International Journal of Applied Earth Observation and Geoinformation 52 (2016) 371–379

Contents lists available at ScienceDirect

International Journal of Applied Earth Observation and Geoinformation

journal homepage: www.elsevier.com/locate/jag

Above ground biomass and tree species richness estimation with airborne lidar in tropical Ghana forests

Gaia Vaglio Laurin[a,d,*], Nicola Puletti[b], Qi Chen[c], Piermaria Corona[b], Dario Papale[a,d], Riccardo Valentini[a,d]

[a] Department for Innovation in Biological, Agro-Food and Forest Systems (DIBAF), University of Tuscia, Viterbo 01100, Italy
[b] Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria, Forestry Research Centre (CREA-SEL), Viale Santa Margherita 80, I-52100 Arezzo, Italy
[c] Department of Geography, University of Hawai'i at Mānoa, 422 Saunders Hall, 2424 Maile Way, Honolulu, HI, 96822, USA
[d] Impacts of Agriculture, Forests and Ecosystem Services Division, Euro-Mediterranean Center on Climate Change (IAFES-CMCC), via Pacinotti 5, Viterbo 01100, Italy

ARTICLE INFO

Article history:
Received 8 December 2015
Received in revised form 8 July 2016
Accepted 12 July 2016
Available online 19 July 2016

Keywords:
Biomass
Carbon monitoring
Lidar
Species richness
Tropical forests
West Africa

ABSTRACT

Estimates of forest aboveground biomass are fundamental for carbon monitoring and accounting; delivering information at very high spatial resolution is especially valuable for local management, conservation and selective logging purposes. In tropical areas, hosting large biomass and biodiversity resources which are often threatened by unsustainable anthropogenic pressures, frequent forest resources monitoring is needed. Lidar is a powerful tool to estimate aboveground biomass at fine resolution; however its application in tropical forests has been limited, with high variability in the accuracy of results. Lidar pulses scan the forest vertical profile, and can provide structure information which is also linked to biodiversity. In the last decade the remote sensing of biodiversity has received great attention, but few studies focused on the use of lidar for assessing tree species richness in tropical forests.

This research aims at estimating aboveground biomass and tree species richness using discrete return airborne lidar in Ghana forests. We tested an advanced statistical technique, Multivariate Adaptive Regression Splines (MARS), which does not require assumptions on data distribution or on the relationships between variables, being suitable for studying ecological variables.

We compared the MARS regression results with those obtained by multilinear regression and found that both algorithms were effective, but MARS provided higher accuracy either for biomass (R^2 = 0.72) and species richness (R^2 = 0.64). We also noted strong correlation between biodiversity and biomass field values. Even if the forest areas under analysis are limited in extent and represent peculiar ecosystems, the preliminary indications produced by our study suggest that instrument such as lidar, specifically useful for pinpointing forest structure, can also be exploited as a support for tree species richness assessment.

1. Introduction

The estimation and monitoring of tropical forests carbon is of great relevance for understanding the global carbon cycle and the effects of climate change on forest resources, as well as to fulfill the reporting requirements of international programs, such as the United Nations Reducing Emissions from Deforestation and Forest Degradation (REDD+) (Gibbs et al., 2007). In tropical countries, such as Ghana, where more than half of the forested areas are selectively logged and the anthropogenic pressure on forest resources is increasing (Hawthorne and Abu-Juam, 1995), carbon density data are needed at high spatial resolution, both for conservation purposes and for selective logging planning.

Forest monitoring is considered a difficult task in remote tropical regions: field surveys are resource demanding and very restricted in extent and frequency. Remote sensing can support the estimation and monitoring of forest resources upscaling the information coming from limited field data over much larger extents (Turner et al., 2003; Zolkos et al., 2013). However, in order to provide fine scale data able to capture the local variability, and thus useful for management purposes, the use of advanced instruments such as lidar (light detection and ranging) is recommended (Corona

* Corresponding author at: Department for Innovation in Biological, Agro-Food and Forest Systems (DIBAF), University of Tuscia, via San Camillo de Lellis s.n.c., Viterbo 01100, Italy.
E-mail address: gaia.vl@unitus.it (G. Vaglio Laurin).

http://dx.doi.org/10.1016/j.jag.2016.07.008
0303-2434/

2016). Lidar pulses penetrate the canopy and provide very detailed forest structure information in three dimensions, which is closely related to forest carbon content and habitat spatial heterogeneity (Asner et al., 2012).

Previous studies showed the usefulness of lidar for aboveground biomass (AGB) estimation in tropical forests (Asner et al., 2012; Asner and Mascaro 2014; Leitold et al., 2015), including in West Africa (Vaglio Laurin et al., 2014a; Chen et al., 2015). However, various reasons justify the need for additional research in the tropical biome. First, lidar has been much more tested in boreal than in tropical regions, for which the number of available literature is still limited. Moreover, in the tropics a high variability in the accuracy of the estimates, and often lower accuracies, has been observed (Zolkos et al., 2013). This variability can be attributed to the use of different instruments, field data and forest types, with more results needed to derive generalizations on best methods and expected accuracies. With the present research we aim at contributing in increasing the number of data useful to clarify limitations and advantages in tropical lidar-based AGB estimation.

Monitoring biodiversity is another urgent priority in tropical forest. Biodiversity has an irreplaceable value and its conservation is the objective of different international agreements and efforts, with 2011–2020 being the United Nations decade on biodiversity; it is an important function of forests and its preservation is critical in forest management. Tropical forests are one of the major repositories of biodiversity, increasingly threatened by human impacts and climate change (Chapin et al., 2000). These impacts are evident in West Africa, where only fragments of the original Upper Guinean forest belt, a hotspot of biodiversity that once entirely covered this region, remain (CEPF, 2003). Biodiversity can also directly influence carbon sequestration (Corona et al., 2011; Diaz et al., 2009; Strassburg et al., 2010). High variability exists in standing biomass and tree species diversity in tropical African forests (Day et al., 2013). Despite this variability, forests with a greater tree species diversity are likely to have higher biomass content, and therefore greater carbon storage: such evidence has been proved worldwide in tropical forests (Poorter et al., 2015), and distinctively reported for Africa (Vroh et al., 2015). Previous studies suggest that the biomass-diversity relationship is also influenced by different factors, including successional stage or disturbance level (Asase et al., 2012; Lasky et al., 2014). Data useful to clarify the relationship between biomass and tree species richness can have important forest management and policy implications, e.g. with respect to the assertion that UN-REDD schemes can provide significant co-benefits for biodiversity conservation.

In the last decade several studies have been directed toward estimating biodiversity with remote sensing data (Foody and Cutler 2006; Gillespie et al., 2008; Rocchini 2007); among the different diversity measures available, species richness was the most commonly adopted.

The majority of the previous studies used information derived from the optical spectral domain, and related to species foliar biochemistry variations or environmental heterogeneity. For instance, the variation in the spectral responses of optical images has been proposed as an indicator of plant species richness (Rocchini, 2007). Hyperspectral data are considered the most suitable tool to capture tree species diversity (Feret and Asner 2013; Nagendra and Rocchini, 2008), thanks to the ability to detect fine variations in biochemical foliar composition; they have been successfully used to estimate species richness in different vegetation types (Lucas and Carter 2008; Psomas et al., 2011) including in West African forests (Vaglio Laurin et al., 2014b). Measures of environmental heterogeneity derived from optical data have also been associated to the species richness of other taxonomic groups, such as bird (Tuanmu and Jetz 2015) and dung beetle (Aguilar-Amuchastegui and Henebry, 2007).

Active sensors, such as radar and lidar, can generate information on vegetation structure and topography. Specifically, lidar pulses penetrate the canopy and scan the forest from the canopy top down to the ground. Adding lidar to hyperspectral data, accurate classification at the species level has been obtained in different forest ecosystems, through the exploitation of both structural and spectral information (Asner and Martin 2008; Clark et al., 2005; Dalponte et al., 2012; Ghosh et al., 2014; Jones et al., 2010; Leutner et al., 2012; Zhang et al., 2016).

The use of lidar as single data for tree species classification has been tested with very few species, and methods usually relied on geometric and vertical distribution features used to detect differences in stems and crowns structure (Hovi et al., 2016; Holmgren and Persson, 2004; Ko et al., 2012; Korpela et al., 2010; Li et al., 2013; Vaughn et al., 2012). Innovative approaches for information extraction include the use of computational geometry, and the development of metrics related to texture, foliage clustering and gap distribution (Kent et al., 2015; Li et al., 2013; Vauhkonen et al., 2009). However, it has been noted that increasing the species number (over 4–5) is associated with a consistent loss in overall accuracy (Vaughn et al., 2012), making single species classification unfeasible in tropical areas, that are characterized by a large number of species.

Different authors suggested that lidar can be used to monitor biodiversity (Bergen et al., 2009; Dees et al., 2012; Gibson et al., 2011; Koch 2010; Turner et al., 2003). The potential of lidar to model animal biodiversity components, such as the assemblage and diversity of insects, spiders and birds have been previously investigated (Goetz et al., 2010; Mueller et al., 2009; Muller and Brandl 2009; Vierling et al., 2011). Tree species diversity is considered a good proxy for diversity of other taxonomic groups (Gentry 1988), and Bergen et al. (2009) suggested lidar as a useful proxy for species richness in forests with high vertical complexity. However, the use of lidar for tree species richness estimation has been tested in an exiguous number of studies. Successful results were obtained in marsh, meadow and woodland habitats in Mississippi (Lucas et al., 2010), in Mediterranean forests (Lopatin et al., 2015; Lopatin et al., 2016; Simonson et al., 2012), where lidar also outperformed hyperspectral data for species richness estimation (Ceballos et al., 2015); and in two tropical forest cases (Hernandez-Stefanoni et al., 2014; Wolf et al., 2012).

Lopatin et al. (2016) argued that lidar can be used to derive three types of information that interacts with plant species richness: micro-topographical, macro-topographical and canopy structural information. Macro-topography factors, such as elevation, aspect and slope, are related to climate and geomorphology, which are known to influence species distribution through the differentiation of soil, hydrology, illumination or temperature conditions. Micro-topography, such as local slope or roughness (also influenced by understory) can act as a proxy of small scale habitat structures, as in the case of shaded humid sinks or areas with deeper soils, which can accommodate peculiar species. Differences in canopy structure, such as height, leaf size and leaf orientation, lead to different canopy closure percentages and ground light conditions, and in turn influence species composition and richness. Stein et al. (2014) also supported this view, suggesting that biodiversity is positively influenced by environmental heterogeneity; while Gilbert and Lechowicz (2004) noted that variations in vegetation structure can lead to multiple niches and increased biodiversity, such as in the case of uneven forest stands.

We recognize that optimal results in species diversity estimation are obtained when both spectral and structural forest information is exploited (Turner, 2014; Vaglio Laurin et al., 2014b). However, based on the capability of lidar to inform on environmental heterogeneity, micro-habitats and forest height variability, and considering the encouraging results obtained by previous lidar-