Potential plant biomass estimation through field measurement and vegetation cover mapping using ALOS satellite imagery: Case study of Fujiyoshida City, Japan

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Abstract. Biomass is a renewable energy source that is produced from living or recently living biological material. Vegetation type and biomass are considered important components that affect biosphere-atmosphere interactions. The ground assessment of biomass, however, has been found to be insufficient due to the limited spatial extent of surveys. This study aims to integrate field measurements with satellite remote sensing data for regional biomass mapping in Fujiyoshida City, Japan. Fujiyoshida City is situated on the northern slope of Mt. Fuji and includes a large area of forest land, named “Onshirin Forest”. From 2011 to 2012, a field survey was conducted to calculate the biomass potential in situ as ground-truthed data. After fieldwork, ortho-rectified ALOS data with an AVNIR-2 scene (22 May 2008) was used to map the vegetation cover types. Japanese larch, Japanese red pine, mixed forest, other forest, grass, bare soil and roads, and buildings were identified using supervised classification. The total plant biomass was 163,252 tons. The biomass potential estimate from field measurements was extrapolated to the large forest area in Fujiyoshida City to estimate the potential plant biomass of specific vegetation cover types.

1. Introduction
Biomass is a renewable energy source that is produced from living or recently living biological material. Vegetation type and biomass are considered important components that affect biosphere-atmosphere interactions [1]. The ground assessment of biomass, however, has been found to be insufficient due to the limited spatial extent of surveys, especially in areas with complex forest structures and environmental conditions [1, 2]. While these traditional techniques are more accurate than new approaches, they are often labor-intensive and time-consuming. Through remote sensing, a sensor mounted on an aircraft or satellite platform measures and records energy and images, which can be used to construct a comprehensive understanding of the landscape beneath the platform [3]. Remote sensing offers a cost- and time-effective solution for the rapid and accurate assessment of biomass.

As part of an eight-year environmental sustainability plan, the Japanese city of Fujiyoshida committed to increasing its use of renewable energy. A significant part of the city is comprised of forestland that is regularly cut according to traditional land management techniques—in 2011, the
Onshirin Regional Public Organization felled trees on approximately 11,000 m$^3$. Onshirin Regional Public Organization manages a vast forest, called “Onshirin Forest”, which covers 12,558 hectares. The city has been seeking non-intrusive and efficient measurement techniques to measure the potential biomass energy that the entire forest holds in an effort to calculate the forest’s value to the city’s energy plan.

This study aims to demonstrate methods that can be used to calculate the regional forest biomass by integrating field-surveyed data and satellite remote sensing data in a case study of Fujiyoshida City, Japan.

2. Methods

2.1. Study area
Fujiyoshida City is located on the northern slope of Mt. Fuji in Yamanashi prefecture, Central Japan. Our field site (approximately 138°45' to 138°49' E and 35°26' to 35°28' N, Japanese Geodetic Datum 2000, Figure 1) mainly consists of forested areas of the Onshirin Forest. The vegetation types are mainly coniferous forest, either Japanese red pine (Pinus densiflora) or Japanese larch (Larix kaempferi). Other forest types are broadleaf or mixed broadleaf-coniferous forest.

![Figure 1. The study area of Fujiyoshida City. Note. The band combination is RGB:321, a true color composite of ALOS data. The numbers correspond to Table 1 and indicate the ID of strata where the field survey was conducted.](image)

2.2. Field survey
From 2011 to 2012, a field survey was conducted to calculate the biomass potential in situ as ground-truthed data. In total, seven strata were established (Table 1; S1 to S4 were surveyed in 2011 and S5 to S7 were surveyed in 2012; Figure 1). In each stratum, a 20 m x 20 m quadrant was constructed and then divided into 10 m x 10 m sub-quadrants. Inside each sub-quadrant, all trees were marked, and tree height and diameter at breast height (DBH) were measured. GPS coordinates at all corners and intersections of the sub-quadrants were recorded.

2.3. Satellite image classification
Advanced Land Observing Satellite (ALOS) data were used to classify vegetation cover types. From an ortho light product of ALOS data with the AVNIR-2 sensor (Scene ID: ALAV2A123842880, Process level: 1B2R, date: 22 May 2008), the area of Yamanashi Prefecture was processed using ENVI 4.8 for the image analysis. The AVNIR-2 sensor has four bands: band 1 at 0.42-0.50 µm (blue), band 2 at 0.52-0.60 µm (green), band 3 at 0.61-0.69 µm (red), and band 4 at 0.76-0.89 µm (near-infrared). The spatial resolution is 10 m. One scene was clipped to cover the sufficient area of the field.
site in Fujiyoshida City (Figure 1). The ALOS data were trained using the plot analysis of the mean DN value and a scatter plot. The maximum likelihood method was applied using supervised classification, and accuracy was assessed using a confusion matrix.

2.4. Biomass calculation

In general, biomass includes the above- and below-ground living mass [2]. For this study, only above-ground biomass (AGB) was estimated. For the Japanese red pine and mixed forests of the Japanese red pine trees and broadleaf trees, the trunk volume $V$ (cubic meters) was estimated using the Stem Volume Calculation program (Kanzaiseki-keisan-puroguramu) [4]. This program calculates the trunk volume based on the measured DBH (in centimeters) and measured tree height $H$ (in meters), using a stand volume table published by the Forestry Agency in Japan. For Japanese larch, stem volumes of $170.0 \text{ m}^3/\text{ha}$ and $124.3 \text{ m}^3/\text{ha}$ were used for unthinned and thinned sites [5], respectively. Although the true percentages are unknown, the proportion of unthinned and thinned sites was assumed to be 40% and 60%, respectively. Next, the above-ground tree volume was converted to AGB using the dry-matter densities of $0.314$, $0.444$, and $0.563 \text{ g/cm}^3$ for Japanese red pine, Japanese larch, and broadleaf trees, respectively [6]. Because the satellite classification used in this study could not differentiate the broadleaf forest clearly, we adopted a dry matter density of $0.438 \text{ g/cm}^3$ ($=(0.314 \times 0.563)/2$; mean of red pine and broadleaf) for the mixed forest of Japanese red pine and broadleaf trees. For the other forest type, a dry matter density of $0.440 \text{ g/cm}^3$ ($=(0.314 + 0.444 + 0.563)/3$; mean of Japanese red pine, Japanese larch, and broadleaf tree densities) was applied because this forest type was assumed to be a mix of Japanese red pine, Japanese larch, and broadleaf trees. The dry-matter density of Japanese lawn grass (Zoysia japonica), $500 \text{ g/m}^2$ [7], was used for grass. After calculating the tree volume and biomass potential for individual trees, the cumulative tree volume and cumulative biomass potential were derived by summing the above values for individual strata. Finally, the areas of the vegetation classes from satellite image classification were multiplied by the above-calculated biomasses to calculate the biomass potential for vegetation types in Fujiyoshida City. We used R version 2.14.0 and Microsoft Excel 2010 as software for analysis.

3. Results

3.1. Field survey

A total of 258 individual trees were surveyed. The mean values of DBH, mean values of tree height, and tree density were measured in the field, while the cumulative tree volume and cumulative biomass potential were calculated (Table 1). The sample numbers for the seven strata were the same as those used for the tree density (/400 m$^2$). The mean DBH ranged from 12.96 cm to 29.86 cm for mixed forest and 25.91 cm to 38.64 cm for the Japanese red pine forest. Among those, the biomass potential of stratum IDs S3 and S4 were relatively higher ($9,479.826 \text{ kg/400 m}^2$ and $9,435.111 \text{ kg/400 m}^2$, respectively). The mean of cumulative biomass potential for the Japanese red pine forest and mixed forest was $7,806.395 \text{ kg/400 m}^2$ and $5,088.685 \text{ kg/400 m}^2$, respectively.

Table 1. Biomass calculation for seven strata based on the field-surveyed data. Note. Mixed forest denotes a mixed forest of Japanese red pine trees and broadleaf trees. Japanese red pine forest denotes the homogeneous pure Japanese red pine forest.

| Stratum ID: forest type | Mean DBH (cm) | Mean tree height (m) | Tree density (/400 m$^2$) | Cumulative tree volume (m$^3$/400 m$^2$) | Cumulative biomass potential (kg/400 m$^2$) |
|------------------------|--------------|----------------------|---------------------------|----------------------------------------|------------------------------------------|
| S1: Mixed forest       | 29.73        | 16.42                | 24                        | 19.72                                  | 6714.781                                 |
| S2: Mixed forest       | 29.86        | 17.79                | 30                        | 23.55                                  | 7722.835                                 |
| S3: Japanese red pine forest | 25.91      | 20.67                | 53                        | 30.19                                  | 9479.826                                 |
| S4: Japanese red pine forest | 38.64      | 26.33                | 23                        | 30.04                                  | 9435.111                                 |
| S5: Japanese red pine forest | 31.29      | 16.19                | 24                        | 14.35                                  | 4504.248                                 |
| S6: Mixed forest       | 22.85        | 8.76                 | 41                        | 14.48                                  | 4549.244                                 |
| S7: Mixed forest       | 12.96        | 7.11                 | 63                        | 4.35                                   | 1367.882                                 |
3.2. Satellite image classification

The mean DN values for seven classes of Japanese red pine forest, Japanese larch forest, mixed forest of Japanese red pine trees and broadleaf trees, other forest, grass, bare soil and roads, and buildings were analyzed (Figure 2). Spectral characteristics of bare soil and roads, buildings, and other vegetation covers were differentiated easily. However, the vegetation cover types such as the Japanese red pine forest, Japanese larch forest, mixed forest of Japanese red pine trees and broadleaf trees, other forest, and grass were distributed in similar ways for bands 1, 2, and 3. The distributional pattern of band 4 is distinguished among vegetation cover types, and hence, the use of band 4 was considered to be appropriate for mapping the vegetation cover using the ALOS data.

Overall accuracy was 97.2 %, and the Kappa coefficient was 0.96 (Table 2). The forest types such as the Japanese red pine forest, Japanese larch forest, mixed forest, and other forest were underestimated and often classified incorrectly as bare soil and roads or as buildings. However, most of the seven classes were classified correctly.

Based on the plot analysis of the mean DN value and scatter plot, the ALOS data were classified into seven classes of vegetation cover and land cover types (Figure 3).
3.3. Biomass potential estimation

The areas and proportions of the classified classes are presented with calculated biomass potentials (Table 3). The Japanese larch forest accounted for 37.85 % (8.16 km$^2$) of all classes, followed by bare soil and roads (16.76 %; 3.61 km$^2$). The Japanese red pine forest, mixed forest, and other forest constituted 10.17 % (2.19 km$^2$), 15.58 % (3.36 km$^2$), and 6.93 % (1.49 km$^2$), respectively. A total of 6.20 % (1.33 km$^2$) was grassland. In total, the biomass potential of vegetation in the study site was 163,252 tons. Among those, the Japanese larch had the largest amount of biomass potential (51,657 tons). The biomass potentials for Japanese red pine forest and mixed forest of Japanese red pine trees and broadleaf trees were almost the same, at approximately 42,740 tons. The biomass potential for other forest was 25,445 tons. The smallest amount of biomass potential was recorded in the grassland (665 tons).

Table 3. Biomass estimation for the forest types of Fujiyoshida City

| Vegetation          | Area (km$^2$) | Proportion (%) | Biomass (kg/ha) | Total biomass for vegetation type (ton) |
|---------------------|--------------|----------------|-----------------|--------------------------------------|
| Japanese red pine   | 2.19         | 10.17          | 195,159.875     | 42,740.013                           |
| Japanese larch      | 8.16         | 37.85          | 63,305.520      | 51,657.304                           |
| Mixed forest        | 3.36         | 15.58          | 127,217.125     | 42,744.954                           |
| Other forest        | 1.49         | 6.93           | 170,775.000     | 25,445.475                           |
| Grass               | 1.33         | 6.20           | 5,000.000       | 665.000                              |
| Bare soil and roads | 3.61         | 16.76          | NA              | NA                                   |
| Buildings           | 1.39         | 6.48           | NA              | NA                                   |
| Total               | 21.53        | 100            | 561,457.520     | 163,252.746                          |

4. Discussion

Our study (Tables 1 and 3) revealed that (1) biomass potential per unit area (kg/ha) greatly depended on vegetation type, (2) Japanese larch had the largest total biomass potential (51,657.304 tons) compared to other vegetation types, and (3) the total biomass potential for our study site in Fujiyoshida was estimated to be 163,252.746 tons. Biomass estimation is crucial for the estimation of carbon emissions [1, 2], and biomass in general is useful as a source of renewable energy [8]. Due to the March 2011 Tohoku earthquake and the failure of the Fukushima Dai-ichi nuclear plant, there has
been a significant and growing awareness of the need for Japan to use more renewable sources of energy. From a regional perspective, this research is significant because it provides a scientific basis from which to promote the use of renewable energy in Fujiyoshida City and to suggest management solutions to the Onshirin Regional Public Organization for the effective use of forest thinning byproducts.

Our study proposes a new method to integrate field observations and remotely sensed data to estimate biomass at a regional scale. Our method has proven useful for classifying major forest types such as the Japanese red pine forest, Japanese larch forest, mixed forest of Japanese red pine trees and broadleaf trees, and other forest types (Overall accuracy = 97.2 %, Table 2, Figure 3). It revealed that band 4 (near-infrared band) of the ALOS data, with the AVNIR-2 sensor, was the most useful for separating vegetation cover types, as the other three bands showed similar distributions (Figure 2). This result indicates that the near-infrared band can detect the chlorophyll reflectance well. ALOS data have the advantage of being available for a reasonable price at a high spatial resolution of 10 m. Different approaches, e.g., field measurement, remote sensing, and GIS, have been applied for AGB estimation [2], but the combination of these approaches has not fully been tested. Our study finds that the integration of field measurements and remotely sensed data is powerful and applicable. Nevertheless, we should note that both measurements have limitations and advantages. Hence, it is important to validate satellite image classification based on ground truth data and to conduct field measurements in the Japanese larch forest, other forest, and grassland types, for which field surveys were not implemented in this study.

Acknowledgement
This research was conducted as a part of a class for the Graduate School of Media and Governance of Keio University and was funded by the International Program for Environmental Innovators, Keio University. We thank the leader of the Program, Dr. Wanglin Yan, for his generous support. We appreciate the kindness of the Onshirin Regional Public Organization for facilitating access to survey sites. We also thank Mr. Mikio Sugita of the Laboratory of Environmental Planning at the Yamanashi Institute of Environmental Sciences for technical advice regarding ALOS data and vegetation cover mapping. Finally, we wish to express our deep thanks to Mr. Kinji Mizukoshi, Fujiyoshida City officer, for providing coordination with local agencies and serving as a field guide.

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