**Assessment of Forest Ecosystem Services Using Unmanned Aerial Vehicles**

－Case study of a *Chamaecyparis obtusa* forest, Takayama, Japan－

**Abstract:** Creating 3D forest datasets has become relatively easy due to the development of the UAV (unmanned aerial vehicle) and SfM (structure from motion) techniques. These methods can cover a wider range of the forest utilizing a small number of people and for a low cost, with higher resolution (up to a several-centimeter scale) compared to conventional methods such as satellite images and aircraft-based LiDAR (Light Detection and Ranging) surveys. A variety of studies have focused on ecosystem service assessment (ESA); however, the number of ESA studies using UAVs is limited. The objective of this study was to develop a method to assess forest ecosystem service (ES) supply potential by using the UAV and SfM techniques. A planted forest of *Chamaecyparis obtusa* in Takayama City, Gifu Prefecture, Japan was selected for this study. Through the development of 3D datasets supported by a field survey, an ESA was conducted, comprising five ESs from regulating and supporting services.

**Keywords**: ecosystem services, forest, Japan, SfM, UAV

**INTRODUCTION**

Forests provide many benefits to human society, termed ecosystem services (ESs), which are classified into four categories according to the Millennium Ecosystem Assessment (MA, 2005). Several methods can be used to assess ESs, e.g., field surveys, ecological modeling, and remote sensing techniques using aircraft and/or satellite data. The scale of analysis for each method is different, so the most appropriate analysis method should be considered depending on the study objective. If the forest study area is relatively small or the study requires species-scale information, a forest field survey can be carried out, including tree height and DBH (diameter at breast height) measurements, vegetation species, and soil surveys (Yonekura et al., 2012). If the study area is large, aircraft and/or satellite images can be used. In addition, the resolution of data obtained by LiDAR (Light Detection and Ranging)—a remote sensing method— is high, with several-centimeter-scale spatial resolution (Yone et al., 2002). However, aircraft-based LiDAR surveys are expensive. As a result, satellite remote sensing datasets are frequently used for a variety of studies, for example, surface temperature (Honjo and Takakura, 1986) and vegetation (Takahashi et al., 2011) monitoring. However, the resolution of satellite remote sensing data is relatively low, with several-meter-scale spatial resolution. In recent years, the UAV (unmanned aerial vehicle) and SfM (structure from motion) method (UAV–SfM method) has been widely applied in many fields, including the construction and civil engineering sectors. Through the UAV–SfM method, 3D point cloud datasets can be obtained at relatively low costs. In addition, this method has seasonal flexibility (Albert et al., 2009; Dunford et al., 2009). Several studies have investigated the application of the UAV–SfM method to forest research (Tamura et al., 2015). However, the number of studies focusing on the assessment of ESs by the UAV–SfM method is limited. The objective of this study was to develop a method to assess forest ES supply potential by utilizing the UAV and SfM techniques.

**MATERIALS & METHODS**

*Study area*

The forest study site is located in Takayama City, Gifu Prefecture, Japan (36.012°N, 137.366°E) (Figure 1 (a)–(c)). The total area of the study site is approximately 0.81 ha. It is easy to distinguish land from trees in the UAV images because strength thinning was conducted in 2015. The main tall tree species in the forest site was *Chamaecyparis obtusa*, and *Cryptomeria* *japonica* and *Larix kaempferi* were also found. The other vegetation included mainly low trees and shrubs. In addition, bamboo grass and fallen trees—owing to thinning activities—still remained in some parts. A small stream flows down from the north-west to the south-east part of the site, below the tree crowns. The study site is located in a remote area so the volume of road traffic is very small.

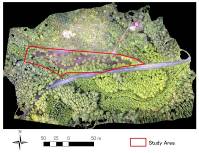
*Methods*

Firstly, aerial photographs were taken during several UAV flights. Secondly, based on the photos, a 3D point cloud dataset, orthophoto (vertical view for every position), and DSM (Digital Surface Model) were developed. Thirdly, basic forest information, such as tree height, crown area, and DBH, were estimated supported by a forest field survey. Finally, five ES supply potentials were calculated.

Figure 2 shows the Phantom 3 Professional (DJI) UAV used in this study. The flights were conducted over two days (September 21st and November 2nd in 2016) using the autopilot mode in the Map Pilot for DJI software (donesmadeeasy.com). The first and second days represented the leafing and autumn leaves stages, respectively. Different flight conditions were tested on each flight day (Table 1). Principally, the camera direction was set to be vertical; however, in the November flight, oblique photographs were also added. This enabled us to view the ground surface easily.

(a)

(b)



(c)

**Figure 1. Maps of the study area: (a) Gifu Prefecture in Japan; (b)** **Gifu Prefecture outlined in black, with the study area outlined in blue; and (c) the study area outlined in red**

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| --- | --- | --- | --- | --- |
| **Table 1. UAV flight conditions** | | | | **Figure 2. Phantom 3 Professional** |
| **Date** | **Photos**  **(Number)** | **AGL**  **(m)** | **weather** |
| September 21, 2016  4:00 PM - 5:00 PM | 129 | 80 | Cloudy |
| November 2, 2016  11:00 AM - 1:00 PM | 1029 | 40, 50, 60 | Sunny |
| Note: Camera direction in Sep.: Vertical,  : :in Nov.: Vertical (AGL 40m and 60m) ±30°(AGL 50m) | | | |

The forest field survey was conducted with the UAV flights. DBH measurements and species identification were conducted for 149 trees in the site on November 2nd, 2016. In addition, the heights of 25 trees selected from these 149 trees were surveyed on December 2nd, 2016. The average tree density in the study site before thinning was carried out was approximately 1100 trees per hectare, based on a pre-survey conducted in October 2015.

The 3D forest dataset as well as DSM and orthophoto were created using the software PhotoScan Professional 1.2.6 (Agisoft), as well as the DSM and orthophoto. To create the 3D point cloud dataset for the November flight, the quality parameter in PhotoScan was set to be “high”. Based on these data, several forest datasets were estimated (Table 2).

**Table 2. Forest data obtained from UAV and field surveys**

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| --- | --- | --- | --- | --- |
| **Data** | **Method** | **Data used** | **Software used** | **Assessed ES** |
| DTM | Visual identification | DSM (Nov.flight)  　Orthophoto (Nov. flight) | ArcGIS 10.4.1  (ESRI) |  |
| DCM | DSM－DTM | DSM (Sep. flight)  DTM | ArcGIS 10.4.1 | Climate regulation  Air purification |
| Tree top and height | Moving windows method | DCM | R software (Free software) |  |
| Tree crown area | Watershed method based on Persson et al.( 2002) | DCM  Tree top | rLiDAR of R software (Free software) | Water regulation |
| DBH | Single regression formula based on Takahashi et al. (2015) | DBH (by field survey)  Tree crown | Excel 2010  (Microsoft Co.) | Soil erosion |
| Stem volume | Inoue and Kurokawa (2001) formula | DBH  Tree height | Excel 2010 | Carbon stock |

Note: DTM: Digital Terrain Model, DCM: Digital Canopy Model.

A DTM (Digital Terrain Model) was made based on the visual identification of ground control points (GCPs) in the DSM and orthophotos from the November flight dataset. One or more GCPs were set in each 5 m × 5 m mesh and the points were interpolated using the Kriging tool in ArcGIS 10.4.1 (Esri). The November flight dataset was used to develop this DTM because of the high-quality photos, which could be used for easy identification of the GCPs. Next, a DCM (Digital Canopy Model) was calculated by extracting the DTM (November flight dataset) from the DSM (September flight dataset).

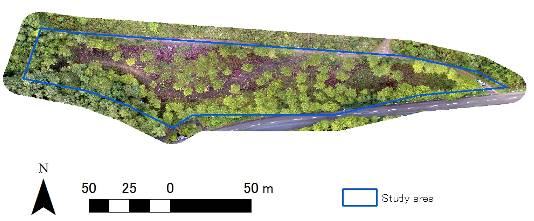
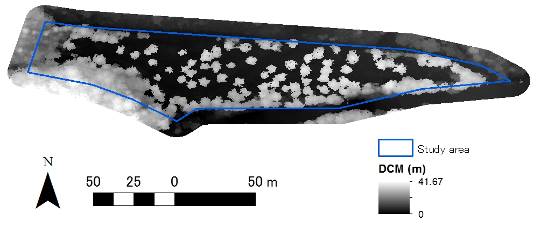
Then, the tree top location and height were estimated by using the moving window method in rLiDAR, which is a package of the statistical software R (Free Software). For the tree top extraction, firstly, smoothing of the DCM was conducted by utilizing a Gaussian filter to avoid extracting too many tree crown tops. Secondly, to select the tree top, the moving window method in rLiDAR was employed. The highest point in each moving window was identified as a tree top in the tree crown, which could be used to estimate the height of each tree.

Regarding the estimation of the tree crown area, the tree top location and height datasets were used with the DCM to divide the tree crowns by using the Watershed method (Persson et al., 2002) in the rLiDAR package of R software. The Watershed method is used to simulate the water flow from each tree top and to calculate the watershed shape in each tree.

In this study, DBH was calculated in Excel 2010 (Microsoft) by simple regression using the DBH measurements obtained in the field survey and the tree crown area. This was done because Takahashi et al. (2015) found a linear relationship between the DBH and the tree crown.

Finally, the stem volume was calculated by using the DBH and tree height datasets, based on a formula in Inoue and Kurokawa (2001). This formula was used because Ishida et al. (2012) showed that it produced good accuracy when applied to a *Chamaecyparis obtusa* and *Cryptomeria* forest in Gero City, Gifu Prefecture, which was located close to the study site.

In this study, five ESs were assessed. Each indicator was selected by referring to previous studies (Kobayashi et al., 2015). The carbon stock service (tC/ha) was estimated from stem volumes that were taller than 5 m in height and the estimated formula had expansion factor for roots, branch and leaves (National Institute for Environmental Studies, 2014). The forest volume (m3/ha), which was obtained from the DCM using the Surface Volume tool in ArcGIS, was set to be the indicator of the climate regulation service, in this case the heat-reduction effect, based on Hiruta and Ishikawa (2012). The tree crown surface area (m2/ha) was used as the air purification service indicator based on Tadaki (1990) which summarized the air purification functions of forest, such as CO2 absorption and contaminant absorption. These were related to the leaf area of trees. The tree crown surface area shows a relationship with leaf area (Itoh et al., 2008); therefore, the tree crown surface area from the DCM using the Surface Volume tool in ArcGIS was used in this study. The water regulation service was estimated by the crown coverage (%) calculated from the projection crown area datasets. This is because Yoshida and Hashimoto (1998) found a relationship between crown coverage and the flood-reduction effect. Finally, the soil erosion prevention indicator (kN/m2) was calculated using the DBH and tree density (Ministry of Agriculture, Forestry and Fisheries (MAFF), 2015).



(a)

(b)

(c)

**Figure 3. Results of analysis: (a) 3D point cloud (November flight); (b) Orthophoto (September flight), and (c) DCM**

**RESULTS & DISCUSSION**

Figure 3 (a)–(c) shows the 3D point cloud, orthophoto, and DCM results. Tree crown extraction accuracy was approximately 76%. Table 3 shows the results of the ES estimation. In this study, the DBH of each tree was estimated by using the tree crown area data, which could only be obtained from the UAV photo analysis. In addition, forest volume and crown surface area were used for the estimation of ESs.

**CONCLUSION**

In this study, five ESs were estimated using UAV-SfM data supported by a forest field survey. This showed the possibility of the future application of UAV-related datasets to forest ES assessment. However, several future issues remain. For example, it is difficult to obtain data from low tree layers using only UAV-RGB photos. Therefore, other tools and methods need to be considered. Also, an increase in the number of ES items studied is required in the future.

**Table 3. Results of the ES estimation**

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| --- | --- | --- | --- | --- |
| **ESs** | | **Indicators** | **Unit** | **Estimated value** |
| **Supporting Services** | |  |  |  |
| a) | Carbon stock | Carbon stock | (tC/ha) | 65.3 |
| **Regulating Services** | |  |  |  |
| b) | Climate regulation | Tree volume | (104m3/ha) | 07.8 |
| c) | Air purification | Surface area of crown | (104m2/ha) | 01.8 |
| d) | Water regulation | Crown coverage | (%) | 36.8 |
| e) | Collapse prevention | Collapse prevention power | (kN/m2) | 31.8 |

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