Assessment of Forest Ecosystem Services Using Unmanned Aerial Vehicles

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

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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 compared to conventional methods such as satellite images and aircraft-based LiDAR (Light Detection and Ranging) surveys. Many 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 four ESs from regulating and supporting services. This study showed usability of a UAV for ESA.

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 (Millennium Ecosystem Assessment (MA), 2005). Several methods can be used to assess ESs, e.g., field surveys, remote sensing techniques using aircraft and/or satellite data. The scale of analysis for each method is different, so an appropriate analysis method should be considered depending on the study objective. If forest area is relatively small or the study requires species-scale information, a field survey can be carried out, including tree height and DBH (diameter at breast height) measurements, species identification, and soil surveys. 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) 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 example, surface temperature estimation (Honjo and Takakura, 1986) and vegetation monitoring (Takahashi et al., 2011). However, the resolution of satellite data is relatively low, with several-meter-scale 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. 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). The UAV–SfM method has a possibility to complement the above mentioned methods. 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 ESAs 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

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 site is approximately 0.81 ha. A strength thinning was conducted in 2015. The main tall tree species in the site was *Chamaecyparis obtusa* with *Cryptomeria japonica*. The other vegetation included low trees and shrubs with bamboo grass and fallen trees by the thinning activities.

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, four 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 (Table 1) using the autopilot mode in the Map Pilot for DJI software (DRONES MADE EASY). 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.

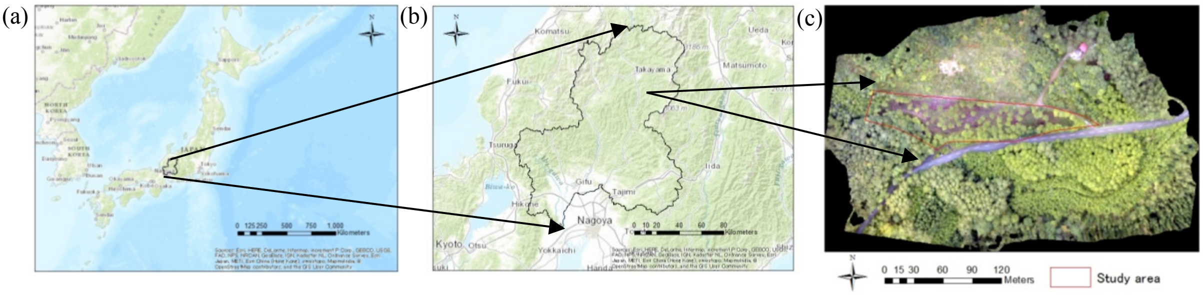

Figure 1. Maps of the study area: (a) Gifu Prefecture in Japan; (b) Gifu Prefecture outlined in black, with the study area; and (c) the study area outlined in red

Table 1. UAV flight conditions

Date	Photos (Number)	AGL(above ground level) (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)

Figure 2. Phantom 3 Professional

A field survey was conducted. DBH measurement and species identification were conducted for 149 trees on November 2nd, 2016. Then, the heights of 25 trees selected were surveyed on December 2nd, 2016 by a Laser range finder (Nikon Laser 550A S). The average tree density in the site before thinning was approximately 1100 trees per hectare, based on a pre-survey conducted by the land manager in 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).

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). Next, a DCM (Digital Canopy Model) was calculated by extracting the DTM from the DSM (September flight dataset).

Table 2. Forest data obtained from UAV and field surveys

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	Voronoi division method	DCM Tree top	rLiDAR of R software (Free software)	Water regulation
Stem volume	Inoue and Kurokawa (2001) formula	DBH Tree height	Excel 2010	Carbon stock

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

The tree top location and height were estimated by using the moving window method in rLiDAR ver. 0.1 on R ver.3.3.1 (Silva et al., 2015), which is a package of the statistical software R language (Free Software). For the tree top extraction, firstly, smoothing the DCM was conducted by utilizing a Gaussian filter by ArcGIS tool 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 voronoi division method in the rLiDAR of R software. In this method, Crown parts are divided by the sector of each tree top.

The DBH was calculated in Excel 2010 (Microsoft) by simple regression using the DBH measurements obtained in the field survey and the tree crown area based on Takahashi et al. (2015).

Finally, the stem volume was calculated by using the DBH and tree height datasets, based on a formula in Inoue and Kurokawa (2001). Ishida et al. (2012) showed that the formula produced good accuracy when applied to *Chamaecyparis obtusa* and *Cryptomeria japonica* in Gero City, Gifu Prefecture, which was close to the study site. In addition, forest volume and crown surface area were used for the estimation of ESs.

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. Four ESs were assessed (Table 3). Each indicator was selected by referring to previous studies (Kobayashi et al., 2016). 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 (m^3/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 (m^2/ha) was used as the air purification service indicator based on Tadaki (1990). 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. The water regulation service was estimated by the crown coverage (%) calculated from the projection crown area referring to Yoshida and Hashimoto (1998).

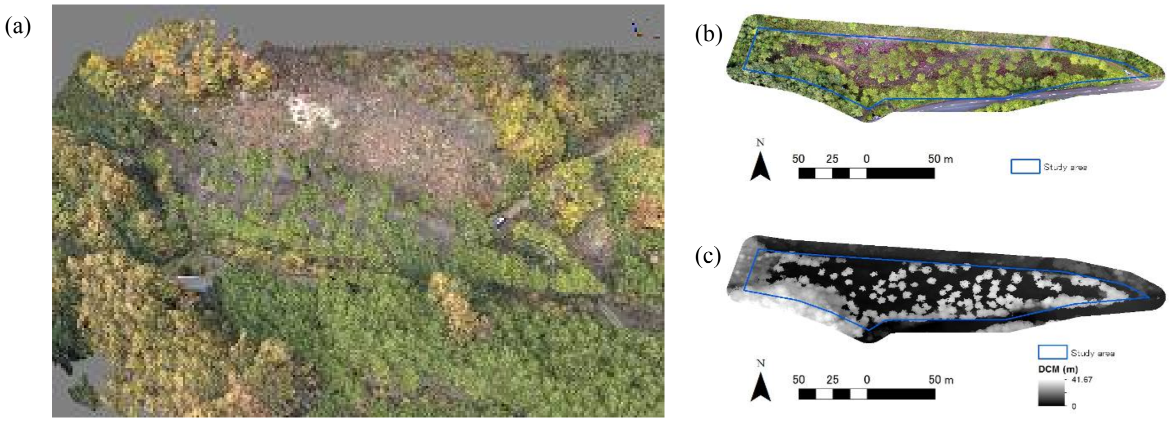

Figure 3. Results of analysis: (a) 3D point cloud (November flight); (b) Orthophoto (September flight), and (c) DCM

Table 3. Results of the ES estimation

ESs		Indicators	Unit	Estimated value
Supporting Services				
a)	Carbon stock	Carbon stock	(tC/ha)	65.3
Regulating Services				
b)	Climate regulation	Tree volume	($10^4 m^3$/ha)	7.8
c)	Air purification	Surface area of crown	($10^4 m^2$/ha)	1.8
d)	Water regulation	Crown coverage	(%)	36.8

CONCLUSION

In this study, four 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. These spatial high-resolution datasets can be got continuously with relatively low cost. Considering DTM, this method might be able to use in other planted forests if it is not so dense. 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, for example, near infrared radiation, laser scanning device. Also, an increase in the number of ES items is required in the future, such as, coverage of low tree layers, habitat.

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