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Monitoring changes of forest canopy density in a temperature forest using high-resolution aerial digital photography

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Abstract. A multiannual series of high-resolution small-format aerial digital photography was employed to assess changes in the forest canopy density in a temperate forest. A combination of conventional and adapted techniques of photogrammetry and photo interpretation was used, establishing a specific method. This method has been proved in a twelve-year period (1999-2011) in the core zone of the Monarch Butterfly Biosphere Reserve, in the states of Mexico and Michoacán, in Mexico, employing orthorectified mosaics as base maps to evaluate biennial changes. Photographs were assessed through traditional photointerpretation marking changes on acetates, located over the paper prints, creating new polygons. These were transferred to the orthomosaic directly through the computer screen using the acetates and at least three control points, complying with the principle of radial triangulation. Forest was separated into the following canopy density classes: closed, semi-closed, semi-open, open, and deforested. Accuracy assessment in forest canopy density classification was estimated by field sampling, and employing error matrices being 95%. Since 2003, this method has been used to determine appropriate payment for environmental services. This payment together with an intense interaction with the communities has led to a reduction in forest degradation and deforestation in the core zone.

Key words: Forest monitoring, temperate forest, forest canopy density, high-resolution, small-format imagery, multitemporal assessment, aerial photographic series.

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Monitoreo de cambios en la densidad de cobertura forestal en bosque templado usando fotografías aéreas digitales de alta resolución

Resumen. Se utilizaron series multitemporales de fotografías aéreas digitales de alta resolución de pequeño formato para evaluar los cambios en la densidad de cobertura forestal en un bosque templado. Una combinación de técnicas convencionales y adaptadas de fotogrametría y fotointerpretación fueron utilizadas para establecer un método específico de evaluación. Este método ha sido probado en un periodo de doce años (1999-2011) en la zona núcleo de la Reserva de la Biosfera Mariposa Monarca, localizada en los estados de México y Michoacán, en México, usando mosaicos ortorectificados como mapas base para evaluar cambios bienales. Las imágenes fueron fotointerpretadas de manera tradicional marcando los cambios sobre acetatos, colocados sobre las imágenes impresas, creando así nuevos polígonos. Éstos fueron transferidos directamente de los acetatos al ortomosaico a través de la pantalla de la computadora, usando al menos tres puntos de control, cumpliendo así con el principio de triangulación radial. El bosque fue separado en las siguientes clases de cobertura forestal: cerrada, semi-cerrada, semi-abierta, abierta y deforestada. La evaluación en la exactitud en la clasificación de densidad de cobertura fue estimada a través de muestreos en campo, empleando matrices de confusión, siendo del 95%. A partir de 2003, este método ha sido utilizado para determinar el pago por servicios ambientales. Dicho pago, junto con una gran interacción con las comunidades, se ha traducido en una reducción en la degradación forestal y la deforestación en la zona núcleo de la Reserva.

Palabras clave: Monitoreo de bosques, bosque templado, la densidad de copas de los árboles, imágenes de alta resolución de pequeño formato, evaluación multitemporal, series aerofotográficas.

INTRODUCTION

Satellite imagery allows an efficient coverage of large areas, with easy integration of these remotely sensed data into geographic information systems (Wulder, 1998), however, this is not the only way to survey extensive zones. In the last two decades, small-format high-resolution imagery has been used also for large-area coverage in an efficient and cost-effective manner, surveying areas ranging from 1 200 to 2 200 km^2 with the main purpose of assessing natural resources (Prado *et al.,* 2006). In general, high-resolution imagery is suitable for many applications, although in some cases the large number of images to be processed could be a disadvantage, because a larger number of lines should be handled to generate an orthomosaic. Nevertheless, with higher spatial and temporal scales, the structure, diversity and function of an ecosystem can be better characterized (Wulder *et al.,* 2004), it is also useful in validation of land-cover maps and the interpretation of satellite data (Mas *et al*., 2002; Wulder *et al*., 2007). High-resolution imagery is particularly important in classification and assessment of changes in forest canopy density, and is a key indicator of possibly illegal logging (Azizi *et al.,* 2008), individual tree classification, estimation of species composition, and biophysical parameters of vegetation (Gougeon and Leckie, 2006; Pouliot and King, 2005; Wulder, 1998; Schlerf *et al., 2005*). Imagery with 1 m resolution is optimal for individual tree categorization; however, greater scales provide direct identification of species, and additionally, inclusion of texture analysis increases the accuracy of classification (Sugumaran *et al*., 2003; Gougeon, 1995; Laliberte and Rango, 2009; Levesque and King, 2003).

In recent years, new platforms and new systems, aerial and space based, have achieved greater spectral and spatial resolutions; even so, use of manned aircraft for aerial photography is highly flexible, with its option of stereo-pairs acquisition and its ability to establish all surveying parameters, such as pixel size on the ground, overlap, etc. (Booth and Tuller, 2003; Prado *et al*., 2006). Automated methods to assess forest canopy density have been developed, in most cases related to volume estimations, tree detection and counting, etc. These methods has improved on traditional expensive and time-consuming photointerpretation techniques (Leckie and Gillis, 1995), however, when no automated process or high-resolution satellite imagery is available, traditional photinterpretation methods remain an option. High-resolution and stereo-pairs