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Using lightweight unmanned aerial vehicles to monitor tropical forest recovery

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ABSTRACT

Large areas of tropical lands are being removed from agriculture and restored to address conservation goals. However, monitoring the ecological value of these efforts at the individual land-owner scale is rare, owing largely to issues of cost and accessibility. Traditional field-based measures for assessing forest recovery and habitat quality can be labour intensive and costly. Here we assess whether remote sensing measurements from lightweight unmanned aerial vehicles (UAV) are a cost-effective substitute for traditional field measures. An inexpensive UAV-based remote sensing methodology, "Ecosynth", was applied to measure forest canopy structure across field plots in a 7–9-yr tropical forest restoration study in southern Costa Rica. Ecosynth methods combine aerial images from consumer-grade digital cameras with computer vision software to generate 3D 'point cloud' models of vegetation at high spatial resolutions. Ecosynth canopy structure measurements were compared to field-based measures and their ability to predict the abundance of frugivorous birds; key seed dispersers that are sensitive to canopy structure. Ecosynth canopy height measurements were highly correlated with field-based measurements ($R^2 \geqslant 0.85$), a result comparable in precision to LiDAR-based remote sensing measurements. Ecosynth parameters were also strongly correlated with above-ground biomass ($R^2 \geqslant 0.81$) and percent canopy openness ($R^2 = 0.82$). Correlations were weaker with proportion-based measures such as canopy roughness ($R^2 = 0.53$). Several Ecosynth metrics (e.g., canopy openness and height) predicted frugivore presence and abundance at levels of accuracy similar to those of field-based measurements. Ecosynth UAV remote-sensing provides an effective alternate methodology to traditional field-based measures of evaluating forest structure and complexity across landscapes. Furthermore, given the volume of data that can be generated in a single flight plan, as well as the ability to use the technology in remote areas, these methods could expand the scope of studies on forest dynamics and recovery when combined with field-based calibration plots.

1. Introduction

Secondary tropical forest cover is increasing rapidly in some regions, particularly in hilly, montane landscapes that are marginal for agriculture (Asner, 2009), due to both natural regeneration and active restoration (Aide et al., 2013; Lamb, 2011). This trend is driven by a complex set of drivers and is facilitated by increasing interest in the role that forest recovery may play in sequestering carbon as part of efforts to reduce emissions from deforestation and forest degradation (REDD+, Edwards et al., 2010; Harvey et al., 2010). An ongoing challenge to such efforts, however, is cost-effective monitoring, particularly for landowners at the local level (De Sy et al., 2012).

Assessments of forest recovery in degraded landscapes typically focus on a number of parameters such as the abundance of tree recruits, community composition of vegetation, structural dynamics such as plant height and branching architecture, or measures of habitat quality in terms of their use by different animal guilds (e.g., Rodrigues et al., 2013). Structural complexity, and in particular plant height, is often strongly associated with increased visitation by avian frugivores, which can lead to greater tree seed dispersal and seedling recruitment (Duncan and Chapman, 1999;

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McDonnell, 1986). Estimates of tree height, in conjunction with diameter at breast height and wood specific gravity, can also be used to estimate aboveground carbon accumulation or stock (Chave et al., 2005). Accordingly, these measures can evaluate how a particular site is responding to a restoration intervention (Holl and Zahawi, 2014), determine if management practices have impacted forests (Imai et al., 2009), or assess how biomass changes in response to a particular pressure such as climate change (Phillips et al., 2011). Collecting these data in the field, however, is time consuming, expensive, and requires skilled field technicians. Additionally, site access can be complicated if it involves multiple landowners. Long-term monitoring of forest recovery and restoration projects is critical to evaluating success and providing guidance on how to invest scarce resources, but such monitoring is commonly inconsistent or lacking (Melo et al., 2013; Ruiz-Jaen and Aide, 2005), in part due to cost.

Alternate approaches to evaluate change in forest structure and composition using remote sensing technology have shown promise in alleviating the need for time consuming and costly field-methods, and may provide additional parameters for assessing habitats that are not logistically feasible with on-the-ground field surveys (Mascaro et al., 2014). Of the remote sensing technologies available, Light Detection and Ranging (LiDAR), which uses laser pulses to determine distances between structures, as well as spectral imaging (hyperspectral, multispectral), have all shown potential value for ecological applications. LiDAR data can quantify structure in three-dimensions (3D), and this information can be used to evaluate habitat suitability for different fauna (Goetz et al., 2007; Jung et al., 2012; Turner, 2014; Vierling et al., 2008), estimate tree height with a high degree of accuracy (Andersen et al., 2006), and determine aboveground biomass and carbon density (Asner et al., 2012; Goetz and Dubayah, 2011; Lefsky et al., 2002) among other applications. Although application of LiDAR to ecological problems has shown great promise, conventional airborne LiDAR acquisitions remain prohibitively expensive for most monitoring projects and field-studies as a typical acquisition costs at least $20,000 per flight, regardless of the size of the study area (Erdody and Moskal, 2010).

Recent advances in remote sensing using lightweight unmanned aerial vehicles (UAV; Fig. 1) (Anderson and Gaston, 2013) are providing an alternate option using digital images and computer software. With costs running from as low as $300 to a few thousand dollars (Koh and Wich, 2012; Schiffman, 2014), UAVs can potentially provide researchers and technicians with a field-portable remote sensing device that enables low-cost collection of data when and where needed. The 'Ecosynth' methodology (http://ecosynth.org/) processes large sets of overlapping digital photographs using open-source software and computer vision 'structure from motion' algorithms to create 3D models of aboveground vegetation (Dandois and Ellis, 2010, 2013). The information is made available in the form of 3D 'point clouds', wherein each individual data point has 3 coordinates describing the horizontal and vertical position of a surface viewed within the photographs, together with red–green–blue (RGB) colour information. Such

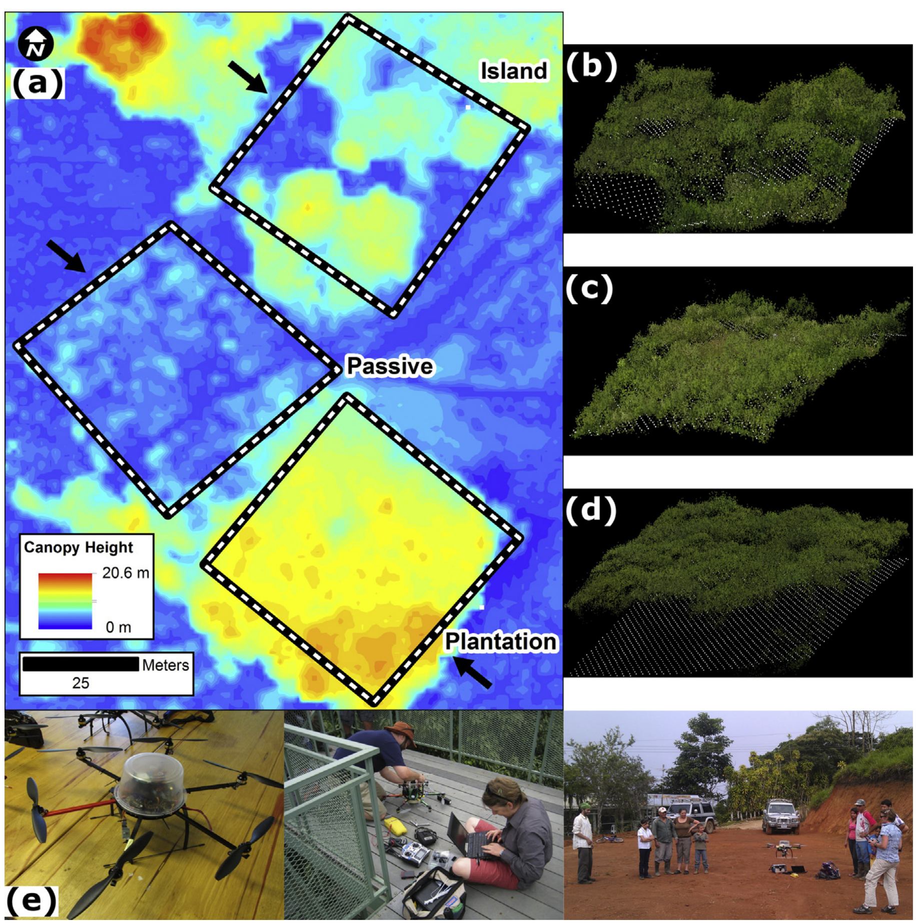

Fig. 1. Overhead view of an Ecosynth *non_GPS* canopy height model (CHM) (a) of one field site showing the three restoration treatments, each outlined by hatch marks. Right panels show oblique views of the Ecosynth 3D-RGB point cloud for the island (b), passive (c), and plantation (d) treatments as in (a) with the *non_GPS* DTM represented as a 1 m grid of white points; approximate viewpoint indicated by black arrow. Photos (e) from left to right: hexacopter; prepping a hexacopter for a flight; and an automated landing approach at a field site.