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Role of Satoyama Forest towards Sustainability: Contributing to Carbon Stock in Japan

Mohammad Nizam Uddin[1,2]*, Juri Fujieda[2]

[1]Forestry Science and Technology Institute, Chittagong, Bangladesh.
[2]Department of Natural Environment Studies, The University of Tokyo, Kashiwa, Japan

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⌧*Corresponding Author:
Mohammad Nizam Uddin,
Forestry Science and Technology Institute, Chittagong, Bangladesh
Email: nz_post@yahoo.com

Abstract

This study investigated the potentials of Satoyama forests to contribute in increasing carbon stock by inclusion of controlled biomass harvesting in the forms of thinning and pruning under a planned forest management intervention. A Satoyama forest named Oaota in Kashiwa, Chiba, Japan was selected for the study. We calculated present carbon stock of the forest by using sample data from four quadratic plots (two in each site) from which we measured the diameter and height of trees including the diameter and length of branches. Five conical shaped leaf traps were used to measure the amount of leaf biomass production in a year. Soil organic carbon was analyzed by NC analyzer for 0-30 cm depth of soil. The study revealed that the Oaota forest contributed to carbon capture in the forms of 158.7 tC/ha (80.95 tC/ha for soil, 76.19 tC/ha for wood and 1.63 tC/ha/y for leaves). Soil carbon accumulation was not considered in this study. The results indicated that by harvesting planned amount of biomass to consume as a zero-emission renewable fuel alternative to replace high carbon emission fuels may help reduction in carbon releases and enhances the carbon capture performace as well as revitalization of Satoyama forests.

1. Introduction

Climate change, the inevitable derivative of global warming, is the most pressing global concern at present which is threatening biosphere and the very existence of human civilization. Rational conservation, maintenance and planned utilization of wood biomass are among the most practicable options in climate change adaptation and mitigation. Wood biomass captures carbon from the atmosphere to harness global warming. Japan has natural forests covering about 60 % of the country's land area (Yokohari *et al.*, 2006) while an additional 20 % of her land contains forest patches - known as 'Satoyama' forest - that has been created through prolonged interaction between human and ecosystems (Alphonse *et al.*, 2008). Satoyama forest consists of human settlements and a collection of intermingled ecosystems - agro-ecosystems, secondary forest ecosystem, wetland ecosystem, grasslands ecosystem and hill or mountain ecosystems which provide diverse ecosystem services such as food, forest products, non-timber forest products, economic, cultural services, etc. This forest, with climate change mitigation oriented management for carbon capture, can be instrumental to maintain environmental sustainability. However, in recent years the overall functioning of Satoyama forests has been declining (Alphonse *et al*. 2008) due to the absence of informed human intervention and the lack of proper forest management activities leading to deterioration in its economic exploitation. Due to abandonment of vegetation management, majority of the Satoyama has

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become unmanaged forest and has lost its ecological working functions and beauty (Nakagoshi and Hong, 2001). In order to maintain Satoyama forests we need to intervene through planned forest management activities such as regular pruning and thinning activities to improve the growth and to reduce competitions for nutrient among the tree species in the forest. Properly harvested wood waste from forest management activities helps in forest conservation on one hand and serves as zero-emission green energy alternative to conventional fuels such as gasoline, coal, diesel etc. However, this aspect of Satoyama forests has not been evaluated in earlier studies.

Traditionally Satoyama forests have been managed by NPOs (non-profit organization) and the primary management objectives are recreation and conservation of local landscapes. Modification to this traditional conservation and management philosophy with the help of NPOs (Japan Satoyama-Satoumi Assessment 2010) in the Satoyama forests to include carbon reduction from the atmosphere as a management objective can be an option to ensure its contribution to climate change mitigation.This paper aims to evaluate the contributions that Satoyama forests may make towards environmentally sustainable carbon capture by adopting a biomass utilization based paradigm shift in the management of these forests.

2. Materials and Methods

2.1. Study Area

Oaota forest of Kashiwa, Chiba, Japan was selected for this research. The forest, having the total area of 42 hectares, is owned by 30 owners and an NPO (non-profit organization) consisting of members from local community manages, use the forest for conservation and recreation purposes. However, the NPO has no legal rights to harvest trees without the prior permission of the owners. Oaota area has 383 households, of them 63 are farmers (www.city.kashiwa.lg.jp) who are directly or indirectly related with ecosystem services from Oaota forest. The NPO assumed management of this abandoned forest area from 2004. The interview of NPO leaders revealed that the vegetation was dominated by Pine species before 1950s and after that period those Pines were gradually destroyed by Pine wilt disease and the vegetation became gradually dominated by the *Quercus species* in natural forest (NF) sites. Forest owners have done enrichment planting with species like Hinoki (*Chamaecyparis obtusa*), Sugi (*Cryptomeria japonica*) in plantation forest (PF) sites of Oaota forest in 1950-60s. Forest resources have never been harvested by the owners.

Figure 1: Map of Oaota Forest, Kashiwa, Chiba, Japan; Colored Boundary Indicates the NPO Managed Forest Area

2.2. Site Selection

Oaota is a typical semi-natural Satoyama forest as it contains both natural vegetation and plantation. We obtained legal permission from the NPO of this forest to conduct the study. This forest has three layers of species composition where *Chamaecyparis obtusa*, *Quercus serrata*, *Carpinus tschonoskii*, *Quercus acutissima*, *Cryptomeria japonica* are dominant in the upper canopy. The study area was selected by studying the aerial photo and also after discussion with the NPO of the forest. The research work was conducted between December 2010 and June 2012. Two sites, one from natural forest (NF) and the other from plantation forest (PF) were randomly selected from the aerial photo of the Oaota forest. Two experimental quadratic plots (20 m X 20 m) in each site were established during the study period to estimate the wood stock and general information of the forest.

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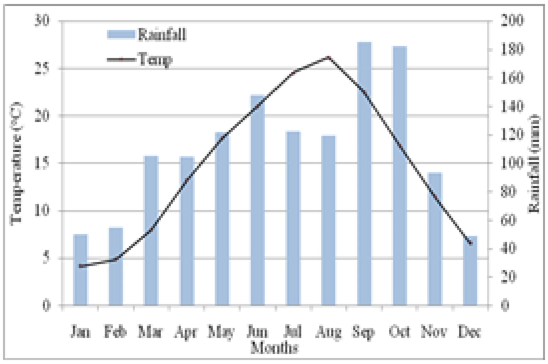


Figure 2: Monthly rainfall and temperature averaged from 1978-2011 in Kashiwa City Area

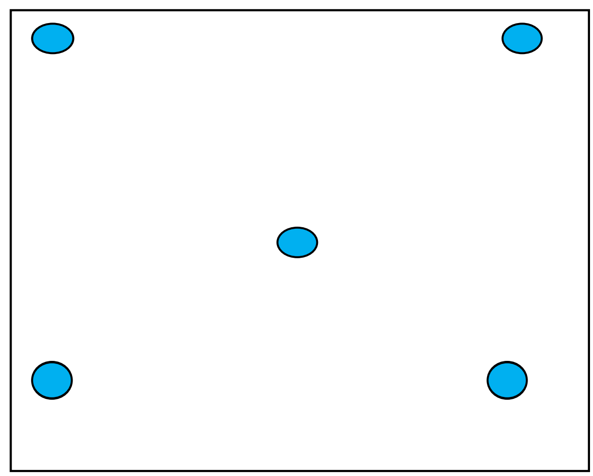
2.3. Tree Measurement

Individual tree diameter over bark at 0.3 m,1.37 m (dbh-diameter at breast height) height were taken by diameter tap (in cm), and diameters at every 2 m interval along the stem of the tree after dbh, were taken by using Criterion RD 1000 upto the limit to which the top diameter can easily be seen through criterion RD 1000 instrument. The top portions of trees whose diameter cannot be measured by Criterion RD1000, photographs were also taken, along with a pole, having the demarcation of 1m length, by a digital camera for those portions of trees and marked and saved according to the tree number in camera memory. Those photographs were then analyzed by ArcGIS 10.0 to measure the length and diameter of those portions of trees. The branches of the trees were also measured by using photographs and ArcGIS 10.0 software. Total heights of trees were also measured by Criterion RD1000.

2.4. Setting Leaf Traps

Five conical shaped leaf traps, 1 meter in diameter (0.7854 m^2 area) each, were set in every plot by maintaining equal distances among the traps within the plots. Nylon nets of about 1.2 mm mesh were used so that fallen leaves can be collected easily. Traps were set 1m high and the bottom of which was 1 foot above the forest floor and traps do not touch the ground (Kimura *et al*., 1982). All traps were in the same height from the ground. Poles were used to erect the traps. Falling leaves were collected between October 2011 and January 2012 at every 15 days interval. Leaves were taken into separate plastic bags for each trap . The dry weights of leaves were measured by electric weighing machine after being oven dried for 48 hours at 65 ^{0}C in electric oven.

(a)



(b)

Figure 3: Leaf Traps in Experimental Plots; (a) Leaf Traps in Forest, (b) Position of leaf traps

2.5. Soil Analysis

Soil samples were collected in that day of the week when there was no rain. Five soil samples of 30 cm depth were taken from each of the plot. Before collection of soil samples sampling points were cleared off leaves, roots, stones and partly decomposed leaves. Each soil sample was then mixed thoroughly and 200 g soil for each sample was oven dried for 48 hours at

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65 ^{0}C in electric oven. Then we took 100 mg soil after cleaning all stones, dead parts of wood, leaves, fine roots etc. Then the soil was grinded by hand grinder and sieved through 250 mm wire mesh. And finally, from each prepared sample we weighed 15 mg of soil by electric scale to analyze by NC analyzer to measure the percentage of soil organic carbon content of the sample. Before analyzing, NC analyzer was calibrated and standard sample size (15 mg) was determined. The average soil organic carbon content for each plot was then calculated.

2.6. Determination of Soil Bulk Density And Soil Organic Carbon Content

We collected three soil samples from each plot by a 100 cm^3 core in days of the week when there was no rain. At sampling points, we cleared leaves, dead or decomposed wood parts and loose soil from forest floor before sampling. The soil cores were dried in electric oven for about 48 hours at 65 ^{0}C till the soil weights became constant. Then the dry weights were taken and the bulk densities of samples as well as their organic carbon contents were determined by the following equations:

Soil Bulk Density (gram / cubic centimeter) = dry weight / volume

Soil organic carbon (t/ha) = (% soil organic carbon) × (bulk density) × (soil depth in cm)

(Guo and Gifford 2002, Mann 1986)

2.7. Calculation of Wood Volume And Wood Carbon Content

We calculated sectional volumes of wood (including bark) for each section from base point (0.3m) to 1.37 m, 1.37 m to 3.3 m, and so on. One meter interval was used only till breast height and then, 2 m interval was used onward. The basal area for each section was calculated by the equation πR^2, where R is the radius of the section. Then the average basal area for each section was calculated by the following equations:

$$\text{Average Basal area} = \pi\sum(R^2_i + R^2_{i+1})] / 2$$

$$\text{Volume} = \pi R^2_i H_j$$

Where, π=3.1416 , R_i is radius at 'i' height

H_j is length of section 'j' between i^{th} and $(i+1)^{th}$ radius measuring points

We calculated the volumes of the top-most secctions of trees, for which, sometimes, the radius cannot be measured, as;

Volume= Basal area at last (top) diameter × length of the portion to top of the tree × 0.3
(Here, factor 0.3 is used assuming conical shape of top portion of the tree)

Wood biomass was then calculated by multiplying the wood volume with their respective wood densities *i.e.* dry wood volume.

Wood carbon content = Dry wood volume × 0.5

(Shin *et al*., 2007; WB, 1998; McDicken, 1997)

Underground biomass was calculated as 15% of the above ground biomass (MacDicken, 1997). For measuring leaf carbon content we used the same equation of wood carbon content because carbon content is 50 % of dry weight of biomass. The sum of above and below ground biomasses gave the total biomass of the sampled trees from which we obtained biomass for the stand.

2.8. Statistical Analysis

Carbon content of individual tree and soil carbon content were normally distributed. Standard errors were calculated for every component of carbon stock like wood, soil and fallen leaves in the forest stand. MS Excel and SPSS 20.0 were used to analyze the data

3. Results and Discussion

In Oaota forest, we found 14 different tree species. Among them, the highest diameter was for *Quercus acutissima* and the minimum diameter was for *Carpinus tschonoskii* and *Styrax japonica*. *Quarcus acutissima* attained the maximum height while *Cryptomeria japonica* showed the minimum height growth.

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Table 1: Descriptive statistics for diameter and height of different species in Oaota forest

Name of species	No. of observations	Diameter (cm)				Height (m)			
		Mean	Max	Min	St.dv.	Mean	Max	Min	St.dv.
Cryptomeria japonica (L. fil.) D. don	15	21.6	27.1	13	4.4	14.7	17.5	3.1	3.6
Quercus serrata Thunb. Ex Murray	22	24.2	36.3	5.9	8.7	17.3	21.9	5.8	4.4
Styrax japonica Sieb. Et Zucc.	7	6.3	8.1	5	0.3	5.6	7.96	4.1	1.4
Carpinus tschonoskii Maxim	41	14.6	37	5	9.3	13.8	21.7	6.2	4.8
Swida controversa (Hemsl.) Sojak.	16	21.9	29.4	15.2	4.3	16	19.2	14.5	1.2
Chamaecyparis obtusa (Sieb. Et Zucc)	21	17.4	27	10.2	4.6	14.7	20.7	10.6	2.7
Quercus acutissima Carruthers	16	27.3	41.5	18.9	6.4	19.3	22.4	15.1	2.2
Quercus myrsinaefolia Blume	2	13	21	5	11.3	10.4	16.4	4.5	8.4
Castanopsis sieboldii (Makino) Hatusima ex	1	-	5.1	-	-	-	5.6	-	-
Magnolia kobus DC	1	-	10.5	-	-	-	12.1	-	-
Prunus grayana Maxim	1	-	10.5	-	-	-	11.4	-	-
Prunus buergeriana Miq.	1	-	10.5	-	-	-	11.3	-	-
Prunus jamasakura Sieb. Ex Koidz.	2	22.3	29.5	15.2	10.1	15.7	15.8	15.6	0.1
Seltis sinensis Pers.	1	-	11.5	-	-	-	8.47	-	-

3.1. Present Biomass Stock at Oaota Forest

In Oaota forest, among 14 available tree species, NF site showed the presence of *Quercus serrata*, *Carpinus tschonoskii*, *Cryptomeria japonica*, *Styrax japonica*, *Seltis sinensis*, *Quercus acutissima*, *Prunus grayana*, *Prunus buergariana* while at PF site the available species were *Swida controversa*, *Chamaecyparis obtusa*, *Quercus serrata*, *Castanopsis sieboldii*, *Carpinus tschonoskii*, *Quercus myrsinaefolia*, *Cryptomeria japonica*. NF site was dominated by the genus *Quercus* while at PF site the dominant species were *Chamaecyparis obtusa*, *Carpinus tschonoskii*, *Swida controversa* and *Cryptomeria japonica* (Figure 4 and Figure 5). *Quercus serrata* showed the largest diameter and height in NF site. The total wood volume of *Quercus serrata* in plot NF-1 and *Quercus acutissima* in NF-2 were 9.37 $m^3/400m^2$ and 9.04 $m^3/400m^2$ (Table 2) respectively which indicated that *Quercus serrata* and *Quercus acutissima* were highly productive in NF than PF site in Oaota forest.

On the other hand for plantations, at plot PF-1, the highest relative density was for *Chamaecyparis obtusa* (54%) followed by *Carpinus tschonoskii* (34%). *Swida controversa* showed maximum density (40 %) followed by *Cryptomeria japonica* (37 %).

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Wood volume production was the highest for *Swida controversa* (0.44 m^3/tree/400m^2) followed by *Prunus jamasakura* (0.42 m^3/tree/400m^2) *Carpinus tschonoskii* (0.38 m^3/tree/400m^2) etc (Table 3) at PF-1 and PF-2 sites.

According to Figure 4 and Figure 5, it was evident that 'Oaota forest' is mainly dominated by *Quercus serrata, Quercus acutissima, Chamaecyparis obtusa, Cryptomeria japonica, Carpinus tschonoskii and Swida controversa.* It was also said by previous study in Japan that the characteristic species in Satoyama forest is dominated by deciduous Oak like *Quercus serrata* and *Quercus acutissima* (Terada *et al*. 2010).

Table 2: Above ground biomass stock of different species in experimental plots (20 m × 20 m)

Plot	Species Name	Number of trees	Avg DBH (cm)	Avg Ht(m)	Total BA (cm^2)/400m^2	Total vol (m^3)/400m^2
NF-1	*Quercus serrata*	18	26.96	18.71	10944.76	9.376662
	Carpinus tschonoskii	3	19.90	16.02	1144.68	1.033215
	Cryptomeria japonica	1	13.00	3.10	132.73	0.012344
	Styrax japonica	6	6.36	5.22	195.74	0.030427
	Seltis sinensis	1	11.50	8.47	103.87	0.026393
Total		*29*			*12521.78*	*10.47904*
NF-2	*Quercus acutissima*	16	27.33	19.38	9880.64	9.043101
	Quercus serrata	3	10.56	9.61	264.42	0.075739
	Carpinus tschonoskii	22	8.85	10.50	2091.03	1.266774
	Prunus buergeriana	1	10.50	11.30	86.59	0.029354
	Prunus grayana	1	10.50	11.38	86.59	0.029562
	Chamaecyparis obtusa	1	27.00	14.50	572.56	0.338276
	Styrax japonica	1	6.30	7.96	31.17	0.007444
	Magnolia kobus	1	10.50	12.10	86.59	0.031432
Total		*46*			*13099.59*	*10.82168*
PF-1	*Swida controversa*	1	27.20	16.20	581.07	0.442264
	Chamaecyparis obtusa	19	16.87	14.81	4514.32	3.192263
	Quercus serrata	1	16.10	15.50	203.58	0.149337
	Castanopsis sieboldii	1	5.10	5.60	20.43	0.003432
	Carpinus tschonoskii	12	22.77	19.20	5298.06	4.655332
	Quercus myrsinaefolia	1	5.00	4.50	19.64	0.002651
Total		*35*			*10637.10*	*8.445279*
PF-2	*Swida controversa*	15	21.54	16.08	5670.56	4.163826
	Chamaecyparis obtusa	1	18.50	12.90	268.80	0.170849
	Carpinus tschonoskii	4	17.87	15.15	1119.93	0.811681
	Cryptomeria japonica	14	22.24	15.55	5591.92	4.137364
	Prunus jamasakura	2	22.35	15.70	864.95	0.854405
	Quercus myrsinaefolia	1	21.00	16.40	346.36	0.247102
Total		*37*			*13862.52*	*10.38523*

(For scientific names; Hara *et al*., 1989)

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Table 3: Characteristics of tree species and respective wood volume in the experimental sites of Oaota forest.

Plot	Species Name	Type of Species	Wood vol/tree/plot (m^3/400 m^2)
NF-1	*Quercus serrata*	Deciduous, BL	0.520926
	Carpinus tschonoskii	Deciduous, BL	0.344405
	Cryptomeria japonica	Coniferous, EG	0.012344
	Styrax japonica	Deciduous,BL	0.005071
	Seltis sinensis	Deciduous,BL	0.026393
NF-2	*Quercus acutissima*	Deciduous, BL	0.565194
	Quercus serrata	Deciduous, BL	0.025246
	Carpinus tschonoskii	Deciduous, BL	0.057581
	Prunus buergeriana	Deciduous,BL	0.029354
	Prunus grayana	Deciduous,BL	0.029562
	Chamaecyparis obtusa	Coniferous, EG	0.338276
	Styrax japonica	Deciduous,BL	0.007444
	Magnolia kobus	Deciduous,BL	0.031432
PF-1	*Swida controversa*	Deciduous,BL	0.442264
	Chamaecyparis obtusa	Coniferous, EG	0.168014
	Quercus serrata	Deciduous, BL	0.149337
	Castanopsis sieboldii	Coniferous,EG	0.003432
	Carpinus tschonoskii	Deciduous, BL	0.387944
	Quercus myrsinaefolia	Evergreen,BL	0.002651
PF-2	*Swida controversa*	Deciduous,BL	0.277588
	Chamaecyparis obtusa	Coniferous, EG	0.170849
	Carpinus tschonoskii	Deciduous, BL	0.202920
	Cryptomeria japonica	Coniferous, EG	0.295526
	Prunus jamasakura	Deciduous,BL	0.427203
	Quercus myrsinaefolia	Evergreen,BL	0.247102

BL=Broad Leaved, EG=Ever Green

3.2. Intensity of Leaf Fall on Forest Floor

The maximum leaf fall occurred during the time of November to December (Figure 4). Oaota forest produced 137.80 tonne of leaves at the rate of 3.281 tonne / ha during the winter. Experiment on leaf fall in Oaota forest resulted that the leaf shading starts from early October and completes at December during which intensive leaf fall occurred in the month of November. Leaf fall of *Quercus serrata* stand increases during the month of October (Watanabe and Yogi, 1984). It was observed that the weight oleaves of different species in NF site were higher than those of different species in PF site (Figure 6). Most of the species in NF site were broad leaved species whereas coniferous species were abundant in NF site.

3.3. Present Carbon Stock Potential of Oaota Forest

Among different forms of carbon stored in Oaota forest, the highest amount of carbon (50.98 % of total carbon storage of the forest) was contained as soil organic carbon at the depth of 30 cm follwoed by above and below ground tree wood biomass including branches which was equivalent to about 3200.085 tonnes of carbon *i.e.*, 47.98 % of total carbon storage of the forest. Amount of carbon contained by tree leaves shed over a year in this forest contained a meager 1% of total carbon storage of the forest (*i.e.*, 68.67 tonnes of carbon). Carbon content of soil and wood did not varied significantly ($p<0.01$) but it

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showed significant variation with the carbon content of leafes ($p<0.01$).

Total carbon storage up to the study period at Oaota forest was equivalent to 6668.65 tonne (Figure 7).Generally the soil contains almost three times carbon than the above ground biomass (Eswaran *et al*., 1993). Because, soil carbon is stored in the soil for a long time and gradually it is also stored into the deeper layers of soil. In this study, we took only 0-30 cm soil depth to measure the organic carbon content of the soil, that is why the soil carbon did not show about three times higher carbon than wood carbon content.

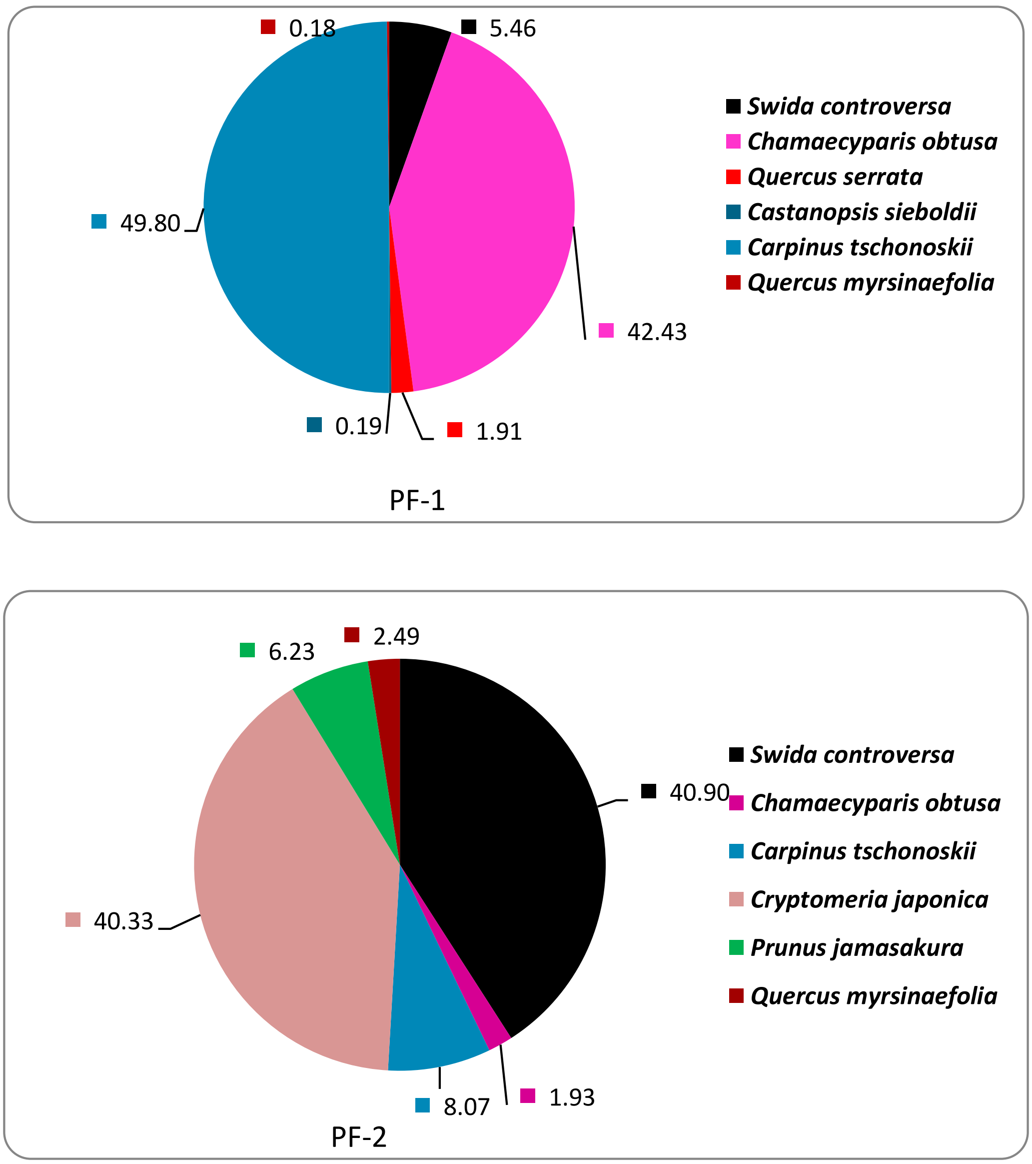

Figure 5: Dominant Species in Plantation Forest Site by basal area (%).

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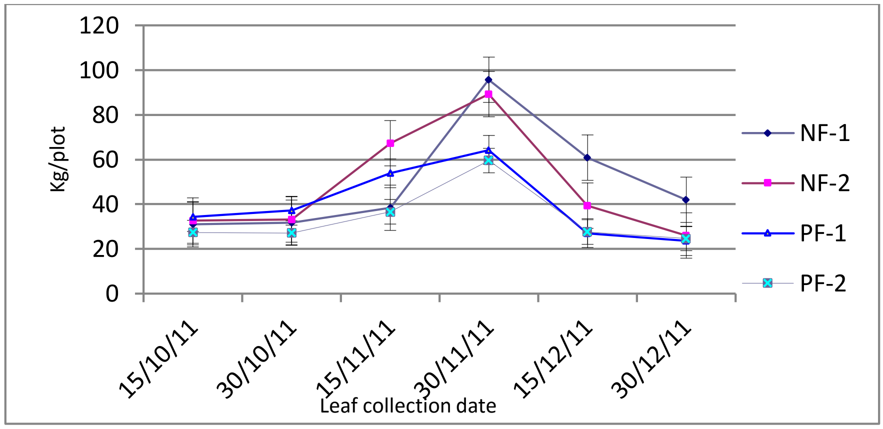

Figure 6: Intensity of Leaf Fall in Experimental Plots from October-December, 2011(Mean ±SE).

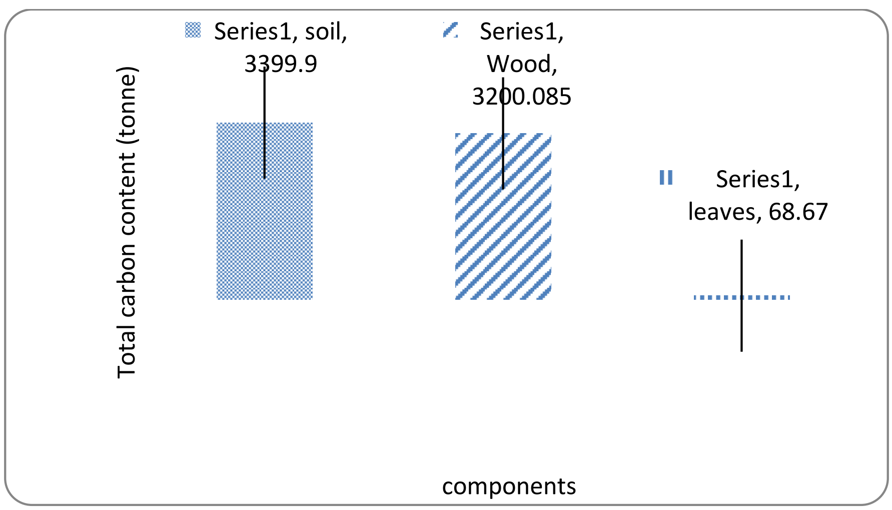

Figure 7: Total Carbon Stock by Oaota Forest in Soil, Wood Biomass and Leaves (Mean ± SE).

The Satoyama forests are one of the vegetation types in Japan with immense potential to contribute provisioning and regulatory ecosystem services to the local societies while contributing towards the global environmental sustainability. Current study on Oaota forest clearly showed the ability of this semi-natural forest ecossytem to offer goods and services to the local society by providing carbon neutral wood biomass energy as an alternative fuel and natural green landscape as recreational facility. In comparison to the PF site in Oaota forest which is dominated by *Chamaecyparis obtusa* and *Cryptomeria japonica* showed wood volume accumulation as 42.0 m^3/ha and 51.71 m^3/ha respectively while the tree density of *Chamaecyparis obtusa* and *Cryptomeria japonica* were 250 tree / ha and 175 tree / ha respectively; which, may be due to remaining unmanaged for a long time in the Satoyama forest areas.Thinning potentially enhances biodiversity as well as increases tree-growth rates in overstocked *Cryptomeria japonica* plantations (Hiroaki *et al.*, 2008). Management interventions like thinning,

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pruning may enhance the growth of trees in the abandoned Satoyama forests which may potentially contribute to increase carbon stock in Japan. The role of Oaota forest as a potential carbon stock, resulted on carbon content of wood stored into the standing trees, carbon content of fallen leaves and soil organic carbon measurement showed that the total carbon content in Oaota forest was 6668.65 tonne contributing soil as the highest sector to store more carbon than wood biomass or leaves. Wood biomass stored carbon 76.19 t / ha in Oaota forest. It was found that agroforestry in the Western Ghats (WG) of peninsular India and Satoyama in rural Japan are traditional systems and carbon stocks of sampled homegarden in WG ranged from 16 to 36 t / ha while in Satoyam woodland showed varying carbon stock 2 to 279 t / ha (Kumar and Takeuchi, 2009).Therefore, the Satoyama forests need to be managed by intervening silvicultural activities like thinning, pruning etc so that the growth of the species could be stimulated and carbon stock potential of Satoyama forests could be increased. On the other hand, the harvested wood biomass could be used as alternative of fossil fuel reducing carbon emission into the atmosphere.

4. Conclusions

In the last two decades, the Satoyama forests in Japan had become important to the national government and local people, especially to NPOs as a means to revitalize the natural ecosystem. The central government of Japan also took initiatives like Biomass Nippon Strategy to introduce biomass utilization in the society and also to conserve the biodiversity. Previous research on Satoyama forests focused mainly on maintenance of these forests through biomass utilization (Terada *et al*., 2010). From the discussion above it was evident that the Oaota forest, a semi-natural Satoyama forest, showed tappable potential to contribute to biomass fuels supply and environmental amelioration for the local and global environment. As the forest remained abandoned for long time without silvicultural activities such as thinning, pruning etc., the biomass accumulation in species of this forest lagged far behind compared to those of hill forests in Japan. Study on 80 years old *Chamaecyparis obtusa* plantation forest showed wood volume accumulation was less than 600 m^3/ ha while for *Cryptomeria japonica* it was greater than 600 m^3/ha although these two species are slow in growth (Fukuda *et al*., 2003). PF site in Oaota forest which was dominated by *Chamaecyparis obtusa* and *Cryptomeria japonica* showed less wood volume accumulation than other managed plantation forests of Japan. If Satoyama forest is properly managed, this low biomass accumlation issue can be addressed. Therefore, in this Oaota forest, management strategy focusing to the high growth of species in both natural and plantation site can play significant role to increase wood production of the stand and subsequently store more atmospheric carbon di-oxide contributing to environmental sustainability. Extraction of wood by thinning and collecting branches, leaves for local use can also help revitalization of Satoyama forest.

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