Figure 4.1 - Different stages of degradation/regeneration/succession of native forest

Chapter 4

AUTOMATING SITE ASSESSMENTS USING DATA FROM UAVS

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ABSTRACT

Much progress has been made in remotely detecting forest loss, particularly by using satellite imagery. However, quantification of different stages of forest degradation continues to be challenging. Compared with satellites, UAVs (or drones) can deliver images of much higher spatial resolution and enable estimation of forest characteristics with greater accuracy. Hence, such data from UAVs may enable the quantification of different levels of forest degradation in greater detail than ever before.

In this paper, we discuss the potential of data from UAVs to i) assess forest degradation at the site level, ii) determine the conditions of reference (or target) forest ecosystems and iii) detect the extent of forest regeneration. Additionally, we quantify and compare several forest stand-level variables, measured in the field (observed) and from UAVs (detected) in a Chilean temperate forest.

Detected values from UAV data were 27-100% of the observed values for species richness, 25-61% for counts of trees and 67-81% for basal areas. Observed vs detected basal area measurements were highly correlated (R^2=0.9). Results, using a canopy structure metric, to predict tree species richness (R^2=0.42) and number of trees (R^2=0.45), were promising.

We conclude that data from UAVs may be useful to detect gradients in vegetation structure, to determine degradation stages of restoration sites and consequently, to establish restoration goals and thus derive the most appropriate methods to achieve them.

***Key words*:** forest degradation, remote sensing, canopy structure.

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WHAT IS A PRE-RESTORATION ASSESSMENT AND WHY IS IT IMPORTANT?

The three main stages of restoration projects are: i) planning, ii) implementation and iii) evaluation. Planning establishes project aims and how to achieve them. HOLL & AIDE (2011) wrote that restoration strategies must be decided on a site-by-site basis. They should consider ecosystem resilience (or the intrinsic recovery rate), degradation levels (or land-use history) and landscape context (or surrounding matrix), as determined by a pre-restoration site assessment. Conducting these analyses prior to selecting restoration approaches should result in efficient use of restoration resources and should maximize the chances of success (HOLL & AIDE 2011).

A pre-restoration site assessment serves several purposes. It quantifies the current degradation stage of the ecosystem and provides a baseline, against which changes due to restoration can be evaluated. It also defines the extent and existing potential of natural forest regeneration and identifies barriers to its progression (ELLIOTT et al., 2013). Thus, site assessments guide restoration, by helping to determine the location and intensity of restoration actions across sites.

The degradation stage of an ecosystem is determined by comparing it to a reference ecosystem (also known as target ecosystem). Observations of a reference ecosystem help to define the levels of ecological attributes (e.g. biomass, structure, biodiversity etc.) aimed for by restoration. The attributes, assessed in a reference ecosystem, can include: species composition, community structure, abiotic conditions, exchanges of organisms and materials with the surrounding landscape and anthropogenic influences. The attributes that are measured depend on the restoration aims, but the same attributes should be assessed when describing both the reference ecosystem and the state of degradation in pre-restoration site assessments (Fig. 4.1). For example, ELLIOTT et al. (2013) defined five levels of tropical forest degradation, distinguishing each by critical thresholds that, once crossed, require major shifts in restoration approach.

The collection of such biophysical information during pre-restoration site assessments allows the identification of methods to re-initiate or accelerate those ecological processes that have been arrested or retarded. Thorough assessments of both the degraded and reference ecosystems are therefore essential for planning effective restoration strategies.

All the ecological indicators, suggested by ELLIOTT et al. (2013) to define degradation stages, can be quantified in the field with a pre-restoration site assessment. However, this requires a large field effort. Instead, we can measure these (or other) attributes using UAVs, to differentiate degradation stages, and to define the reference ecosystem for auto-site assessment in large and remote areas for the whole site.

The approaches of ELLIOTT et al. (2013) and HOLL & AIDE (2011) emphasize the important role of pre-restoration site assessments. Three levels of information are needed: i) landscape or land cover, including landscape structure and composition of the site and surrounding matrix and spatial relationships among landscape elements; ii) vegetation structure, including species composition, diversity, density, size and spatial distribution of adult trees and iii) forest regeneration, including the size and spatial distribution of natural regenerants.

At the landscape level, quantifying forest loss has progressed greatly, since the development of remote sensing by satellites. Distinguishing between native forest and other forms of land cover (e.g. pasture, exotic forest plantations, crops etc.) is relatively easy. However, quantifying different degradation stages, within native fores,t is more difficult, since logging, fires and cattle browsing cause different qualitative changes in forest structure and composition, which are difficult to distinguish.

Quantifying structural changes within forests is more challenging than measuring wholesale forest loss and requires images with high spatial resolution, to distinguish among tree species. For example, in the Barro Colorado (Panama) tropical forest, GARZÓN-LOPEZ et al. (2013) achieved high accuracy of species identification, using aerial photographs with 8.5 cm spatial resolution, clearly demonstrating the usefulness of very high resolution images for forest surveys and highlighting the need to complement the high spectral resolution of satellite images over large scales with more detailed imagery at closer quarters.

Quantifying forest regeneration presents a major challenge, due to: (i) the small size of regenerants (e.g. tree seedling or sapling or tree stumps) and (ii) the fact that they may be hidden beneath a canopy of herbaceous weeds. Even using very high-resolution images over open spaces, counting small seedlings, is difficult let alone identifying them. These tasks become even more challenging when regenerants are hidden beneath a canopy of trees (such as in stage-1 degradation) or where the cover of herbaceous weeds is dense. UAV-mounted lidar technology opens up the possibility of obtaining below-canopy measurements from flying above the canopy or between the trees inside the forest CHISHOLM et al. (2013) (see Chapter 12). Another promising technology, which could be used to assess forest regeneration, is "structure from motion" (SfM) algorithms that create 3D surface models, using RGB images, taken with UAV-mounted digital cameras (ZAHAWI et al. 2015). Such technology is used to construct point clouds of forest structure similar to those that are created by lidar, including canopy height models and roughness metrics (DANDOIS & ELLIS 2013).

HOW CAN DATA FROM UAV HELP WITH SITE ASSESSMENTS?

Various UAV platforms can be used for pre-restoration site assessments. Principle differentiating characteristics include aerodynamic profile, endurance, maximum range, flying time and altitude (SALAMI et al., 2014). The remote sensors that can be mounted on UAVs also vary. Some record images passively (e.g. regular digital cameras) or actively by emitting their own energy (e.g. lidar). Regular visible multispectral cameras (including the infrared band) are the most common sensors currently used with UAVs, but promising trials have been conducted with hyperspectral sensors, lidar and thermal cameras (ZARCO-TEJADA et al., 2012; CHISHOLM et al., 2013; GARZÓN-LOPEZ et al., 2013, SALAMI et al., 2014)

The selection of both UAV type and remote sensor depends on project objectives. Practitioners should choose a platform that is not only capable of achieving project goals, but one that is also labour- and cost-effective. Selection of appropriate technologies depends on the size of the restoration area, budget limitations, the detail and accuracy needed for the project and the costs of geo-referencing, orthorectification and image processing. With larger sites, UAVs become less cost-effective platforms for sensors compared with aircraft or satellites, although UAVs are nearly always more flexible in their use and can achieve high spatial resolution and precision, by flying closer to the vegetation (MATESE et al., 2015).

According to ELLIOTT et al. (2013), pre-restoration site assessments require the measurement of different landscape, diversity and regeneration variables. How much of this information can we get from a UAV? Using a regular RGB camera, mounted on a UAV, three different types of data can be generated a) very high resolution and geo-referenced RGB mosaic images; b) very high resolution surface elevation models and c) point clouds of surface elevation from different viewpoints. RGB mosaics and elevation raster data can have a spatial resolution ranging from 5 to 20 cm, depending on flight altitude and sensor type (Fig. 4.3 and 4.4). From the point cloud data (c) (Fig. 4.5) we can estimate an important number of surface properties, similar to those estimated by lidar, such as canopy structure and roughness (ZAHAWI et al., 2015). All this data can be combined to generate useful inputs for site assessments and the drafting of project plans, although different levels of information need different approaches (Table 4.1). An important issue for future UAV research is: what is the minimum information, needed to generate effective restoration plans.

USING REGULAR CAMERAS FOR SITE ASSESSMENTS: AN EXAMPLE FROM SOME TEMPERATE FORESTS OF CHILE

To test some of the technologies described above, we evaluated the capability of RGB images from UAVs, to quantify different stand-level variables in old growth and secondary forests in Araucanía region. In this study, tree plots of 45x45 m were established in each forest type All trees >5 cm DBH were identified and mapped, using a Cartesian system, defined in the field, and recognized in a very-high-spatial-resolution RGB image. The image was captured using a Bormatec Maja fixed-wing airframe, equipped with an APM 2 and Canon S100, flying 100 m above the forest.

We compared field data with those derived from UAV imagery: tree species richness, number of trees and basal area. We also related a canopy structure metric (standard deviation of tree height), calculated from a very-high-resolution surface-elevation model for each plot, with tree species richness and number of trees.

Detected values from the UAV imagery were 27-100% of the observed values for species richness, 25-61% for counts of trees and 67-81% for basal areas (Fig. 4.2). Observed vs detected basal area measurements were highly correlated (R^2=0.9). Use of the canopy structure metric to predict tree species richness (R^2=0.42) and number of trees (R^2=0.45), was promising, but less conclusive.

These preliminary results allow us to infer that data from RBG cameras, mounted on UAVs, may be useful for detecting gradients in vegetation structure, for pre- and post-restoration surveys and monitoring and to establish restoration targets from reference ecosystems.

Table 4.1 – The pros and cons of using UAVs to measure variables used for pre-restoration site surveys (ELLIOTT et al, 2013)

LANDSCAPE	
Intact forest	Easy to detect different land cover types (Fig. 1), but more difficult to determine degradation levels of different forest landscape patches. Distance from remnant forest (seed sources) to restoration sites easily determined.
Herb cover	Can be distinguished, by combining spectral data from herb canopy with digital surface models (e.g. ZAHAWI et al., 2015).
VEGETATION STRUCTURE	
Big Trees	Delineation of individual tree crowns can be done using segmentation imaging techniques: combining spectral information and digital surface models. Crown projected areas and volumes can be calculated – especially for dominant and emergent trees.
Dominant species	Using images with 7-cm spatial resolution, 1 m^2 objects can be detected in forest (GETZIN et al., 2014). Pixel-based species classification is more difficult, because of wide spectral variability in very high-resolution images. Following segmentation, crown texture of individual trees can be quantified. Variability in lighting (e.g. time of day, cloud cover etc.) can change spectral information of the same species across large mosaics.
Richness	For determining canopy species richness, the same approach as used for dominant species can be applied. For the under-storey, it is possible to use different canopy metrics to estimate florist diversity, combining the various data obtained with UAV (very-high-resolution images, surface model and point clouds (ZAHAWI et al., 2015). For example, GETZIN et al. (2012) found that plant diversity was correlated with gap-shape metrics.
REGENERATION	
Regenerants, seedlings, saplings & live tree stumps	Using UAV imagery and sensors to determine regeneration is challenging. Only lidar can be used to directly measure under-storey properties. In closed forest, an approach similar to that of GETZIN et al. (2012) can be used. Another option is to carry out a direct UAV measurements by flying below the forest canopy (CHISHOLM et al., 2013) (Chapter 12). In open spaces, VEPAKOMMA et al. (2015) counted individual regenerants fairly accurately using an algorithm to distinguish trees.

Figure 4.2 - Comparison between field data versus data derived from UAV imagery. The whole bar represents the value measured in the field, whereas the orange bar represents the value detected by the UAV-mounted sensor in six different plots.

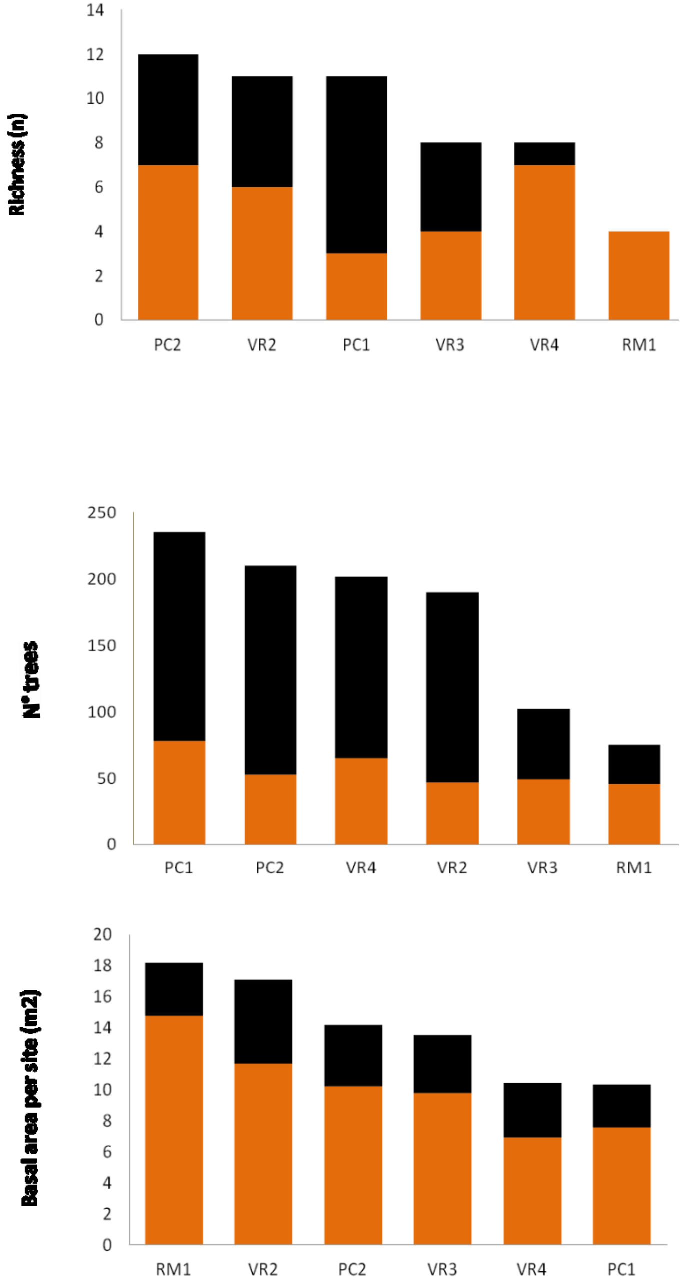

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Figure 4.3 - Very high spatial resolution image of a forest stand

Figure 4.4 – A very high spatial resolution digital canopy surface model of a forest stand

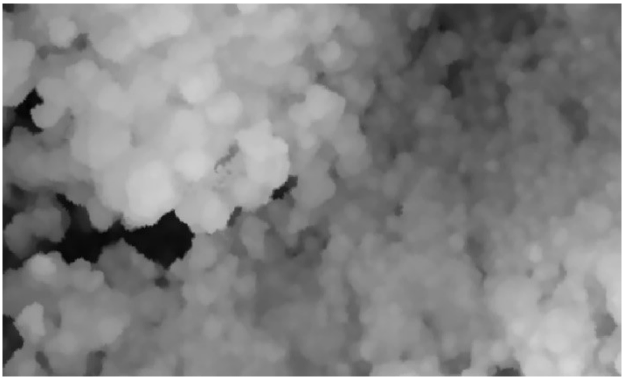

Figure 4.5 – A point cloud of a forest stand