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Estimating the annual carbon budget of a weekend tourist resort in a temperate secondary forest in Korea

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ABSTRACT

In this paper, we estimated the amount of carbon sequestered by and emitted from tourism activities related to the Oak Valley resort, a ski and golf resort located in a temperate secondary forest in the City of Wonju, Korea, in 2006. Annual carbon sequestration by a forest in the resort was estimated using discrete-return light detection and ranging (LiDAR) remote sensing data, and annual carbon emissions from the resort tourism were estimated using visitor survey and energy consumption data. The total annual carbon emissions from the resort tourism were estimated to be 8453 Mg C yr^{-1} (9.2 kg C yr^{-1} $visitor^{-1}$). Electricity consumption by resort facilities, fuel consumption for the transportation of resort visitors, and liquefied petroleum gas (LPG) and liquefied natural gas (LNG) consumptions for heating were the major sources of carbon emissions. The forest in the resort sequestered 6703 Mg C yr^{-1} (7.3 kg C yr^{-1} $visitor^{-1}$), which offset 79.3% of the total carbon emissions from the resort tourism activities. The resort tourism had the net carbon deficit of 1750 Mg C yr^{-1} (1.9 kg C yr^{-1} $visitor^{-1}$). From these results, we drew several policy implications for low carbon sustainable tourism.

Introduction

Tourism is one of the biggest contributors to global climate change. Tourism is by nature energy intensive because it usually takes place in a distant area that requires a long distance travel (Gössling, 2002; Martín-Cejas and Sánchez, 2010). According to the United Nations World Tourism Organization, the United Nations Environment Programme, and the World meteorological Organization (UNWTO-UNEP-WMO, 2008), tourism sector was responsible for 5% of the total anthropogenic carbon dioxide emissions.

The international community has recognized the impact of tourism activities on climate change. The Davos declaration is a well acknowledged international effort to promote low carbon sustainable tourism. In the Davos declaration, the international community calls for tourism sector to take a leadership in climate change mitigation by investing in energy-efficiency tourism programs, designing and operating carbon free environment, and conserving carbon sinks in tourism destinations through forest management (UNWTO-UNEP-WMO, 2008).

Assessing an accurate carbon budget is perhaps the first step toward low carbon sustainable tourism. Previous studies examined the carbon budgets of various tourism activities using different methods. Some studies assessed tourism-related carbon emissions at national levels. Dwyer et al. (2010) employed both production and expenditure-based carbon footprint analysis methods and found that the entire Australian tourism sector emitted 14.9–16.8 Tg C yr^{-1}. Using similar methods, Becken and Patterson (2006) estimated that the New Zealand tourism sector emitted 0.4–0.7 Tg C yr^{-1}. Other studies focused on carbon emissions from individual tourism activities or destinations. Dawson et al. (2010) estimated that polar bear viewing tourism in Churchill, Canada, released 5.7 Gg C yr^{-1} using visitor survey data, and Howitt et al. (2010) calculated that cruise ship tour from and to New Zealand emitted 14.3 Gg C yr^{-1}. Others include the amount of carbon sequestered in tourism destinations. Walz et al. (2008), for instance, assessed that forests and building materials in the Davos region, Switzerland, absorbed 4.0 Gg C yr^{-1}, which accounted for 17.7% of the total carbon emissions from this region. Adding carbon sequestration and emissions together, the Davos region was estimated to have a net carbon deficit of 25.9 Gg C yr^{-1} (Walz et al., 2008).

One of the difficulties in estimating tourism carbon budget is to quantify the amount of carbon sequestered by forests in tourism

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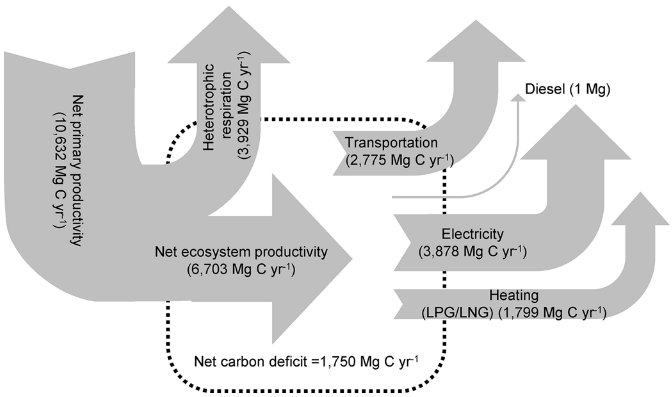

Fig. 1. Carbon budget of the Oak Valley resort tourism.

destinations. Light detection and ranging (LiDAR) remote sensing data, an active remote sensing system that transmits light to the ground and records backscattered energy, can be used to estimate the carbon budget of forests (Asner et al., 2010). Because the transmitted light either returns from tree canopy or penetrates it and returns from the ground, LiDAR data can be used to obtain canopy height and other physical properties of trees that can be derived from canopy height, such as biomass and carbon stock of trees (Lim and Treitz, 2004; Patenaude et al., 2004).

In this study, we present an annual carbon budget of tourism activities related to the Oak Valley resort, a weekend recreational resort located in a temperate secondary forest in Korea, using discrete return LiDAR remote sensing data with tree ring data. The carbon budget include both the amount of carbon sequestered by the forest in the resort and the amount of carbon emitted from different sources of energy consumptions related to the resort tourism (Fig. 1).

Study area

The study area is the Oak Valley resort, a recreational resort complex (37.41°N, 127.83°E) in the peri-urban area of the City of Wonju, Korea (Fig. 2). The 1224-ha resort consists of 6-km long ski slopes, 63-hole golf course, 1105-room condominium hotels, and a 958-ha forest. In each year, almost one million tourists visit

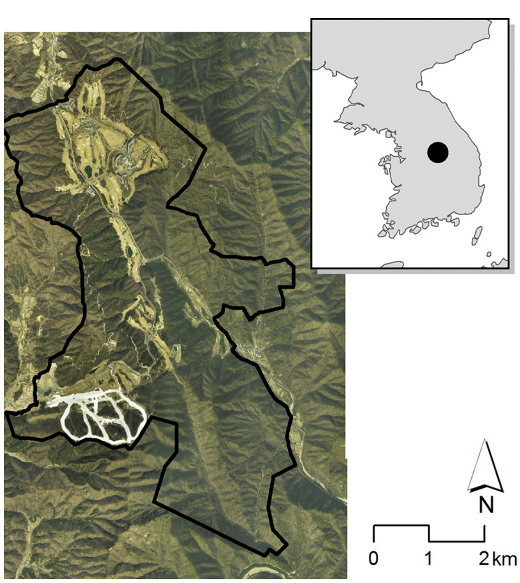

Fig. 2. Location of the Oak Valley resort.

the resort, 84% of which come from the Seoul metropolitan area, located 127 km east of the resort (Yoo et al., 2007). Foreign visitors are rare.

The Oak Valley resort was constructed in a steep mountainous region with an average slope of 52.5%. Forests in this region had long been harvested for fuel wood by local people, but were reforested in the 1970s as a part of a nationwide reforestation campaign. The reforestation was done by planting fast growing tree species, such as pitch pine (*Pinus rigida*), Korean pine (*Pinus koraiensis*), and black locust (*Robinia pseudoacacia*) (National Archives of Korea, 2013). Many other tree species also naturally grew in this region. Before the resort was built in the mid-1990s, the study area was covered by a secondary forest with a few patches of farmlands. The average annual temperature is 11.3 °C, and the average annual precipitation is 1344 mm, about half falling in two peak summer months of July and August (Korea Meteorological Administration, 2012).

Estimating carbon budget

The annual carbon budget of Oak Valley resort tourism was estimated by accounting for (1) the amount of carbon emitted from energy consumptions by resort facilities, (2) the amount of carbon emitted from transportation of visitors between their homes and the resort, and (3) the amount of carbon sequestered by the forest in the resort in 2006 (Fig. 1). The amount of carbon sequestered by the forest in the resort was estimated using discrete return LiDAR remote sensing data and tree ring data collected in the resort. The LiDAR data were processed following Lim and Treitz's (2004) and Patenaude et al.'s (2004) procedure. The detailed procedure is described in the next section (Fig. 3). The annual carbon budget was estimated for activities occurring within 2006, i.e., carbon emissions and sequestration that occurred before or after the budget year, such as removing existing trees and planting ornamental trees during the resort construction, were excluded from the analysis. The budget year 2006 was slightly wetter than normal. The mean annual temperature and annual precipitation in 2006 were 12.2 °C and 1561 mm, respectively (Korea Meteorological Administration, 2006).

Estimating forest carbon sequestration

Ground reference data collection

Ground reference data were collected at eighteen 10 × 10 m reference plots in 2003. Due to the logistics of data collection, the reference plots were randomly chosen within 100 m buffer from trails. The average slope of the eighteen reference plots was 52.9%, which was very similar to the average slope of the entire resort area, and aspects were evenly distributed. Diameters at breast heights (DBHs) were measured for all trees and shrubs within the plots. To estimate the amount of carbon sequestered by the forest in a year, cores of five sawtooth oaks (*Quercus acutissima*) and three Korean pines (*P. koraiensis*) randomly chosen from the 10-m reference plots were taken, and annual DBH growth (ΔDBH) equations were derived by fitting exponentially decaying curves to the tree ring data of sawtooth oaks (for hardwood) and Korean pines (for softwood). The coefficients of determination (R^2) of the fitted regression equations were 0.30 and 0.22 for hardwood and softwood, respectively, suggesting that there was a large yearly variation in DBH growth in the study area (Fig. 4). To incorporate this uncertainty into the analysis, the first and third quartile prediction intervals around the fitted curves were also derived to estimate the lower and upper bounds of ΔDBHs of trees in the resort.

Then, carbon stocks of all trees in the reference plots were estimated using allometric equations, species-specific equations for predicting carbon stock in tree biomass from DBH (Smith and