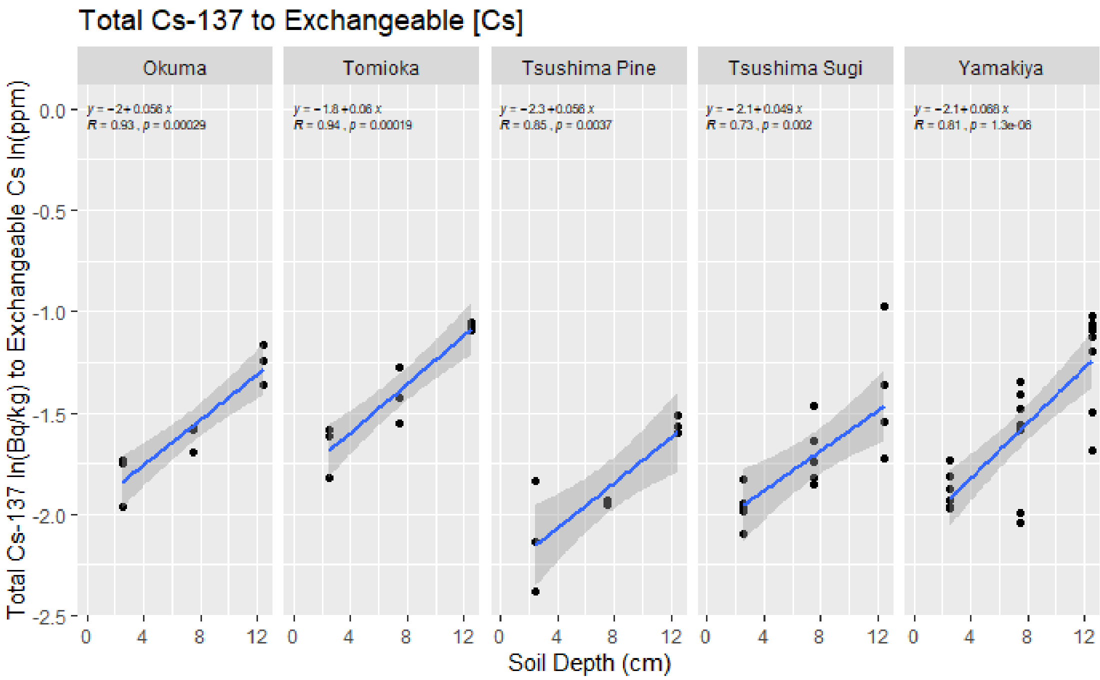


Figure 46: Total ^{137}Cs to exchangeable [Cs] ratio

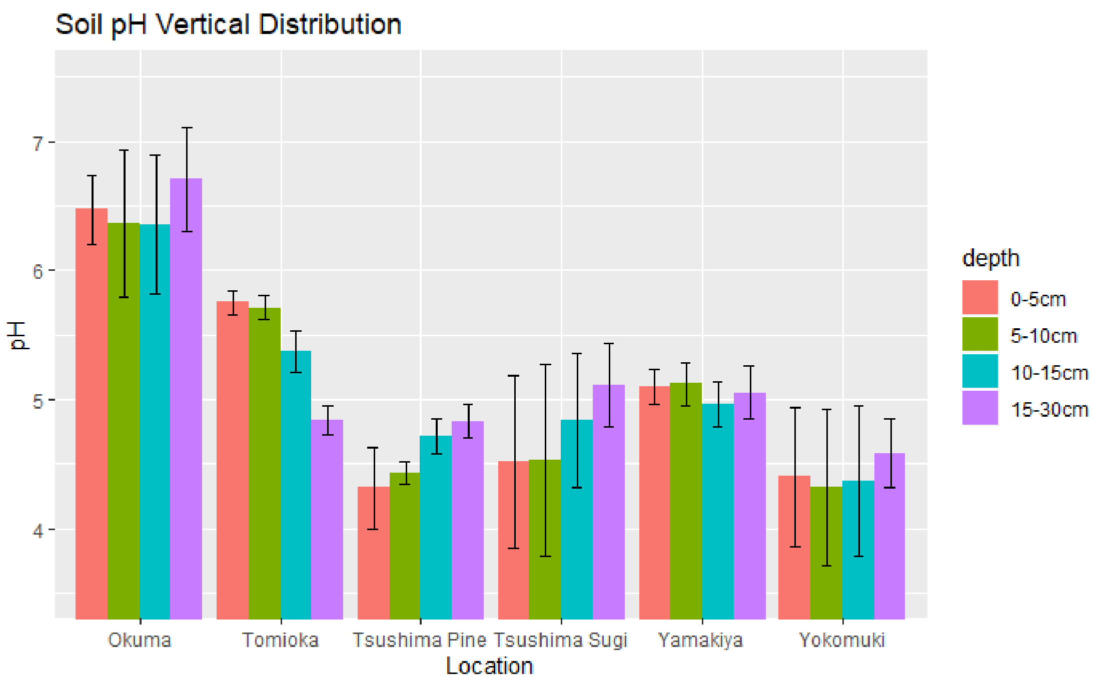


Figure 47: Soil pH vertical distribution

3.5 Soil to Plant Transfer Factor Linear Fit Model

Models do not include any data from Yokomuki due to the large uncertainty and lack of correlations found in any of the measured factors, except for pH in relation to soil depth as with the other five sampling sites. Only data from plant species with three or more distinct sampling locations were used for the transfer factor linear fit models. Tables 7 and 8 show all five variables used for the linear model. Tables 9 and 10 use the variables for the linear best fit model with the dredge function model comparison shown in Appendix F. Tables 11 and 12 show only the soil ^{137}Cs activity concentration factor in the linear model. Soil depth is not added as a factor as each depth had its own transfer factor calculated in the dataset. Tables 13 and 14 have the linear models using separate depth categories along with different combinations of the vertical distribution depths. Figures 48 to 50 show the observed to predicted transfer factors using the three different linear models.

Table 6: Linear model variables

Factor	**Unit**	**Variable**
Y	ln(Transfer Factor) - Unitless	Y
Intercept	N/A	B_0
Exchangeable $[K^+]$	ppm	B_1
Exchangeable $[Cs^+]$	ppt	B_2
^{137}Cs Activity Concentration	ln(Bq/kg)	B_3
Exchangeable ^{137}Cs Concentration	ln(Bq/kg)	B_4
pH	$-\log_{10}[H^+]$	B_5

Table 7: Transfer factor linear fit model

Plant	Y	B_0	B_1	B_2	B_3	B_4	B_5
All	Y_T	8.538e00	6.632e-03	1.090e04	-8.751e-01	-7.530e-02	-3.531e-01
Bamboo Grass	Y_{BG}	1.103e01	5.906e-04	-4.364e03	-1.258e00	2.975e-01	-3.658e-01
Glory-Bower	Y_{GB}	1.081e00	7.841e-02	5.764e04	9.415e-01	-2.2021e00	-1.285e00
Wisteria	Y_W	1.228e01	-1.685e-02	-1.316e04	-1.232e00	2.142e-01	-2.739e-01
Fern	Y_F	1.810e01	-7.304e-02	-3.753e03	-1.123e00	4.193e-01	-1.563e00
Hydrangea	Y_{UA}	1.424e01	-3.818e-03	1.229e04	-1.129e00	1.830e-01	-1.222e00
Maple	Y_M	9.796e00	-1.339e-02	-2.476e03	-1.223e00	1.919e-01	-8.182e-02
Japanese Lacquer	Y_K	1.110e01	2.091e-02	2.480e04	-2.769e-01	-5.345e-01	-1.668e00
Unknown	Y_{UB}	5.289e00	7.014e-02	3.100e04	-4.620e01	-8.923e-01	3.480e-02

Table 8: Linear fit model R^2 and residual standard error – all factor model

Transfer Factor	Multiple R^2	Adjusted R^2	Residual Standard Error	Degrees of Freedom
Y_T	0.8678	0.8640	0.8032	174
Y_{BG}	0.9269	0.9117	0.5192	24
Y_{GB}	0.9619	0.8985	0.7391	3
Y_W	0.9766	0.9702	0.3745	18
Y_F	0.9827	0.9770	0.3398	15
Y_{UA}	0.9899	0.9815	0.3039	6
Y_M	0.9953	0.9913	0.1730	6
Y_L	0.9888	0.9702	0.3235	3
Y_{UB}	0.9721	0.9256	0.5290	3

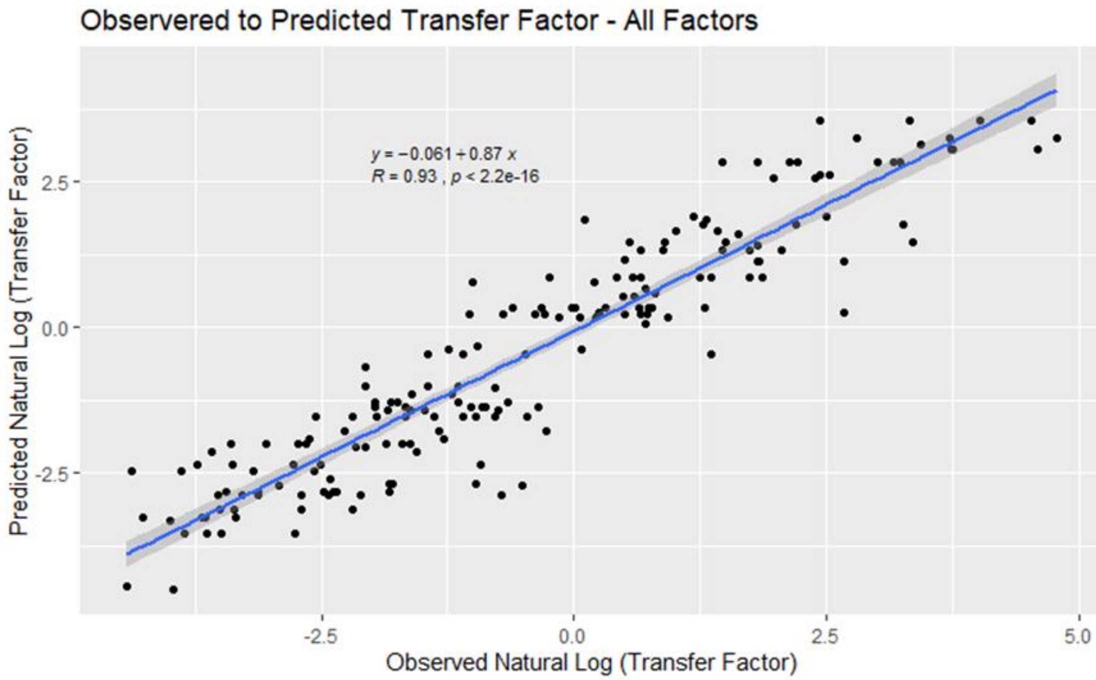


Figure 48: Observed to predicted transfer factors (Y_T – All Factors)

Table 9: Transfer factor linear fit model – dredge best fit

Plant	**Y**	**B_0**	**B_1**	**B_2**	**B_3**	**B_4**	**B_5**
All	Y_T	9.122e0		8.477e3	-9.330e-1		3.786e-1
Bamboo Grass	Y_{BG}	1.019e1			-1.225e0	3.121e-1	-3.143e-1
Glory-Bower	Y_{GB}	8.383e0			-9.737e-1		
Wisteria	Y_W	8.567e0			-9.773e-1		
Fern	Y_F	1.717e1	-7.176e-2		-1.058e0	3.612e-1	-1.485e0
Hydrangea	Y_{UA}	1.333e1		1.362e4	-9.865e-1		-1.173e0
Maple	Y_M	8.924e0	2.232e-2		-1.113e0		
Japanese Lacquer	Y_K	7.527e0			-1.009e0		
Unknown	Y_{UB}	4.377e0		3.191e4	-6.708e-1		

Table 10: Linear fit model R^2 and residual standard error – dredge best fit

Transfer Factor	Multiple R^2	Adjusted R^2	Residual Standard Error	Degrees of Freedom
Y_T	0.8670	0.8647	0.8011	176
Y_{BG}	0.9246	0.9159	0.5066	26
Y_{GB}	0.9325	0.9229	0.6444	7
Y_W	0.9687	0.9672	0.3924	22
Y_F	0.9825	0.9781	0.3312	16
Y_{UA}	0.9888	0.9846	0.2778	8
Y_M	0.9944	0.9932	0.1534	9
Y_L	0.9590	0.9531	0.4056	7
Y_{UB}	0.9559	0.9412	0.4702	6

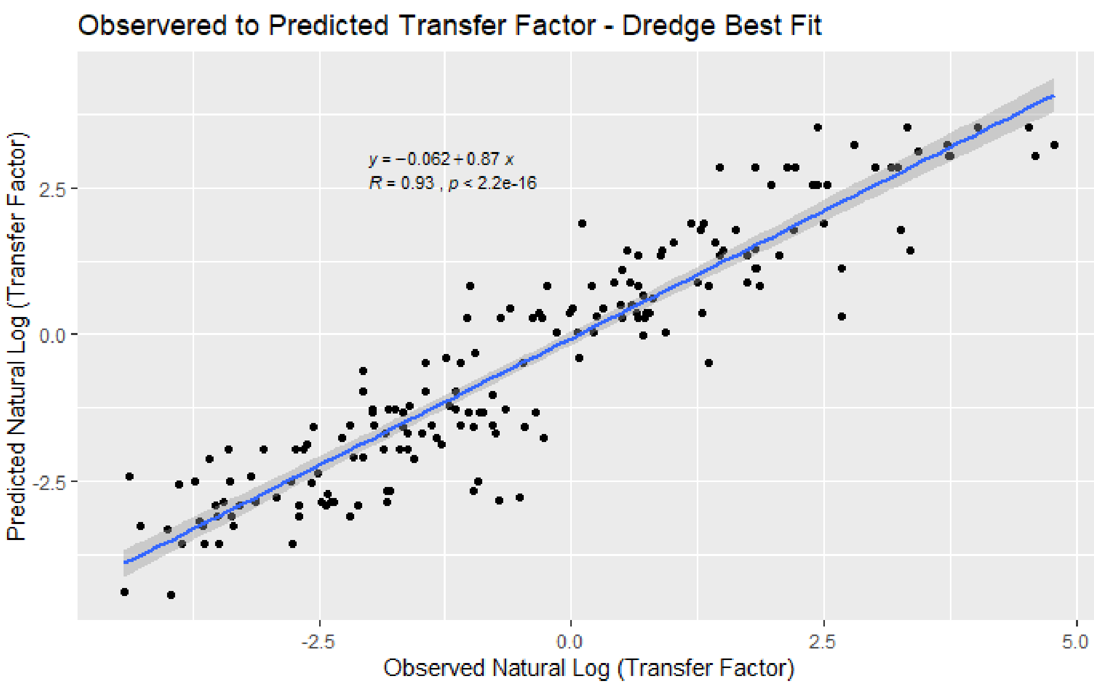


Figure 49: Observed to predicted transfer factors (Y_T – Dredge Best Fit)

Table 11: Transfer factor linear fit model – ^{137}Cs activity

Plant	Y	B_0	B_3
All	Y_T	7.98683	-0.95982
Bamboo Grass	Y_{BG}	7.56568	-0.96440
Glory-Bower	Y_{GB}	8.39327	-0.97372
Wisteria	Y_W	8.56651	-0.97727
Fern	Y_F	8.77076	-0.99740
Hydrangea	Y_{UA}	8.08484	-0.97912
Maple	Y_M	8.37936	-1.01827
Japanese Lacquer	Y_K	7.52735	-1.00877
Unknown	Y_{UB}	10.2081	-1.0533

Table 12: Linear fit model R2 and residual standard error – ^{137}Cs activity

Transfer Factor	Multiple R^2	Adjusted R^2	Residual Standard Error	Degrees of Freedom
Y_T	0.8465	0.8456	0.8558	178
Y_{BG}	0.8838	0.8797	0.6061	28
Y_{GB}	0.9325	0.9229	0.6444	7
Y_W	0.9687	0.9672	0.3924	22
Y_F	0.8635	0.8563	0.8487	19
Y_{UA}	0.9173	0.9091	0.6740	10
Y_M	0.9814	0.9796	0.2652	10
Y_L	0.9590	0.9531	0.4056	7
Y_{UB}	0.8667	0.8477	0.757	7

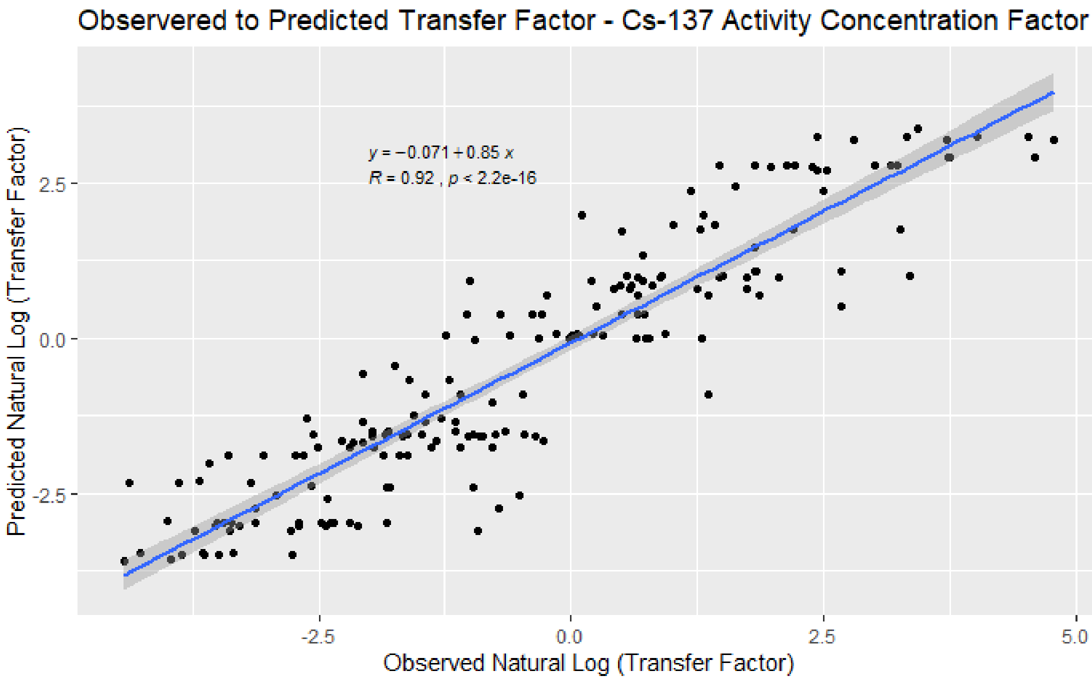


Figure 50: Observed to predicted transfer factors (Y_T – ^{137}Cs)

There is a chance that the linear fit could be due to a mixture of unrelated predicted transfer factors between the three depth categories. To find how transfer factors could be affected on a per depth basis, ^{137}Cs factor linear models were made for all combinations of the three soil depths as shown in Tables 13 and 14. The correlation between all of the seven possible depth category combination models are shown in Figures 51 and 52.

Table 13: Y_T Transfer factor linear fit model per depth category– ^{137}Cs activity

Model	B_0	B_3
0-5 cm (1)	5.6835	-0.7568
5-10 cm (2)	7.24509	-0.87568
10-15 cm (3)	7.69557	-0.90341
0-10cm (4)	7.55458	-0.92036
0-5 cm & 10-15 cm (5)	8.10099	-0.97277
5-15 cm (6)	7.8285	-0.9339
0-15 cm (7)	7.98683	-0.95982

Table 14: Y_T linear fit model R^2 and residual standard error per depth category – ^{137}Cs activity

Depth Category	Multiple R^2	Adjusted R^2	Residual Standard Error	Degrees of Freedom
0-5 cm (Model 1)	0.3368	0.3253	0.8478	58
5-10 cm (Model 2)	0.6538	0.6478	0.8536	58
10-15 cm (Model 3)	0.6495	0.6434	0.8600	58
0-10 cm (Model 4)	0.7306	0.7283	0.8537	118
0-5 cm & 10-15 cm (Model 5)	0.8800	0.8790	0.8599	118
5-15 cm (Model 6)	0.7737	0.7718	0.8550	118
0-15 cm (Model 7)	0.8465	0.8456	0.8558	178

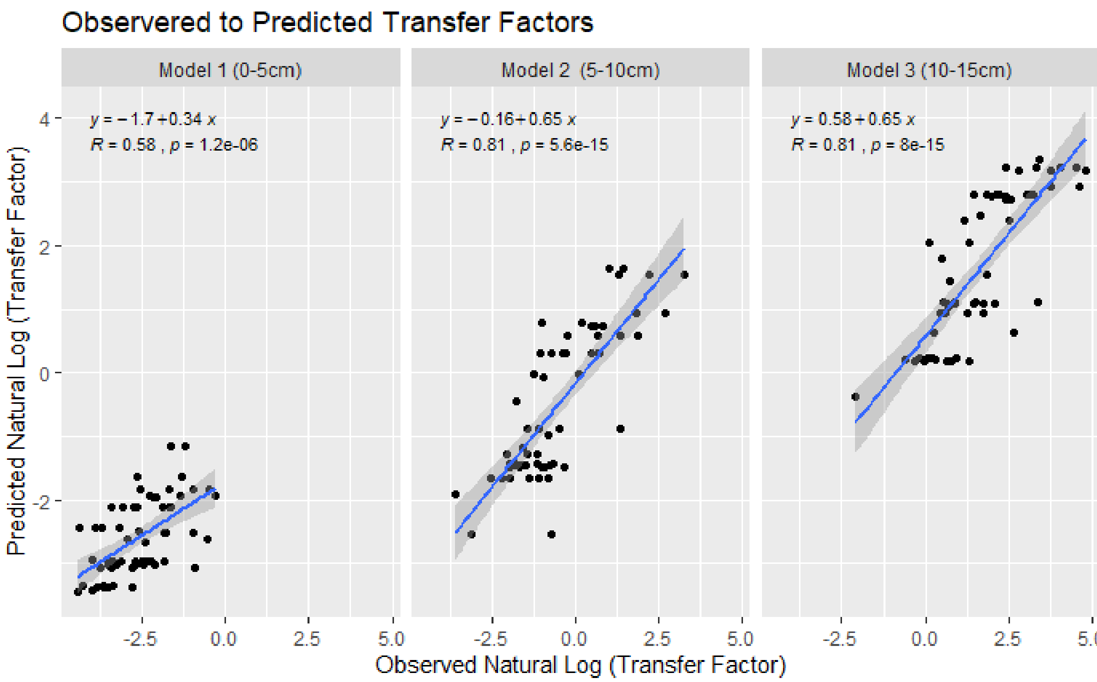


Figure 51: Model 1-3 observed to predicted transfer factors per individual depth (Y_T – ^{137}Cs)

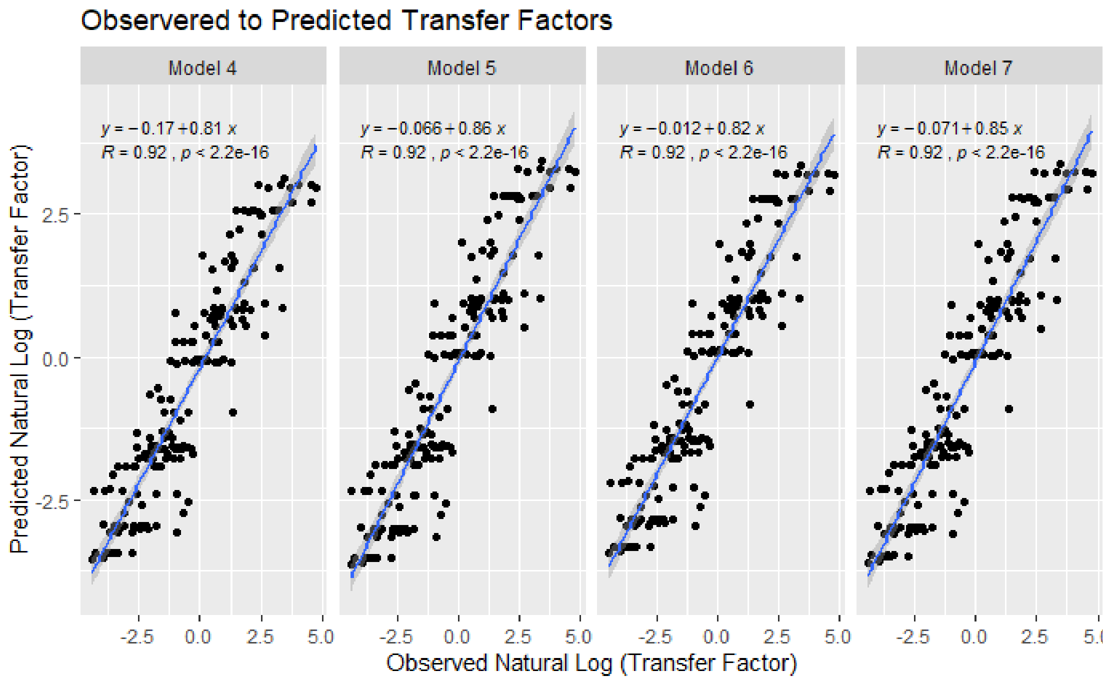


Figure 52: Model 4-7 observed to predicted transfer factors for depth 0-15cm (Y_T – ^{137}Cs)

Figures 53 shows the predicted to observed plant activity concentration using the dredge best fit and ^{137}Cs linear models with data from all sampled plant species. The predicted plant activity concentration did not correlate well with the observed plant activity. More accurate per plant species (Y_{BG}, Y_{GB},…. Y_{UB}) models were made to find better success in the prediction of the plant activity concentration. The predicted to observed soil-to-plant transfer factors for the dredge best fit and ^{137}Cs per plant species model is shown in Figure 54 and the accompanied predicted plant activity concentration model results are shown in Figure 55.

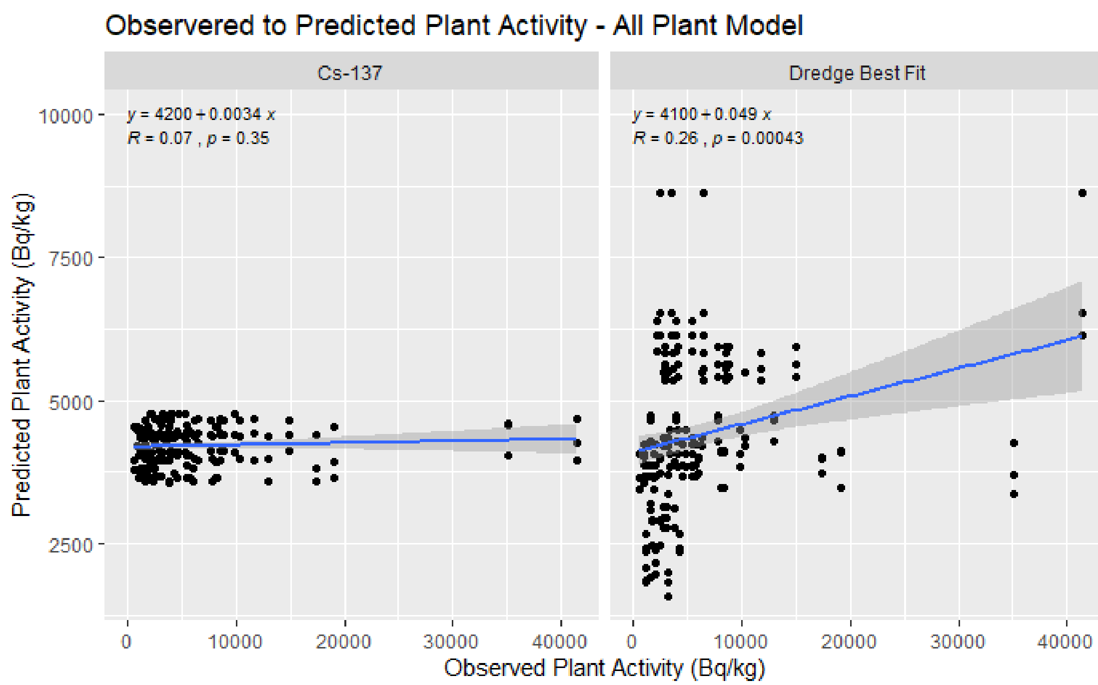


Figure 53: Predicted to observed plant activity concentration – Y_T models

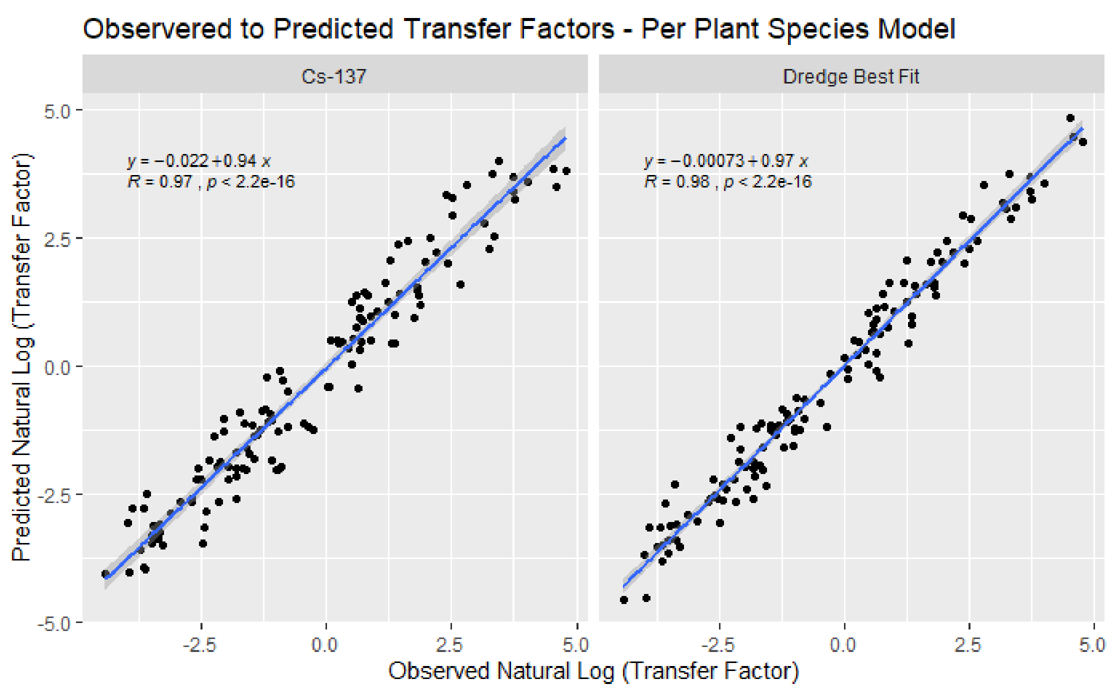


Figure 54: Predicted to observed soil-to-plant transfer factor – per plant species models

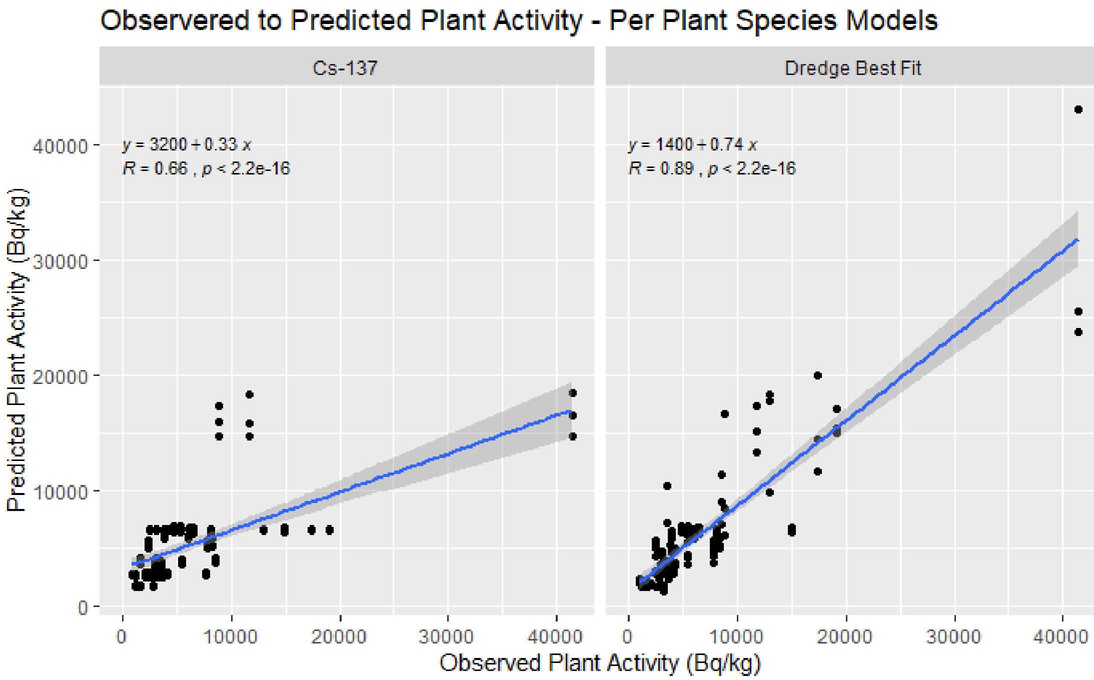


Figure 55: Predicted to observed plant activity concentration – per plant species models

Figures 56 to 59 show the scatterplot for different variables found in relation to the plant activity concentration. These are segregated per soil depth category as well as location at which the samples were taken.

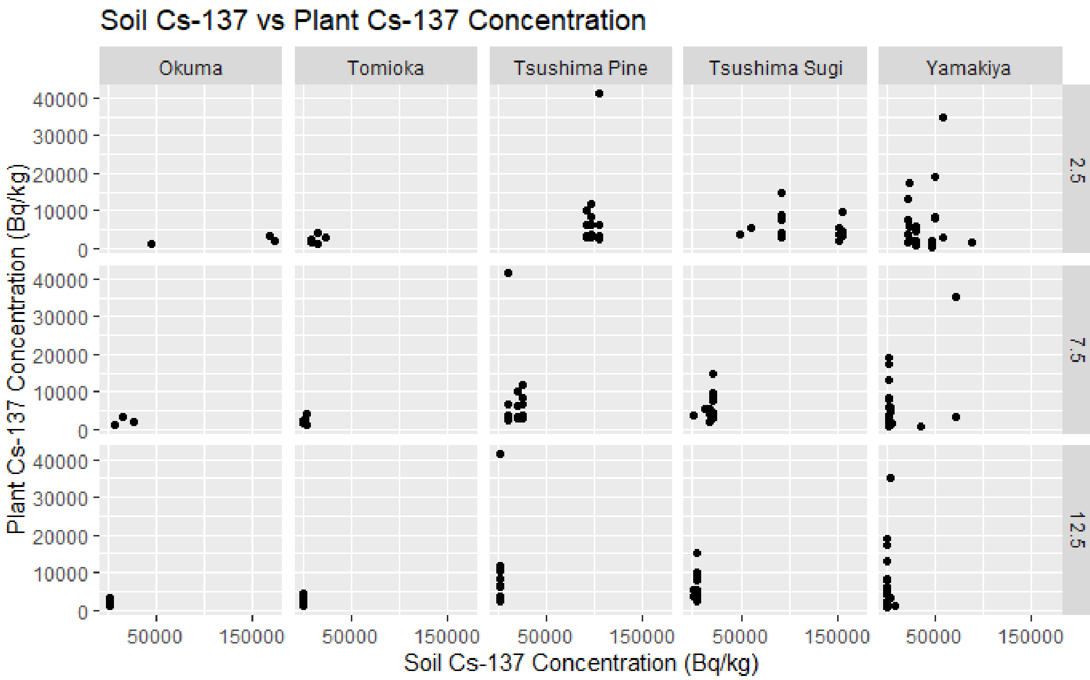


Figure 56: Soil activity vs plant activity concentration per soil depth (cm)

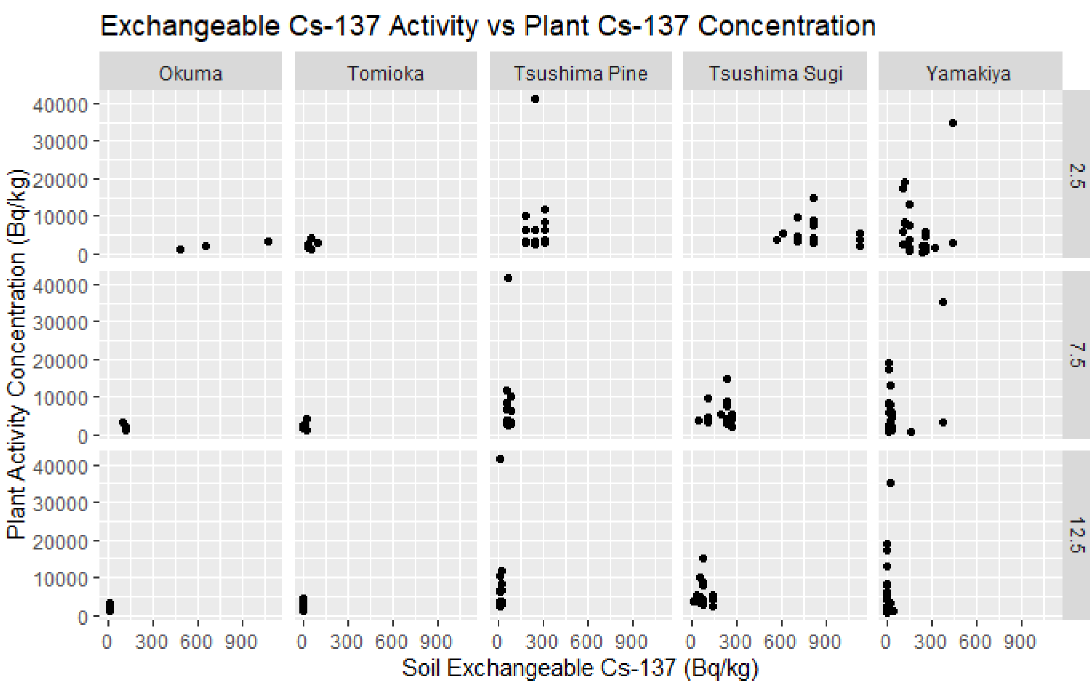


Figure 57: Soil exchangeable activity vs plant activity concentration – per soil depth (cm)

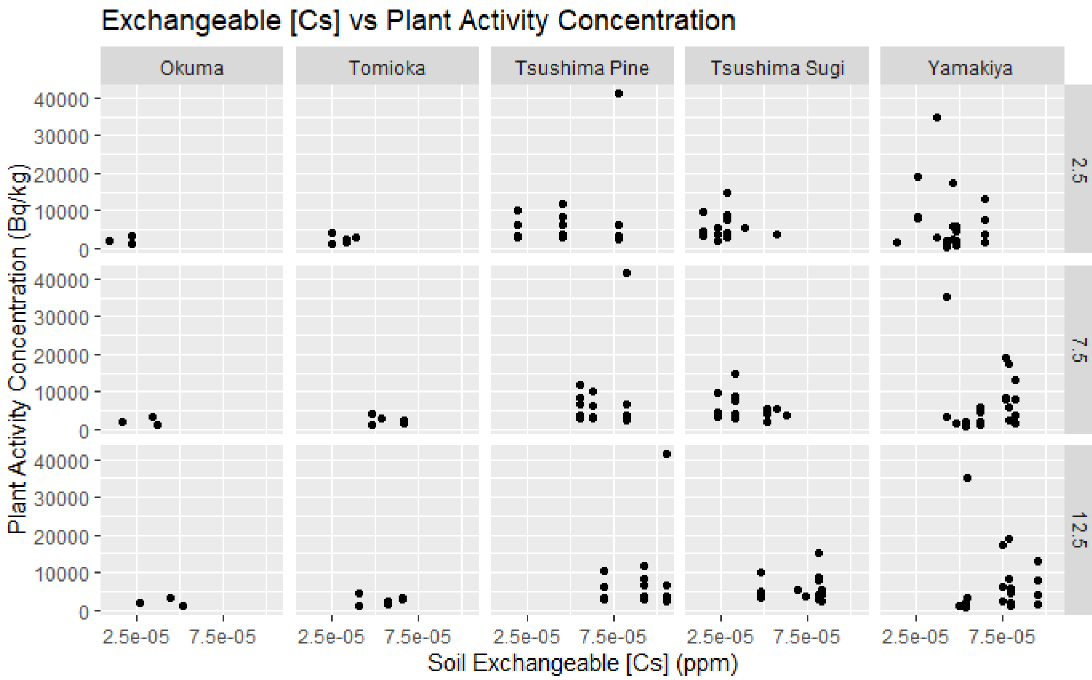


Figure 58: Exchangeable [Cs] vs plant activity concentration per soil depth (cm)

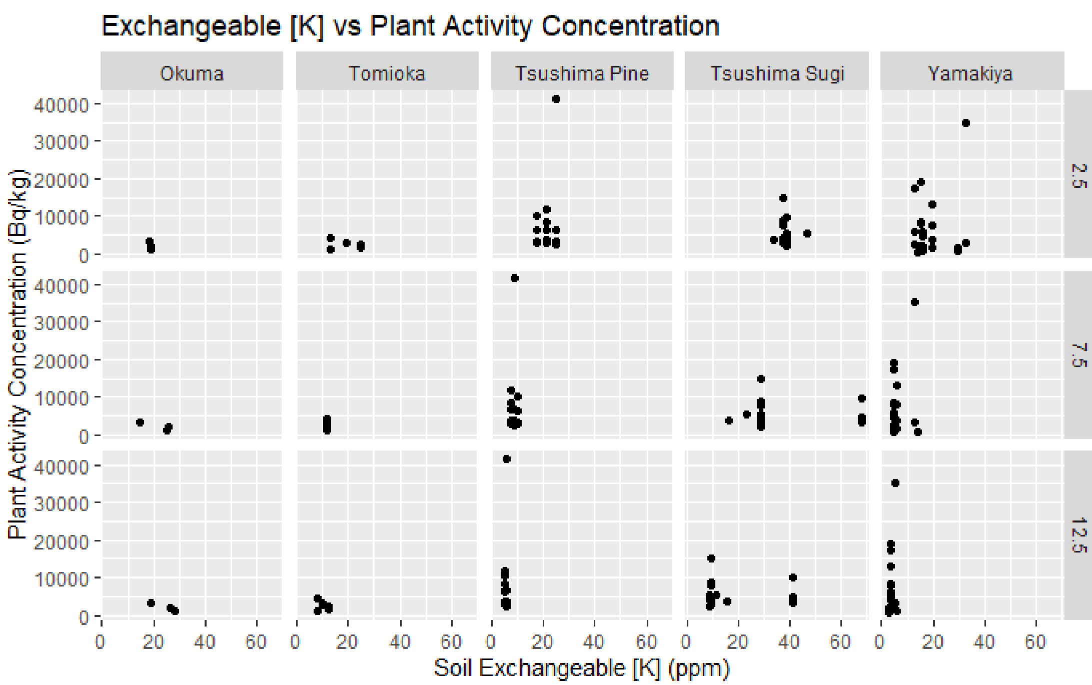


Figure 59: Exchangeable [K^+] vs plant activity concentration – per soil depth (cm)

DISCUSSIONS

4.1 ^{137}Cs Soil Deposition

The ^{137}Cs deposition density found in this study best correlated with past surveys and studies using the disturbed areas post disturbance effective half-life of 4.39 years (as described in Hayes et al 2020).

The ^{137}Cs soil deposition density correlated well with samples taken in the same locations during Oct 2018 (GSI, 2019) and Mar 2013 (Nuclear Regulation Authority, 2013) after decay correction was applied. The best correlation was using decay corrected deposition densities and an effective half-life of 4.39 years for disturbed areas post disturbance (Hayes et al, 2010) instead of the radiological half-life of 30.17 years for ^{137}Cs as shown in Table 15b. Decay corrections using the normal radiological decay half-life of ^{137}Cs of 30.17 years did not match with the expected deposition density ranges for Mar 2013 for the Tomioka, Tsushima Pine, Tsushima Sugi, and Yamakiya sites (Table 15a). The deposition density of the soil at Yamakiya was found to be 1,000 kBq/m^2 in 2016. Decay correcting using an effective half-life of 4.39 years for results in a soil deposition density of 1091±532kBq/m^2 (Workman 2019). This is important as the 2016 study used the exact same soil collection methods, tools, and detectors as the ones in this study. However, other samples collected at Yamakiya from 2014 to 2017 showed a decrease in ^{137}Cs deposition density to soil and litter closer to the radiological half-life with a deposition density respectively which also matches with the deposition density measurements (Table 15c). Using the 4.39 year half-life matches with the decay correction comparison with the GIS and Nuclear Regulatory Authority while using the 30.17 year half-life matches with the decay correction comparisons with the soil samples collected by the Dr. Yoschenko. As the soil samples collected by Dr. Yoschenko were much closer to the actual sample site and used the same soil collection methods, tools, and detectors as the ones in this study, it is assumed to be more accurate than the data from the GIS and Nuclear Regulatory Authority.

The effective half-life decay correction deposition density was found to be much higher than the one found by the initial deposition study (Table 4). The initial deposition estimates were found through an airborne survey based on correlations between the measured air dose rate and the contribution to dose rate by ^{137}Cs measured by an in-situ germanium detector at 1-m height (Kato, H and Onda Y., 2019). The lower than expected initial deposition density could have been influenced by the fact that most of the radiocesium was intercepted by the tree canopies during this time period and had not yet been transported down to the soil through litterfall, throughfall, and stemflow (Yoschenko et al, 2017).

Table 15a: Radiological half-life (30.17 years) decay corrected soil deposition density

1. Deposition range from Nuclear Regulation Authority, 2013

2. Deposition range from GIS, 2019

Location	Mar 2013 Deposition Density Range[1] (K-kBq/m^2)	Oct 2018 Deposition Density Range[2] (kBq/m^2)	Sample Mar 2013 Decay Corrected Deposition Density (kBq/m^2)	Sample Oct 2018 Decay Corrected Deposition Density (kBq/m^2)
Okuma	>3000	>3000	7007±3260	6163±2867
Tomioka	1000-3000	600-1000	643±256	566±225
Tsushima Pine	>3000	1000-3000	1425±182	1254±160
Tsushima Sugi	>3000	1000-3000	1397±68	1228±60
Yamakiya	1000-3000	600-1000	799±390	702±343
Yokomuki	N/A	<10	29±16	26±14

Table 15b: Effective half-life (4.39 years) decay corrected soil deposition density

1. Deposition range from Nuclear Regulation Authority, 2013

2. Deposition range from GIS, 2019

Location	Mar 2013 Deposition Density Range[1] (kBq/m^2)	Oct 2018 Deposition Density Range[2] (kBq/m^2)	Sample Mar 2013 Decay Corrected Deposition Density (kBq/m^2)	Sample Oct 2018 Decay Corrected Deposition Density (kBq/m^2)
Okuma	>3000	>3000	17434±8111	7214±3356
Tomioka	1000-3000	600-1000	1600±637	662±264
Tsushima Pine	>3000	1000-3000	3547±452	1468±187
Tsushima Sugi	>3000	1000-3000	3475±169	1438±70
Yamakiya	1000-3000	600-1000	1987±969	822±401
Yokomuki	N/A	<10	72±41	30±17

Table 15c: IER Yamakiya soil sample deposition density comparison

1. (Personal communication, 24 Mar 2020, Vasyl Yoschenko)

2. 2019 collected sample deposition density

3. Yoschenko, 2018

4. Decay corrected from sampled deposition density data

Yamakiya	2014	2015	2016	2017	2019
Sampled Deposition Density (kBq/m^2)	722[1]	714[1]	741[1]	696[1]	691±334[2]
2014 Radiological Decay corrected Deposition Density (kBq/m^2)	746±400[3]	730±370[3]	780±140[3]	746	775±375[4]

The ^{137}Cs vertical profiles of the soil samples show a logarithmic decrease in both ^{137}Cs concentration (Bq/kg) and ^{137}Cs activity distribution (Bq/m^2) as a function of soil depth (Figures 20a and 21a). Over 90% of the total ^{137}Cs deposition was located at the top 10 cm of the soil (Figure 22). The total litter ^{137}Cs litter contribution has shown a continually decreasing trend at both the Yamakiya and Tsushima Sugi sites. From 2016 to 2019, the Yamakiya site litter contribution decreased from 8±4% to 4.9% and at Tsushima Sugi site it decreased from 4±2% to 2.2% (Yoschenko et al, 2018). These trends correspond with the soil profiles found in previous years at Yamakiya and Tsushima except for the Yokomuki site samples (Yoschenko et al, 2018). The large uncertainty and p-value for the Yokomuki samples could be due to wild boar that disturb the soil at the sampling locations resulting in ^{137}Cs vertical profiles being very different from the expected trend found at the other sampling locations (Figure 60).

Figure 60: Yokomuki sampling site

4.2 Understory Plant ^{137}Cs Dynamics and Contribution to Yamakiya ^{137}Cs Inventory

There are large variations between ^{137}Cs activity concentrations in different plant species and location, and between the same species of understory plants. It should be noted that some plants sampled were of the same genus, but not necessarily of the same species (Table 5). All of the plants were subdivided using the term species even if they are only part of the same genus and not species for continuity purposes in the discussions. There is a correlation between the ^{137}Cs activity concentrations of stems, branches, and leaves of saplings as well as that of non-woody seedlings of the same species. Higher concentrations of radiocesium were found in the metabolically active portions of the understory plants with leaves having a higher radiocesium concentration then the branches and stem. This correlates with previous observations in which the root of the plant had higher radiocesium concentration than leaves which in turn was higher than that in the woody portions of the plant (Y-G. Zhu and E. Smolders, 2000). All of the understory plants' leaves, branches, and stems, were measured for radiocesium. The leaves of the understory plants were found to have a higher ^{137}Cs concentration than the branches, and the plant stem had even higher concentrations than all other plant tissues (Figures 23-26). Non-woody saplings have a ^{137}Cs concentration in between that of the leaves and the woody parts of the mature plants. One understory plant species could not be properly identified. The unidentified plant was only found in the high elevation sampling areas of Tsushima and Yokomuki (Figure 61). Future research in these areas during the summer months should require further samples to better identify the unknown plant species.

Figure 61: Unknown plant

The soil to plant ^{137}Cs concentration ratios show a large variance between both plant species and locations (Figure 27). The concentration ratio for fern at Yamakiya is much greater than any other plant at any other location including fern at other sampling sites. The concentration ratio of wisteria at Yamakiya is also much greater than at other locations. The variance of the concentrations ratios for maple is much less between sampling sites as compared with any other plant species. Possible explanations for the variability in concentration ratios could be due to differences of exchangeable [K], [Cs], and [^{137}Cs] in different soils along with differences in soil pH and how each of the factors change per soil depth. All sites except for the Yokomuki site followed the general logarithmic decrease in radiocesium present in the vertical soil profile as shown in Figures 28 to 36.

For aboveground biomass, the radiocesium inventory in trees was found to be 47±21 kBq/m^2 in 2014 decreasing to 37±21 kBq/m^2 in 2015 after which it remained stable at 32±18 kBq/m^2 in 2016 (Yoschenko et al, 2018). ^{137}Cs inventory in trees was found to be 157 kBq/m^2 in 2019, a fivefold increase compared to previous years (Figure 62). The higher radiocesium inventory in trees could be due to the difference in tree density in the sampled area as compared to the site sampled in 2016, as well as the previous samples being taken in the winter compared to the summer in 2019. The trees would have increased ^{137}Cs concentration in the summer due to the increased metabolic activity that occurs during the warmer months. Similarly, litterfall from Japanese cherry trees was shown to have radiocesium concentrations 2.5 times greater in early September 2011 as compared to late October 2011 which shows that radiocesium concentrations are higher in trees during the warmer months of the year (Yoshihara et al, 2014).

Radiocesium contribution from understory plants was found to be negligible in both terms of biomass and radiocesium deposition in 2014. Studies in 2015 and 2016 did not include understory plants as part of the total radiocesium deposition inventory (Yoschenko et al, 2017). Sampling of understory plants in 2019 showed similar conclusions, with understory plants contributing negligible amounts of ^{137}Cs and biomass at Yamakiya. Only 0.067% of the total aboveground ^{137}Cs deposition and 0.073% of the total aboveground biomass were from understory plants at Yamakiya. Factoring in ^{137}Cs deposition contribution by soil, understory plants comprise only 0.013% of the radiocesium deposition at Yamakiya. Due to the inconsistencies in the time of the year at which samples were taken, it is difficult to establish continuing trends of radiocesium contributions by the different compartments using data from previous years. However, the trend of a sharp decrease in litter contribution to the radiocesium inventory was found to have continued as shown in Table 16.

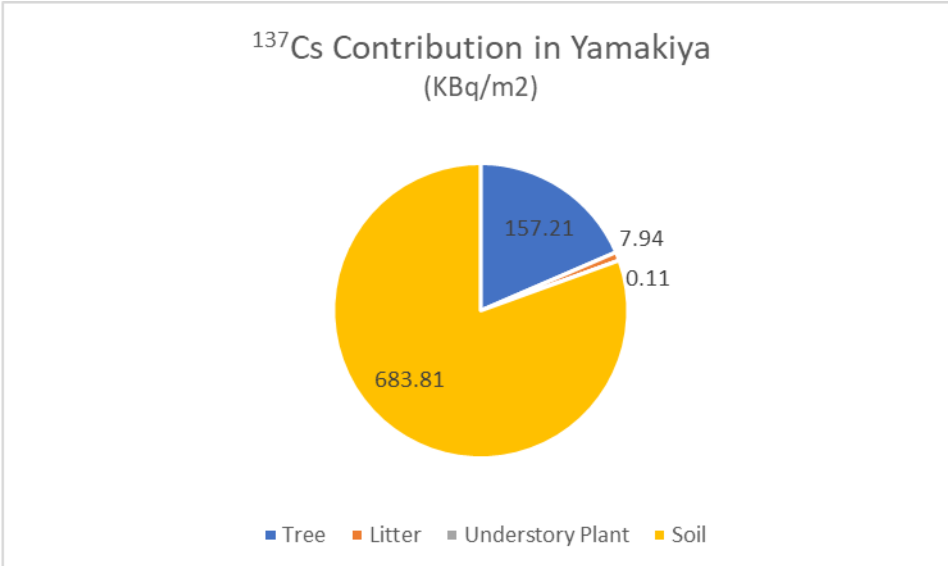


Figure 62: Contribution to total ^{137}Cs inventory in Yamakiya

Table 16: Litter ^{137}Cs contribution in Yamakiya

2014 – 2016 data from Yoschenko et al, 2018

Year	2019	2016	2015	2014
Deposition Density (kBq/m^2)	7.94±2.80	37±14	53±25	150±47

4.3 Soil Factor Correlations

Exchangeable ^{137}Cs concentration follows a logarithmic decrease with increasing soil depth similar to that of the total ^{137}Cs concentration (Figure 40b). The total to exchangeable ^{137}Cs ratio shown in Figure 41 shows a decrease with soil depth, where more exchangeable ^{137}Cs is in the soil as a function of depth. Exchangeable stable Cs concentration increases with increasing soil depth in a linear fashion, unlike the logarithmic decreases found in total ^{137}Cs and exchangeable ^{137}Cs concentration (Figure 42). The exchangeable K concentration in the soil decreases linearly with increasing soil depth, with the exception of the Okuma site (Figure 43).

The exchangeable Cs to K concentration ratio has a noticeable linear increase with soil depth at the Tsushima Pine and Yamakiya sites. Cs and K permanently come into the topsoil mainly from decomposing litter and precipitation in Fukushima forest tree crowns, similar to large K concentration increases after seasonal litterfall events in watershed areas (Tripler et al, 2006). Okuma has much less aboveground biomass available compared to the other five sites. The Okuma litter is composed of bamboo grass, which does not easily decompose compared to other understory plant species. The Tsushima Pine and Yokomuki sites have thin and fast decomposing litter layers, while the Tsushima Sugi and Tomioka sites have thick and slow decomposing litter layers. The lower Cs/K ratio could be due to the more chemically active K fixation into limited exchangeable sites, causing Cs to go deeper down into the soil.

The soil pH of Tomioka and Yamakiya was within a pH range of 5.0 – 7.4 for Japanese Sugi trees (Cornell, 2020). Tsushima Sugi was also a Japanese Sugi dominant forest, but the pH was below 5.0 (less than ideal) for the top 15 cm of soil, which is still tolerable for the Japanese Sugi tree. The soil for both Tsushima Pine and Tsushima Sugi sites were similar due to their proximity to each other. The soil pH at the Sugi dominant forest at the Tsushima Sugi site is at the lower pH range for Sugi trees. At the nearby Tsushima Pine site, pine trees which are more tolerant of acidic soil become the dominant tree species in the forest. Okuma had a higher pH compared to the other sites which could be due to the sandy makeup of the soil along with its proximity to the coast and nearby stream. The pH of the soil was found to be statistically different on the basis of location, but not soil depth, through ANOVA, with a p-value of a variance in means of 1.39×10^{-7} and 0.8927 respectively (Appendix E7). The pH values used in the models were averages across the 15 cm soil depth.

4.4 Transfer Factor Linear Fit Models

The linear model for predicting the soil to plant transfer factors was created using five soil factors, exchangeable [K^+], exchangeable [Cs^+], ^{137}Cs activity concentration, exchangeable ^{137}Cs activity concentration, and pH. The natural log transformed linear model using all five factors had an adjusted R^2 = 0.8640 when all data for all plants collected were used. Using a linear model that was understory plant specific yielded, a much higher adjusted R^2 with the lowest being the glory bower plant (*Clerodendrum trichotomum*) with an adjusted R^2 = 0.8985 and the highest being hydrangea plant with an adjusted R^2 = 0.9815 as shown in Table 8. The prediction of transfer factors was not dependent on all five factors in the model. Different understory plant species had the total ^{137}Cs activity concentration in the soil as the main variable with respect to radiocesium concentration, and a various mix of other different factors influenced the predicted transfer factor depending on the understory plant species (Appendix F).

A dredge test were used to find the best fit model that could be used to predict the soil to plant transfer factors using data of all sampled understory plants and individual understory plant species. The total soil ^{137}Cs activity concentration is the only factor that was shown to have a good correlation in predicting transfer factors across all understory plant species. A total soil ^{137}Cs activity concentration factor model was created for understory plant species along with each individual understory plant species. The adjusted R^2 value for the dredge best fit model and ^{137}Cs model was 0.8647 and 0.8456 respectively. As shown in Figure 63, all three models are very similar in their prediction of the transfer factors with a slope close to one, indicating a more accurate one to one predicted transfer factor to observed transfer factor ratio. All three models utilize a natural log transform of the actual transfer factors where small variance in the model would lead to a much larger variance when predicting non-transformed transfer factors.

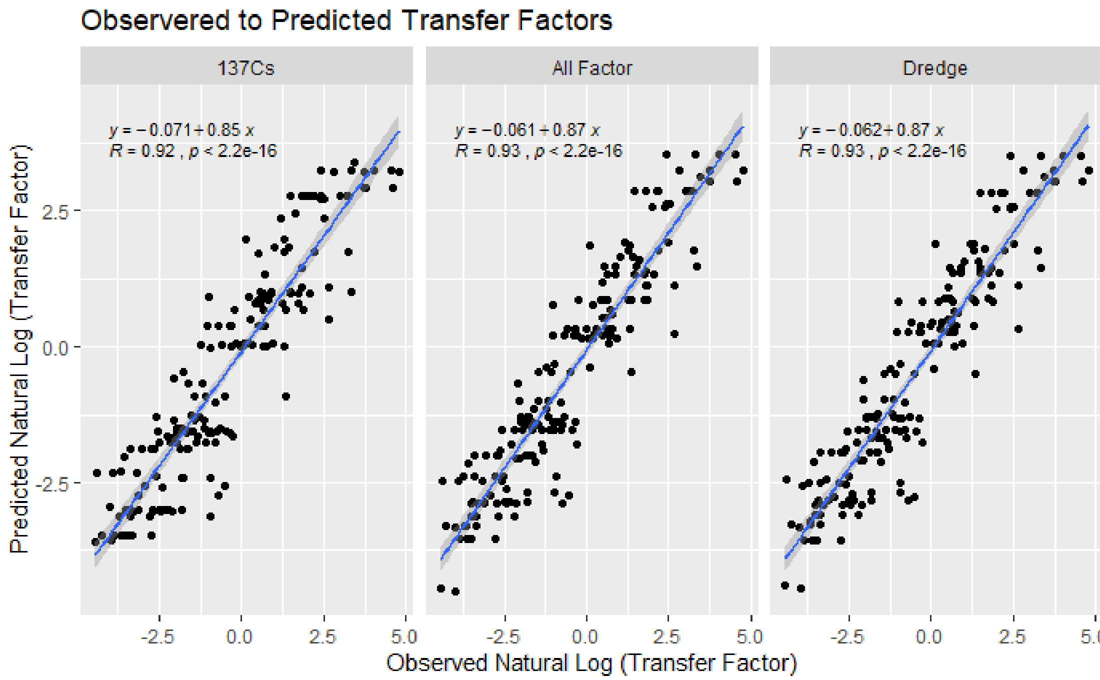


Figure 63: All plant species transfer factor models

The ^{137}Cs transfer factor linear models were made using each of the 5 cm depth layers as well as any combination of the three to see how they impacted the correlation between predicted and observed transfer factors. It was found that the 0-5 cm depth had a lower correlation (r = 0.58) compared to the 5-10 cm (r = 0.81) and 10-15 cm (r = 0.81) layers. This difference between the upper layer and the bottom two layers could be due to differences in the root structure between plants even those in the same species in the 0-5 cm soil layer. The different plants possibly have their roots start at different depths within the 0-5 cm layer causing a variance in ^{137}Cs uptake at this layer compared to 5-10 cm and 10-15 cm layers. Linear models created using different combinations of the three soil layers yielded the same correlation as the 0-15 cm model (r = 0.92) indicating that the main difference in the r-value between the individual 5 cm soil layers and the 0-15 cm model is caused mainly by the larger sample size used for the 0-15 cm model.

The transfer factors from the ^{137}Cs linear model for all plants did not predict plant radiocesium concentration and were not significant (p-value = 0.35). The dredge best fit model for ^{137}Cs transfer factors did show a significant correlation (p-value = 0.00043) for plant radiocesium concentration as shown in Figure 53. The dredge best fit model had a weak linear relationship (r = 0.26) between the transfer factor and plant radiocesium concentration. Dredge best fit linear models of transfer factors were used to predict ^{137}Cs concentration for eight of the most sampled understory plant species. The dredge models yielded a stronger correlation (0.94 and 0.97 slope), very close to the desired one to one slope ratio (Figure 54). The dredge best fit per plant species basis model had a better correlation (r = 0.89) compared to the ^{137}Cs per plant species basis model (r = 0.66) for predicted to observed plant activity concentration. The dredge best fit and ^{137}Cs models have a much larger variance and smaller correlation than the predicted to observed correlations of the natural of the transfer factors with an r of 0.97 and 0.97, respectively. This shows that correlating the natural log of the transfer factors while making it easier to see a trend in the graphs, also hides the large variances between the observed and predicted transfer factors. Figures 56 to 59 show how each of the factors, except for pH, was correlated with plant activity concentration for each individual plant sample. The lack of relationship between the factors and plant concentration may indicate additional factors not considered are important, or differences between the plant species are more important than these factors.

The Absalom 1999 transfer model had a natural log predicted ^{137}Cs to observed transfer factor with a linear correlation r^2 ranging from 0.59 for cabbage to 0.92 for straw wheat using crop specific parameters. The Absalom 2001 model for predicting the transfer factor for barley had an $r^2 = 0.52$ (Absalom et al, 1999 and Absalom et al, 2001). Our per plant species ^{137}Cs model yielded an overall better transfer factor correlation with an adjusted r^2 ranging from 0.8477 for the unknown plant to 0.9796 for maple. Figure 53 shows that even with a high r^2 value for the all plant ^{137}Cs transfer factor model, the predicted plant activity concentration for a specific plant may still vary greatly from actual observed plant activity concentration. Since a log transform is performed on all data, small changes in values yield large changes in results. Care should be taken when using transfer factor models to predict actual plant activity concentration even if the transfer factor models have exceptional correlation with results.

CONCLUSION

The ^{137}Cs deposition density data collected at various forests sites in Fukushima provide further evidence of the natural logarithmic decrease in ^{137}Cs activity concentration with increasing soil depth. Additionally, the soil measurements support the effective half-life of 4.39 years given for disturbed areas post disturbance areas more than the radiological half-life of 30.17 years using comparisons with deposition density data from the GIS and Nuclear Regulatory Authority. Comparisons with soil measurements by Dr. Yoschenko, however, shows a gradual decrease with the radiological half-life (Personal communication, 24 Mar 2020, Vasyl Yoschenko). The discrepancies between the GIS data and the data collected by the IER should be further explored.

The majority of the ^{137}Cs inventory in Yamakiya is from soil (80.54%) and trees (18.52%). The ^{137}Cs contribution by trees in summer of 2019 was found to be much higher than the one found in the winter 2014 to 2016 studies possibly due to differences in seasons. Results still show a continuing declining trend of litter contribution to ^{137}Cs inventory at Yamakiya. Understory plants make up a negligible contribution to both the aboveground biomass and ^{137}Cs activity inventory at Yamakiya. The ^{137}Cs activity concentrations of different understory plant compartments show that the more metabolically active compartments have higher ^{137}Cs activity concentrations. Leaves have a higher ^{137}Cs concentration then the woody portions of plants. The non-woody juvenile saplings of the same species of plant were shown to have an activity concentration in between that of the leaf and woody compartments of their more mature counterparts.

The per plant species dredge best fit linear model was found to be able to predict the ^{137}Cs soil to plant transfer factor and actual plant activity concentration with an r-value of 0.98 and 0.89, respectively. The per plant species ^{137}Cs linear model, however, could also be a predictor for soil to plant transfer factors (r = .66). If time constraints exist, the preparation and analysis for only soil total ^{137}Cs would be sufficient to yield a reasonable estimate of plant activity concentration. The use of an overall linear model of all plant species to predict ^{137}Cs plant activity is not advisable due to the large variance when converting from natural log transfer factors, however, it can still be used to illustrate general soil-to-plant transfer factor trends for a desired area.

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Appendix

Results Tables

Appendix A

Plant and Soil Total Radiocesium Count

Appendix A1.1 Yamakiya Site A-C Total Radiocesium Count

Yamakiya Sugi				Cs-134 (Bq/kg)		Cs-137 (Bq/kg)		err/Activity		Live time (s)	Radio-Cs in U8 (Bq)		D.W. (g)	Weight (g) in U8
Date	Label	Part	Type	Activity	Act. err	Activity	Act. err	Cs-134	Cs-137		Cs-134	Cs-137		
6/6/2019	S-L1	Litter	Litter	409.25	18.14	5441.8	65.616	4.43249847	1.2057775	3600	12.482125	165.9749	150.19	30.5
6/6/2019	S-A5	0-5 cm	Core soil	3949.3	76.638	50217	274.55	1.94054643	0.5467272	1903	80.605213	1024.92897	21.2	20.41
6/6/2019	S-A10	5-10 cm	Core soil	96.412	9.7305	1331.3	35.965	10.0926233	2.70149478	1897	4.98257216	68.801584	51.68	51.68
6/6/2019	S-A15	10-15 cm	Core soil	15.239	2.7469	194.86	9.6245	18.025461	4.93918711	3270	0.88096659	11.2648566	59.31	57.81
6/6/2019	S-A30	15-30 cm	Core soil	5.8221	1.2182	65.8	3.272	20.9237217	4.97264438	8593	0.38751898	4.379648	137.5	66.56
6/6/2019	S-GB1	Glory-Bower	Plant	647.32	58.833	8322.7	200.28	9.0887042	2.40643061	3600	1.5665144	20.140934	2.82	2.42
6/6/2019	S-F1	Fern	Plant	1560.3	64.53	19089	217.07	4.13574313	1.13714705	3600	8.11356	99.2628	5.98	5.2
6/6/2019	S-W1	Wisteria	Plant	677.94	37.57	8139.7	122.85	5.54178836	1.50926938	3600	4.5354186	54.454593	7.2	6.69
6/6/2019	S-L2	Litter	Litter	642.52	23.259	8155.1	82.348	3.61996514	1.00977303	3600	18.31182	232.42035	91.01	28.5
6/6/2019	S-B5	0-5 cm	Core soil	1727.9	49.494	23068	179.31	2.86440188	0.77731056	1906	38.048358	507.95736	22.78	22.02
6/6/2019	S-B10	5-10 cm	Core soil	54.929	5.2646	670.08	18.179	9.58437255	2.71295965	3600	2.52563542	30.8102784	45.98	45.98
6/6/2019	S-B15	10-15 cm	Core soil	11.948	2.0811	146.16	7.2338	17.4179779	4.94923372	4543	0.6655036	8.141112	55.92	55.7
6/6/2019	S-B30	15-30 cm	Core soil	ND	ND	76.858	3.8322	-	4.98607822	8374	0	5.50149564	145.32	71.58
6/6/2019	S-GB2	Glory-Bower	Plant	205.95	15.923	2399.3	53.002	7.73148823	2.20906098	3600	2.2469145	26.176363	12.31	10.91
6/6/2019	S-F2	Fern	Plant	1314.5	46.38	17390	168.58	3.52833777	0.96940771	3600	16.32609	215.9838	13.35	12.42
6/6/2019	S-W2	Wisteria	Plant	467.18	40.878	6052.4	141.9	8.74994649	2.34452449	3600	1.6398018	21.243924	4.2	3.51
6/6/2019	S-L3	Litter	Litter	883.85	26.509	10967	93.976	2.99926458	0.85689797	3600	26.144283	324.40386	113.16	29.58
6/6/2019	S-C5	0-5 cm	Core soil	1628.3	43.099	20495	151.88	2.64687097	0.74105879	1907	44.794533	563.81745	28.98	27.51
6/6/2019	S-C10	5-10 cm	Core soil	118.89	10.567	2015.4	42.413	8.88804778	2.10444577	1900	5.7209868	96.981048	49.74	48.12
6/6/2019	S-C15	10-15 cm	Core soil	11.937	2.0931	139.89	6.9501	17.5345564	4.96826078	4602	0.76910091	9.0131127	68.18	64.43
6/6/2019	S-C30	15-30 cm	Core soil	ND	ND	46.711	2.5794	-	5.52203978	10000	0	3.6574713	144.28	78.3
6/6/2019	S-GB3	Glory-Bower	Plant	651.12	64.888	7782.7	209.27	9.96559774	2.68891259	3600	1.2631728	15.098438	2.3	1.94
6/6/2019	S-F3	Fern	Plant	1078	35.751	12952	121.9	3.31641929	0.94116739	3600	15.67412	188.32208	17.86	14.54
6/6/2019	S-W3	Wisteria	Plant	304.69	15.845	3888.5	54.316	5.20036759	1.39683683	3600	6.7245083	85.819195	22.75	22.07
6/6/2019	S-M1	Myoga	Plant	ND	ND	1583.2	108.1	-	6.82794341	10000	0	0.981584	0.72	0.62

Appendix A1.2 Yamakiya Site D-F Total Radiocesium Count

Yamakiya Sugi				Cs-134 (Bq/kg)		Cs-137 (Bq/kg)		err/Activity		Live time (s)	Radio-Cs in U8 (Bq)		D.W. (g)	Weight (g) in U8
Date	Label	Part	Type	Activity	Act. err	Activity	Act. err	Cs-134	Cs-137		Cs-134	Cs-137		
6/6/2019	S-L4	Litter	Litter	293.99	15.89	3795	56.326	5.40494575	1.48421607	3600	8.466912	109.296	99.11	28.8
6/6/2019	S-D5	0-5 cm	Core soil	4478.8	116.21	58412	410.78	2.59466821	0.70324591	1908	38.875984	507.01616	9.24	8.68
6/6/2019	S-D10	5-10 cm	Core soil	5533.7	89.077	71432	320.47	1.60971863	0.44863647	1906	117.978484	1522.93024	23.53	21.32
6/6/2019	S-D15	10-15 cm	Core soil	182.76	12.273	2444.8	43.671	6.71536441	1.78628109	1903	8.8675152	118.621696	51.22	48.52
6/6/2019	S-D30	15-30 cm	Core soil	32.174	4.4354	478	18.347	13.7856654	3.83828452	1891	2.44329356	36.29932	140.86	75.94
6/6/2019	S-MY2	Myoga	Plant	2730.9	221.82	35078	734.07	8.12259695	2.09267917	3600	1.993557	25.60694	0.93	0.73
6/6/2019	S-U1	Hydrangea	Plant	254.74	37.824	3144.4	125.56	14.8480804	3.99313064	3600	0.6215656	7.672336	2.79	2.44
6/6/2019	S-L5	Litter	Litter	559.17	22.088	7803.5	81.996	3.95014039	1.05075927	3600	15.5728845	217.327475	97.43	27.85
6/6/2019	S-E5	0-5 cm	Core soil	7092.1	131.43	88478	459.78	1.85318876	0.5196546	1903	74.892576	934.32768	11.16	10.56
6/6/2019	S-E10	5-10 cm	Core soil	325.82	18.115	4245.6	64.398	5.5598183	1.51681741	1904	12.4332912	162.012096	39.45	38.16
6/6/2019	S-E15	10-15 cm	Core soil	28.274	4.4016	319.85	15.773	15.5676593	4.93137408	2273	1.42670604	16.139631	50.46	50.46
6/6/2019	S-E30	15-30 cm	Core soil	7.6151	1.5954	106.53	5.2493	20.95048	4.92753215	5822	0.53252394	7.4496429	138.95	69.93
6/6/2019	S-U2	Hydrangea	Plant	167.23	30.613	1630	80.97	18.305926	4.96748466	7300	0.267568	2.608	2.04	1.6
6/6/2019	S-L6	Litter	Litter	562.61	20.579	6898.9	71.484	3.65777359	1.03616519	3600	18.1272942	222.282558	108.5	32.22
6/6/2019	S-F5	0-5 cm	Core soil	2315.1	52.679	29285	186.64	2.27545246	0.63732286	1904	60.262053	762.28855	27.26	26.03
6/6/2019	S-F10	5-10 cm	Core soil	195.65	12.772	2778.6	48.774	6.52798364	1.75534442	1904	11.136398	158.157912	56.92	56.92
6/6/2019	S-F15	10-15 cm	Core soil	12.47	2.8312	226.68	11.035	22.7040898	4.86809599	2939	0.8049385	14.632194	67.5	64.55
6/6/2019	S-F30	15-30 cm	Core soil	8.6646	1.4652	74.32	3.6801	16.9101863	4.95169537	7707	0.65660339	5.6319696	178.45	75.78
6/6/2019	S-U3	Hydrangea	Plant	358.09	57.161	5389.3	206.39	15.9627468	3.82962537	3600	0.8737396	13.149892	1.49	2.44
6/6/2019	S-ML	Maple	Plant	451.85	28.372	5743	94.725	6.27907491	1.64939927	3600	3.578652	45.48456	8.28	7.92
6/6/2019	S-MSB	Maple	Plant	177.67	12.531	2072.2	41.808	7.05296336	2.01756587	3600	4.6034297	53.690702	82.68	25.91
6/6/2019	S-MS+B	Maple	Plant	65.326	6.9304	981.57	25.545	10.6089459	2.6024634	3600	2.2733448	34.158636	72.86	34.8
6/6/2019	S-HL	Hazelnut	Plant	350.25	25.746	4580.6	91.738	7.35074946	2.00275073	3600	2.837025	37.10286	8.53	8.1
6/6/2019	S-HSB	Hazelnut	Plant	136.55	11.653	1903	43.354	8.53387038	2.27819233	3600	3.3495715	46.68059	54.27	24.53
6/6/2019	S-HS+B	Hazelnut	Plant	99.381	7.7398	1385.6	28.538	7.78800777	2.05961316	3600	3.69498558	51.516608	56.01	37.18

Appendix A1.3 Yamakiya Site G-H Total Radiocesium Count

Yamakiya Sugi				Cs-134 (Bq/kg)		Cs-137 (Bq/kg)		err/Activity		Live time (s)	Radio-Cs in U8 (Bq)		D.W. (g)	Weight (g) in U8
Date	Label	Part	Type	Activity	Act. err	Activity	Act. err	Cs-134	Cs-137		Cs-134	Cs-137		
6/6/2019	S-L7	Litter	Litter	543.33	21.69	6723.6	75.008	3.99204903	1.11559284	3600	15.430572	190.95024	84.51	28.4
6/6/2019	S-G5	0-5 cm	Core soil	3515.1	48.804	46365	180.99	1.38841	0.39035911	3600	105.347547	1389.55905	29.97	29.97
6/6/2019	S-G10	5-10 cm	Core soil	98.459	9.333	1580.8	36.365	9.47907251	2.30041751	1899	5.13069849	82.375488	52.11	52.11
6/6/2019	S-G15	10-15 cm	Core soil	39.97	5.683	520.8	20.847	14.2181636	4.00288018	1893	1.9933039	25.972296	49.87	49.87
6/6/2019	S-G30	15-30 cm	Core soil	19.856	3.5906	326.02	14.654	18.083199	4.49481627	1888	1.64566528	27.0205376	153.64	82.88
6/6/2019	S-DGL	Dogwood	Plant	147.29	23.343	1925.8	75.58	15.8483264	3.92460276	3600	0.8866858	11.593316	9.15	6.02
6/6/2019	S-DGB	Dogwood	Plant	51.03	9.9112	582.75	25.995	19.4223006	4.46074646	3600	0.7057449	8.0594325	16.03	13.83
6/6/2019	S-L8	Litter	Litter	523.06	20.852	7117.1	75.762	3.98654074	1.06450661	3600	15.4355006	210.025621	56.21	29.51
6/6/2019	S-H5	0-5 cm	Core soil	3672.4	71.157	46193	250.49	1.93761573	0.54226831	1904	69.22474	870.73805	19.66	18.85
6/6/2019	S-H10	5-10 cm	Core soil	2734	56.44	34113	199.34	2.06437454	0.58435201	1903	66.62758	831.33381	25.83	24.37
6/6/2019	S-H15	10-15 cm	Core soil	607.3	23.741	7469.6	82.318	3.90927054	1.10204027	1907	25.032906	307.896912	41.99	41.22
6/6/2019	S-H30	15-30 cm	Core soil	45.166	5.6536	599.23	21.108	12.5173803	3.52252057	1896	3.23975718	42.9827679	110.47	71.73
6/6/2019	S-BG	Bamboo Grass	Plant	ND	ND	942.35	47.038	-	4.99156364	8400	0	2.563192	2.98	2.72

Appendix A2.1 Tsushima Sugi Site A-B Total Radiocesium Count

Tsushima Sugi				Cs-134 (Bq/kg)		Cs-137 (Bq/kg)		err/Activity		Live time (s)	Radio-Cs in U8 (Bq)		D.W. (g)	Weight (g) in U8
Date	Label	Part	Type	Activity	Act. err	Activity	Act. err	Cs-134	Cs-137		Cs-134	Cs-137		
6/11/2019	TS-L1	Litter	Litter	677.33	34.61	8696	123.79	5.10976924	1.42352806	1905	18.96524	243.488	121.75	28
6/11/2019	TS-A5	0-5 cm	Core soil	7133.5	132.99	92243	485.31	1.86430224	0.52612122	1904	98.228295	1270.18611	13.82	13.77
6/11/2019	TS-A10	5-10 cm	Core soil	1709.8	57.501	21269	203.22	3.36302492	0.9554751	1908	31.272242	389.01001	18.33	18.29
6/11/2019	TS-A15	10-15 cm	Core soil	304.95	15.302	4080.1	54.39	5.01787178	1.33305556	1908	18.699534	250.191732	62.22	61.32
6/11/2019	TS-A30	15-30 cm	Core soil	47.23	4.9405	603.94	17.564	10.4605124	2.90823592	1901	4.8330459	61.8011802	260.45	102.33
6/11/2019	TS-HS+B	Hazelnut	Plant	237.55	13.327	2955.4	46.725	5.61018733	1.58100426	3703	7.858154	97.764632	35.84	33.08
6/11/2019	TS-HSB	Hazelnut	Plant	293.07	13.892	4018.1	51.532	4.74016447	1.2824967	3702	10.7791146	147.785718	42.56	36.78
6/11/2019	TS-HL	Hazelnut	Plant	671.24	42.672	8576.1	152.93	6.35718968	1.78321148	3701	5.067862	64.749555	7.89	7.55
6/11/2019	TS-BG1	Bamboo Grass	Plant	616.06	56.254	7710.9	196.85	9.13125345	2.55287969	3693	1.6448802	20.588103	2.71	2.67
6/11/2019	TS-UB1	Unknown	Plant	764.76	32.072	8814.8	106.52	4.19373398	1.2084222	3697	9.1694724	105.689452	12.55	11.99
6/11/2019	TS-W1	Wisteria	Plant	1268	90.402	14942	297.79	7.12949527	1.99297283	3706	2.67548	31.52762	2.13	2.11
6/11/2019	TS-L2	Litter	Litter	1828.1	53.141	23254	191.51	2.90689787	0.82355724	1906	53.56333	681.3422	102.5	29.3
6/11/2019	TS-B5	0-5 cm	Core soil	11801	202.14	152990	736.74	1.71290569	0.48156089	1905	107.97915	1399.8585	9.24	9.15
6/11/2019	TS-B10	5-10 cm	Core soil	1251.6	37.399	16881	137.26	2.98809524	0.81310349	1906	40.814676	550.48941	33.11	32.61
6/11/2019	TS-B15	10-15 cm	Core soil	292.05	14.543	3932.3	52.689	4.97962678	1.33990286	1906	15.6918465	211.282479	54.12	53.73
6/11/2019	TS-B30	15-30 cm	Core soil	64.072	5.9408	945.61	22.936	9.27206892	2.42552426	1902	6.214984	91.72417	218.31	97
6/11/2019	TS-BG2	Bamboo Grass	Plant	297.04	32.907	3953.5	111.41	11.078306	2.81800936	3699	1.2297456	16.36749	4.83	4.14
6/11/2019	TS-UC1	Japanese Knotweed	Plant	191.91	18.19	2148.9	61.59	9.47840133	2.86611755	3686	1.4431632	16.159728	7.87	7.52
6/11/2019	TS-W2	Wisteria	Plant	404.24	17.666	5354.5	63.915	4.37017613	1.19366888	3704	12.1959208	161.545265	84.05	30.17

Appendix A2.2 Tsushima Sugi Site C-E Total Radiocesium Count

Tsushima Sugi				Cs-134 (Bq/kg)		Cs-137 (Bq/kg)		err/Activity		Live time (s)	Radio-Cs in U8 (Bq)		D.W. (g)	Weight (g) in U8
Date	Label	Part	Type	Activity	Act. err	Activity	Act. err	Cs-134	Cs-137		Cs-134	Cs-137		
6/11/2019	TS-L3	Litter	Litter	2012.2	58.111	26305	213.94	2.88793361	0.81330546	1907	53.12208	694.452	115.42	26.4
6/11/2019	TS-C5	0-5 cm	Core soil	12132	188.52	155240	683.55	1.55390702	0.44031822	1906	131.0256	1676.592	10.95	10.8
6/11/2019	TS-C10	5-10 cm	Core soil	1581.1	50.423	20824	185.41	3.18910885	0.89036688	1907	34.120138	449.38192	22.64	21.58
6/11/2019	TS-C15	10-15 cm	Core soil	251.42	15.338	3862.5	58.035	6.10054888	1.50252427	1906	12.3547788	189.80325	51.38	49.14
6/11/2019	TS-C30	15-30 cm	Core soil	71.105	6.1255	969.88	23.068	8.6147247	2.37843857	1904	7.70991515	105.164088	188.67	108.43
6/11/2019	TS-BG3	Bamboo Grass	Plant	315.15	19.821	4103.4	69.167	6.28938601	1.68560218	3701	4.8627645	63.315462	18.31	15.43
6/11/2019	TS-UBB2	Unknown	Plant	460.6	17.795	5828.3	62.761	3.86343899	1.07683201	3704	16.411178	207.662329	39.92	35.63
6/11/2019	TS-UBL2	Unknown	Plant	1209.4	48.199	16010	173.88	3.98536464	1.08607121	3702	12.964768	171.6272	11.26	10.72
6/11/2019	TS-W3	Wisteria	Plant	419.12	42.995	4760.1	138.28	10.2583985	2.90498099	3700	1.3369928	15.184719	3.29	3.19
6/11/2019	TS-ML+SB	Maple	Plant	759.43	27.248	9835.8	96.217	3.58795412	0.97823258	3700	14.3836042	186.290052	19.3	18.94
6/11/2019	TS-MB2	Maple	Plant	239.48	14.66	3308.6	53.244	6.12159679	1.60926071	3702	5.7331512	79.207884	24.93	23.94
6/11/2019	TS-L4	Litter	Litter	672.55	34.866	8870.7	125.99	5.18414988	1.42029378	1904	19.4165185	256.097109	170.21	28.87
6/11/2019	TS-D5	0-5 cm	Core soil	4780.9	75.357	61304	272.74	1.5762095	0.44489756	1907	131.522559	1686.47304	28.38	27.51
6/11/2019	TS-D10	5-10 cm	Core soil	949.03	28.225	12069	100.55	2.97408933	0.83312619	1907	41.7668103	531.15669	44.86	44.01
6/11/2019	TS-D15	10-15 cm	Core soil	65.63	6.7701	896.5	25.833	10.3155569	2.88153932	1901	5.2904343	72.266865	81.38	80.61
6/11/2019	TS-D30	15-30 cm	Core soil	6.0323	1.3587	86.297	4.2611	22.5237472	4.9377151	5268	0.67839246	9.70496062	291.01	112.46
6/11/2019	TS-M1	Maple	Plant	407.15	28.549	5486.5	104	7.01191207	1.89556183	3695	2.679047	36.10117	7.25	6.58
6/11/2019	TS-L5	Litter	Litter	351.36	23.703	4241.6	85.023	6.7460724	2.00450302	1901	10.1859264	122.963984	101.52	28.99
6/11/2019	TS-E5	0-5 cm	Core soil	3910.5	58.354	49501	210.63	1.49223884	0.42550656	1906	168.659865	2134.97813	44.39	43.13
6/11/2019	TS-E10	5-10 cm	Core soil	129.68	8.6502	1683.1	32.325	6.67041949	1.92056325	1905	9.6144752	124.785034	74.17	74.14
6/11/2019	TS-E15	10-15 cm	Core soil	11.717	2.0761	121.46	6.0048	17.7186993	4.94384983	4509	0.92482281	9.5868378	79.07	78.93
6/11/2019	TS-E30	15-30 cm	Core soil	3.9893	0.81465	52.486	2.6196	20.4208758	4.99104523	10000	0.33155072	4.36211146	190.68	83.11
6/11/2019	TS-F1	Fern	Plant	407.66	71.383	3758.5	186.26	17.5104254	4.95570041	5762	0.3546642	3.269895	1.15	0.87

Appendix A3 Tsushima Pine Total Radiocesium Count

Tsushima Pine				Cs-134 (Bq/kg)		Cs-137 (Bq/kg)		err/Activity		Live time (s)	Radio-Cs in U8 (Bq)		D.W. (g)	Weight (g) in U8
Date	**Label**	**Part**	**Type**	**Activity**	**Act. err**	**Activity**	**Act. err**	**Cs-134**	**Cs-137**		**Cs-134**	**Cs-137**		
6/11/2019	TP-L1	Litter	Litter	4337.4	82.899	56454	305.41	1.9112602	0.54098912	1905	120.623094	1569.98574	52.31	27.81
6/11/2019	TP-A5	0-5 cm	Core soil	7073.7	107.52	92188	390.93	1.51999661	0.42405736	1900	141.474	1843.76	20.24	20
6/11/2019	TP-A10	5-10 cm	Core soil	1584.2	50.401	19736	174.51	3.18147961	0.88422173	1904	26.266036	327.22288	17.1	16.58
6/11/2019	TP-A15	10-15 cm	Core soil	142.85	12.105	1793.4	44.039	8.4739237	2.45561503	1898	5.0526045	63.432558	35.84	35.37
6/11/2019	TP-A30	15-30 cm	Core soil	36.094	5.8065	400.83	19.235	16.0871613	4.79879251	1887	2.23891082	24.8634849	89.87	62.03
6/11/2019	TP-BG1	Bamboo Grass	Plant	220.2	31.518	2753	101.47	14.3133515	3.68579731	3678	0.805932	10.07598	3.86	3.66
6/11/2019	TP-H1	Hazelnut	Plant	799.51	46.033	10247	160.2	5.75765156	1.56338441	3697	4.1414618	53.07946	5.23	5.18
6/11/2019	TP-M1	Maple	Plant	251.04	19.989	3203.6	71.087	7.9624761	2.21897241	3694	2.0685696	26.397664	8.88	8.24
6/11/2019	TP-W1	Wisteria	Plant	506.95	33.505	6237	113.74	6.60913305	1.82363316	3696	3.7869165	46.59039	7.83	7.47
6/11/2019	TP-L2	Litter	Litter	2241.3	58.91	28257	213.11	2.62838531	0.7541848	1903	68.494128	863.53392	87	30.56
6/11/2019	TP-B5	0-5 cm	Core soil	8047.1	116.71	104460	427.3	1.45033615	0.4090561	1903	163.838956	2126.8056	20.64	20.36
6/11/2019	TP-B10	5-10 cm	Core soil	810.68	29.108	10607	104.39	3.59056594	0.9841614	1907	35.2321528	460.98022	44.51	43.46
6/11/2019	TP-B15	10-15 cm	Core soil	115.77	10.179	1455.6	37.103	8.79243327	2.54898324	1903	6.2481069	78.558732	53.98	53.97
6/11/2019	TP-B30	15-30 cm	Core soil	12.253	2.484	212.34	10.455	20.2725863	4.92370726	3437	0.78210899	13.5536622	146.54	63.83
6/11/2019	TP-BG2	Bamboo Grass	Plant	205.12	21.691	2500.7	76.636	10.5747855	3.06458192	3687	1.3907136	16.954746	7.26	6.78
6/11/2019	TP-H2	Hazelnut	Plant	485.83	22.323	6508.2	79.735	4.59481712	1.22514674	3702	10.153847	136.02138	21.07	20.9
6/11/2019	TP-M2	Maple	Plant	267.66	15.854	3562.9	58.192	5.92318613	1.63327626	3700	5.7734262	76.851753	22.83	21.57
6/11/2019	TP-W2	Wisteria	Plant	-	-	-	-	-	-	-	0	0	-	-
6/11/2019	TP-UB1	Unknown	Plant	3453.2	116.51	41447	390.95	3.37397197	0.94325283	3660	11.533688	138.43298	3.55	3.34
6/11/2019	TP-L3	Litter	Litter	1378.5	48.424	18323	176.08	3.51280377	0.96097801	1906	39.631875	526.78625	86.63	28.75
6/11/2019	TP-C5	0-5 cm	Core soil	7718.9	128.42	97070	453.74	1.66370856	0.46743587	1905	91.932099	1156.1037	11.91	11.91
6/11/2019	TP-C10	5-10 cm	Core soil	1921.8	44.126	25711	163.53	2.29607659	0.63603127	1908	67.243782	899.62789	34.99	34.99
6/11/2019	TP-C15	10-15 cm	Core soil	111.86	11.056	1500.1	40.509	9.8837833	2.70041997	1897	5.0829184	68.164544	45.54	45.44
6/11/2019	TP-C30	15-30 cm	Core soil	12.803	2.5529	175.18	8.642	19.9398578	4.93321155	4270	0.74654293	10.2147458	136.55	58.31
6/11/2019	TP-BG3	Bamboo Grass	Plant	306.12	32.185	3647.3	107.03	10.5138508	2.93449949	3695	1.4724372	17.543513	5.15	4.81
6/11/2019	TP-M3	Maple	Plant	223.11	20.606	2888.1	69.92	9.23580297	2.4209688	3701	1.6911738	21.891798	7.9	7.58
6/11/2019	TP-W3	Wisteria	Plant	405.56	45.009	6491	168.49	11.097988	2.59574796	3700	1.1842352	18.95372	3.1	2.92
6/11/2019	TP-U1	Hydrangea	Plant	ND	ND	8515.5	423.6	-	4.97445834	7288	0	2.469495	0.42	0.29
6/11/2019	TP-UB2	Unknown	Plant	901.84	40.95	11688	139.24	4.54071676	1.19130732	3660	6.718708	87.0756	7.85	7.45

Appendix A4 Tomioka Total Radiocesium Count

Tomioka				Cs-134 (Bq/kg)		Cs-137 (Bq/kg)		err/Activity		Live time (s)	Radio-Cs in U8 (Bq)		D.W. (g)	Weight (g) in U8
Date	Label	Part	Type	Activity	Act. err	Activity	Act. err	Cs-134	Cs-137		Cs-134	Cs-137		
6/12/2019	TO-L1	Litter	Litter	788.41	34.962	10582	126.48	4.43449474	1.1952372	1907	25.8835003	347.40706	56.85	32.83
6/12/2019	TO-A5	0-5 cm	Core soil	1162.1	27.468	15711	101.82	2.36365201	0.64808096	1902	66.541846	899.61186	57.9	57.26
6/12/2019	TO-A10	5-10 cm	Core soil	287.93	13.676	3962.6	50.028	4.74976557	1.26250442	1908	22.804056	313.83792	79.35	79.2
6/12/2019	TO-A15	10-15 cm	Core soil	20.257	3.3933	351.87	14.684	16.7512465	4.17313212	1892	1.73825317	30.1939647	87.44	85.81
6/12/2019	TO-A30	15-30 cm	Core soil	9.4487	1.6681	111.66	5.5172	17.6542805	4.94107111	3881	1.08461627	12.8174514	221.08	114.79
6/12/2019	TO-PO1	Japanese Lacquer	Plant	93.021	12.709	1151.1	41.192	13.6625063	3.57849014	3683	1.03532373	12.811743	11.65	11.13
6/12/2019	TO-F1	Fern	Plant	336.34	23.421	4295.9	83.201	6.96348933	1.93675365	3694	3.2389542	41.369517	10.14	9.63
6/12/2019	TO-L2	Litter	Litter	775.81	34.157	10158	123.55	4.40275325	1.21628273	1907	25.4776004	333.58872	125.94	32.84
6/12/2019	TO-B5	0-5 cm	Core soil	1749.3	35.802	23869	132.76	2.04664723	0.55620261	1905	88.33965	1205.3845	50.67	50.5
6/12/2019	TO-B10	5-10 cm	Core soil	122.33	8.2221	1685.4	31.795	6.72124581	1.88649579	1902	9.7142253	133.837614	81.05	79.41
6/12/2019	TO-B15	10-15 cm	Core soil	20.01	3.6248	242.98	11.654	18.1149425	4.79627953	1890	1.8461226	22.4173348	92.38	92.26
6/12/2019	TO-B30	15-30 cm	Core soil	ND	ND	30.732	1.8256	-	5.94038787	10000	0	3.72502572	272.96	121.21
6/12/2019	TO-PO2	Japanese Lacquer	Plant	231.96	20.307	2756.4	71.781	8.75452664	2.6041576	3687	1.9971756	23.732604	8.95	8.61
6/12/2019	TO-F2	Fern	Plant	259.69	26.12	3045.6	89.244	10.0581463	2.93026005	3686	1.8723649	21.958776	7.77	7.21
6/12/2019	TO-L3	Litter	Litter	612.55	31.416	7349.2	108.84	5.12872419	1.48097752	1906	18.7869085	225.399964	85.71	30.67
6/12/2019	TO-C5	0-5 cm	Core soil	618.59	21.434	8317	77.65	3.4649768	0.93362991	1902	36.8865217	495.94271	59.63	59.63
6/12/2019	TO-C10	5-10 cm	Core soil	41.064	4.9186	604.62	19.669	11.9778882	3.25311766	1897	3.55449984	52.3359072	86.56	86.56
6/12/2019	TO-C15	10-15 cm	Core soil	13.938	2.9259	229.33	11.157	20.9922514	4.86504164	2051	1.31964984	21.7129644	94.74	94.68
6/12/2019	TO-C30	15-30 cm	Core soil	ND	ND	68.28	3.3923	-	4.9682191	6489	0	7.2998148	255.93	106.91
6/12/2019	TO-PO3	Japanese Lacquer	Plant	127.24	12.555	1659.1	44.317	9.86718013	2.67114701	3692	2.0078472	26.180598	16.04	15.78
6/12/2019	TO-F3	Fern	Plant	175.44	21.14	2500.4	76.628	12.0497036	3.06462966	3685	1.3965024	19.903184	8.36	7.96

Appendix A5 Okuma Total Radiocesium Count

Okuma				Cs-134 (Bq/kg)		Cs-137 (Bq/kg)		err/Activity		Live time (s)	Radio-Cs in U8 (Bq)		D.W. (g)	Weight (g) in U8
Date	Label	Part	Type	Activity	Act. err	Activity	Act. err	Cs-134	Cs-137		Cs-134	Cs-137		
6/13/2019	O-L1	Litter	Litter	369.37	65.161	5599.7	80.464	17.6411187	1.43693412	3704	7.3837063	111.938003	187.01	19.99
6/13/2019	O-A5	0-5 cm	Core soil	3343.3	40.45	45211	151.49	1.20988245	0.33507332	1898	356.228615	4817.23205	118.55	106.55
6/13/2019	O-A10	5-10 cm	Core soil	487.14	15.788	6582.2	57.905	3.24095742	0.87972107	1904	48.6311862	657.101026	102.15	99.83
6/13/2019	O-A15	10-15 cm	Core soil	41.702	5.6032	689.71	20.16	13.436286	2.92296762	1898	3.87286474	64.0533677	107.28	92.87
6/13/2019	O-A30	15-30 cm	Core soil	6.373	1.2098	90.925	4.5201	18.9832104	4.97124003	5050	0.63583421	9.07158725	326.7	99.77
6/13/2019	O-BG1	Bamboo Grass	Plant	88.555	17.622	1142.2	48.539	19.8994975	4.24960602	3673	0.6039451	7.789804	7.11	6.82
6/13/2019	O-L2	Litter	Litter	2616.2	55.345	35562	207.79	2.11547282	0.58430347	3704	48.92294	665.0094	29.64	18.7
6/13/2019	O-B5	0-5 cm	Core soil	12689	84.129	168030	311.31	0.66300733	0.18527049	1882	917.92226	12155.2902	89.25	72.34
6/13/2019	O-B10	5-10 cm	Core soil	1156.5	24.357	15095	88.776	2.10609598	0.58811527	1903	99.11205	1293.6415	94.48	85.7
6/13/2019	O-B15	10-15 cm	Core soil	115.75	7.7491	1585.9	28.309	6.69468683	1.78504319	1903	11.8747925	162.697481	105.86	102.59
6/13/2019	O-B30	15-30 cm	Core soil	215.95	10.841	3196.4	41.297	5.02014355	1.29198473	1903	23.2815695	344.603884	153.25	107.81
6/13/2019	O-BG2	Bamboo Grass	Plant	247.61	19.356	3201.1	70.275	7.81713178	2.1953391	3696	2.4810522	32.075022	10.35	10.02
6/13/2019	O-L3	Litter	Litter	1524.2	39.31	21350	148.72	2.57905787	0.6965808	3703	33.440948	468.419	201.83	21.94
6/13/2019	O-C5	0-5 cm	Core soil	13130	92.294	173110	340.82	0.7029246	0.1968806	1889	743.2893	9799.7571	58.09	56.61
6/13/2019	O-C10	5-10 cm	Core soil	1887.5	35.197	25625	132.87	1.86474172	0.51851707	1904	133.937	1818.35	75.74	70.96
6/13/2019	O-C15	10-15 cm	Core soil	75.379	6.4164	1019.8	24.085	8.51218509	2.3617376	1902	6.77129557	91.608634	97.52	89.83
6/13/2019	O-C30	15-30 cm	Core soil	10.257	1.8033	127.74	6.35	17.5811641	4.97103491	3104	1.21945473	15.1870086	215.08	118.89
6/13/2019	O-BG3	Bamboo Grass	Plant	204.37	18.627	2076.8	62.171	9.11435142	2.99359592	3685	2.1417976	21.764864	10.95	10.48

Appendix A6 Yokomuki Total Radiocesium Count

Yokomuki				Cs-134 (Bq/kg)		Cs-137 (Bq/kg)		err/Activity		Live time (s)	Radio-Cs in U8 (Bq)		D.W. (g)	Weight (g) in U8
Date	Label	Part	Type	Activity	Act. err	Activity	Act. err	Cs-134	Cs-137		Cs-134	Cs-137		
6/19/2019	C-M	Moss	Plant	45.307	2.8886	565.97	8.5557	6.37561525	1.5116879	82871	0.20931834	2.6147814	5.09	4.62
6/19/2019	C-A5	0-5 cm	Core soil	33.831	2.1702	492.26	6.8441	6.41482664	1.3903425	20000	1.01391507	14.7530322	30.82	29.97
6/19/2019	C-A10	5-10 cm	Core soil	ND	ND	23.824	1.3022	-	5.46591672	30000	0	0.8826792	38.02	37.05
6/19/2019	C-A15	10-15 cm	Core soil	ND	ND	9.6205	0.60402	-	6.27846786	70000	0	0.36817654	38.78	38.27
6/19/2019	C-A30	15-30 cm	Core soil	ND	ND	4.2057	0.13149	-	3.12647122	362483	0	0.32632026	151.22	77.59
6/19/2019	C-F1	Fern	Plant	37.107	5.8104	396.22	13.118	15.6585011	3.31078694	20628	0.18998784	2.0286464	5.36	5.12
6/19/2019	C-M1	Maple	Plant	7.9765	1.8538	59.674	2.1389	23.2407698	3.58430807	86489	0.05814869	0.43502346	7.58	7.29
6/19/2019	C-BG1	Bamboo Grass	Plant	ND	ND	69.153	2.998	-	4.33531445	86748	0	0.48337947	7.42	6.99
6/19/2019	C-L1	Litter	Litter	11.515	2.6063	164.23	7.0354	22.6339557	4.28387018	10000	0.3551226	5.0648532	82.15	30.84
6/19/2019	C-B5	0-5 cm	Core soil	135.09	8.4801	1556.8	24.671	6.27737064	1.58472508	20000	0.8091891	9.325232	6.28	5.99
6/19/2019	C-B10	5-10 cm	Core soil	174.96	10.042	2233.8	31.738	5.73959762	1.42080759	14660	1.22472	15.6366	7.82	7
6/19/2019	C-B15	10-15 cm	Core soil	70.648	1.6923	997.33	5.7359	2.3953969	0.57512559	100000	1.18971232	16.7950372	18.56	16.84
6/19/2019	C-B30	15-30 cm	Core soil	8.5627	0.51976	143.84	1.6498	6.070048	1.14696885	86149	0.60170093	10.1076368	124.82	70.27
6/19/2019	C-F2	Fern	Plant	21.856	3.6515	311.71	6.3808	16.7070827	2.04703089	65901	0.1158368	1.652063	5.68	5.3
6/19/2019	C-M2	Maple	Plant	10.772	1.6162	90.275	2.853	15.0037133	3.1603434	100000	0.06807904	0.570538	6.61	6.32
6/19/2019	C-U1	Hydrangea	Plant	ND	ND	31.556	4.9172	-	15.5824566	610542	0	0.0520674	1.81	1.65
6/19/2019	C-BG2	Bamboo Grass	Plant	16.974	2.3605	211.5	5.6987	13.906563	2.6944208	100000	0.07112106	0.886185	4.59	4.19
6/19/2019	C-UB1	Unknown	Plant	13.573	2.2588	121.84	3.0008	16.6418625	2.46290217	274792	0.03352531	0.3009448	2.68	2.47
6/19/2019	C-C5	0-5 cm	Core soil	55.217	2.3561	803.92	8.3825	4.26698299	1.04270325	20000	2.35666156	34.3113056	47.6	42.68
6/19/2019	C-C10	5-10 cm	Core soil	3.9844	0.69171	69.836	1.9158	17.3604558	2.74328427	30000	0.21699042	3.80326856	58.07	54.46
6/19/2019	C-C15	10-15 cm	Core soil	2.1708	0.35395	33.414	0.69134	16.3050488	2.06901299	100000	0.15733958	2.42184672	97.31	72.48
6/19/2019	C-C30	15-30 cm	Core soil	7.5548	0.67188	98.424	1.9098	8.89341875	1.9403804	30000	0.70320078	9.16130592	202.14	93.08
6/19/2019	C-F3	Fern	Plant	ND	ND	106.79	7.6229	-	7.13821519	363009	0	0.0608703	0.64	0.57
6/19/2019	C-M3	Maple	Plant	7.5545	1.7306	97.962	4.6034	22.9082004	4.69916907	22154	0.11769911	1.52624796	16.21	15.58
6/19/2019	C-U2	Hydrangea	Plant	ND	ND	40.16	2.03	-	5.05478088	429075	0	0.0855408	2.28	2.13
6/19/2019	C-BG3	Bamboo Grass	Plant	6.4586	1.0586	64.301	2.0937	16.390549	3.25609244	66514	0.09468308	0.94265266	15.3	14.66

Appendix B

Soil Exchangeable Radiocesium Count

Appendix B1.1 Yamakiya Site A-D Exchangeable Radiocesium Count

Yamakiya				Cs-134 (Bq/kg)		Cs-137 (Bq/kg)		err/Activity		Live time (s)	Radio-Cs in U8 (Bq)		Soil Weight (g)	MH4Ac Added (ml)	Weight in U8 (g)
Date	Label	Part	Type	Activity	Act. err	Activity	Act. err	Cs-134	Cs-137		Cs-134	Cs-137			
6/6/2019	S-A5	0-5 cm	Core soil	8.3384	1.3957	113.7	3.5579	16.7382232	3.12919965	50073	0.07379484	1.006245	2.98	10	8.85
6/6/2019	S-A10	5-10 cm	Core soil	ND	ND	10.517	0.94884	-	9.02196444	69710	-	0.09633572	3	12	9.16
6/6/2019	S-A15	10-15 cm	Core soil	ND	ND	2.1931	0.21689	-	9.88965391	538632	-	0.02024231	3.01	12.5	9.23
6/6/2019	S-A30	15-30 cm	Core soil	-	-	-	-	-	-		-	-	3.04	12.5	6.97
6/6/2019	S-B5	0-5 cm	Core soil	9.4075	1.4915	110.65	3.2808	15.8543715	2.96502485	50101	0.0955802	1.124204	3.15	12	10.16
6/6/2019	S-B10	5-10 cm	Core soil	ND	ND	7.8192	0.7756	-	9.91917332	100000	-	0.07092014	2.94	13	9.07
6/6/2019	S-B15	10-15 cm	Core soil	ND	ND	1.3206	0.20621	-	15.614872	772310	-	0.01291547	3.03	12	9.78
6/6/2019	S-B30	15-30 cm	Core soil	-	-	-	-	-	-		-	-	3.17	12.5	10.26
6/6/2019	S-C5	0-5 cm	Core soil	11.951	1.8687	146.23	4.8015	15.6363484	3.28352595	39559	0.09154466	1.1201218	2.89	11	7.66
6/6/2019	S-C10	5-10 cm	Core soil	ND	ND	14.921	1.4782	-	9.9068427	54096	-	0.14383844	3.15	12	9.64
6/6/2019	S-C15	10-15 cm	Core soil	ND	ND	1.9452	0.27796	-	14.2895332	700000	-	0.01943255	3.2	12.5	9.99
6/6/2019	S-C30	15-30 cm	Core soil	-	-	-	-	-	-		-	-	3.03	13	10.51
6/6/2019	S-D5	0-5 cm	Core soil	30.12	2.0305	439.92	6.8745	6.74136786	1.56267049	30066	0.4704744	6.8715504	3.1	20	15.62
6/6/2019	S-D10	5-10 cm	Core soil	34.672	2.722	375.6	6.6577	7.85071527	1.77255059	50088	0.27494896	2.978508	3	11.5	7.93
6/6/2019	S-D15	10-15 cm	Core soil	2.3609	0.76076	23.017	1.242	32.2233047	5.39601164	86797	0.02242855	0.2186615	3.01	11.5	9.5
6/6/2019	S-D30	15-30 cm	Core soil	-	-	-	-	-	-		-	-	3.08	12	8.56

Appendix B1.2 Yamakiya Site E-H Exchangeable Radiocesium Count

Yamakiya				Cs-134 (Bq/kg)		Cs-137 (Bq/kg)		err/Activity		Live time (s)	Radio-Cs in U8 (Bq)		Soil Weight (g)	MH4Ac Added (ml)	Weight in U8 (g)
Date	Label	Part	Type	Activity	Act. err	Activity	Act. err	Cs-134	Cs-137		Cs-134	Cs-137			
6/6/2019	S-E5	0-5 cm	Core soil	20.038	2.2895	315.52	7.7627	11.425791	2.46028778	30105	0.16691654	2.6282816	3.11	12.5	8.33
6/6/2019	S-E10	5-10 cm	Core soil	ND	ND	15.052	1.5009	-	9.97143237	85074	-	0.1648194	3.07	13.5	10.95
6/6/2019	S-E15	10-15 cm	Core soil	ND	ND	3.375	0.33749	-	9.9997037	700000	-	0.030375	2.96	11.5	9
6/6/2019	S-E30	15-30 cm	Core soil	-	-	-	-	-	-		-	-	2.98	12.5	7.09
6/6/2019	S-F5	0-5 cm	Core soil	18.875	2.4365	252.57	7.2263	12.9086093	2.86110781	30097	0.14439375	1.9321605	2.93	10	7.65
6/6/2019	S-F10	5-10 cm	Core soil	ND	ND	26.592	2.3007	-	8.65185018	50080	-	0.2579424	3.01	13	9.7
6/6/2019	S-F15	10-15 cm	Core soil	ND	ND	2.3284	0.22732	-	9.76292733	533491	-	0.02337714	3.05	12.5	10.04
6/6/2019	S-F30	15-30 cm	Core soil	-	-	-	-	-	-		-	-	3.09	13	11.31
6/6/2019	S-G5	0-5 cm	Core soil	16.875	3.5087	233.18	6.9261	20.7922963	2.97028047	30090	0.13584375	1.877099	3.06	10	8.05
6/6/2019	S-G10	5-10 cm	Core soil	ND	ND	12.645	1.2476	-	9.86635034	100000	-	0.12253005	3.12	12	9.69
6/6/2019	S-G15	10-15 cm	Core soil	ND	ND	3.692	0.30932	-	8.37811484	347676	-	0.03776916	3.13	12	10.23
6/6/2019	S-G30	15-30 cm	Core soil	-	-	-	-	-	-		-	-	2.97	13	10.42
6/6/2019	S-H5	0-5 cm	Core soil	ND	ND	148.19	5.6775	-	3.83123018	30078	-	1.1751467	2.92	10.5	7.93
6/6/2019	S-H10	5-10 cm	Core soil	16.298	2.2618	161.02	4.6524	13.8777764	2.88933052	50108	0.13266572	1.3107028	3.17	10.5	8.14
6/6/2019	S-H15	10-15 cm	Core soil	3.7718	0.93545	35.987	1.2641	24.8011559	3.51265735	88086	0.03971705	0.37894311	3.19	12	10.53
6/6/2019	S-H30	15-30 cm	Core soil	-	-	-	-	-	-		-	-	3.15	12	9.8

Appendix B2 Tsushima Sugi Exchangeable Radiocesium Count

Tsushima Sugi				Cs-134 (Bq/kg)		Cs-137 (Bq/kg)		err/Activity		Live time (s)	Radio-Cs in U8 (Bq)		Soil Weight (g)	MH4Ac Added (ml)	Weight in U8 (g)
Date	Label	Part	Type	Activity	Act. err	Activity	Act. err	Cs-134	Cs-137		Cs-134	Cs-137			
6/11/2019	TS-A5	0-5 cm	Core soil	52.81	2.5356	805.91	9.2612	4.80136338	1.14916058	30071	0.8159145	12.4513095	3.18	20	15.45
6/11/2019	TS-A10	5-10 cm	Core soil	20.174	1.7996	235.55	4.3012	8.92039258	1.8260242	50088	0.25479762	2.9749965	3.1	20	12.63
6/11/2019	TS-A15	10-15 cm	Core soil	4.8402	1.4972	75.755	2.3038	30.9326061	3.0411194	82444	0.05135452	0.80376055	3.09	11	10.61
6/11/2019	TS-A30	15-30 cm	Core soil	-	-	-	-	-	-		-	-	3.08	12.5	12.97
6/11/2019	TS-B5	0-5 cm	Core soil	72.706	2.7376	1115.5	10.3	3.76530135	0.92335276	30077	1.28035266	19.643955	3.17	30	17.61
6/11/2019	TS-B10	5-10 cm	Core soil	18.998	1.8255	264.97	5.0881	9.6089062	1.92025512	50093	0.18998	2.6497	3.03	13	10
6/11/2019	TS-B15	10-15 cm	Core soil	11.414	0.97623	138.02	2.4267	8.55291747	1.75822345	68448	0.1318317	1.594131	3.06	12.5	11.55
6/11/2019	TS-B30	15-30 cm	Core soil	-	-	-	-	-	-		-	-	2.98	12.5	9.77
6/11/2019	TS-C5	0-5 cm	Core soil	39.38	2.4405	698.76	9.128	6.19730828	1.30631404	30069	0.5402936	9.5869872	2.96	30	13.72
6/11/2019	TS-C10	5-10 cm	Core soil	11.001	1.9654	105.38	3.8736	17.8656486	3.67583982	30074	0.14224293	1.3625634	3	13	12.93
6/11/2019	TS-C15	10-15 cm	Core soil	7.8662	3.3425	45.298	4.0342	42.4919275	8.90591196	7353	0.11382391	0.65546206	3.18	13	14.47
6/11/2019	TS-C30	15-30 cm	Core soil	-	-	-	-	-	-		-	-	3.03	12.5	9.72
6/11/2019	TS-D5	0-5 cm	Core soil	39.694	2.9996	606.76	10.331	7.55680959	1.70265014	30068	0.3473225	5.30915	3.04	13	8.75
6/11/2019	TS-D10	5-10 cm	Core soil	ND	ND	187.98	6.009	-	3.19661666	30079	-	1.654224	2.92	11	8.8
6/11/2019	TS-D15	10-15 cm	Core soil	6.9971	2.213	23.529	2.2761	31.6273885	9.67359429	19279	0.0704608	0.23693703	2.99	13	10.07
6/11/2019	TS-D30	15-30 cm	Core soil	-	-	-	-	-	-		-	-	2.94	13.5	13.02
6/11/2019	TS-E5	0-5 cm	Core soil	37.107	2.5077	560.04	8.705	6.75802409	1.55435326	30065	0.43971795	6.636474	3.09	15	11.85
6/11/2019	TS-E10	5-10 cm	Core soil	ND	ND	36.95	2.9451	-	7.97050068	30084	-	0.3927785	3.03	12.5	10.63
6/11/2019	TS-E15	10-15 cm	Core soil	1.318	0.60406	4.4295	0.35905	45.831563	8.10588102	582571	0.0086329	0.02901323	2.96	13.5	6.55
6/11/2019	TS-E30	15-30 cm	Core soil	-	-	-	-	-	-		-	-	3.19	12.5	8.69

Appendix B3 Tsushima Pine Exchangeable Radiocesium Count

Tsushima Pine				Cs-134 (Bq/kg)		Cs-137 (Bq/kg)		err/Activity		Live time (s)	Radio-Cs in U8 (Bq)		Soil Weight (g)	MH4Ac Added (ml)	Weight in U8 (g)
Date	Label	Part	Type	Activity	Act. err	Activity	Act. err	Cs-134	Cs-137		Cs-134	Cs-137			
6/11/2019	TP-A5	0-5 cm	Core soil	12.264	1.4989	187.29	4.2705	12.2219504	2.28015377	50087	0.1244796	1.9009935	3.07	15	10.15
6/11/2019	TP-A10	5-10 cm	Core soil	7.47	1.0086	93.372	2.31	13.502008	2.47397507	69771	0.0640926	0.80113176	2.99	10	8.58
6/11/2019	TP-A15	10-15 cm	Core soil	ND	ND	15.491	1.4539	-	9.38544962	50093	-	0.15971221	3.02	12.5	10.31
6/11/2019	TP-A30	15-30 cm	Core soil	-	-	-	-	-	-		-	-	3.11	12.5	9.87
6/11/2019	TP-B5	0-5 cm	Core soil	15.653	1.4119	250.95	4.7541	9.01999617	1.89444112	50084	0.16811322	2.695203	2.94	15	10.74
6/11/2019	TP-B10	5-10 cm	Core soil	5.8594	1.7539	64.168	3.315	29.933099	5.16612642	50113	0.04505879	0.49345192	2.9	10	7.69
6/11/2019	TP-B15	10-15 cm	Core soil	ND	ND	17.926	1.0721	-	5.98069843	78664	-	0.21762164	2.93	12.5	12.14
6/11/2019	TP-B30	15-30 cm	Core soil	-	-	-	-	-	-		-	-	3.18	11.5	8.71
6/11/2019	TP-C5	0-5 cm	Core soil	22.193	1.7817	319.19	5.9838	8.02820709	1.87468279	50089	0.199737	2.87271	3.05	15	9
6/11/2019	TP-C10	5-10 cm	Core soil	ND	ND	56.345	3.7432	-	6.64335788	25117	-	0.50992225	3.05	10	9.05
6/11/2019	TP-C15	10-15 cm	Core soil	ND	ND	24.419	1.7255	-	7.06621893	50070	-	0.26055073	2.94	13.5	10.67
6/11/2019	TP-C30	15-30 cm	Core soil	-	-	-	-	-	-		-	-	3	13	9.83

Appendix B4 Tomioka Exchangeable Radiocesium Count

Tomioka				Cs-134 (Bq/kg)		Cs-137 (Bq/kg)		err/Activity		Live time (s)	Radio-Cs in U8 (Bq)		Soil Weight (g)	MH4Ac Added (ml)	Weight in U8 (g)
Date	Label	Part	Type	Activity	Act. err	Activity	Act. err	Cs-134	Cs-137		Cs-134	Cs-137			
6/12/2019	TO-A5	0-5 cm	Core soil	ND	ND	59.959	3.1589	-	5.26843343	30087	-	0.70331907	2.91	13	11.73
6/12/2019	TO-A10	5-10 cm	Core soil	2.105	0.48923	19.831	0.93197	23.2413302	4.69956129	89414	0.0259757	0.24471454	2.98	13.5	12.34
6/12/2019	TO-A15	10-15 cm	Core soil	ND	ND	1.6659	0.1624	-	9.7484843	690803	-	0.02152343	2.98	13.5	12.92
6/12/2019	TO-A30	15-30 cm	Core soil	-	-	-	-	-	-		-	-	3.08	13	11.57
6/12/2019	TO-B5	0-5 cm	Core soil	ND	ND	97.246	4.2335	-	4.35339243	30069	-	0.94912096	3.1	11.5	9.76
6/12/2019	TO-B10	5-10 cm	Core soil	ND	ND	9.1492	0.40072	-	4.37983649	277129	-	0.11079681	3.17	13	12.11
6/12/2019	TO-B15	10-15 cm	Core soil	ND	ND	1.2483	0.16722	-	13.3958183	750000	-	0.01541651	3	13	12.35
6/12/2019	TO-B30	15-30 cm	Core soil	-	-	-	-	-	-		-	-	3.11	13	13.03
6/12/2019	TO-C5	0-5 cm	Core soil	ND	ND	31.023	2.4066	-	7.75747026	30097	-	0.34001208	2.98	11.5	10.96
6/12/2019	TO-C10	5-10 cm	Core soil	ND	ND	3.3403	0.29617	-	8.86656887	334694	-	0.03881429	3.03	13	11.62
6/12/2019	TO-C15	10-15 cm	Core soil	ND	ND	2.1797	0.24199	-	11.1019865	750000	-	0.01852745	3.11	13	8.5
6/12/2019	TO-C30	15-30 cm	Core soil	-	-	-	-	-	-		-	-	3	13.5	13.47

Appendix B5 Okuma Exchangeable Radiocesium Count

Okuma				Cs-134 (Bq/kg)		Cs-137 (Bq/kg)		err/Activity		Live time (s)	Radio-Cs in U8 (Bq)		Soil Weight (g)	MH4Ac Added (ml)	Weight in U8 (g)
Date	Label	Part	Type	Activity	Act. err	Activity	Act. err	Cs-134	Cs-137		Cs-134	Cs-137			
6/13/2019	O-A5	0-5 cm	Core soil	30.866	3.8829	477.11	14.79	12.5798613	3.09991407	8726	0.38767696	5.9925016	3.19	13	12.56
6/13/2019	O-A10	5-10 cm	Core soil	8.9953	2.1445	115.3	3.1245	23.8402277	2.70988725	50057	0.11630923	1.490829	3.13	13	12.93
6/13/2019	O-A15	10-15 cm	Core soil	ND	ND	14.561	0.91217	-	6.26447359	89209	-	0.14298902	3.05	13	9.82
6/13/2019	O-A30	15-30 cm	Core soil	-	-	-	-	-	-		-	-	3.03	13	11.57
6/13/2019	O-B5	0-5 cm	Core soil	68.071	3.1763	1066.6	12.124	4.66615739	1.13669604	30075	0.77056372	12.073912	2.89	13.5	11.32
6/13/2019	O-B10	5-10 cm	Core soil	8.9331	1.4602	91.527	2.85	16.3459493	3.11383526	50101	0.11407569	1.16879979	3.06	13.5	12.77
6/13/2019	O-B15	10-15 cm	Core soil	ND	ND	13.873	0.82625	-	5.95581345	86752	-	0.15995569	3.11	13	11.53
6/13/2019	O-B30	15-30 cm	Core soil	-	-	-	-	-	-		-	-	2.98	12.5	9.5
6/13/2019	O-C5	0-5 cm	Core soil	52.209	1.4172	655.29	4.2818	2.71447452	0.65342062	85000	0.67610655	8.4860055	2.9	13.5	12.95
6/13/2019	O-C10	5-10 cm	Core soil	9.6248	1.5008	117.84	3.153	15.5930513	2.67566191	50061	0.12310119	1.5071736	2.95	13.5	12.79
6/13/2019	O-C15	10-15 cm	Core soil	ND	ND	12.829	0.75182	-	5.86031647	83278	-	0.17665533	3.19	13	13.77
6/13/2019	O-C30	15-30 cm	Core soil	-	-	-	-	-	-		-	-	3.12	13	12.38

Appendix B6 Yokomuki Exchangeable Radiocesium Count

Okuma				Cs-134 (Bq/kg)		Cs-137 (Bq/kg)		err/Activity		Live time (s)	Radio-Cs in U8 (Bq)		Soil Weight (g)	MH4Ac Added (ml)	Weight in U8 (g)
Date	Label	Part	Type	Activity	Act. err	Activity	Act. err	Cs-134	Cs-137		Cs-134	Cs-137			
6/19/2019	C-A5	0-5 cm	Core soil	ND	ND	3.6202	0.37651	-	10.4002541	354860	-	0.03091651	2.96	11	8.54
6/19/2019	C-A10	5-10 cm	Core soil	ND	ND	1.0041	0.19975	-	19.8934369	779329	-	0.0102619	2.95	12	10.22
6/19/2019	C-A15	10-15 cm	Core soil	ND	ND	ND	ND	-	-	749322	-	-	3.16	12.5	11.25
6/19/2019	C-A30	15-30 cm	Core soil	-	-	-	-	-	-		-	-	3.02	13	9.11
6/19/2019	C-B5	0-5 cm	Core soil	ND	ND	20.597	1.1691	-	5.67606933	87826	-	0.27023264	2.95	19	13.12
6/19/2019	C-B10	5-10 cm	Core soil	ND	ND	7.0428	0.27589	-	3.91733401	662877	-	0.06592061	2.93	18.5	9.36
6/19/2019	C-B15	10-15 cm	Core soil	17.203	0.56708	211.72	1.177	3.29640179	0.55592292	661898	0.24514275	3.01701	3.07	15.5	14.25
6/19/2019	C-B30	15-30 cm	Core soil	-	-	-	-	-	-		-	-	3.13	11	7.55
6/19/2019	C-C5	0-5 cm	Core soil	ND	ND	4.5075	0.41037	-	9.10415973	266813	-	0.05760585	3.17	10	12.78
6/19/2019	C-C10	5-10 cm	Core soil	ND	ND	2.1802	0.29215	-	13.4001468	747871	-	0.026206	3.07	13	12.02
6/19/2019	C-C15	10-15 cm	Core soil	ND	ND	1.5024	0.26403	-	17.5738818	749695	-	0.02050776	3.02	13	13.65
6/19/2019	C-C30	15-30 cm	Core soil	-	-	-	-	-	-		-	-	3.07	13	10.05

Appendix C
Plant Exchangeable [K] & [Cs]

Appendix C1 Yamakiya Plant Exchangeable [K] & [Cs]

Plant Sample	Concentration	
	Cs-133 [ppb]	K [ppm]
S-BG	0.021	318
S-DGL	0.009	318
S-DGB	0.003	25
S-F1	0.087	375
S-F2	0.028	352
S-F3	0.030	476
S-GB1	0.019	512
S-GB2	0.011	215
S-GB3	0.013	330
S-HL	0.006	268
S-HS+B	0.001	13
S-HSB	0.002	51
S-M1	0.014	133
S-M2	0.007	227
S-ML	0.007	119
S-MS+B	0.000	15
S-MSB	0.002	59
S-UA1	0.007	495
S-UA2	0.039	498
S-UA3	0.006	328
S-W1	0.005	219
S-W2	0.005	167
S-W3	0.006	216

Appendix C2 Tsushima Sugi Plant Exchangeable [K] & [Cs]

Plant Sample	Concentration	
	Cs-133 [ppb]	**K [ppm]**
TS-BG1	0.001	114
TS-BG2	0.002	138
TS-BG3	0.002	136
TS-F1	0.002	400
TS-HL	0.002	165
TS-HS+B	0.001	28
TS-HSB	0.002	67
TS-M1	0.002	151
TS-MB2	0.001	35
TS-ML+SB	0.002	171
TS-UB1	0.001	144
TS-UBB2	0.002	52
TS-UBL2	0.005	267
TS-UC1	0.003	278
TS-W1	0.002	218
TS-W2	0.003	68
TS-W3	0.003	229

Appendix C3 Tsushima Pine Plant Exchangeable [K] & [Cs]

Plant Sample	Concentration	
	Cs-133 [ppb]	**K [ppm]**
TP-BG1	0.004	152
TP-BG2	0.002	105
TP-BG3	0.002	275
TP-H1	0.005	155
TP-H2	0.003	131
TP-M1	0.002	117
TP-M2	0.002	119
TP-M3	0.003	129
TP-UA1	0.001	65
TP-UB1	0.008	299
TP-UB2	0.003	244
TP-W1	0.003	190
TP-W3	0.002	168

Appendix C4 Tomioka Plant Exchangeable [K] & [Cs]

Plant Sample	Concentration	
	Cs-133 [ppb]	K [ppm]
TO-F1	0.016	614
TO-F2	0.013	520
TO-F3	0.007	478
TO-PO1	0.013	381
TO-PO2	0.018	465
TO-PO3	0.013	522

Appendix C5 Okuma Plant Exchangeable [K] & [Cs]

Plant Sample	Concentration	
	Cs-133 [ppb]	K [ppm]
O-BG1	0.001	233
O-BG2	0.003	292
O-BG3	0.001	315

Appendix C6 Yokomuki Plant Exchangeable [K] & [Cs]

Plant Sample	Concentration	
	Cs-133 [ppb]	K [ppm]
C-BG1	0.029	238
C-BG2	0.044	227
C-BG3	0.062	131
C-F1	0.131	438
C-F2	0.378	516
C-F3	0.047	119
C-M1	0.017	80
C-M2	0.022	128
C-M3	0.051	108
C-MO1	0.033	47
C-UA1	0.076	556
C-UA2	0.064	434

Appendix D

Soil Exchangeable [K] & [Cs]

Appendix D1 Yamakiya Soil Exchangeable [K] & [Cs]

Soil Sample	**Concentration**	
	Cs-133 [ppb]	**K [ppm]**
S-A5	2.6	15.3
S-A10	7.7	4.5
S-A15	7.9	3.4
S-A30	12.8	4.0
S-B5	4.7	12.7
S-B10	7.9	4.5
S-B15	7.5	3.3
S-B30	15.1	4.6
S-C5	6.4	19.7
S-C10	8.3	6.2
S-C15	9.5	3.5
S-C30	14.5	5.8
S-D5	3.7	32.7
S-D10	4.2	12.8
S-D15	5.5	5.2
S-D30	12.0	6.9
S-E5	1.4	29.4
S-E10	4.9	6.2
S-E15	5.2	4.5
S-E30	11.4	6.2
S-F5	4.8	15.8
S-F10	6.2	4.6
S-F15	8.0	3.4
S-F30	9.8	24.3
S-G5	4.3	13.8
S-G10	5.4	4.4
S-G15	5.4	3.0
S-G30	11.2	3.8
S-H5	4.2	29.3
S-H10	5.3	13.9
S-H15	5.0	5.9
S-H30	12.9	7.6

Appendix D2 Tsushima Sugi Soil Exchangeable [K] & [Cs]

Soil Sample	Concentration	
	Cs-133 [ppb]	K [ppm]
TS-A5	2.8	37.2
TS-A10	3.3	28.8
TS-A15	8.2	9.8
TS-A30	9.7	7.8
TS-B5	2.3	38.4
TS-B10	5.2	28.8
TS-B15	8.3	9.0
TS-B30	11.7	20.3
TS-C5	1.4	38.9
TS-C10	2.3	67.6
TS-C15	4.8	41.2
TS-C30	7.0	9.3
TS-D5	3.9	46.8
TS-D10	5.7	23.1
TS-D15	6.9	11.4
TS-D30	9.5	8.2
TS-E5	5.7	34.0
TS-E10	6.2	16.3
TS-E15	7.4	15.8
TS-E30	12.7	14.9

Appendix D3 Tsushima Pine Soil Exchangeable [K] & [Cs]

Soil Sample	Concentration	
	Cs-133 [ppb]	K [ppm]
TP-A5	2.0	17.7
TP-A10	6.4	9.8
TP-A15	7.0	5.2
TP-A30	11.2	4.8
TP-B5	7.8	24.7
TP-B10	8.3	9.0
TP-B15	10.6	5.6
TP-B30	25.9	12.1
TP-C5	4.6	21.0
TP-C10	5.6	7.4
TP-C15	9.3	4.9
TP-C30	17.0	7.3

Appendix D4 Tomioka Soil Exchangeable [K] & [Cs]

Soil Sample	Concentration	
	Cs-133 [ppb]	K [ppm]
TO-A5	2.5	13.1
TO-A10	4.8	11.8
TO-A15	4.1	8.1
TO-A30	6.8	7.8
TO-B5	3.9	18.9
TO-B10	5.4	12.0
TO-B15	6.6	9.6
TO-B30	15.6	7.7
TO-C5	3.4	24.5
TO-C10	6.7	11.7
TO-C15	5.7	12.4
TO-C30	8.4	7.5

Appendix D5 Okuma Soil Exchangeable [K] & [Cs]

Soil Sample	Concentration	
	Cs-133 [ppb]	K [ppm]
O-A5	3.7	18.8
O-A10	5.2	25.4
O-A15	10.0	28.2
O-A30	2.2	29.3
O-B5	3.4	18.5
O-B10	4.4	14.9
O-B15	7.3	19.3
O-B30	0.9	41.9
O-C5	1.6	18.7
O-C10	2.6	25.7
O-C15	8.3	26.4
O-C30	3.7	42.8

Appendix D6 Yokomuki Soil Exchangeable [K] & [Cs]

Soil Sample	**Concentration**	
	Cs-133 [ppb]	**K [ppm]**
C-A5	14.0	33.9
C-A10	25.5	7.7
C-A15	29.0	4.5
C-A30	40.9	4.4
C-B5	9.7	49.1
C-B10	10.6	43.4
C-B15	5.7	38.9
C-B30	32.7	25.1
C-C5	8.4	22.9
C-C10	13.5	9.6
C-C15	28.3	5.2
C-C30	42.1	5.9

Appendix E

Soil pH

Appendix E1 Yamakiya Soil pH

Soil Sample	pH	Soil Weight (g)
S-A5	5.044	2.03
S-A10	5.118	2.06
S-A15	4.798	1.94
S-A30	4.902	1.96
S-B5	5.000	2.05
S-B10	5.117	1.94
S-B15	4.943	2.03
S-B30	5.211	2.04
S-C5	5.209	2.05
S-C10	4.986	2.03
S-C15	4.748	1.98
S-C30	4.802	1.99
S-D5	5.166	2.01
S-D10	4.949	1.97
S-D15	5.255	2.01
S-D30	5.143	2.04
S-E5	5.106	1.98
S-E10	5.445	2.01
S-E15	5.157	1.96
S-E30	4.896	2.04
S-F5	4.947	2.04
S-F10	5.214	2.00
S-F15	5.018	2.04
S-F30	5.282	2.02
S-G5	4.992	2.03
S-G10	4.947	2.05
S-G15	4.887	2.02
S-G30	5.298	2.03
S-H5	5.352	2.02
S-H10	5.195	2.01
S-H15	4.890	1.97

Appendix E2 Tsushima Sugi Soil pH

Soil Sample	pH	Soil Weight (g)
TS-A5	4.043	1.95
TS-A10	3.783	1.96
TS-A15	4.440	1.97
TS-A30	5.034	2.01
TS-B5	3.806	2.04
TS-B10	3.831	2.08
TS-B15	4.384	2.07
TS-B30	4.748	2.08
TS-C5	4.323	2.04
TS-C10	4.565	2.01
TS-C15	4.683	2.03
TS-C30	4.943	2.05
TS-D5	4.965	2.03
TS-D10	4.900	2.01
TS-D15	5.038	2.04
TS-D30	5.209	2.02
TS-E5	5.425	1.96
TS-E10	5.558	2.00
TS-E15	5.639	2.06
TS-E30	5.599	2.03

Appendix E3 Tsushima Pine Soil pH

Soil Sample	pH	Soil Weight (g)
TP-A5	4.518	1.98
TP-A10	4.528	1.96
TP-A15	4.857	1.92
TP-A30	4.890	1.94
TP-B5	3.947	1.93
TP-B10	4.395	2.09
TP-B15	4.708	1.99
TP-B30	4.915	2.01
TP-C5	4.476	1.95
TP-C10	4.371	1.91
TP-C15	4.574	1.91
TP-C30	4.678	2.01

Appendix E4 Tomioka Soil pH

Soil Sample	pH	Soil Weight (g)
TO-A5	5.783	1.94
TO-A10	5.819	1.95
TO-A15	5.560	2.06
TO-A30	4.715	2.05
TO-B5	5.645	2.04
TO-B10	5.659	2.05
TO-B15	5.279	2.07
TO-B30	4.939	2.06
TO-C5	5.827	1.99
TO-C10	5.649	2.01
TO-C15	5.286	1.98
TO-C30	4.861	2.04

Appendix E5 Okuma Soil pH

Soil Sample	pH	Soil Weight (g)
O-A5	6.603	2.00
O-A10	6.654	1.93
O-A15	6.234	1.97
O-A30	6.278	2.04
O-B5	6.644	2.03
O-B10	6.735	2.06
O-B15	6.942	2.08
O-B30	6.757	2.07
O-C5	6.164	1.99
O-C10	5.706	1.99
O-C15	5.884	2.07
O-C30	7.081	2.07

Appendix E6 Yokomuki Soil pH

Soil Sample	pH	Soil Weight (g)
C-A5	4.980	2.08
C-A10	4.926	2.05
C-A15	4.828	2.03
C-A30	4.717	1.94
C-B5	3.912	2.08
C-B10	3.707	2.09
C-B15	3.711	1.96
C-B30	4.276	1.92
C-C5	4.315	2.05
C-C10	4.306	1.97
C-C15	4.549	2.09
C-C30	4.751	1.97

Appendix E7 Soil pH Analysis of Variance Table

```
Analysis of Variance Table

Response: mean
          Df  Sum Sq Mean Sq F value   Pr(>F)
location   5 11.4510 2.29020  33.026 1.39e-07 ***
depth      3  0.0422 0.01408   0.203   0.8927
Residuals 15  1.0402 0.06935
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Appendix F

Total Understory Plant Fresh Weights

Appendix F1 Yamakiya Total Understory Plant Fresh Weight

Species	Plant Part	Fresh Weight (g)
Japanese Wisteria	Whole	2038.2
Japanese Glory-Bower	Whole	1791.4
Fern	Whole	903.3
Myoga	Whole	10.4
Smooth Japanese Maple	Leaves	380.0
	Small Branches	287.4
	Stem & Branches	167.4
	Whole	128.4
Hazelnut	Leaves	227.4
	Small Branches	137.4
	Stem & Branches	1147.4
Hydrangea	Whole	178.5

Appendix F2 Tsushima Sugi Total Understory Plant Fresh Weight

Species	Plant Part	Fresh Weight (g)
Bamboo Grass	Whole	950.65
Japanese Wisteria	Whole	196.87
Japanese Knotweed	Whole	65.27
Hazelnut	Leaves	225.29
	Branches	149.96
	Stem & Branches	253.24
	Whole	394.8
Unknown	Leaves	11.26
	Branches	39.92
	Whole	447.4
Maple	Whole	7.25

Appendix F3 Tomioka Total Understory Plant Fresh Weight

Species	Plant Part	Fresh Weight (g)
Japanese Lacquer	Whole	4383.6
Fern	Whole	1260.6

Appendix G

Yamakiya Practicum Data

Appendix G1 Yamakiya Practicum Tree Radiocesium Count

Yamakiya Sugi			*Cs-134 (Bq/kg)*		*Cs-137 (Bq/kg)*		*err/Activity*		*Live time (s)*	*Weight in U8 (g)*
Date	**Label**	**Part**	**Activity**	**Act. err**	**Activity**	**Act. err**	**Cs-134**	**Cs-137**		
7/6/2019	B1BB	big branch	144.19	5.3258	1909.5	16.794	3.69359872	0.87949725	30000	13.35
7/6/2019	B1SB	small branch	200.93	25.741	2302.5	80.04	12.8109292	3.4762215	2400	5.8
7/6/2019	B1YF	young leaves	1780	204.41	17043	613.12	11.4837079	3.59748871	600	2.46
7/6/2019	B1OF	old leaves	66.363	8.8881	938.38	30.598	13.3931558	3.26072593	10000	6.86
7/6/2019	B3BB	big branch	244.59	31.826	2777.3	101.24	13.0119792	3.64526699	2400	5.18
7/6/2019	B3SB	small branch	181.12	14.21	2263	46.022	7.84562721	2.03367212	7200	5.71
7/6/2019	B3YF	young leaves	1515.4	174.52	17524	539.82	11.5164313	3.08046108	610	3.1
7/6/2019	B3OF	old leaves	86.531	7.5385	1178.5	26.707	8.71190672	2.26618583	10000	10.64
7/6/2019	B10BB	big branch	159.12	5.2755	2205.6	18.045	3.31542232	0.81814472	30000	10.79
7/6/2019	B10SB	small branch	120.46	6.8493	1621.5	19.417	5.68595384	1.19747148	30000	5.59
7/6/2019	B10YF	young leaves	1177	74.918	14804	255.67	6.36516568	1.72703323	3600	2.9
7/6/2019	B10OF	old leaves	90.371	7.2136	1098.4	25.047	7.98220668	2.28031682	10000	12.15
7/6/2019	IB99	inner bark	155.69	26.59	1838.8	73.636	17.0788105	4.0045682	10000	1.12
7/6/2019	OB99	outer bark	198.14	26.732	2256.2	72.511	13.4914707	3.21385515	7200	2.61
7/6/2019	SW99 1-3	sapwood 1-3	ND	ND	719.51	68.333		9.49715779	177313	0.07
7/6/2019	SW99	sapwood	62.115	12.187	821.55	28.752	19.6200596	3.49972613	10000	3.3
7/6/2019	HW	heartwood	39.536	10.444	531.5	15.012	26.4164306	2.82445908	84011	1.08
7/6/2019	moss_N2	new leaves	1403.8	428.31	14923	701.25	30.5107565	4.69912216	14500	0.07
7/6/2019	moss_45	old leaves	3262	377.56	31975	1141.9	11.5744942	3.57122752	665	1.24
7/6/2019	moss_59	root	12675	1048.5	152590	3613.1	8.27218935	2.36784848	1200	0.42
7/6/2019	moss_N18	tree buck	7876.5	780.13	91712	2575.2	9.90452612	2.80792045	500	0.86
7/6/2019	B1BB	big branch	144.19	5.3258	1909.5	16.794	3.69359872	0.87949725	30000	13.35

Appendix H
Linear Model Tables

Appendix H1.1 All Plant Models

```
Global model call: lm(formula = tf1 ~ exk + csppm + lncon + lnexcon + ph, data = metapred)
---
Model selection table
```

	(Intrc)	csppm	exk	lncon	lnxcn	ph	df	logLik	AICc	delta	weight
22	9.1220	8477		-0.9330		-0.37860	5	-213.463	437.3	0.00	0.420
24	8.8470	10180	5.302e-03	-0.9385		-0.34950	6	-213.098	438.7	1.41	0.207
30	9.0070	8621		-0.9020	-3.602e-02	-0.38380	6	-213.413	439.3	2.04	0.151
32	8.5380	10900	6.632e-03	-0.8751	-7.530e-02	-0.35310	7	-212.900	440.5	3.18	0.086
21	10.6700			-1.0020		-0.47480	4	-216.377	441.0	3.71	0.066
23	10.6600		-2.505e-03	-0.9932		-0.47940	5	-216.273	442.9	5.62	0.025
29	10.6700			-1.0020	-8.500e-07	-0.47480	5	-216.377	443.1	5.83	0.023
31	10.6800		-2.626e-03	-1.0030	1.177e-02	-0.47740	6	-216.268	445.0	7.75	0.009
8	6.3130	15680	1.096e-02	-0.8894			5	-217.680	445.7	8.43	0.006
6	6.4580	12860		-0.8676			4	-219.297	446.8	9.55	0.004
16	6.0600	16270	1.201e-02	-0.8411	-5.694e-02		6	-217.572	447.6	10.36	0.002
14	6.5530	12730		-0.8877	2.266e-02		5	-219.278	448.9	11.63	0.001
5	7.9870			-0.9598			3	-226.369	458.9	21.60	0.000
13	8.3610			-1.0490	1.058e-01		4	-225.969	460.2	22.90	0.000
7	7.9860		-4.108e-05	-0.9597			4	-226.369	461.0	23.70	0.000
15	8.3600		-1.287e-03	-1.0490	1.119e-01		5	-225.945	462.2	24.96	0.000
28	2.8090	25790	1.936e-02		-9.631e-01	-0.26090	6	-240.424	493.3	56.06	0.000
12	1.1250	29370	2.301e-02		-9.237e-01		5	-242.352	495.0	57.78	0.000
26	3.7190	20130			-9.258e-01	-0.34740	5	-243.793	497.9	60.66	0.000
10	1.5700	23690			-8.598e-01		4	-247.274	502.8	65.51	0.000
25	6.6770				-1.099e+00	-0.58600	4	-256.606	521.4	84.17	0.000
27	6.6870		-2.498e-03		-1.088e+00	-0.58850	5	-256.543	523.4	86.16	0.000
9	3.5580				-1.031e+00		3	-266.061	538.3	100.99	0.000
11	3.5570		-8.221e-04		-1.027e+00		4	-266.055	540.3	103.07	0.000
18	-7.6160	62970				0.74790	4	-334.630	677.5	240.22	0.000
20	-6.4560	56700	-1.643e-02			0.63700	5	-333.690	677.7	240.45	0.000
4	-2.7490	50140	-3.095e-02				4	-338.364	685.0	247.68	0.000
2	-3.8960	61560					3	-342.048	690.2	252.96	0.000
3	0.9561		-8.632e-02				3	-363.907	733.9	296.68	0.000
19	0.5166		-8.532e-02			0.08687	4	-363.836	735.9	298.63	0.000
17	-3.2480					0.57130	3	-392.665	791.5	354.19	0.000
1	-0.4655						2	-395.014	794.1	356.82	0.000

Appendix H1.2 All Plant All Factors Model

```
lm(formula = tf1 ~ exk + csppm + lncon + lnexcon + ph, data = meta)

Residuals:
    Min      1Q  Median      3Q     Max 
-1.8945 -0.5741 -0.0512  0.4710  2.4109 

Coefficients:
              Estimate Std. Error t value Pr(>|t|)    
(Intercept)  8.538e+00  1.088e+00   7.851 4.06e-13 ***
exk          6.632e-03  6.649e-03   0.997  0.31997    
csppm        1.090e+04  4.233e+03   2.576  0.01083 *  
lncon       -8.751e-01  1.109e-01  -7.890 3.23e-13 ***
lnexcon     -7.530e-02  1.217e-01  -0.618  0.53708    
ph          -3.531e-01  1.160e-01  -3.045  0.00269 ** 
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.8032 on 174 degrees of freedom
Multiple R-squared:  0.8678,	Adjusted R-squared:  0.864 
F-statistic: 228.5 on 5 and 174 DF,  p-value: < 2.2e-16
```

Appendix H1.3 All Plant Best Fit Model

```
lm(formula = tf1 ~ csppm + lncon + ph, data = meta)

Residuals:
     Min       1Q   Median       3Q      Max 
-1.94537 -0.56520 -0.03343  0.46178  2.34387 

Coefficients:
              Estimate Std. Error t value Pr(>|t|)    
(Intercept)    9.12177    0.90645  10.063  < 2e-16 ***
csppm       8477.31343 3522.42509   2.407 0.017133 *  
lncon         -0.93298    0.04171 -22.369  < 2e-16 ***
ph            -0.37858    0.11027  -3.433 0.000744 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.8011 on 176 degrees of freedom
Multiple R-squared:  0.867,	Adjusted R-squared:  0.8647 
F-statistic: 382.4 on 3 and 176 DF,  p-value: < 2.2e-16
```

Appendix H1.4 All Plant ^{137}Cs Model

```
lm(formula = tf1 ~ lncon, data = meta)

Residuals:
     Min       1Q   Median       3Q      Max 
-2.05077 -0.52801 -0.08379  0.57614  2.35271 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept)  7.98683    0.27725   28.81   <2e-16 ***
lncon       -0.95982    0.03064  -31.33   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.8558 on 178 degrees of freedom
Multiple R-squared:  0.8465,	Adjusted R-squared:  0.8456 
F-statistic: 981.4 on 1 and 178 DF,  p-value: < 2.2e-16
```

Appendix H1.5 All Plant ^{137}Cs Model – 0-5cm depth

```
lm(formula = tf1 ~ lncon, data = hi)

Residuals:
    Min      1Q  Median      3Q     Max 
-1.9283 -0.5391 -0.1175  0.5759  2.1386 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept)   5.6835     1.5280   3.720 0.000452 ***
lncon        -0.7568     0.1395  -5.427 1.17e-06 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.8478 on 58 degrees of freedom
Multiple R-squared:  0.3368,	Adjusted R-squared:  0.3253 
F-statistic: 29.45 on 1 and 58 DF,  p-value: 1.175e-06
```

Appendix H1.6 All Plant ^{137}Cs Model – 5-10cm depth

```
lm(formula = tf1 ~ lncon, data = hi)

Residuals:
    Min      1Q  Median      3Q     Max 
-1.7931 -0.5752 -0.1546  0.5497  2.2347 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept)  7.24509    0.74555   9.718 8.87e-14 ***
lncon       -0.87568    0.08368 -10.465 5.60e-15 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.8536 on 58 degrees of freedom
Multiple R-squared:  0.6538,	Adjusted R-squared:  0.6478 
F-statistic: 109.5 on 1 and 58 DF,  p-value: 5.602e-15
```

Appendix H1.7 All Plant ^{137}Cs Model – 10-15cm depth

```
lm(formula = tf1 ~ lncon, data = hi)

Residuals:
    Min      1Q  Median      3Q     Max 
-1.9320 -0.5241 -0.1869  0.5379  2.2331 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept)  7.69557    0.59255   12.99  < 2e-16 ***
lncon       -0.90341    0.08715  -10.37 8.04e-15 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.8607 on 58 degrees of freedom
Multiple R-squared:  0.6495,	Adjusted R-squared:  0.6434 
F-statistic: 107.5 on 1 and 58 DF,  p-value: 8.04e-15
```

Appendix H1.8 All Plant ^{137}Cs Model – 0-10cm depth

```
lm(formula = tf1 ~ lncon, data = hi)

Residuals:
    Min      1Q  Median      3Q     Max 
-2.0425 -0.5459 -0.0970  0.5888  2.3394 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept)  7.55458    0.51379   14.70   <2e-16 ***
lncon       -0.92036    0.05145  -17.89   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.8537 on 118 degrees of freedom
Multiple R-squared:  0.7306,	Adjusted R-squared:  0.7283 
F-statistic: 319.9 on 1 and 118 DF,  p-value: < 2.2e-16
```

Appendix H1.9 All Plant ^{137}Cs Model – 0-5cm and 10-15cm depth

```
lm(formula = tf1 ~ lncon, data = hi)

Residuals:
    Min      1Q  Median      3Q     Max 
-2.0257 -0.5397 -0.1019  0.5935  2.3329 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept)  8.10099    0.30152   26.87   <2e-16 ***
lncon       -0.97277    0.03307  -29.41   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.8599 on 118 degrees of freedom
Multiple R-squared:   0.88,	Adjusted R-squared:  0.879 
F-statistic: 865.3 on 1 and 118 DF,  p-value: < 2.2e-16
```

Appendix H1.10 All Plant ^{137}Cs Model – 5-15cm depth

```
lm(formula = tf1 ~ lncon, data = hi)

Residuals:
     Min       1Q   Median       3Q      Max 
-1.94778 -0.53640 -0.09068  0.55491  2.32208 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept)   7.8285     0.3685   21.24   <2e-16 ***
lncon        -0.9339     0.0465  -20.08   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.855 on 118 degrees of freedom
Multiple R-squared:  0.7737,	Adjusted R-squared:  0.7718 
F-statistic: 403.4 on 1 and 118 DF,  p-value: < 2.2e-16
```

Appendix H2.1 Bamboo Grass Models

Global model call: lm(formula = tf1 ~ exk + csppm + lncon + lnexcon + ph, data = bg)

Model selection table

	(Intrc)	csppm	exk	lncon	lnxcn	ph	df	logLik	AICc	delta	weight
29	10.1900			-1.2250	0.3120	-0.314300	5	-20.019	52.5	0.00	0.318
21	9.5130			-0.9998		-0.318300	4	-21.761	53.1	0.58	0.237
30	11.0900	-4645		-1.2610	0.2995	-0.369600	6	-19.560	54.8	2.23	0.104
22	10.5900	-5372		-1.0520		-0.382000	5	-21.209	54.9	2.38	0.097
23	9.4870		0.0067410	-1.0150		-0.312700	5	-21.290	55.1	2.54	0.089
31	10.1200		0.0045270	-1.2200	0.2913	-0.310800	6	-19.791	55.2	2.70	0.083
24	10.2400	-3711	0.0034330	-1.0440		-0.359500	6	-21.138	57.9	5.39	0.021
32	11.0300	-4364	0.0005906	-1.2580	0.2975	-0.365800	7	-19.558	58.2	5.67	0.019
13	8.2930			-1.1990	0.3251		4	-25.148	59.9	7.36	0.008
5	7.5660			-0.9644			3	-26.510	59.9	7.40	0.008
7	7.5770		0.0081400	-0.9838			4	-26.007	61.6	9.08	0.003
14	7.7380	4509		-1.1690	0.3351		5	-24.712	61.9	9.39	0.003
6	7.0480	4039		-0.9305			4	-26.191	62.0	9.44	0.003
8	6.4200	9107	0.0157400	-0.9255			5	-24.741	62.0	9.44	0.003
15	8.2400		0.0058670	-1.1940	0.2980		5	-24.874	62.2	9.71	0.002
16	7.1030	8701	0.0132400	-1.1270	0.2831		6	-23.633	62.9	10.38	0.002
9	3.3060				-1.0680		3	-42.018	91.0	38.42	0.000
10	2.1400	12290			-0.9434		4	-40.892	91.4	38.84	0.000
12	1.3000	19800	0.0254000		-0.9567		5	-39.479	91.5	38.92	0.000
25	4.8150				-1.1040	-0.265400	4	-40.974	91.5	39.01	0.000
11	3.2610		0.0090040		-1.0990		4	-41.809	93.2	40.68	0.000
26	3.4630	8410			-1.0050	-0.167900	5	-40.569	93.6	41.10	0.000
27	4.7420		0.0079440		-1.1310	-0.259600	5	-40.799	94.1	41.56	0.000
28	1.5550	18880	0.0245200		-0.9668	-0.028630	6	-39.471	94.6	42.05	0.000
2	-3.5540	38260					3	-53.075	113.1	60.54	0.000
18	-5.7280	43240				0.384700	4	-52.113	113.8	61.29	0.000
20	-8.2040	57770	0.0390200			0.572600	5	-50.783	114.1	61.53	0.000
4	-4.2920	44570	0.0203500				4	-52.685	115.0	62.43	0.000
1	-1.7570						2	-58.800	122.0	69.51	0.000
3	-1.1700		-0.0270700				3	-58.089	123.1	70.56	0.000
17	-1.8030					0.009102	3	-58.800	124.5	71.98	0.000
19	-0.9922		-0.0273500			-0.034120	4	-58.083	125.8	73.23	0.000

Models ranked by AICc(x)

Appendix H2.2 Bamboo Grass All Factors Model

```
lm(formula = tf1 ~ exk + csppm + lncon + lnexcon + ph, data = yo)

Residuals:
    Min      1Q  Median      3Q     Max 
-0.9417 -0.2432  0.0168  0.2340  0.8824 

Coefficients:
              Estimate Std. Error t value Pr(>|t|)    
(Intercept)  1.103e+01  1.734e+00   6.361 1.41e-06 ***
exk          5.906e-04  9.798e-03   0.060   0.9524    
csppm       -4.364e+03  7.116e+03  -0.613   0.5455    
lncon       -1.258e+00  1.542e-01  -8.156 2.24e-08 ***
lnexcon      2.975e-01  1.822e-01   1.633   0.1156    
ph          -3.658e-01  1.336e-01  -2.737   0.0115 *  
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.5192 on 24 degrees of freedom
Multiple R-squared:  0.9269,    Adjusted R-squared:  0.9117 
F-statistic: 60.88 on 5 and 24 DF,  p-value: 7.581e-13
```

Appendix H2.3 Bamboo Grass Best Fit Model

```
lm(formula = tf1 ~ lncon + lnexcon + ph, data = bg)

Residuals:
     Min       1Q   Median       3Q      Max 
-0.94555 -0.24037  0.06908  0.32951  0.90194 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept) 10.18642    0.88540  11.505 1.06e-11 ***
lncon       -1.22470    0.13769  -8.895 2.29e-09 ***
lnexcon      0.31205    0.17438   1.789  0.08520 .  
ph          -0.31432    0.09654  -3.256  0.00314 ** 
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.5066 on 26 degrees of freedom
Multiple R-squared:  0.9246,    Adjusted R-squared:  0.9159 
F-statistic: 106.3 on 3 and 26 DF,  p-value: 1.021e-14
```

Appendix H2.4 Bamboo Grass ^{137}Cs Model

```
lm(formula = tf1 ~ lncon, data = bg)

Residuals:
     Min       1Q   Median       3Q      Max 
-1.09963 -0.25976  0.08268  0.35974  1.08877 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept)  7.56568    0.64825   11.67 2.86e-12 ***
lncon       -0.96440    0.06608  -14.60 1.29e-14 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.6061 on 28 degrees of freedom
Multiple R-squared:  0.8838,	Adjusted R-squared:  0.8797 
F-statistic:   213 on 1 and 28 DF,  p-value: 1.291e-14
```

Appendix H3.1 Glory-Bower Models

```
Global model call: lm(formula = tf1 ~ exk + csppm + lncon + lnexcon + ph, data = gb)
---
Model selection table 
   (Intrc) csppm       exk   lncon     lnxcn       ph df  logLik  AICc  delta weight
5    8.393                 -0.9737                     3  -7.685  26.2   0.00  0.641
9    4.203                         -1.19600            3  -8.851  28.5   2.33  0.200
10   1.238 32310                   -0.91560            4  -6.470  30.9   4.77  0.059
6    6.519 14770           -0.8599                     4  -7.320  32.6   6.47  0.025
21  14.070                 -0.9241            -1.2110  4  -7.429  32.9   6.69  0.023
7    8.717         0.03239 -1.0520                     4  -7.595  33.2   7.02  0.019
13   8.200                 -0.9281 -0.05730            4  -7.682  33.4   7.19  0.018
11   4.192         0.04857         -1.34400            4  -8.717  35.4   9.26  0.006
25   6.583                         -1.17000  -0.4901  4  -8.822  35.6   9.47  0.006
3    3.738        -0.32350                             3 -13.804  38.4  12.24  0.001
2   -5.389 93760                                   NA  3 -14.001  38.8  12.63  0.001
18  25.120 77510        NA      NA       NA  -5.8800  4 -11.316  40.6  14.46  0.000
4   -1.023 53240 -0.19160      NA       NA       NA  4 -11.329  40.7  14.49  0.000
26   8.579 35560        NA      NA -0.80240  -1.5730  5  -5.970  41.9  15.77  0.000
12   1.132 33310  0.06487      NA -1.10500       NA  5  -6.055  42.1  15.94  0.000
14  -3.274 48390        NA  0.7053 -1.64100       NA  5  -6.231  42.5  16.29  0.000
22  14.620 21320        NA -0.7313       NA  -1.9050  5  -6.685  43.4  17.20  0.000
19  21.340    NA -0.27230      NA       NA  -3.6070  4 -13.138  44.3  18.11  0.000
8    6.851 13920  0.02249 -0.9209       NA       NA  5  -7.275  44.5  18.38  0.000
23  14.560    NA  0.03456 -1.0070       NA  -1.2410  5  -7.321  44.6  18.47  0.000
29  15.260    NA       NA -1.0410  0.15430  -1.3540  5  -7.408  44.8  18.65  0.000
15   8.122    NA  0.04086 -0.9120 -0.20200       NA  5  -7.559  45.1  18.95  0.000
17  51.510    NA       NA      NA       NA -10.0900  3 -17.306  45.4  19.24  0.000
1    1.111    NA       NA      NA       NA       NA  2 -19.815  45.6  19.46  0.000
27   6.054    NA  0.04668      NA -1.31800  -0.3832  5  -8.699  47.4  21.23  0.000
20  18.310 55240 -0.12990      NA       NA  -3.9980  5  -9.775  49.5  23.38  0.000
16  -5.593 57470  0.08553  1.0460 -2.24200       NA  6  -5.506  65.0  38.84  0.000
28   7.946 36240  0.05913      NA -0.98340  -1.4580  6  -5.589  65.2  39.01  0.000
30   4.210 49460       NA  0.6177 -1.44400  -1.4840  6  -5.768  65.5  39.37  0.000
24  14.900 20500  0.02114 -0.7891       NA  -1.8970  6  -6.638  67.3  41.11  0.000
31  14.700    NA  0.03375 -1.0200  0.01997  -1.2590  6  -7.321  68.6  42.47  0.000
32   1.081 57640  0.07841  0.9415 -2.02100  -1.2850  7  -5.106 136.2 110.04  0.000
Models ranked by AICc(x) 
```

Appendix H3.2 Glory-Bower All Factors Model

```
lm(formula = tf1 ~ exk + csppm + lncon + lnexcon + ph, data = yo)

Residuals:
       1        2        3       10       11       12       19       20       21
 0.30247  0.52434  0.66397 -0.55477 -0.09646 -0.65658  0.10874 -0.26653 -0.02517

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  1.081e+00  1.642e+01   0.066    0.952
exk          7.841e-02  1.137e-01   0.689    0.540
csppm        5.764e+04  4.174e+04   1.381    0.261
lncon        9.415e-01  1.615e+00   0.583    0.601
lnexcon     -2.021e+00  1.832e+00  -1.103    0.351
ph          -1.285e+00  2.434e+00  -0.528    0.634

Residual standard error: 0.7391 on 3 degrees of freedom
Multiple R-squared:  0.9619,    Adjusted R-squared:  0.8985
F-statistic: 15.17 on 5 and 3 DF,  p-value: 0.02435
```

Appendix H3.3 Glory-Bower Best Fit Model

```
lm(formula = tf1 ~ lncon, data = gb)

Residuals:
    Min      1Q  Median      3Q     Max
-0.8743 -0.7413  0.3491  0.4366  0.4949

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  8.39327    0.77106  10.885 1.22e-05 ***
lncon       -0.97372    0.09902  -9.833 2.39e-05 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.6444 on 7 degrees of freedom
Multiple R-squared:  0.9325,    Adjusted R-squared:  0.9229
F-statistic:  96.7 on 1 and 7 DF,  p-value: 2.39e-05
```

Appendix H4.1 Wisteria Models

```
Global model call: lm(formula = tf1 ~ exk + csppm + lncon + lnexcon + ph, data = w)
---
Model selection table
    (Intrc)     csppm       exk   lncon      lnxcn      ph df  logLik  AICc delta weight
5    8.5670                     -0.9773                      3 -10.560  28.3  0.00  0.237
21  10.4200                     -1.0100             -0.3392  4  -9.236  28.6  0.26  0.208
23  10.6400           -0.007308 -0.9838             -0.4100  5  -8.410  30.2  1.83  0.095
13   8.9590                     -1.0760  1.208e-01           4 -10.136  30.4  2.06  0.085
7    8.4710           -0.004310 -0.9578                      4 -10.289  30.7  2.36  0.073
6    8.7500   -1274.0           -0.9898                      4 -10.535  31.2  2.85  0.057
22  10.5200    -757.2           -1.0170             -0.3376  5  -9.226  31.8  3.47  0.042
29  10.4200                     -1.0100  4.607e-06 -0.3392  5  -9.236  31.8  3.49  0.041
16  11.5200  -15620.0 -0.017760 -1.3240  3.342e-01          6  -7.676  32.3  3.97  0.032
24  11.7700   -7457.0 -0.012080 -1.0380             -0.4399  6  -7.728  32.4  4.08  0.031
15   8.9410           -0.006146 -1.0780  1.570e-01          5  -9.600  32.5  4.21  0.029
8    9.2160   -5693.0 -0.007787 -0.9979         NA      NA  5  -9.948  33.2  4.91  0.020
14   9.4750   -3092.0        NA -1.1240  1.422e-01      NA  5  -9.996  33.3  5.00  0.019
31  10.5900        NA -0.007451 -1.0030  2.744e-02 -0.3858  6  -8.393  33.7  5.41  0.016
32  12.2800  -13160.0 -0.016850 -1.2320  2.142e-01 -0.2739  7  -7.032  35.1  6.75  0.008
30  10.5200    -906.7        NA -1.0260  1.049e-02 -0.3275  6  -9.224  35.4  7.07  0.007
26   7.6690   24490.0        NA      NA -9.783e-01 -1.1440  5 -21.316  56.0 27.65  0.000
28   6.7530   29980.0  0.012910      NA -9.827e-01 -1.0600  6 -20.692  58.3 30.01  0.000
10   1.6550   25550.0        NA      NA -8.059e-01      NA  4 -25.249  60.6 32.28  0.000
12   0.9457   33670.0  0.019380      NA -8.314e-01      NA  5 -24.174  61.7 33.36  0.000
25  10.3800        NA        NA      NA -1.235e+00 -1.2050  4 -25.983  62.1 33.75  0.000
27  10.6100        NA -0.009656      NA -1.189e+00 -1.2580  5 -25.638  64.6 36.29  0.000
9    4.1540        NA        NA      NA -1.064e+00      NA  3 -29.059  65.3 37.00  0.000
11   4.1310        NA -0.005180      NA -1.036e+00      NA  4 -28.982  68.1 39.75  0.000
2   -4.1440   70020.0        NA NA             NA      NA  3 -38.540  84.3 55.96  0.000
18  -6.1220   66520.0        NA NA             NA  0.4742  4 -38.283  86.7 58.35  0.000
4   -4.3620   72350.0  0.004728 NA             NA      NA  4 -38.519  87.1 58.82  0.000
20  -6.8320   70650.0  0.009384 NA             NA  0.5406  5 -38.205  89.7 61.42  0.000
3    1.2710        NA -0.079540 NA             NA      NA  3 -46.588 100.4 72.06  0.000
19  -3.5100        NA -0.067340 NA             NA  0.9930  4 -46.030 102.2 73.85  0.000
17 -10.5900        NA        NA NA             NA  2.2680  3 -49.515 106.2 77.91  0.000
1   -0.1835        NA        NA NA             NA      NA  2 -52.114 108.8 80.48  0.000
Models ranked by AICc(x)
```

Appendix H4.2 Wisteria All Factors Model

```
lm(formula = tf1 ~ exk + csppm + lncon + lnexcon + ph, data = yo)

Residuals:
     Min       1Q   Median       3Q      Max 
-0.44367 -0.23473 -0.02352  0.18280  0.78500 

Coefficients:
              Estimate Std. Error t value Pr(>|t|)    
(Intercept)  1.228e+01  1.701e+00   7.221 1.02e-06 ***
exk         -1.685e-02  8.873e-03  -1.899   0.0737 .  
csppm       -1.316e+04  8.949e+03  -1.470   0.1588    
lncon       -1.232e+00  1.993e-01  -6.179 7.82e-06 ***
lnexcon      2.142e-01  2.067e-01   1.036   0.3138    
ph          -2.739e-01  2.749e-01  -0.996   0.3323    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.3745 on 18 degrees of freedom
Multiple R-squared:  0.9766,    Adjusted R-squared:  0.9702 
F-statistic: 150.5 on 5 and 18 DF,  p-value: 4.948e-14
```

Appendix H4.3 Wisteria Best Fit Model

```
lm(formula = tf1 ~ lncon, data = w)

Residuals:
     Min       1Q   Median       3Q      Max 
-0.52644 -0.26074 -0.05126  0.08202  0.85640 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept)  8.56651    0.34499   24.83   <2e-16 ***
lncon       -0.97727    0.03748  -26.08   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.3924 on 22 degrees of freedom
Multiple R-squared:  0.9687,    Adjusted R-squared:  0.9672 
F-statistic: 679.9 on 1 and 22 DF,  p-value: < 2.2e-16
```

Appendix H5.1 Fern Models

```
Global model call: lm(formula = tf1 ~ exk + csppm + lncon + lnexcon + ph, data = f)
---
Model selection table
```

	(Intrc)	csppm	exk	lncon	lnxcn	ph	df	logLik	AICc	delta	weight
31	17.110		-0.07176	-1.0580	0.361200	-1.4850	6	-3.736	25.5	0.00	0.590
23	16.990		-0.05049	-0.8016		-1.6980	5	-6.556	27.1	1.64	0.260
32	18.100	-3754	-0.07304	-1.1230	0.419300	-1.5630	7	-3.599	29.8	4.34	0.067
24	15.290	6533	-0.05423	-0.7603		-1.5030	6	-6.033	30.1	4.59	0.059
21	19.450			-0.9085		-2.1260	4	-11.077	32.7	7.18	0.016
22	19.190	1105		-0.9028		-2.0990	5	-11.067	36.1	10.66	0.003
29	19.480			-0.9164	0.009514	-2.1250	5	-11.075	36.2	10.68	0.003
30	19.100	1383	NA	-0.8934	-0.009590	-2.0920	6	-11.066	40.1	14.66	0.000
8	5.563	24920	-0.09282	-0.6145	NA	NA	5	-13.844	41.7	16.22	0.000
15	10.440	NA	-0.12850	-1.2400	0.673700	NA	5	-14.749	43.5	18.03	0.000
16	7.446	17480	-0.10870	-0.8928	0.326700	NA	6	-13.192	44.4	18.91	0.000
7	8.152	NA	-0.10050	-0.7489	NA	NA	4	-18.495	47.5	22.02	0.000
26	9.488	31340	NA	NA	-0.851900	-1.4740	5	-16.983	48.0	22.49	0.000
28	7.536	32780	-0.04105	NA	-0.732700	-1.0870	6	-15.871	49.7	24.27	0.000
12	1.242	42970	-0.07235	NA	-0.626000	NA	5	-18.123	50.2	24.77	0.000
10	0.540	48250	NA	NA	-0.822600	NA	4	-21.540	53.6	28.11	0.000
25	16.350	NA	NA	NA	-0.985600	-2.3460	4	-21.891	54.3	28.81	0.000
6	5.665	29360	NA	-0.8166	NA	NA	4	-22.090	54.7	29.21	0.000
14	2.793	39460	NA	-0.3438	-0.493800	NA	5	-20.995	56.0	30.52	0.000
27	15.180	NA	-0.02945	NA	-0.904400	-2.0970	5	-21.541	57.1	31.61	0.000
5	8.771	NA	NA	-0.9974	NA	NA	3	-25.303	58.0	32.55	0.000
13	9.079	NA	NA	-1.0680	0.084400	NA	4	-25.271	61.0	35.57	0.000
11	4.547	NA	-0.10460	NA	-0.759900	NA	4	-27.297	65.1	39.62	0.000
4	0.167	53620	-0.16790	NA	NA	NA	4	-28.227	67.0	41.48	0.000
9	4.094	NA	NA	NA	-1.086000	NA	3	-30.488	68.4	42.91	0.000
20	-1.933	56490	-0.17310	NA	NA	0.3734	5	-28.113	70.2	44.75	0.000
3	4.219	NA	-0.23730	NA	NA	NA	3	-34.836	77.1	51.61	0.000
19	9.324	NA	-0.21320	NA	NA	-1.0130	4	-34.272	79.0	53.57	0.000
2	-3.956	87820	NA	NA	NA	NA	3	-37.208	81.8	56.36	0.000
18	1.700	77840	NA	NA	NA	-0.9484	4	-36.854	84.2	58.74	0.000
17	19.970	NA	NA	NA	NA	-3.5050	3	-42.561	92.5	67.06	0.000
1	1.265	NA	NA	NA	NA	NA	2	-46.214	97.1	71.62	0.000

Models ranked by AICc(x)

Appendix H5.2 Fern All Factors Model

```
lm(formula = tf1 ~ exk + csppm + lncon + lnexcon + ph, data = yo)

Residuals:
     Min       1Q   Median       3Q      Max 
-0.54970 -0.26752 -0.01194  0.22555  0.41995 

Coefficients:
              Estimate Std. Error t value Pr(>|t|)    
(Intercept)  1.810e+01  2.634e+00   6.873 5.30e-06 ***
exk         -7.304e-02  1.852e-02  -3.943 0.001303 ** 
csppm       -3.754e+03  8.439e+03  -0.445 0.662807    
lncon       -1.123e+00  1.947e-01  -5.768 3.71e-05 ***
lnexcon      4.193e-01  2.119e-01   1.978 0.066569 .  
ph          -1.563e+00  3.302e-01  -4.733 0.000267 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.3398 on 15 degrees of freedom
Multiple R-squared:  0.9827,	Adjusted R-squared:  0.977 
F-statistic: 170.7 on 5 and 15 DF,  p-value: 1.146e-12
```

Appendix H5.3 Fern Best Fit Model

```
lm(formula = tf1 ~ exk + lncon + lnexcon + ph, data = f)

Residuals:
     Min       1Q   Median       3Q      Max 
-0.50811 -0.28860 -0.03504  0.25343  0.42369 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept) 17.10687    1.35962  12.582 1.03e-09 ***
exk         -0.07176    0.01784  -4.023 0.000983 ***
lncon       -1.05826    0.12541  -8.438 2.76e-07 ***
lnexcon      0.36118    0.16269   2.220 0.041207 *  
ph          -1.48495    0.27262  -5.447 5.38e-05 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.3312 on 16 degrees of freedom
Multiple R-squared:  0.9825,	Adjusted R-squared:  0.9781 
F-statistic: 224.6 on 4 and 16 DF,  p-value: 7.795e-14
```

Appendix H5.4 Fern ^{137}Cs Model

```
lm(formula = tf1 ~ lncon, data = f)

Residuals:
    Min      1Q  Median      3Q     Max 
-0.9700 -0.7636 -0.4269  0.9667  1.0724 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept)  8.77076    0.70915   12.37 1.55e-10 ***
lncon       -0.99740    0.09097  -10.96 1.17e-09 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.8487 on 19 degrees of freedom
Multiple R-squared:  0.8635,	Adjusted R-squared:  0.8563 
F-statistic: 120.2 on 1 and 19 DF,  p-value: 1.172e-09
```

Appendix H6.1 Hydrangea Models

```
Global model call: lm(formula = tf1 ~ exk + csppm + lncon + lnexcon + ph, data = ua
---
Model selection table
```

	(Intrc)	csppm	exk	lncon	lnxcn	ph	df	logLik	AICc	delta	weight
22	13.3300	13620		-0.9865		-1.1730	5	0.778	18.4	0.00	0.856
21	16.8200			-1.0500		-1.6270	4	-4.848	23.4	4.97	0.071
6	6.4990	20440		-0.9131			4	-5.845	25.4	6.96	0.026
30	14.2600	12690		-1.1250	0.162300	-1.2310	6	1.374	26.1	7.61	0.019
24	13.4000	13770	0.002028	-0.9938		-1.1820	6	0.793	27.2	8.77	0.011
29	18.1900			-1.3150	0.319100	-1.6790	5	-3.846	27.7	9.25	0.008
23	16.1800		-0.011290	-1.0060		-1.5510	5	-4.649	29.3	10.85	0.004
5	8.0850			-0.9791			3	-11.199	31.4	12.95	0.001
8	6.3760	19490	-0.009517	-0.8813	NA	NA	5	-5.729	31.5	13.01	0.001
14	6.4760	20470	NA	-0.9079	-0.006297	NA	5	-5.844	31.7	13.24	0.001
7	7.3180	NA	-0.037040	-0.8432	NA	NA	4	-10.312	34.3	15.89	0.000
31	17.3700	NA	-0.021060	-1.3020	0.405300	-1.5510	6	-3.072	34.9	16.50	0.000
10	2.0860	25600	NA	NA	-1.026000	NA	4	-11.070	35.9	17.41	0.000
13	8.7430	NA	NA	-1.1360	0.191400	NA	4	-11.081	35.9	17.43	0.000
32	14.2400	12290	-0.003818	-1.1290	0.183000	-1.2220	7	1.422	39.2	20.71	0.000
9	3.6380	NA	NA	NA	-1.104000	NA	3	-15.150	39.3	20.86	0.000
15	8.5060	NA	-0.046800	-1.1400	0.404500	NA	5	-9.749	39.5	21.05	0.000
16	6.5720	19070	-0.011560	-0.9243	0.059810	NA	6	-5.707	40.2	21.77	0.000
25	10.1900	NA	NA	NA	-1.162000	-1.2710	4	-13.731	41.2	22.73	0.000
26	5.2590	22520	NA	NA	-1.061000	-0.5797	5	-10.619	41.2	22.79	0.000
12	2.0840	25740	0.001273	NA	-1.031000	NA	5	-11.069	42.1	23.69	0.000
11	3.3900	NA	-0.046140	NA	-0.897900	NA	4	-14.530	42.8	24.33	0.000
27	9.1970	NA	-0.027690	NA	-1.030000	-1.1080	5	-13.484	47.0	28.52	0.000
3	1.4500	NA	-0.177000	NA	NA	NA	3	-19.639	48.3	29.83	0.000
28	5.3520	23140	0.006454	NA	-1.089000	-0.5984	6	-10.600	50.0	31.56	0.000
4	0.6350	13160	-0.162700	NA	NA	NA	4	-19.318	52.3	33.91	0.000
19	0.3415	NA	-0.176800	NA	NA	0.2224	4	-19.620	53.0	34.51	0.000
1	-0.7317	NA	NA	NA	NA	NA	2	-26.157	57.6	39.20	0.000
2	-2.8020	42700	NA	NA	NA	NA	3	-24.580	58.2	39.72	0.000
20	-2.8020	16720	-0.158300	NA	NA	0.6454	5	-19.166	58.3	39.89	0.000
17	-2.4760	NA	NA	NA	NA	0.3507	3	-26.140	61.3	42.84	0.000
18	-10.8900	49400	NA	NA	NA	1.5610	4	-24.190	62.1	43.65	0.000

Models ranked by AICc(x)

Appendix H6.2 Hydrangea All Factors Model

```
lm(formula = tf1 ~ exk + csppm + lncon + lnexcon + ph, data = yo)

Residuals:
     Min       1Q   Median       3Q      Max 
-0.36772 -0.19687  0.03742  0.11994  0.40181 

Coefficients:
              Estimate Std. Error t value Pr(>|t|)    
(Intercept)  1.424e+01  2.258e+00   6.305 0.000743 ***
exk         -3.818e-03  1.727e-02  -0.221 0.832386    
csppm        1.229e+04  4.751e+03   2.586 0.041407 *  
lncon       -1.129e+00  1.820e-01  -6.205 0.000808 ***
lnexcon      1.830e-01  2.246e-01   0.815 0.446378    
ph          -1.222e+00  3.302e-01  -3.700 0.010090 *  
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.3039 on 6 degrees of freedom
Multiple R-squared:  0.9899,    Adjusted R-squared:  0.9815 
F-statistic: 117.8 on 5 and 6 DF,  p-value: 6.658e-06
```

Appendix H6.3 Hydrangea Best Fit Model

```
lm(formula = tf1 ~ csppm + lncon + ph, data = ua)

Residuals:
     Min       1Q   Median       3Q      Max 
-0.31419 -0.21306  0.01645  0.15122  0.43114 

Coefficients:
              Estimate Std. Error t value Pr(>|t|)    
(Intercept)  1.333e+01  1.757e+00   7.583 6.41e-05 ***
csppm        1.362e+04  3.862e+03   3.526  0.00778 ** 
lncon       -9.865e-01  4.389e-02 -22.478 1.62e-08 ***
ph          -1.173e+00  2.922e-01  -4.015  0.00387 ** 
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.2778 on 8 degrees of freedom
Multiple R-squared:  0.9888,    Adjusted R-squared:  0.9846 
F-statistic: 234.8 on 3 and 8 DF,  p-value: 3.897e-08
```

Appendix H6.4 Hydrangea ^{137}Cs Model

```
lm(formula = tf1 ~ lncon, data = ua)

Residuals:
     Min       1Q   Median       3Q      Max 
-0.92637 -0.40088  0.04908  0.47680  0.81208 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept)  8.08484    0.85923   9.409 2.77e-06 ***
lncon       -0.97912    0.09294 -10.535 9.84e-07 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.674 on 10 degrees of freedom
Multiple R-squared:  0.9173,	Adjusted R-squared:  0.9091 
F-statistic:   111 on 1 and 10 DF,  p-value: 9.842e-07
```

Appendix H7.1 Maple Models

```
Global model call: lm(formula = tf1 ~ exk + csppm + lncon + lnexcon + ph, data = m)
---
Model selection table 
     (Intrc)   csppm      exk   lncon   lnxcn       ph df  logLik AICc delta weight
7    8.92400          0.02232 -1.1130                   4   7.192 -0.7  0.00  0.519
13   8.93500                  -1.2600  0.3906           4   6.694  0.3  1.00  0.315
15   8.96400          0.01351 -1.1860  0.1787           5   7.865  4.3  4.94  0.044
23   7.97700          0.01926 -1.0860          0.15990  5   7.481  5.0  5.71  0.030
8    9.15700 -1673.0  0.02162 -1.1250                   5   7.452  5.1  5.77  0.029
29   7.74900                  -1.2010  0.3242  0.20010  5   7.136  5.7  6.40  0.021
14   9.22900 -2098.0          -1.2700  0.3771           5   7.079  5.8  6.51  0.020
21   4.86200                  -0.9602          0.64470  4   3.508  6.7  7.37  0.013
5    8.37900                  -1.0180                   3  -0.006  9.0  9.68  0.004
22   1.84800  7048.0          -0.8646          1.00400  5   4.709 10.6 11.25  0.002
16   9.20000 -1701.0  0.01274 -1.1990  0.1799           6   8.166 12.5 13.14  0.001
6    9.02300 -4312.0          -1.0570                   4   0.556 12.6 13.27  0.001
31   8.25500          0.01205 -1.1590  0.1622  0.11910  6   8.036 12.7 13.40  0.001
24   8.34600  -613.4  0.01992 -1.0980          0.11200  6   7.490 13.8 14.49  0.000
30   8.11700  -613.7          -1.2180  0.3360  0.15250  6   7.144 14.5 15.18  0.000
32   9.79600 -2476.0  0.01339 -1.2230  0.1919 -0.08182  7   8.186 25.6 26.30  0.000
26 -15.32000 31140.0                  -0.6772  3.27200  5  -3.806 27.6 28.28  0.000
20 -22.77000 42410.0 -0.04873                  4.24500  5  -6.649 33.3 33.97  0.000
25  -8.15400                          -1.1220  2.57900  4 -10.683 35.1 35.75  0.000
28 -13.98000 29670.0  0.01144         -0.8043  3.08300  6  -3.693 36.2 36.86  0.000
18 -23.85000 56040.0                           4.12500  4 -11.518 36.8 37.42  0.000
11   6.89600          0.11520         -2.2480           4 -11.934 37.6 38.25  0.000
27  -3.02000          0.05836         -1.6630  1.78500  5  -9.383 38.8 39.44  0.000
9    4.38000                          -1.2700           3 -16.351 41.7 42.37  0.000
12   5.94300  7548.0  0.11380         -2.1380           5 -11.703 43.4 44.08  0.000
19 -18.60000         -0.09437                  4.09300  4 -15.866 45.4 46.12  0.000
10   3.13700 10170.0                  -1.1380           4 -16.150 46.0 46.68  0.000
2   -4.45500 49890.0                                    3 -20.736 50.5 51.14  0.000
17 -17.90000                                   3.62200  3 -21.232 51.5 52.13  0.000
3    0.04756         -0.08134                           3 -21.904 52.8 53.48  0.000
1   -1.21700                                            2 -23.918 53.2 53.84  0.000
4   -3.12600 38790.0 -0.03915                           4 -20.252 54.2 54.89  0.000
Models ranked by AICc(x) 
```

Appendix H7.2 Maple All Factors Model

```
lm(formula = tf1 ~ exk + csppm + lncon + lnexcon + ph, data = yo)

Residuals:
     Min       1Q   Median       3Q      Max 
-0.26788 -0.07645  0.01939  0.09101  0.15649 

Coefficients:
              Estimate Std. Error t value Pr(>|t|)    
(Intercept)  9.796e+00  4.309e+00   2.273  0.06338 .  
exk          1.339e-02  1.256e-02   1.066  0.32726    
csppm       -2.476e+03  6.356e+03  -0.390  0.71026    
lncon       -1.223e+00  1.999e-01  -6.119  0.00087 ***
lnexcon      1.919e-01  2.233e-01   0.859  0.42332    
ph          -8.182e-02  5.879e-01  -0.139  0.89387    
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.173 on 6 degrees of freedom
Multiple R-squared:  0.9953,    Adjusted R-squared:  0.9913 
F-statistic: 251.7 on 5 and 6 DF,  p-value: 6.973e-07
```

Appendix H7.3 Maple Best Fit Model

```
lm(formula = tf1 ~ exk + lncon, data = m)

Residuals:
     Min       1Q   Median       3Q      Max 
-0.23954 -0.11613  0.01659  0.05927  0.23140 

Coefficients:
             Estimate Std. Error t value Pr(>|t|)    
(Intercept)  8.924346   0.273084  32.680 1.16e-10 ***
exk          0.022319   0.004885   4.569  0.00135 ** 
lncon       -1.112920   0.032962 -33.764 8.65e-11 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.1534 on 9 degrees of freedom
Multiple R-squared:  0.9944,    Adjusted R-squared:  0.9932 
F-statistic: 799.1 on 2 and 9 DF,  p-value: 7.356e-11
```

Appendix H7.4 Maple ^{137}Cs Model

```
lm(formula = tf1 ~ lncon, data = m)

Residuals:
     Min       1Q   Median       3Q      Max 
-0.27740 -0.17816 -0.08324  0.09629  0.43207 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept)  8.37936    0.42460   19.73 2.45e-09 ***
lncon       -1.01827    0.04431  -22.98 5.50e-10 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.2652 on 10 degrees of freedom
Multiple R-squared:  0.9814,	Adjusted R-squared:  0.9796 
F-statistic:   528 on 1 and 10 DF,  p-value: 5.502e-10
```

Appendix H8.1 Japanese Lacquer Models

```
Global model call: lm(formula = tf1 ~ exk + csppm + lncon + lnexcon + ph, data = l)
---
Model selection table
```

	(Intrc)	csppm	exk	lncon	lnxcn	ph	df	logLik	AICc	delta	weight
5	7.52700			-1.0090			3	-3.519	17.8	0.00	0.546
9	2.42900				-1.11800		3	-5.082	21.0	3.13	0.114
6	5.23300	24590		-0.8604			4	-1.525	21.0	3.21	0.110
21	15.68000			-0.8638		-1.647	4	-1.752	21.5	3.67	0.087
25	14.26000				-0.91050	-2.190	4	-2.393	22.8	4.95	0.046
10	0.46800	31400			-0.91290		4	-2.398	22.8	4.96	0.046
7	7.54200		0.02823	-1.0620			4	-3.158	24.3	6.48	0.021
13	8.15600			-1.1340	0.14110		4	-3.495	25.0	7.15	0.015
26	10.85000	26800			-0.76570	-1.870	5	1.484	27.0	9.19	0.006
11	2.19500		0.02635		-1.17300		4	-4.864	27.7	9.89	0.004
22	12.86000	22670		-0.7396		-1.504	5	0.915	28.2	10.33	0.003
8	5.29600	24050	0.02508	-0.9106			5	-1.078	32.2	14.32	0.000
23	15.35000		0.02207	-0.9113		-1.577	5	-1.430	32.9	15.02	0.000
14	4.44800	25420		-0.7142	-0.15900		5	-1.481	33.0	15.12	0.000
29	15.19000			-0.6568	-0.22300	-1.748	5	-1.672	33.3	15.51	0.000
12	0.26260	31190	0.02458		-0.96590		5	-2.050	34.1	16.26	0.000
27	13.86000		0.02069		-0.95770	-2.150	5	-2.150	34.3	16.46	0.000
17	42.10000					-7.513	3	-12.626	36.1	18.21	0.000
2	-5.23700	108100					3	-12.698	36.2	18.36	0.000
15	7.96100		0.02780	-1.1440	0.09419		5	-3.146	36.3	18.46	0.000
18	22.83000	65960				-4.642	4	-9.532	37.1	19.23	0.000
19	36.59000		-0.10880			-6.268	4	-11.530	41.1	23.22	0.000
4	-2.97000	90130	-0.10370				4	-11.758	41.5	23.68	0.000
1	-0.05849						2	-17.889	41.8	23.94	0.000
3	3.05100		-0.22920				3	-15.721	42.2	24.40	0.000
20	21.67000	58300	-0.06724			-4.206	5	-8.795	47.6	29.75	0.000
28	10.48000	26720	0.02001		-0.81190	-1.833	6	2.041	49.9	32.08	0.000
30	11.43000	25070		-0.2497	-0.51380	-1.723	6	1.691	50.6	32.78	0.000
24	12.60000	22330	0.01966	-0.7837		-1.444	6	1.384	51.2	33.39	0.000
16	4.31800	25070	0.02585	-0.7296	-0.19860		6	-1.003	56.0	38.17	0.000
31	14.79000		0.02277	-0.6817	-0.24900	-1.688	6	-1.324	56.6	38.81	0.000
32	11.10000	24800	0.02091	-0.2769	-0.53450	-1.668	7	2.330	121.3	103.50	0.000

Models ranked by AICc(x)

Appendix H8.2 Japanese Lacquer All Factors Model

```
lm(formula = tf1 ~ exk + csppm + lncon + lnexcon + ph, data = yo)

Residuals:
      154       155       156       160       161       162       166       167       168 
-0.104490 -0.185490  0.060600  0.033583  0.482524 -0.062797 -0.006929 -0.150236 -0.066766 

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept)  1.110e+01  4.960e+00   2.238    0.111
exk          2.091e-02  3.089e-02   0.677    0.547
csppm        2.480e+04  1.279e+04   1.938    0.148
lncon       -2.769e-01  6.206e-01  -0.446    0.686
lnexcon     -5.345e-01  6.379e-01  -0.838    0.464
ph          -1.668e+00  9.192e-01  -1.814    0.167

Residual standard error: 0.3235 on 3 degrees of freedom
Multiple R-squared:  0.9888,	Adjusted R-squared:  0.9702 
F-statistic: 53.04 on 5 and 3 DF,  p-value: 0.003977
```

Appendix H8.3 Japanese Lacquer Best Fit Model

```
lm(formula = tf1 ~ lncon, data = l)

Residuals:
     Min       1Q   Median       3Q      Max 
-0.42745 -0.39413 -0.05715  0.44251  0.48274 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept)  7.52735    0.60834   12.37 5.17e-06 ***
lncon       -1.00877    0.07887  -12.79 4.14e-06 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.4056 on 7 degrees of freedom
Multiple R-squared:  0.959,	Adjusted R-squared:  0.9531 
F-statistic: 163.6 on 1 and 7 DF,  p-value: 4.141e-06
```

Appendix H9.1 Unknown Models

```
Global model call: lm(formula = tf1 ~ exk + csppm + lncon + lnexcon + ph, data = ub)
---
Model selection table
     (Intrc) csppm       exk   lncon   lnxcn       ph df  logLik  AICc  delta weight
6    4.37800 31910             -0.6708                 4  -4.155  26.3   0.00  0.659
5   10.21000                   -1.0530                 3  -9.134  29.1   2.76  0.166
9    6.63300                           -1.4080         3  -9.880  30.6   4.25  0.079
2   -4.19900 63340                                     3 -10.919  32.6   6.33  0.028
13   9.10700                   -0.6213 -0.6560         4  -7.672  33.3   7.03  0.020
10   2.08300 29890                     -0.8641         4  -8.045  34.1   7.78  0.013
11   9.14400        0.102800           -2.3090         4  -8.429  34.9   8.55  0.009
7    9.13900       -0.030830 -0.8897                   4  -8.635  35.3   8.96  0.007
21   7.61600                   -0.9973          0.47670 4  -9.021  36.0   9.73  0.005
22   6.69000 34320             -0.7014         -0.50630 5  -3.813  37.6  11.32  0.002
25   8.64100                           -1.4790 -0.38990 4  -9.829  37.7  11.35  0.002
8    4.30500 35080  0.014570 -0.7101                   5  -3.920  37.8  11.53  0.002
14   4.55200 29960             -0.6225 -0.1088         5  -4.085  38.2  11.86  0.002
3    2.21800       -0.131300                           3 -13.694  38.2  11.88  0.002
4   -2.78700 51070 -0.035690                           4 -10.524  39.0  12.74  0.001
18  -6.25200 59230                              0.54120 4 -10.826  39.7  13.34  0.001
12   4.50300 31670  0.110100           -1.7960         5  -5.156  40.3  14.00  0.001
17 -17.53000                                    4.08500 3 -15.725  42.3  15.94  0.000
1    0.05298                                           2 -18.204  42.4  16.10  0.000
15  10.03000        0.060090 -0.4835 -1.3490           5  -7.083  44.2  17.86  0.000
29  10.78000                   -0.6188 -0.7179 -0.32610 5  -7.615  45.2  18.92  0.000
19   2.07500       -0.130700                    0.03089 4 -13.694  45.4  19.08  0.000
26   5.55200 31350                     -0.9671 -0.71680 5  -7.789  45.6  19.27  0.000
27   5.20200        0.127500           -2.3650  0.88290 5  -8.167  46.3  20.02  0.000
23  10.43000       -0.036400 -0.8922           -0.27270 5  -8.612  47.2  20.91  0.000
20  -1.71100 51220 -0.040440                   -0.23390 5 -10.513  51.0  24.72  0.000
16   5.44100 31060  0.068960 -0.4645 -0.8843           6  -2.097  58.2  31.88  0.000
30   7.69000 31290             -0.6177 -0.2084 -0.65240 6  -3.559  61.1  34.81  0.000
24   6.14300 35260  0.006759 -0.7128           -0.39390 6  -3.777  61.6  35.24  0.000
28   2.23500 30820  0.124900           -1.8440  0.53590 6  -4.961  63.9  37.61  0.000
31   8.23200        0.073470 -0.4558 -1.4290  0.39070 6  -7.020  68.0  41.73  0.000
32   5.28900 31000  0.070140 -0.4620 -0.8923  0.03480 7  -2.095 130.2 103.88  0.000
Models ranked by AICc(x)
```

Appendix H9.2 Unknown All Factors Model

```
lm(formula = tf1 ~ exk + csppm + lncon + lnexcon + ph, data = yo)

Residuals:
       82        83        84       136       137       138       151       152       153 
-0.004723  0.133365 -0.187536 -0.231655  0.715719  0.165963 -0.007110 -0.186127 -0.397896 

Coefficients:
             Estimate Std. Error t value Pr(>|t|)  
(Intercept)  5.289e+00  5.405e+00   0.978   0.4000  
exk          7.014e-02  6.533e-02   1.074   0.3617  
csppm        3.100e+04  1.270e+04   2.442   0.0924 .
lncon       -4.620e-01  2.827e-01  -1.634   0.2007  
lnexcon     -8.923e-01  7.654e-01  -1.166   0.3280  
ph           3.480e-02  1.112e+00   0.031   0.9770  
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.529 on 3 degrees of freedom
Multiple R-squared:  0.9721,	Adjusted R-squared:  0.9256 
F-statistic: 20.92 on 5 and 3 DF,  p-value: 0.01542
```

Appendix H9.3 Unknown Best Fit Model

```
lm(formula = tf1 ~ csppm + lncon, data = ub)

Residuals:
     Min       1Q   Median       3Q      Max 
-0.63492 -0.25696 -0.03956  0.37234  0.55706 

Coefficients:
              Estimate Std. Error t value Pr(>|t|)   
(Intercept)     4.3783     1.9229   2.277  0.06307 . 
csppm       31909.7765  9157.6277   3.485  0.01307 * 
lncon          -0.6708     0.1465  -4.580  0.00377 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.4702 on 6 degrees of freedom
Multiple R-squared:  0.9559,	Adjusted R-squared:  0.9412 
F-statistic: 65.07 on 2 and 6 DF,  p-value: 8.561e-05
```

Appendix H9.3 Unknown ^{137}Cs Model

```
lm(formula = tf1 ~ lncon, data = ub)

Residuals:
    Min      1Q  Median      3Q     Max 
-0.6808 -0.5146 -0.3005  0.8123  1.0400 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept)  10.2081     1.5260   6.689 0.000280 ***
lncon        -1.0533     0.1561  -6.748 0.000266 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.757 on 7 degrees of freedom
Multiple R-squared:  0.8667,	Adjusted R-squared:  0.8477 
F-statistic: 45.53 on 1 and 7 DF,  p-value: 0.0002656
```